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Introduction

Printing and media technology research in 2006

Preface

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Research in the field of media technology and graphic arts is carried out at a large number of research institutes and university departments all over the world. In many ways, this research is becoming increasingly important and topical since the industries served are currently going through radical changes. The changing media landscape forces the printing and publishing industry to determine its position within it, to improve its competitiveness at the same time as it develops its business strategies. In this situation, an improved understanding of the basic processes and technologies as well as of the current development trends becomes a matter of high priority. Here, industry related research has an immediate impact.

This volume of the Advances in Printing and Media Technology contains the scientific and technical research contributions presented at the 33rd International Research Conference of iarigai, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries, held in Leipzig, Federal Republic of Germany, on September 10 to 13, 2006. The peer reviewed papers (total 37 of them) address on one hand the basic theoretical issues of printing technology and color reproduction, on the other hand the practical problems of quality, productivity and business strategies.

Altogether 87 authors from 34 different research organizations contributed to this book. Their papers are assembled in five sections, thus representing the principal fields of interest of the research. After an introductory review of trends in packaging printing, the first section of this book, on media industry issues, develops this introductory theme further by discussing smart packaging issues. It also focuses on some additional current industry trends and challenges, such as interactive media, hybrid media and the need for a restructuring of the media industry.

The section on non-conventional printing addresses the problems of printing electronic components, issues in security and electrophotographic printing, and non impact printing technology, whereas the section on conventional printing contains research on print processes and ink in screen, flexographic, gravure and offset printing.

The challenges of achieving and measuring print quality are discussed in a section exploring paper surface quality, ink strength, paper elongation, streaks, mottle and blanket build-up. The final section is concerned with always interesting and attractive color reproduction, device characterization, and color management.

All in all, this volume provides an overview of current international research in the broad and diverse field of media and printing technology. Hopefully, it will give practitioners new insights and ideas, and researchers deeper knowledge and inspiration for further work, results of which are expected to be published in the further volumes of this series.

Trends in packaging printing

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Abstract

Printing of packaging materials has been changed in the last years. Depending on the functions of the packaging solution the demands for specialization of printing processes are increasing. New technical solutions as well as special developments in inks and safety elements are discussed.

1. Introduction

In the 21st century the magnifying of informations dominate all the business and trade fields as well as private processes. The transmission of informations by means of ink or coating systems on any substrate is realized by printing processes. Since many years the traditional printing processes are in competition with the new electronic media. While in classical printing applications like the production of books, magazines, newspapers and forms the number of copies are stagnating the print production runs of advertising and packaging materials are increasing.

The variety of the existing printing processes guarantees printing results with a high image quality if the process parameters could be realized in defined limits and the technical conditions are optimized. Especially the printing on packaging materials is characterized by a large range of substrates with different material parameters and in general a high variety in the shape of the surfaces (plane, cylindric, cone or irregular). Printing on packaging materials demands detailed knowledge of the mechanical, thermal and optical behaviour and more and more of the chemistry of the used substrates, inks, varnishes and adhesives. So it is necessary to use comparable measuring systems describing the relevant parameters and to use these informations for the decisions which printing process should be used for the special product and which special finishing steps could be added.

The present situation in the packaging industry shows a high rate in introducing of high automated techniques in the production of packaging solutions. Higher speeds of the packaging machines are in contrast to the decreasing production runs with a parallel increasing of the variety of the constructions of the packaging systems and demands an 100%-control of quality parameters.

2. Demands on packaging solutions

Worldwide the developments in the packaging industry are influenced not only by the introduction of new materials in each case of the packaging solution. The different cultural situations, the national and international laws and rules and - as observed in the last years - specific marketing events become more important for the packaging industry and their partners in the printing industry.

The functions of packaging materials are defined in many publications (Tenzer, 1985; Klockner, 1992; Fraunhofer Gesellschaft, 1997) as the following:

- function of protection (avoiding relationships between the packaged product and the surrounding like mechanical and climatic stresses, lost of weight and mass, biological influences, avoiding of damage and pollution and - last but not least - forging),
- function of communication (labelling, explanation of usage, advertising, marketing),
- function of transport and storage (optimization of sizes, weights and handling),
- function of environmental impact.

Which of these functions could be of interest for the printing industry? In general is to be said that all these special functions could be related to the printing processes because of the effects on the properties of the finished packaging materials during the printing process. The function of transport and storage and the function of the environmental usage are both important for developing printing inks for instance. But the function of communication will be of special interest for the printing industry as well as the function of protection in avoiding forging and will be discussed in the next part of this paper.

3. Function of communication

The function of communication determines the optical characteristics of the surfaces of the packaging materials. Different informations have to be placed in special developed layouts on the packaging materials. Informations like text modules, images, lines, codes or modified structures like holograms have to be printed in a sophisticated printing quality. Summarising all the demands of the producers and users of packaging materials the following design principles could be derived:

- no overdesigning,
- clear informations,
- high printing quality.

A difficult task for the printing industry is to define print quality. In the monography (Helbig, 1992) the print quality is defined as the sum of the relevant properties of the printed matter which under special circumstances in using the printed matter and considering the claims of the consumers are able to describe it.

In the packaging industry many different consumers demands can be discussed. In general the demands of the manufacturers of the packaging materials especially of brands are different to that of the consumers. In most cases the consumers are less critical in viewing the packaging surfaces and there is no knowledge about coating and printing techniques. But the real definition of the printing quality of packaging materials is defined at first by the manufacturers of the products which have to be packaged and the chain of stores. So the following demands for printing quality of packaging materials are typically:

- exact reproduction of all elements (text, lines, areas, images),
- exact colour fidelity of special colours (Pantone, HKS or others),
- possibilities in finishing (varnishing, stamping, die cutting, perforation, holography),
- application of special inks (effect pigmented inks, inks with smell, fluorescent inks, magnetic inks, conductive inks or inks for scratching),
- possibilities for further manufacturing in packaging machines (mechanical and thermic behaviour of the printed surfaces).

The criteria mentioned above will influence the printing process which will be used for manufacturing the special packaging materials. Very often it is not possible to realize the production with only one printing process. The number of printing presses which are able to print with different printing modules is slightly increasing (for example sheedfed offset printing presses with varnishing modules based on flexographic printing or gravure machines with flexographic or digital printing units).

Otherwise the production of brand named products (a sample is shown in figure 1) causes the print production on different materials in sheedfed or web printing machines and special printing machines for printing tubes and tins.



Figure 1: Production range of a brand printed in different printing processes

The demands in realizing a consequent controlled reproduction of the special blue ink of the brand name sample in the Figure 1 is only possible with comparable workflow solutions in the different printing processes. So color management with defined colorimetric measuring data and tolerances will be used more and more in the future. In present time the difficulties are found in the different situation of the standardization of the printing processes. Only in offset printing the international standardization of the process parameters is highly qualified and leads to repeatable printing results. In gravure, flexo and screen printing usable standardized solutions do not exist, so that the definition of reliable targets is very difficult.

4. Function of protection

The protection of brands is an international problem. Worldwide, especially brand names in the pharmaceutical industry, in the food industry and in the production of so called Lifestyle-products are fighting against forging. To protect the brands it is necessary to investigate the possibilities to integrate special elements in the printing process.

More and more the printing process is not only a creative process of transfering ink and inducing colour impressions. The classical scientific definition of printing processes is that printing is a special coating process where structured layers are applicated on different surfaces. These coating processes could be realized by using roll coating, dip coating, blade coating or spray coating systems. Distinguishing marks of these techniques are to realize thin ink layers in the range of micrometers or less with constant ink film thicknesses in printing machines with maximum rates of about 10 to 12 ml/sec. Extremely short length of stay and different printing forces induce high stresses on the materials.

The knowledge of the basic printing processes and their technical principles are helpful to investigate the possibilities to transfer no printing inks but special coatings on the surfaces of packaging materials. In (dd, 2005) ten different safety characteristics are defined (for cardboards):

- printing of special targets with fluorescent inks,
- design of sophisticated graphical safety elements by using special software,
- mixing of stamping and printing of special inks for threedimensional impressions,
- printing of special effect pigments with different colour impressions under variable viewing angles,
- editing of extremely small letters ("nanotext"),
- special inks which only can be seen by special laser beaming,
- special barcodes for personalizing of the cardboards,

- special infrared effect inks with special colour effects after IR radiation,
- integration of Invisible Constant Information (ICT) technology,
- integrating of special coatings in finishing processes like concealing.

The mentioned possibilities can not be realized in every printing unit and not all packaging material need all those elements. But in the future more and more packaging printers will be interested in offering their customers more detailed and personalized solutions for printing not only 4, 6 or 8 colour prints but, integrated safety elements too.

5. Further trends

In the last years a lot of investigation has been done to develop the so called RFID (Radiofrequency identification) tags (Figure 2). These special elements cause new possibilities for labelling and protecting packaging materials. The RFID tags allow new identification possibilities (like personal identification) and special labelling information of packaging materials.



Figure 2: RFID tag

Simultanously with the special new possibilities in brand protection of packaging materials there are observed technical developments in all printing processes. Especially using of laser modifications in exposing printing plates (offset, flexo, gravure, screen printing) is integrated more and more in the printing process. New materials for printing plates (waterless offset, computer-to-plate-technologies in offset and flexo printing) are able to improve the printing quality and to get more and more photorealistic reproductions, because of the high resolution of the images. The demands for more complex finishing processes may induce problems with conventional inking systems. So new compatible inking systems have to be developed.

All these facts show that now and in the future the packaging printing processes will specialize more and more in all segments: printing machines, inks, plates and substrates.

References

dd, 2005; *Gegen Produktfiilschungen und Markenmissbrauch (Against product forging and misuse, Deutscher Drucker,15, 2005,* 15-16

Fraunhofer Gesellschaft, 1997, *Verpackungstechnik (Packaging Technology), Hiithig-Verlag,*

Helbig, 1992, *Druckqualitiit (Printing quality), Polygraph, Frankfurt/Main*

Klöckner, 1992, *Verpackung. Fluch oder Segen? (Packaging: curse or blessing?), Heusenstamm*

Tenzer, 1985, *Verpackungstechnik: Mittel und Methoden zur Losung der Verpackungsaufgabe (Packaging Technology: Ways and methods for solving packaging problems), Fachbuchverlag, Leipzig*

1

Media industry developments

Smart packaging: new communications concepts and models

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Abstract

New technologies are beginning to replace traditional packaging printing, in terms of integrating digital information onto physical, material-based packaging, and are characterized by the wide application of electronic processing environments and the processing of both printed and electronic media. Packaging thereby forms the centre of an intensive research field into new technologies that integrate digital data on a traditional package. Various applications are being implemented and pilot tests are being performed, fuelled by developments in electronics technology, materials and processes, which are characterized as being "intelligent" or "smart". The new intelligent packaging incorporates microchips, antennas and new materials such as thermochromic inks and various indicators that track changes and provide real-time responses and wireless communication capabilities.

This paper explores the new packaging concepts, and also examines the new communication models in the smart packaging sector.

Keywords

Communications concepts and models, conventional packaging, cross-media, smart packaging

1. Introduction

The packaging sector forms an integral part of the communications sector, and involves adapting various characteristics of surfaces to cover the storage, distribution and disposal requirements of products. Promotion systems have also been developed due to the presence of commercial competition. Packaging has changed through considerable scientific investigations so as to adapt it to specific requirements. One recent development in packaging is in the use of printed antennas and the incorporation of microchips, which requires new models of printing management to be applied to intelligent packaging.

In this section we describe work related to the definitions of conventional packaging, intelligent packaging, radiofrequency identification (RFID), and intelligent products, and also describe the aim of the paper. In Section 2 we describe the cross-media concept, and determine the basic elements of conceptual models in both the conventional and smart-packaging sectors. In Sections 3, 4 and 5 we present the developments of a new communications concept and propose a new enlarged conceptual model for use in intelligent packaging. Finally, we present the conclusions and areas for further research in Section 6 and references in Section 7.

1.2 Definitions of packaging

According to Abbot [Abbot DA-1989], packaging is defined as a means for (1) providing information of the contents, (2) protecting the contents from climatic changes during distribution and storage, (3) determining the contents themselves and their design, form, colours and graphics, and (4) determining

the usefulness of the contents. According to Hine, [Hine T-1997], packaging includes wrappings made from metal, glass, cardboard and other related materials, each of which has its own functional qualities. This sector involves the development of marketing and influencing culture and publicity. It also informs about the content and notifies of precautions related to the product's attributes and characteristics.

The package is used to protect the product against the deteriorative effects of the external environment, communicate with the consumer as a marketing tool, provide the consumer with greater ease of use and time-saving convenience, and contain products of various sizes and shapes. These functions are not mutually exclusive since, for example, the communication function of the package through warning labels and cooking instructions can also help to enhance food protection and convenience, [Kit L Yam et al-2005].

1.3 Definitions of intelligent packaging

Smart packaging is now a commonly used term that still has no official definition, [Raghu Das-2004]. It refers to relatively new packaging features that go beyond simple changes in shape or colour, graphics, bar codes or better protection. Certain features such as coverings that let some gases out and other gases in or radio tags that return a signal when interrogated electronically are common, as is including modern forms of anti-counterfeiting or anti-tamper features in the definition [Peter Harrop-2005].

1.4 Radiofrequency identification

According to the Massachusetts Institute of Technology [MIT Auto-ID Labs-2004], RFID (A) is an automated identification technology, (B) is not simply a bar-code replacement, (C) has greater identification capabilities than bar codes, such as reading through obstacles and in hostile environments, and (D) has greater functional capabilities than bar codes, such as making read/write memory, on-tag sensors, and active communication possible:

A. Applications determine what data are collected and how they are utilized so as to yield benefits from implementing the system.
B. Problems to address include which frequency is appropriate in terms of the type of product, operating environment, tag antenna and packaging, and reader deployment for compliance with regulations.

Unique Identification. Unique item identification is required to capture item-specific information. This enables a plethora of applications, specific asset management, and the synchronization of financial flows, information, flows and physical flows [IDTechEx-2005].

1.5 Intelligent products

Smart labels. ID TechEx defines a flat responsive device that is usually electronic. It includes smart tickets and laminates in the definition, but not smart cards even when they work at a distance. These tags do not contain data. Tags are the most common form of smart labels, and are analogous to the tags that have been used in all areas of business and industry for centuries. They are produced from cast-coated paperboard, plastic or other materials, with cloth tags being frequently called **"law labels".** RFID tags provide a product description and allow content identification, and fall into two main categories:

1. Passive tags are RFID tags that are powered solely by the RFID interrogator. The interrogator irradiation powers the microchip on the tag when it is within range of the RF field. When the power to the microchip on the tag meets the minimum voltage threshold required to turn it on, the microchip can then send back information on the same radio frequency. The range is usually limited to several metres.

2. Active tags are RFID tags that have their own power source, so they can work in the presence of a weaker signal from the interrogator (i.e. be further away), with the power source on the tag also boosting the return signal. These types can have ranges of many tens or even hundreds of metres, but cost more because of their relative size and sophistication. Battery life can also limit the life of the tag.
3. Semi-passive tags, refer to tags with a power source (usually a laminar, flexible, low-cost battery) [Raghu Das-2004].

1.6 Aim

Packaging is one of the most dynamic sectors in the printing industry, and is moving in new directions with printed electronics and the incorporation of microchips, antennas and batteries, transforming packaging from inanimate into packaging that has a communicative, computer-science and dynamic character. This work investigated the ability of communication in the existing environment of printed conventional technology, with a view to optimizing the collaboration between the conventional and digital information types. We also investigated that structure of the environment so as to transform static optical messages into dynamic ones coexisting in the same surface as the natural sub layer of the packaging. We present the developments of new communications concepts, and propose a new enlarged conceptual model in intelligent packaging.

2. Cross-media concepts

The packaging workflow can be compared to a cross-media workflow based on the model suggested by Kipphan in 2001 [Kipphan-2001], (Figure 1), which combines print, electronic media and multimedia documents with workflow and transmission media for customer use.

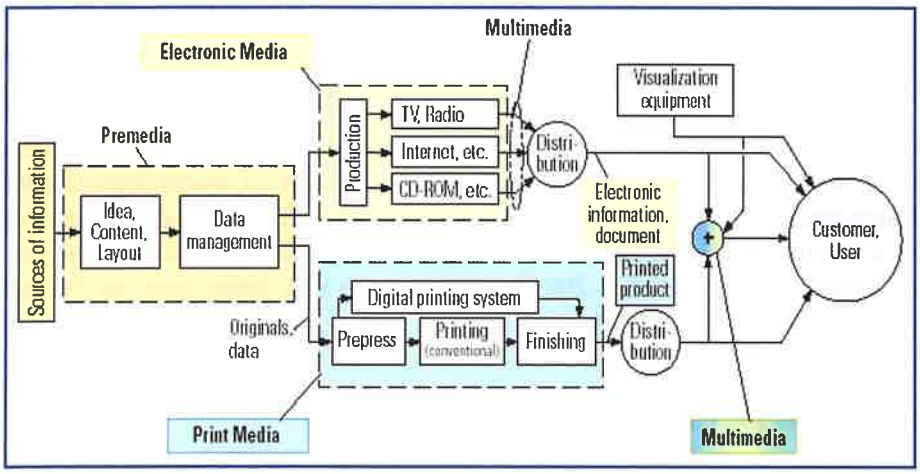


Figure 1: Cross-media workflow (Kipphan 2001)

Politis, A., [Politis A-2004], suggested applying the cross-media concept to publishing [GATF-2000], whose main characteristics were classified as follows:

- Application of new workflows based on the common processing of data for printed and electronic media.
- Development of asset and content management software.
- Increasing applications of new processing technologies for publishing based on XML.
- Development of new standards and formats for production management and workflow in publishing such as Job ticket, CIP 4 initiative, and the Job-definition format (JDF) PPML [Gen-Daniel Lt, Brown G.-2002].

Cross-media concepts are widely used in the media industry and account for numerous applications [Politis, A.-2002]. Generally speaking, cross-media applications are to be found in two main areas in the graphic arts and media industry: (1) in the publishing process, mainly applied as guiding concepts for managing the workflow of data for various input and output media, a prominent output example of which is newspapers with both printed and electronic editions; and (2) in the application of specific technologies to multiple media (mainly the use of machinery and production systems and the application of software), compared to their traditional use oriented to only one media type.

In a similar vein, cross-media publishing is an emerging concept in the production process of print and electronic media, whose main features can be seen in one or combinations of the following descriptions:

- As workflow production applications for the publishing process.
- As common processing of data for publishing of print and electronic media.
- As the application of production tools and new software applications (such as XML editors).
- As the establishment of production workflow systems [e.g. JDF-(Job Definition Format)], applied from prepress to finishing for print media, combining production and management processes.
- As the reorientation of existing production systems, processes and tools (scanning, image processing, colour management and proofing) into common production environments for print and electronic media.
- As content management of any sort, such as formatting and multimedia (any combination of text, images, graphics, sound and video) [Politis, A.-2002].

3. Printing of smart and intelligent packaging

The continuing developments in driver materials (inks) and production methods as well as the industrial methods of printing have enormously extended the capabilities in product packaging. Antennas can now be printed in all forms of packaging, where in combination with microchips can work as intelligent packaging. Moreover, the printing of thermochromic inks allows the time within a product's lifespan to be determined.

A prerequisite for the efficient production of smart packaging, in terms of easy of usage and low cost printing methods, using functional models of the incorporation of microchips/antennas on smart packaging, [Baumann, R. & Weiss, R.,-2005]. The optical characteristics of packaging can be extended from a natural sub layer (paper or cardboard or polymer) to a new *hybrid information carrier*, via cross-media [Nomikos et al-2005] and also, with new behaviours, as *dynamic-intelligent or smart packaging* [John Cooney-2003].

4. Packaging concepts for conventional packaging

Following [Stewart B.-1996], we present a conceptual model of packaging under two main headings. Firstly, packaging can provide the following functionality:

1. CONTAINMENT: Integration of containment of the product so as to dispense, deliver dosage and provide convenience.
2. PROTECTION: Provide an extended shelf life, choice, guaranteed freshness, tamper evidence and child resistance.
3. IDENTIFICATION: Provide imagery, branding and product segregation.

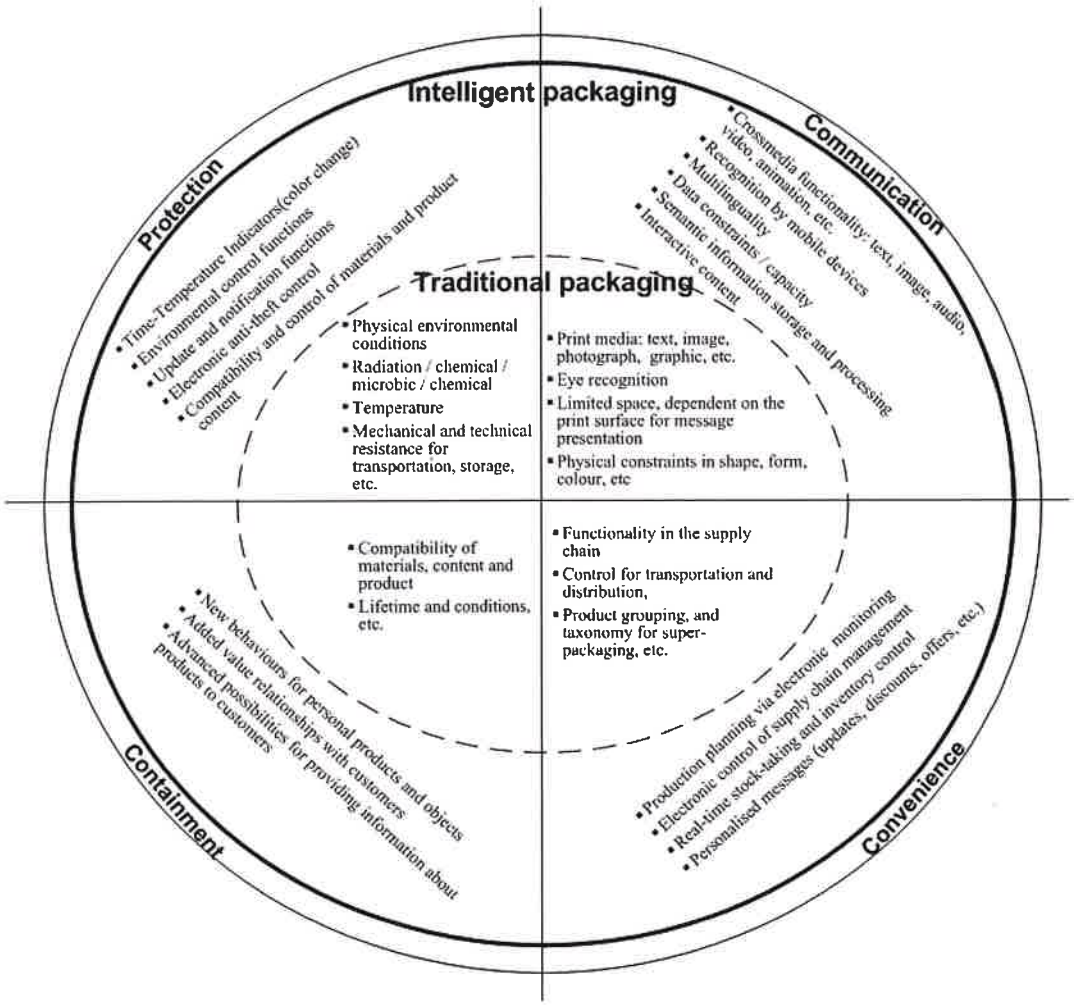
Secondly, packaging *should* provide the following functionality:

1. CONTAINMENT: Prevent disintegration and leakage.
2. PROTECTION: Protect against transit damage, moisture, gases, odour and degradation.
3. IDENTIFICATION: Describe, inform and promote the contents.

The above features should be implemented at the right cost and with minimum impact on the environment. The following packaging functions have been suggested, [Kit L.Yam et.al.-2005]:

1. Communication → Intelligent packaging
2. Protection → Active packaging
3. Containment
4. Convenience

5. A new conceptual model for smart packaging



Protection

- Colour and temperature indicators [Taoukis PS, Labuza TP.2003] and intelligent inks [Intelligent Inks-2005].
- Environmental control functions, such as electronic smart packaging (EAS) [Electronic Smart Packaging Reports-2005].
- Update and notification functions, e.g. GASPIAN: tracking everything and everywhere. [G.A.S.P.I.A.N.-2004] / (RFID Privacy).
- Electronic anti-theft control (EAS) [Electronic Smart Packaging Reports-2005], [MIT's Auto-ID -2004].
- Compatibility and control of materials and product content (e.g. EAS) [Electronic Smart Packaging Reports-2005].

Communication

- Cross-media functionality, such as text, images, audio, video and animations [Nomikos et al-2005].
- Recognition by mobile devices, [www.aimglobal.org], [Trinetra: Assistive Technologies for the Blind-2006].
- Multilinguality, [Nomikos et al-2005] - [Trinetra: Assistive Technologies for the Blind-2006].
- Data constraints and capacity, e.g. Cypak AB/2005.
- Semantic information storage and processing, [J. Lindsay, et.al -2004].
- Interactive content, e.g. the PHT product suite. [PHT Product Suite.www.phtcorp.com].

Convenience

- Production planning via electronic monitoring, [www.future-store.org].
- Electronic control of supply-chain management [RFID Privacy].
- Real-time stocktaking and inventory control, [RFID Privacy], [Electronic Smart Packaging Reports-2005/b].
- Personalized messages, such as updates, discounts and offers, [Nomikos et al-2005].

Containment

- New behaviours for personal products and objects [www.rfid-weblog.com].
- Added-value relationships with customers [www.rfid-weblog.com].
- Advanced possibilities for providing information about products to customers, [Nomikos et al-2005].

6. Conclusions and further research

This research was based on a study of the literature concerned with conventional packaging sectors, cross-media concepts and applications within the media landscape, as well as that on conventional, smart/intelligent and active packaging concepts. The final conclusion is that these developments require a new conceptual model for smart packaging.

6.1. Areas of further research

Further research is required in order to define further the information types and flow within packaging production as well as the range of information defined as electronic data. It is perhaps here that the cross-media concept will prove most useful. Areas of further research include the following:

1. The effects of smart/intelligent packaging on functional models in the packaging industry.
2. New models of design for identifying the new elements of work to be managed via JDF in the sector in smart packaging.
3. New rules of design to be developed and defined for the communication content in smart packaging applications.
4. New rules of design to be developed and new workflows, in industrial printing, for smart packaging applications.

References

1. [Abbot DA-1989] Abbott DA. Packaging Perspectives. Kendall/Hunt, Dubuque, IA, 1989
2. [Hine T-1997], The total Package-ISBN780316 365468-Back Bay Books
3. [Kit L.Yam et.al.-2005], KIT L.YAM, PAUL T.TAKHISTOV, JOSEPH MILTZ, Journal of Food Packaging,Vol. 70, Nr. 1, 2005

4. [Nomikos et al-2005], Exploring cross-media concepts for future packaging - Challenges for the printing industry
5. Spyridon Nomikos, Anastasios E. Politis, Jenny Darzentas, Thomas Spyrou, John Darzentas' Proceedings, 32nd international Conf. Iarigai.4-7 - Sept 2005, Digitalisation and Print Media p.p. 317-319
6. [Raghu Das-2004] Raghu Das 2004, Peter Harrop ,Glyn Holland , The A to Z of printed and disposable Electronic, IDTechEx, Cambridge, UK
7. [MIT Auto-ID Labs-2004], MIT Auto-Id Labs, 6-8 April 2004, Presentations
8. [IDTechEx-2005] ID Tech EX, Presentations 19-20/4/2005 Cambridge. [Smart Packaging, Conference]
9. [Kipphan 2001], Kipphan H., (2001), Handbook of Print Media, Springer Verlag, Berlin
10. [GATF-2000], GATF, 2000. Technology Trends for the New Millennium, GATF 2000 technology forecast, USA
11. Gen-Daniel Lt, Brown G., (2002) Smart Packaging Journal July/August 2002, IDTechEx, Vol. 1, Issue 1 pp. 3-5
12. [Politis, A.,-2004], Politis, A., -2004. "Human capital development and competence structures in changing media production environments" Doctoral Thesis, Royal Institute of Technology, Stockholm, Sweden
13. [Politis, A.-2002). Politis, A. (2002) "The influence of the human factors on the performance of media enterprise - case studies on cross - media publishing in Greek media enterprises", Media Firms: Structures, Operations and Performance, pp 205-224, Lawrence Erlbaum Associates Publishers, Mahwah, New Jersey USA
14. [Baumann, R. & Weiss, R.,-2005) "Industrial Printing Opportunities for Polymer Electronics", MAN Roland Druckmaschinen AG, in the Printed Electronics Europe conf., Cambridge, UK, (IDTechEx)
15. [John Cooney-2003]. John Cooney-Barry Winkless, University, College Cork, Ireland. (TRIZ methodologies and develop, next generation of food packaging concept)
16. [Stewart B.-1996] Stewart B., Packaging Design Strategy-Pira International-(ISBN 1 85802 064 6) Edition 1994-1995 twice-1996. / www.pira.co.uk
17. [Peter Harrop - 2005]. An Introduction to Smart Packaging. Cambridge IDTechEx 19-20/April/2005
18. [RFID Privacy]. The Microsoft Perspective (Submitted to the Federal Trade Commission) as a follow-on to the Workshop on RFID: Applications and Implications for Consumers, June 21, 2004
19. [Thomas Lindner] Printed Electronics Cambridge, UK, April 25 2005-HP- Technology beyond, Ink on Paper Hewlett Packard Co]
20. [Taoukis PS, Labuza TP. 2003]. Time-temperature indicators (TTIs). In: Ahvenainnen R, editor. Novel food packaging techniques. Cambridge U.K.: Woodhead Publishing Limited. p 103-126
21. [PHT Product Suite.www.phtcorp.com]. The PHT Product Suite.www.phtcorp.com/ Solutions/product_suite.asp
22. [Intelligent Inks-2005]. Conductive Inks in Packaging Applications, Vienna, Austria, 8-9 November 2005
23. [Electronic Smart Packaging Reports-2005/a]. IDTech, Raghu Das., pp. 10-18,Cambridge 2005
24. [G.A.S.P.I.A.N.-2004] - Tracking everything, everywhere, Katherine Albrecht-2004 www.gaspian.com
25. (MITs Auto-ID Center]; Article represented / cooperation, in G.A.S.P.I.A.N. [Consumers Against Supermarket Privacy Invasion and Numbering]
26. [J. Lindsay,et.al -2004] Retail RFID Systems without Smart Selves-J. Lindsay,et.al.-Publ. 23/Dec. 2003 - Nov.7, 2003
27. [www.aimglobal.org]. The Association for Automatic Identification and Mobility

28. [Cypak AB/2005], Cypak AB /2005. Smart, secure and connected solutions for time-tagged data capturing. Marie Wall, VP Business Development. IDTech-Printed Electronics. 19-20/2005-present. Cypak AB
29. [Electronic Smart Packaging Reports-2005/b]. Electronic Smart Packaging. Reports. IDTech, Raghu Das., pp 7-8,Cambridge 19-20/April/2005
30. [www.future-store.org]. METRO-Future Store (www.future-store.org)
31. [www.rfid-weblog.com]
32. [Trinetra: Assistive Technologies for the Blind-2006], Patrick E. Lanigan, Aaron M. Paulos-Andrew W. Williams, Priya Narasimhan; May 1, 2006-Carnegie Mellon University

Smart packaging printing: what do packaging printers need to know?

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Abstract

Packaging is currently the centre of intensive research that is being carried out regarding new technologies that integrate digital data on a package. This has been fuelled by developments in electronics technology, materials and processes that have the potential to create packages that can carry digital - machine readable data. These developments concern in particular, new materials (such as printed polymers) and tagging applications (such as RFID and EAS systems) which are described as "intelligent", "smart" or "active" packaging.

One matter of particular interest is how these types of digital information can be integrated and implemented into the existing production workflow of packaging, which is normally consisted by the processes of packaging design, prepress, printing and finishing. Therefore, the objective of the study is to examine the various factors and parameters that might affect the production management and workflow of the traditional/existing packaging design and production.

The paper is based mainly on a literature study on smart packaging applications and their developments as well as on findings from leading research institutes, manufacturers and academia, as it regards new technology applications for packaging printing production.

The present survey resulted in that only some general recommendations can be done, as it concerns the implications for packaging printing companies. These recommendations can be summarized as follows:

- All major printing processes will be used in smart packaging applications. Packaging design, prepress and plate/cylinder making does not seem to be affected at present, although the gradual integration of smart packaging applications is expected to cause considerable changes in these production fields.
- There is a high degree of involvement of other sectors such as the electronics, information technology and new substrates and materials for smart packaging applications.

A final outcome from the present survey is that packaging printing production management is expected to be subjected in changes (investments, production workflow, integration of new/additional processes, quality controls etc).

Keywords

Packaging printing, smart packaging applications

1. Introduction

Packaging is currently the centre of developments as it regards new technologies that integrate digital data on a package. Recent developments in various fields and industry sectors including electronics, information technology - IT-, materials and processes lead to new applications in packaging which are described as "intelligent", "smart" or "active". These developments concern in particular new materials (printed organic materials such as organic polymers) and tagging applications (such as RFID applications).

Numerous studies reveal that although packaging will continue to be printed on a substrate (paper, board, polymer, aluminum or on a multilayer substrate), new types of information carriers (as those mentioned above) are to be embedded in and/or on packaging. As a result, packaging is changing, being transformed to a «hybrid» information carrier and becomes a physical carrier of both printed and electronic information.

Previous study conducted has revealed that packaging printing companies want to be more informed and be in a better position to understand the potential of future smart packaging applications. Data derived from a survey analysis among packaging printing companies [Nomikos et. al 2005], show quite a strong degree of interest in new technologies and the understanding of the influence that they will have on future packaging production. This exists for all types of packaging printers including those that operate offset, gravure, letterpress and flexographic printing plants. It concerns also packaging design, prepress and finishing processes.

Another outcome from this survey revealed that packaging printing companies are only relatively aware of the applicability of the new technologies to packaging. This in particular includes the willingness of the companies in being more informed on the implementation of the new technologies in the existing production workflow and the importance of these new technologies to be applied in the production process of the companies.

A more detailed analysis of the requirements of packaging printing companies regarding information on the new technologies to be applied in packaging printing production include the following:

- They want to be thoroughly informed more properly on the specifications, production characteristics and integration processes of smart packaging applications in the existing production workflow;
- The willingness of the companies (ownership, management) to proceed with investments in the new technologies after they will mature and be ready for installation;
- They are keen to further develop their know-how for full integration of printing and producing smart packaging elements (such as antennas, tags, microchips) in their own production process;
- Their willingness to take the lead and to stay ahead in their business and production activities with everything that is new in this field.

Based on the above mentioned issues, one question that arises is which type of information can be considered important and useful for the packaging printing companies, so they can be aware on the developments that take place in the field of packaging. The issue that arises is that there is a enormous amount of information on the developments regarding smart packaging applications. As such the problem is to determine the various factors and parameters that might affect the existing packaging printing production and production management.

As a result, the main objective of the present study is to examine the various factors and parameters that affect the production management and workflow of the traditional/existing packaging design and production. But how can we define what is important and what not from all these developments on smart packaging?

A prerequisite to implement this objective is to examine the technologies, developments and applications, currently taking place in the field of smart packaging.

2. Methods

During our study we have found a plethora of information and resources on smart packaging applications presented by a quite diverse range of organizations, networks, research initiatives and private companies. Resources and literature were ranging from Universities to private companies and

from associations to expert groups. The fields and sectors were quite diverse as well, ranging from electronics to automatic identification fields and from pharmaceutical to military sectors.

The diversification of the resources has influenced significantly our study since it has been proved as a difficult task to monitor information regarding factors and parameters affecting packaging printing production and the implications for management from all these resources. The information of interest to our study, were mostly hidden among other subjects and only a few reference were clearly oriented in packaging printing of smart packaging elements. This fact has led as to reorient our initial objectives.

As a result, instead of examining the status of the technological developments enabling the efficient production of smart packaging applications in real production, and the level of integration in prepress, printing and finishing processes, our study has been oriented in examining the generic environment where these developments are taking place.

Our study has been finally focused in finding information on the implications in management of packaging printing production, caused by smart packaging applications. What is, finally presented in the paper are these findings that we were able to extract from this considerably large amount of resources.

3. Background

Before entering the actual study it is considered useful to present some terms and definitions on smart/intelligent/hybrid packaging. This is important since these terms are widely used, however they are still not globally accepted and their use sometimes creates misunderstandings, mainly in cases where, the same term is used by different people having a different meaning in mind.

3.1 Smart and intelligent packaging - some definitions

Abbot defines packaging as a means for:

a) displaying the information relating to a package's content;
b) protecting content from the climatic changes during distribution and storage;
c) achieving communication about the content, via elements applied by the package design, its form, colors and graphics [Abbot, 1989].

Such a definition expresses also today and tomorrow what packaging stands for. However, the new so-called smart and intelligent applications are aiming in extending these fundamental characteristics of packaging.

According to IDTechEX (2005), all types of packaging can become smart. The intelligent - smart packaging is part of a communication system, whose heart is the desired information and knowledge about the product. It is made up of autogenous parts (chip, antenna, battery), which can collaborate partially or globally and create a group of collaborations, resulting in the creation of an RFID system [IDTechEx, 2005].

As it is further stated in the IDTechEx study, smart packaging has no official definition but it is a commonly used term. It refers to relatively new packaging features that go beyond simple changes of shape or colour, alphanumerics, graphics, barcodes or better inactive protection. The heart of the subject is responsive features such as coverings that let certain gases out and other gases in or radio tags that return a signal when interrogated electronically. Furthermore, some applications of smart packaging would include modern forms of counterfeiting or tamper feature in the definition [IDTechEx, 2005].

Harrop claims further that smart packaging can involve primary, secondary or tertiary packaging. Examples include primary packaging that automatically lets the bad gases out to preserve meat; secondary packaging that is radio tagged for automated traceability and data capture; and tertiary packaging, radio tagged as an automated tamper alert [Harrop, 2005].

Finally, as it is suggested by Yam et. al, we can approximate smart packaging as a model that can apply various elements such as tags and antennas which, can be activated and communicate in different distances, carrying a significant number of advantages for the consumer [Yam et. al, 2005].

3.1.1 Printed electronics

Again, based on an IDTechEx white paper, Printed Electronics, typically being thin film silicon or inorganic or organic semiconductors, can be used to form Thin Film Transistor Circuits (TFTCs), such as replacing the functionality of simple silicon chips. TFTCs also employ thin film conductors and dielectrics and the ultimate objective is to make many different components at the same time - such as displays, batteries, sensors and microphones.

TFTCs can be printed using high resolution printing processes such as inkjet printing, lithography, gravure; and unlike silicon, other components such as batteries, sensors, displays, etc, can be printed using similar materials and processes. Other than these, two key benefits of printed electronics are:

a) Materials and manufacture costs are very low,
b) Circuits can be deposited onto flexible substrates such as plastic film and foils.

Additionally, printed electronics offer the possibility of using electronics in applications where the cost of silicon would have made it impossible or where silicon properties - such as size or rigidity - are inadequate. Suitable applications include among others, "small area" electronics such as the electronic sensors and the changing use-by date on a pack of meat or medicines [IDTechEx, 2005-1].

Another definition for printed electronics is introduced by Kahn (2005). He introduces Printable Electronics: as "The Chemistry of Making Devices with Printing Processes". Based on scientific experiments, an "all-printed" chemical vapor sensor was fabricated by printing polyanilineon silver interdigitated electrodes using flexographic printing. Kahn suggests that polymers are easily processable, can be made into devices of almost any shape and ultimately be cheaper to manufacture. According to Kahn, Printable Electronics are also known as Plastic Electronics, Plastronics, Flexible electronics, Wearable electronics and Macroelectronics [Kahn, 2005].

3.1.2 What is RFID?

As it can be derived from a study conducted by MIT Auto-Id Labs, RFID can be defined as an automated identification technology, being not simply a bar code replacement. RFID has greater identification and functional capabilities than bar codes, such as reading through obstacles and in hostile environments, and can carry sensors, and read/write memories possible. As such it can lead to active communication [MIT, 2004].

Furthermore, Roos (2005) classifies RFID tags as either integrated circuits (IC) with memory or as chipless tags with no onboard IC. Circuits with memories need chips which could be integrated by various in-lay technologies (such as embossing) on the substrate, in contrast with chipless tags which can be printed directly by all major printing methods on the respective substrate. The application of one or another RFID tags production, determines the printing process which should be applied. In the first case the process needs to be done by a machine that integrates the chip on the substrate (by

laminating it on the actual packaging material), whereas in the chipless tags this process can be eliminated [Roos, 2005].

3.2 Trends and developments in supply chain and packaging

Packaging lies in a quite strong relation with the supply chain, being subjected to changes and developments caused within the more generic field of the supply chain. Within this context, smart and intelligent applications for packaging are emerging from this more generic context of the supply chain. Packaging as the means for serving the supply chain, is affected by these developments.

3.2.1 Smart or intelligent?

Regarding future developments in packaging, on one hand, general packaging production trends, such as shorter delivery times, larger selections and smaller product quantities, are setting higher and higher demands on package production and packaging logistics. On the other hand, developing communication and printing technologies are providing new tools for solving problems, boosting production and giving value addition to packages. An increasingly important task for packaging is to improve brand protection, because forgers usually try to falsify the package rather than the product itself [VTT, 2002]. Methods such as visible or invisible printed bar codes and electronic RFID tags can be effectively used for brand protection and theft prevention This can be implemented with the development of "smart" or "intelligent" systems. According to VTT, a "smart" system adapts to expected situations in a predictable manner. An "intelligent" system is able to adapt to unexpected situations, such as reasoning and learning [VTT, 2002].

In addition, data derived from a joint Pira International and IDTechEx conference (2005) show that "packaging is changing; ten years from now packaging won't just be able to do a lot more, it will be expected to". According to statements from the conference intelligent and smart packaging comes at this crucial time when key players are working together to make intelligent packaging a commercially viable, cost-effective catalyst for change [PIRA and IDTechEx, 2005].

3.2.2 Intelligent packaging

As it can be derived from OEA (Organics Electronics Association), intelligent packaging is an integration of display, logic, keys, sensors, memory, power supply and speakers. As a result, organic electronics are defined as electronics based on organic materials and polymers. Various studies estimate that their global market until 2015 will reach a market volume of 30 Billion USD. As they are thin, flexible and lightweight, they can be printed with the traditional printing methods of flexible substrates (offset, gravure, flexography, ink-jet and laser printing processes) [Hecker, 2006].

3.2.3 Active, communicative packaging

Again, according to VTT scientists, active, communicative packaging can be defined as packaging with an effective logistics system for sensitive, demanding products. The aim is to develop a comprehensive system for new kinds of package production chain which pays attention to the special needs of consumer packages as regards product information, identification and appearance. VTT has also launched a project called PRINTO (Printable Optics and Electronics) aimed at investigating the potential to fabricate passive and active electrical, optical and opto-electronic elements for packages and printed products.

Furthermore, an important issue is the involvement of various sectors in the development of smart packaging applications; these include among others the informatics, electronics and material development sectors. A good example can be shown in Figure 1:

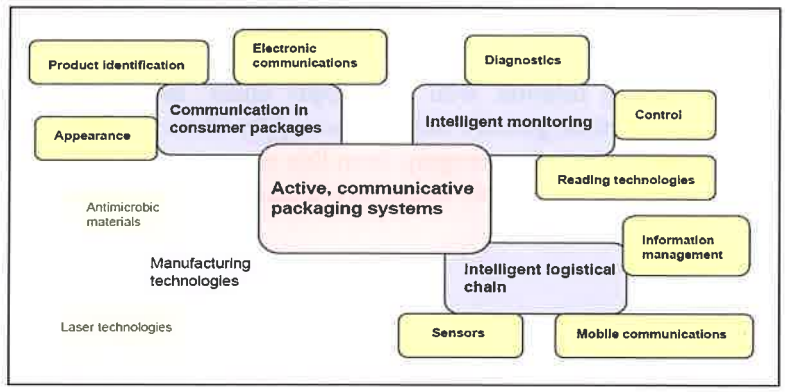


Figure 1: Technology map of Active, Communicative Packaging Systems
Source: VTT Information Technology, Finland

In addition to that, according to BITCOM (2005), even in the highly competitive IT market, it is possible to define basic structures upon which different providers can agree as it regards RFID systems and applications. This benefits companies seeking to deploy RFID procedures and therefore needing to combine components from different providers to establish comprehensive, stable, and inter-enterprise IT infrastructures.

3.2.4 RFID in the supply chain

Much has been written in recent years about the way RFID technology will affect the retail industry, based primarily on the experiences of the department store chains Metro Group (Germany), Tesco (United Kingdom), and Wal-Mart (United States). The impression given was often that the mass merchants of these companies were about to equip all their products with RFID tags, fully automate the shelf-stocking process, and have customers check out their goods themselves. However, until mid 2005, only a marginal number of articles amounting to single-figure percentages are fitted with RFID tags, while widespread RFID supported self-service checkouts are still very much a thing of the future. In this area, bar codes continue to be the dominant and globally accepted means of product identification [BITCOM, 2005].

According to BITCOM Radio frequency identification (RFID) denotes the technology that enables objects to be identified without contact and without their RFID tags being visible. The list of areas that have already embraced RFID technology is substantial, including ski passes, remote controls for vehicle central locking systems, anti-theft protection in department stores, logistics processes for retail objects such as pallets, containers, clothing, and identification for domestic and slaughter animals. In many market sectors, RFID technology is set to replace bar codes. In supermarkets, however, where consumer articles are concerned, the bar code will continue to dominate for many years [BITCOM, 2005].

3.2.5 Which drivers for change for smart packaging?

The application of smart packaging elements causes changes in management attitudes. As Lindner (2005) points out, there is an amount of works to be done for the efficient application of smart elements in packaging; these are:

a) Materials optimization, materials compatibility, device modelling, inkjet architecture.
b) Benefits to ink jet printing electronics.
c) Low-cost atmospheric processing.
d) Compatible with variety of substrates.
e) Reduced materials costs.
f) Reduced environmental impact.
g) Large area processing.
h) Alignment during deposition.
i) Direct control of composition, gradients [Lindner, 2005].

3.2.6 Attitudes have changed?

According to a recent study in the UK industry [Benchmark Research, 2006], responsible decision makers in large manufacturing and retail businesses do not invest in new technology simply because it is hyped as "the next big thing". Increased media coverage of RFID does not mean we can assume that senior business managers are necessarily familiar with the technology and what it can do.

Indeed, according to the study, 28% of senior decision makers in large UK manufacturing companies and 36% of retailers claim to have never heard of RFID. A further 25% of manufacturers and 24% of retailers have heard of the term but know nothing about the technology beyond the acronym. Indeed, only 25% of manufacturers and 14% of retailers can be described as being reasonably well educated as to what the technology is and what it can do. The study concludes with the statement that "The case for RFID needs to be made in practical business terms. UK industry is currently in the very earliest phases of RFID adoption" [Benchmark Research, 2006].

3.3 Packaging Market - Trends and prospects

3.3.1 Evolution of packaging materials

Based on a Kodak survey, packaging materials show a rather stable progress up to 2008. As it can be shown in Table I, flexible packaging materials show an increasing use in comparison with the other materials:

Table I: Packaging market segmentation
Source: Kodak - Graphic Communications Group presentation, by Olivier Michaud

	Year 2003	Year 2008
Corrugated	30%	29%
Flexible	25%	28%
Folding carton	20%	19%
Labels and tags	15%	14%
Others	10%	10%

3.3.2 Supply chain added value

Based on data derived from various studies, the new supply chain model will require greater flow of information between retailer and manufacturing plant and rely on close collaboration across the supply chain if a win-win situation is to be achieved. Customization of packaging will play a large part and will necessitate upstream collaboration, perhaps in hole in the wall type operations, to ensure customer demands are met.

3.3.3 Adaptive packaging models

According to Cooney and Winkless (2003), through the use of the TRIZ Technology Trends and the Evolutionary Potential methodology is evolved into a next generation CAPE (Conceptual Adaptive Packaging Evolutionary) Model. Future food packaging development directions and innovations are then presented focusing on the evolutionary jump from smart/intelligent to adaptive packages.

In light of these potential evolutionary developments, it is apparent that smart packaging could very quickly evolve into "Adaptive Packaging". Figure 2 illustrates the Conceptual Adaptive Packaging Evolutionary (CAPE) proposed Model to improve food safety throughout the value chain. The inclusion of innovative enabling technologies such as thermo chromic, indicators and ICT systems will provide a technological platform from which to develop next generation adaptive packaging systems. At the core of these AFP's is food safety considerations such as improved visibility, control, integrity, security and a new intelligent feedback system, considered as a current reactive approach to a proactive approach in the management of food safety in the value chain with regard smart packaging technologies [Cooney and Winkless, 2003].

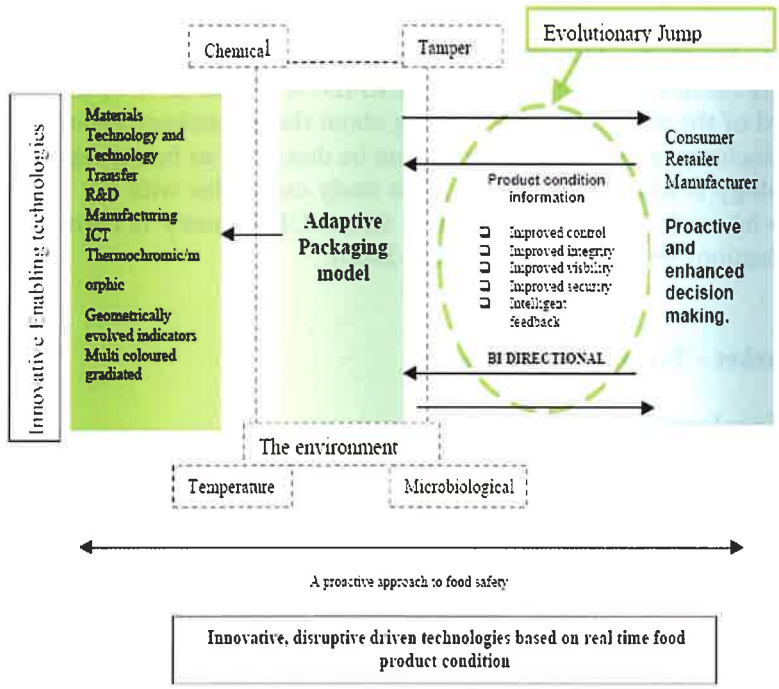


Figure 2: The conceptual adaptive packaging evolutionary, model Cooney and Winkless, (2003)

3.3.4 "Smart" box by Pfizer

As it is stated by Pfizer, in order to enhance patient safety and combat counterfeiting of prescription pharmaceutical products, Pfizer U.S. Pharmaceuticals will begin shipping Viagra® that incorporates a passive radio frequency device encoded with a unique Electronic Product Code (EPC) into its packaging. Pfizer claims to be the first pharmaceutical company to implement such a comprehensive program that will initially provide a means for all pharmacies and wholesalers having appropriate hardware to authenticate the EPC found on the Viagra packaging. This is considered by Pfizer as an important step in a process that may eventually enable the ability to track and trace pharmaceutical products throughout the U.S. distribution channel to the pharmacy level [Pfizer, 2006]. In Figure 3 the box of Viagra is presented.



Figure 3: The Viagra package
Source: Pfizer, www.pfizer.com/counterfeit/viagra/rfid

3.4 Trends and developments in smart packaging printing and finishing

In this chapter we present some examples and case studies of smart packaging applications regarding their printing characteristics. With these examples we intend to present shortly the various applications and technologies for the new forms of packaging, under the scope of importance for packaging printers.

3.4.1 The trends of the information society

As Huebler points out, there are two main trends in the further development of the information society: (a) The huge quantity of information needs more and more technologies for retrieval and individualization. (b) The global and mobile way of life needs an easy access to the information and flexible ways to handle the information. The two main groups of media, electronics (e-media) and printed paper (p-media), will develop technologically along these two demands of users. According to Huebler, the big changes will come either for the e-media as for the p-media. And with the new key technology of printed electronics, the printing industry starts to get new hope for a renaissance, [Huebler, 2003].

3.4.2 Evolution of the printing processes

As it regards tendencies in the development of different printing processes, during the next years the offset printing will be at the top of all printing processes. A further automatization will simplify the process and decrease the costs. Nevertheless digital printing and flexographic printing will take away market shares from the offset printing. On the field of the packaging printing the flexographic printing is continuously extending its market position by increasing importantly. The machines are simple, robust and very economical [Doersam, 2004].

Nonetheless, printing processes may enable electronic components manufacturers to produce them in an efficient and cost effective way. A lot of development is going on and some solutions already exist. As far as RFID is concerned, printing antennas simultaneously with board packages is already foreseeable and could save one step along the line, all the more so as papers or board containing chips are already produced. The large variety of printing processes may eventually lead to printing all components of an RFID device. The applications in the packaging market could then be countless [Blayo and Pinaeux, 2005].

3.4.3 Printing processes and smart packaging

IDTechEx has attempted to classify the suitability of each printing process regarding the current printing of smart packaging applications/elements as it is shown in Figure 4.

	Ink jet	Screen	Offset litho	Thermal/ ablation
Experience and intentions	This is the favourite process of the 30 or so developers of TFTCs partly because they wish to deposit on undulating polymer films without masks. Xerox and Plastic Logic are examples	Favourite process for conductors, dielectrics, passivation layers, electroluminescent layers, antennas and batteries when printed because it gives thick layers at one pass to compensate for the primitive nature of many electronic inks	Mainly a hope for the future as inks improve e.g. Poly IC TFTCs, X-ink for conductors.	Not receiving much attention
Resolution	Fair	Poor	Good	Fair
Production speed	Low	Low	High	Low
Platemaking cost	None	High	Low	Nione
Ink volume	Low	High	Medium	medium
Thin print possible	Fair	No	Yes	Fair
Thick print possible in one pass	Yes	Yes	No	Medium
Particulates tolerated	Yes	Yes	Yes	No
Soluble polymers tolerated	Yes	Yes	Yes	Yes
Great variety of inks	Yes, particularly piezo	No	No	No

Source: IDTechEx

Figure 4: Printing processes for smart packaging
Source: IDTechEx

In addition, according to Baumann (2006), printing industry is today a champion in cheating the eye! Printing industry can contribute to new forms of packaging by adding new elements to colors and separations. This can be realized by building layers of functionality, made by printing. According to Baumann, all major printing processes - namely flexo, offset, gravure, Ink-jet and Toner based digital printing can be established in electronics fabrication. The existing printing and finishing processes can integrate OLED or sensors, various indicators, batteries, and they can print/produce organic semiconductors, such as conducing polymers and transistor patterns [Baumann, 2006].

Baumann concludes with a classification of future manufacturing of functional printed products for future packaging applications. Based on this classification the modular printing system can combine traditional printing with the process colours (CMYK), circuits consisting of antenna, wirings, transistors diodes and batteries) (printed with additional colors) and the integration of additional elements such as supplemental electronics [Baumann, 2006].

Furthermore based on an analysis by Fraunhofer Institute, "roll to roll (reel to reel) manufacturing technology can be applied for printed electronics and smart packaging applications". As Bock points out, UV-lithography, flexo and screen printing as well as coating, laminating and die-bonding processes can be applied for producing various forms of electronics such as polymer transistors [Bock, 2006].

OMET and XINK companies, have already printed antenna with flexographic methods. Research conducted has led to the development of the production and testing of flexographically printed UHF antennas on paper. For this purpose, OMET has dedicated their new FlexO press to these trials at their new technology center, where it can be used to produce pilot quantities of UHF printed antenna on substrates ranging from PET, to paper, to liner board. Xink Laboratories has teamed with OMET to develop and test RFID products using water-based flexographic printed antenna technology. Recent

RFID antenna printing tests at OMET on a Flexo press have produced exceptional quality XINK antennas at speeds of up to 200 m/min (650 ft/min) [Xink, 2005].

In addition, as it regards gravure, conductive circuits have been printed by gravure. Omron has used an aluminium-etched circuit as the conductive material for Strap PCB and under testing use of aluminium as an antenna material for UHF band RFID tags. Etching the tag circuit is made following this process; put a resist layer conformed to each circuit pattern on the aluminium layer laminated to a film base made of PET or equivalent material, and then dissolve away the metals exposed under the resist layer with a chemical. Normally, photolithography is used to make the resist layer. Note: This method requires a chemical process to dissolve the resist layer away. The gravure printing is the most popular and economical printing method currently available. It enables Strap PCB and antenna circuits to be produced at higher speed, in larger quantities, and at a lower cost than other methods. On one production line, 100.000 pieces of UHF antennas per hour can be produced [OMRON, 2004].

Concerning digital printing, inkjet (inkjet - thermic) and the diffusion technology (dye sublimation), have presented applications in the antenna printing and in the incorporation of a chip on the substrate. but they have limited possibilities of high volume production [Menegon, 2005]. Furthermore, INDIGO presented a high quality digital and security printing of RFID smart labels.

Another interesting option is the one presented by XAAR. XAAR claims to be the leading inkjet print head partner in printable electronics and displays, being active across a number of entry points in the industry, including printed circuit boards, displays, electronics, packaging & labeling. The XAAR intensive research includes applications on packaging end labeling, coding & marking, printed circuit boards, flat panel displays and printed electronics [XAAR, 2005].

3.4.4 Changeable inks

Another research effort has led to the introduction of colour separation with dynamically changeable inks. Johansson and Kruse suggested that with dynamic image reproduction it is possible to add more information to the printed product. The dynamic images in this study consist of conventional process ink layers combined with dynamic ink layers that can be brought to different optical states where they display a certain colour or turn transparent, thus revealing the underlying process ink [Johansson and Kruse, 2005].

3.4.5 Printed antennas

Based on data derived by EPCglobal, printed antennas are really very easy to produce. The antenna is attached as a flat structure to a substrate. The next stage in the production process often involves attaching the chip to the substrate and connecting it to the antenna. This assembly is called an inlay. An inlay becomes a tag or transponder when it is fixed to an adhesive label or a smart card. It must be noted, however, that the electromagnetic properties of the materials surrounding the inlay affect the tag's ability to communicate. In extreme cases, tags cannot be read if unsuitable reader antennas are selected [EPCglobal, 2005].

3.5 Smart packaging printing workflows

According to Baumann and Weiss (2005), the packaging production workflow, with the integration of printed electronics, tags or antennas is structured in the following way:

- Design and print antennas (with semiconductor ink),

- Print (texts, images, graphics, colour printing),
- Put a chip (at the necessary point),
- Lamination,
- Folding/transformation/transfer/distribution [Baumann and Weiss, 2005].

Bielomatik suggests a range of solutions concerning integration of smart packaging applications on packaging substrates. In Figure 5 this workflow is presented.

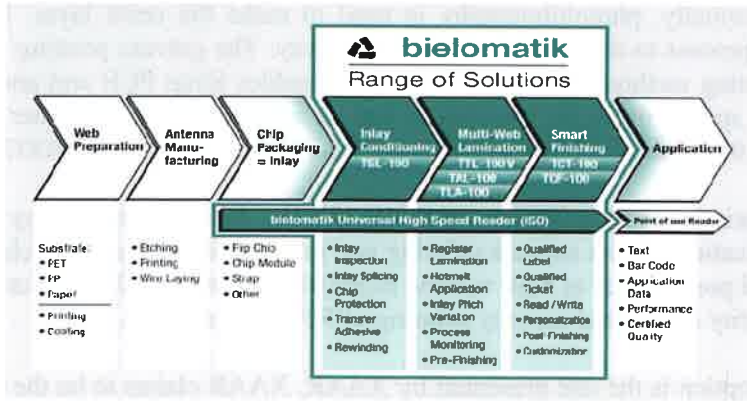


Figure 5: RFID System: - The Principle of Operation
Source: Bielomatik (www.bielomatik.com)

Furthermore, according to a Precisia presentation, RFID is a first step towards truly smart packaging into the supply chain. However, the application of relative strengths and weaknesses of using RFID inlays or labels, vs. RFID integrated into packaging need to be addressed. An important issue is to use existing printing processes to achieve low cost antennas. An approximate percentage of 80% of bar codes are currently printed on the package. However, around 20% (billions and billions) are attached as labels. For RFID, this ratio will likely start at 99+% labels or inlays. The equilibrium value in 5 years may still be 50% [Precisia, 2004].

Finally, Kahn suggests further a pathway to adoption of printable electronics on to a package. This adoption can be made:

a) By the attachment of complete tags to items, either with antennas made by etching or antennas made by printing,
b) Print antennas on item by attaching the chip,
c) All printed - by printing the antenna and the electronics All Printed [Kahn, 2005-1].

4. Discussion

The survey has indicated that there is a huge potential market for the so-called "smart" applications. This field is of high interest for many industrial and commercial activities and for a quite diverse range of sectors. Particularly, the IT industry, the electronics, the material science and its developments as well as automation (with the new field of Automatic Identification) seem to be the areas of significant technological development.

Packaging is one of the sectors where the "smart" applications are of significant interest, among the totality of the retail production chain. Smart packaging printing seem to be interesting in this context, only as it concerns the capability of the existing printing methods and processes to print the new substrates or to integrate the smart elements on to the package.

A first result from these findings is that packaging printing production will have to adapt to the new demands of the retail market and industry, whatever this means for the traditional printing companies as it regards changes in production, equipment workflow and management.

Currently, there is a noticeable struggle on the issues of the technology that will be established in the market as the dominating application. RFID seem to take the lead, however, its application are to be currently found in secondary packaging, transport and identification in storages and pallets. Printing of RFIDs, are mainly labels, which are attached as normal labels on to the packages.

The RFID technology is competing with the printed electronics field of development, namely the organic polymers, where the active carrier is the substrate itself. Such a development can be applied at consumer packages offering the possibility for extending smart packaging applications to everyday life within the supply chain of products and goods.

The study revealed that the majority of smart packaging elements (tags, antennas, printed polymers) are thin, flexible and printable with all major printing processes. However, an issue of importance is whether smart packaging applications will be based on the direct printing of these elements on the substrate or will be taking place following various inlay processes (such as laminating or embossing of preprinted tags for example on the printed substrate).

As a result, the smart packaging applications are currently realized by the three major processes:

- As labels to be embedded on the package substrate.
- Through direct printing, mainly on new substrates with "smart" characteristics.
- Via an inlay process (e.g. mainly laminating or embossing).

For the time being, the production of smart applications for packaging, seem to be based on labels. However, the other technologies evolve further and, consequently it is not possible to make an accurate prediction on which technology will be the most applicable.

5. Conclusions

The present survey resulted in that only some general recommendations can be done, as it concerns the implications of smart packaging developments for packaging printing companies. These recommendations can be summarized as follows:

All major printing processes will be used in smart packaging applications. Packaging design, prepress and plate/cylinder making does not seem to be affected at present, although the gradual integration of smart packaging applications is expected to lead to changes in these production fields.

However, as technological developments evolve as it concerns new substrates, printable electronics, inks and layers, it is quite possible that printing processes will need to be adapted into new production environments. To give an example, investments might be required for the application of quality control of antennas, the activation of tags or the verification of smart elements on to the package.

Such a progress will surely require changes in production workflow and its management, calling for alterations in the production workflow, new investments in machinery and equipment, the integration of new/additional processes, and additional quality controls. In addition, the packaging printers will need to cope with new materials and substrates. One of the most important issues is the new competence that will be required for the smooth and effective integration of new processes of smart applications in the traditional packaging printing production.

A final outcome from the present survey is that packaging printing production will change. An open question remains how soon and in which extend such changes will occur. Such an issue requires additional research to be carried out. And it is also a challenge in entering new fields in research, extending the graphic arts scientific field.

6. Future research

One significant issue to examine further is the suitability of each printing process for the integration of smart packaging applications. An additional further study might be useful to be carried out on the specific graphic arts production processes classified in to the following sub-production fields:

- The process in the prepress field (digital files, digital workflows, output for printing machines and systems).
- The process of printing forms (offset plates, gravure cylinders, flexographic plates)
- The inks to be used in smart packaging applications (thermochromic inks, semiconductive inks etc.).
- New technical requirements for the printing machines operating for packaging printing.
- Finishing of smart packaging application (e.g. chip integration on the packaging substrate).

Another issue that might need to be revisited is packaging design. It might be required to think over new design approaches, which need to take under consideration the structure of the smart packaging elements (dimensions, colours, shapes, integration into the package surface). Should a new concept for package design be necessary or it will be enough to leave an empty space for inserting the smart packaging element?

As a conclusion, clear answers are required on the issue of changes that are expected to happen in the traditional packaging printing production towards the integration of smart packaging applications.

Finally, a range of various implications will possibly occur and these need to be addressed for future study. These include the appropriate procedure to implement smart packaging applications, the orientation of investments, the management attitudes and requirements and the competence characteristics of the human capital.

References

1. Abbot, (1989) Abbot D., A.: "Packaging Perspectives", Kendall/Hunt, Dubuque, IA, 1989
2. [Baumann, 2006] Baumann R: "Printing electronics ... from the perspective of a commercial press maker", MAN Roland Druckmaschinen AG, Presentation at IPEX, Birmingham, UK 2006
3. [Baumann and Weiss, 2005] Baumann, R. and Weiss, R.: "Industrial Printing - Opportunities for Polymer Electronics", MAN Roland Druckmaschinen AG, in the Printed Electronics Europe conference., Cambridge, UK, 2005
4. [Benchmark Research, 2006] Benchmark Research Ltd, www.benchmark-research.co.uk
5. [BITCOM, 2005] Bonn, H., P.: "RFID White Paper - Technology, Systems, and Applications", BITKOM - German Association for Information Technology, Telecommunications and New Media e.V., Germany, 2005
6. [Blayo and Pinaeux, 2005] Blayo, A. and Pineaux, B.: "Printing Processes and their Potential for RFID Printing" Oc-EUSAI Conference Grenoble, October 2005
7. [Bock, 2006] Bock, K.: "Reel to reel manufacturing of printed electronics and systems" Polytronic Systems Department Fraunhofer Institute IZM, Germany, 2006
8. [Cooney and Winkless, 2003] Cooney, J. and Winkless, B.: "Utilising TRIZ methodologies to evolve and develop next generation food packaging concepts", University College Cork, Ireland, 2003

9. [Doersam, 2004] Doersam, E.: "Tendenzen in der Entwicklung verschiedener Druckverfahren (II) Tendenzen in der Entwicklung verschiedener Druckverfahren (II)", ZELLCHEMING-Hauptversammlung 2004, Institut fuer Druckmaschinen und Druckverfahren, TU Darmstadt, Germany, 29 June 2004
10. [EPCglobal, 2006] EPCglobal Inc.: www.EPCglobalinc.org.
11. [Huebler, 2003] Huebler, A. (2003): "Printing in the Electronic Age - Challenges and Opportunities" Published October/November 2003
12. [Harrop, 2005] Harrop, P.: "Operations in Smart Packaging", IDTechEX, presentation, 19-20/ April/2005 Cambridge
13. [Hecker, 2006] Hecker, K.: "Organic Electronics Association", www.oe-a.org, VDMA, Frankfurt, Germany 2006
14. [IDTechEx, 2005] 19-20/4/2005 "Reports in Smart Packaging", IDTechEx, April 2005, Cambridge
15. IDTechEx, (2005-1) Ranghou Das, "Printed Electronics White Paper - Technology Overview and Applications" IDTechEx Ltd., UK, 2005
16. [Johansson and Kruse, 2005] Johansson, L., Kruse, B.: "Colour separation with dynamically changeable inks" Center for Creative Media and Technology, Department of Science and Technology, Linköping University, Sweden, 2005
17. Kahn, (2005) Kahn, E., B.: "Printable electronics" Imaging & Photographic Technology; Materials Science & Engineering Rochester Institute of Technology Rochester, NY, USA, 2005
18. Kahn, (2005-1) Kahn, E., B: "Presentation on RFID", Wisconsin RFID Conference, Waukesha, WI, June 22, 2005
19. [Lindner, 2005] Lindner T.: "HP- Technology beyond, Ink on Paper", Printed Electronics Conference, Cambridge, UK, April 25, 2005
20. [Menegon, 2005] Christian Menegon, Ch., Industrial Printing Presses HP Indigo, U.S. Presented at Printed Electronics Europe 2005, Cambridge, UK, April 25, 2005
21. [MIT, 2004] MIT Auto-Id Labs, Presentations, MIT USA April 2004
22. [Nomikos et al, 2005] Nomikos, S., Politis, A., Darzentas, J., Spyrou, Th., Darzentas, John: "Exploring cross-media concepts for future packaging - Challenges for the printing industry" Proceedings, 32nd IARIGAI international conference, 4-7 September 2005, Porvoo, Finland, p.p.317-319
23. [OMRON, 2005] OMRON: "Technology to produce RFID tags", June 02 2005, OMRON Corporation.
24. [Pfizer, 2006] www.pfizer.com/counterfeit/viagra/rfid
25. [PIRA and IDTechEx, 2005] Pira International and IDTechEx: 'Intelligent and Smart Packaging", Pira International and IDTechEx conference, 25 and 26 January 2005, The Wyndham Resort, Orlando, USA http://www.idtechex.com/intelligentsmartpackaging/en/index.asp
26. [Precisia, 2004] Lawrence, D.: "REvolution of RFID into the supply chain", Precisia Presentation, Las Vegas, January 2004
27. [Roos, 2005] Roos, J.: "The reality of the RFID" Corporation-2005 CERT Conference, Nebraska 10 August 2005
28. [VTT, 2002] Heilmann, J., Juhola, H. and Linna, H.: "Communication and brand protection of consumer packages", VTT Information Technology, Finland, 2002
29. [Yam et. al., 2005] Yam, K., L., Paul, Takhistov, T., Miltz, J.: "Food packaging", Journal of Food Packaging, Vol. 70, Nr. 1, 2005
30. XAAR, (2005) XAAR TECHNOLOGY: "Radical Print Head Technology for Manufacturing Printed Electronics", XAAR, Sweden, 2005
31. [Xink, 2005] Xink Labs Ltd.: ""High-speed printing is the most feasible option to supply RFID tags in the high billions" Ottawa, Ontario, Canada, September 2005



Quality requirements in magazines' value chain

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1. Introduction

The competition in the printing industry in Western Europe is tough due to the saturation of the print markets. In Finland the print industry concentrates on the national markets and only a few companies have invested on exporting. Traditionally printing houses compete with the price, which, in the long run, can be harmful for the whole line of business. The print industry needs to invest on the co-operation and networking within the industry as well as with closely related lines of business. The key issue in the survival of the print industry is to offer the services that customers want and need. [1]

Based on the report by Finnish Forest Industries Federation and Finnish Paper Workers' Union [2] the forest industry in Finland is facing very similar challenges to the print industry. The profitability of the paper companies is weak. There is a severe over-capacity among several paper grades in Europe. The paper prices are low. The report suggests that the research and development in the forest cluster should be shifted towards the end of the value chain, i.e. based on the needs of the consumers and advertisers.

This paper describes *the requirement analysis method*, which can be utilized as the primary step in the product development process. The aim of the requirement analysis is to take the customer perspective into account already in the very beginning of the paper development. Current product development process in the paper industry is strongly focused on improving the effectiveness of the paper making process as well as enhancing the technical properties of paper. At the moment, the need for product development is strongly technology driven. Customer needs are highly valuated but the practical solutions for taking them into account are not yet developed.

2. Methods

2.1 Data gathering

The information on the important quality requirements of different customer sectors was gathered by interviewing several professionals in each sector of the magazine's value chain. Magazine's value chain is illustrated in Figure 1. The target of the interviews was to clarify the processes in and between different sectors throughout the product's value chain. Furthermore, the aim was to identify the most important requirements set to the product as well as other actors in the value chain. A semi-structured interviewing method (focused interview) was used. Interviewing themes were set beforehand for all interviews, but the actual questions and the order of questions could vary every time. [3]

The interviewees in each sector were selected to represent all actors in the sector. In the publishing sector, the selection criteria included also aspects concerning the size of the publisher and different

roles of the professionals. For example, both the business expertise and the journalistic expertise are represented. In the printing sector, the size of the printing house was a variable in selecting the interviewees. All interviewees were Finnish. The interviewees are presented in Table I.

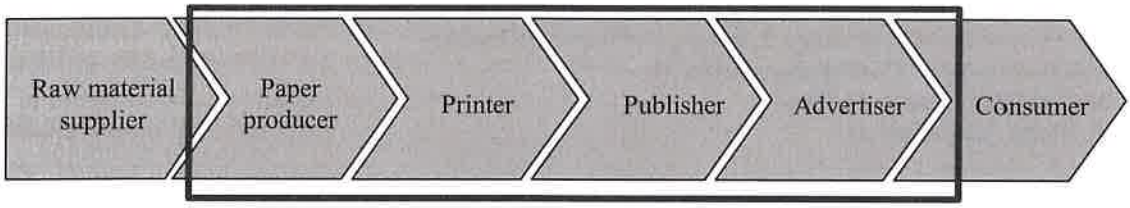


Figure 1: Actors in magazine's value chain

Table I: Interviewees in different sectors of magazine's value chain

Sector in the value chain	Employment	Number
Advertiser	Photographer studio	1
	Reproduction	2
	Advertising agency	4
	Media Agency	2
	Advertiser	2
Publisher	Large publishing company	3
	Small publishing company	2
Printer	Large printing house	2
	Small printing house	2

The interviews were conducted from the following themes:

- Production process in each sector;
- Connections with other sectors, responsibilities;
- Factors that have effects on product's quality;
- Future of magazine publishing.

2.2 Linking the customer requirements with product's properties using Quality Function Deployment (QFD)

Quality function deployment (QFD) is a tool for converting the customers' demands into quality characteristics and developing a target quality for the end product. These are achieved by systematically analyzing the relationships between the demands and characteristics starting with the quality of each functional component and extending the deployment to the quality of each part and process. The overall quality of the product will be formed through this network of relationships. The Quality Chart (Figure 2) is the tool used to assist in the conversion of customers' demands to corresponding quality characteristics. Quality Chart is a two-dimensional matrix consisting of a demanded quality chart (Customer Needs and Benefits), combined with a quality characteristics deployment chart (Technical Response). Combining the two matrices expresses the relationships between the qualities and quality characteristics in demand. Planning matrix is used to prioritize the customer needs, the present state of the company and the sales arguments. Technical matrix is for benchmarking the product's behaviour in the market. [4, 5, 6]

In the requirement analysis the QFD is utilized in linking the needs of the customer sector with the means of the previous sector in the value chain. Different sectors of the value chain are linked together using interrelated QFD matrices, where the technical matrix of the producer will be used as the customer needs and benefits matrix in the next House of Quality. For example, in the first House of Quality the

needs of the advertising sector are listed as Customer needs and benefits and the Technical response chart includes the means of the publishing sector. The Technical matrix contains the most important features of magazine publishing based on the advertisers' needs. The second House of Quality contains the needs of the publishing sector listed as the Customer needs and benefits and the Technical response chart includes the means of the printing sector. The third House of Quality contains the needs of the printing sector as the Customer needs and benefits and the Technical response chart includes the means of the paper production sector.

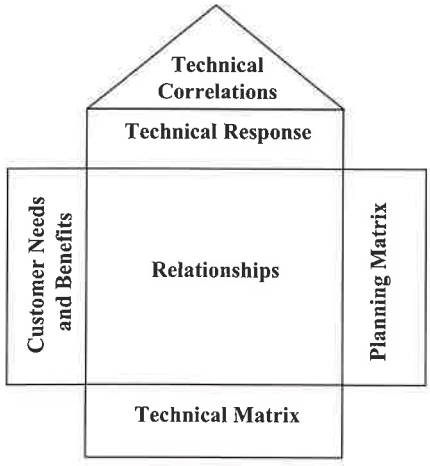


Figure 2: House of Quality [4]

3. Results

3.1 Needs in the advertising sector

In advertiser's point of view the most important quality factors of a magazine as an advertising medium are its audience and editorial content. The definition of target group is changing from an age-perspective to a lifestyle-perspective. Also the values, attitudes and habits of the readers are of interest to advertisers. Magazine's appearance, editorial content and advertisements should convey the same message to the reader. Advertising sector appreciates information about magazine's image and any changes in it. The customer deployment chart of the advertising sector was conducted based on the data from the interviews (Table II).

Magazines are a typical example of a product which combines aspects of a physical end product and aspects of service. The physical end product includes the appearance of the magazine - the layout, the printing and the paper. Also the special effects in advertising are included in the physical product. The service part, on the other hand, includes the target group - the definition of the target group, the penetration in the target group, information on how the target group reads the magazine, etc. Also the editorial content is part of the service. In this study, the different roles of magazine were taken into account by dividing the information from interviews in publishing sector into two groups: physical product and service. The groups were analyzed separately. Based on the interviews, the publisher means were deployed according to the quality characteristic deployment chart (Table III).

With QFD the correlations between advertiser needs and publisher means were estimated and the most important publisher means in advertiser's point of view were identified. When we consider magazine as a physical product, the most important properties are:

- Information on a reform and definition of a reform,
- Visual quality,
- Picture rendering (dependent on paper properties),

- Picture quality (printing house responsible),
- Feel of paper,
- Magazine's layout harmonious,
- Flexible choice of paper in advertisements,
- Flexibility in printing.

Table II: Advertisers' needs deployment chart

1st level	2nd level	3rd level
Message reaches its target group	Definition of the target group	- Knowing the reader - Knowing the reading habits
	Reaching the target group	- Penetration in the target group - Advertisement awakes interest
Advertisement fits into the magazine	Editorial content and advertisements are in line	- Magazine's image is defined - Constant image
	Magazine's pleasant appearance	- High-quality paper - Pleasant feel - Luxurious pictures - High-quality printing - Layout beneficial for the advertisement
Advertisement is designed for the magazine	Specifications for the advertisement	- No limits for imagination - Advertisement's size versatile - Advertisement's shape versatile - Versatile colours - Possibilities for special effects

Table III: Quality characteristics deployment chart of magazine publishing

1st level	2nd level
Magazine as service	- High-quality content - Planned content - Readers
Magazine as physical product	- Information on changes - Appearance - Flexibility in realization

These properties can rather easily be linked with paper properties, but when we consider magazine as a service, the links to paper are far from obvious. The most important magazine properties in the case of service are:

- Knowing the reader: databank of advertisements, reader profile, penetration in the target group, national media survey, popularity of articles,
- Reader is committed to the magazine,
- Content is defined,
- Advertisement suits the magazine,
- Yearly plan for the content,
- Magazine's brand is the basis of the paper selection.

3.2 Needs in the publishing sector

For a publisher, the magazine's appearance and high print quality are important. In addition to that, also the process from the editors to the reader should run smoothly and without errors. The appearance of the magazine is affected by the printing process and the paper. Of course the layout and planning of the

appearance are important factors, but they are the publisher's responsibility. The appearance and high print quality are defined as visual quality and the feel of paper. Visual quality depends on the reproduction stage, i.e. screening and colour separation, on printing parameters and on paper. The faults in quality are e.g. misregister, differences between two sheets when the picture continues from one sheet to another, hue or colour errors, too much variation in print, ghosting and paper waviness. The feel of a magazine is affected naturally by the paper choice, but also printing has an effect on the feel.

Table IV: Publishers' need deployment chart

1st level	2nd level
Service from the printing house	- Good relationships with the printing house - Good technical facilities - High efficiency - Trustworthiness and fast scheduling - Flexibility in service - Long relationship important - One printing house is used - Information on the usage of other printing house - Printing house consults in paper selection - Publisher is willing to buy the paper in the future - Printer must be satisfied with the paper
Magazine's pleasant appearance	- Visual quality - High quality level - Even quality - Colours are correct - The difference between two pages is critical - Perception is important - Colour gamut is important - Good rendering in advertisements - Paper is good enough - Adhesive binding - Dispersion varnish on covers
Avoiding quality problems	- Ghosting problem - Cutting problems are significant - Binding mistakes - Register problems - Problems in colours - Too much variation in print quality
Paper properties	- Waviness is current problem - Brightness development typical - Attractive feel of paper - Paper selected according to magazine's brand
Flexibility for new solutions	- Different paper in advertisements - Flexible printing solutions - Added value from hybrid media - Versatile special features

The process from the printing house to the consumer involves the printer, including printing and finishing, paper supplier, other suppliers, and delivery. The problems in this chain include finishing problems, e.g. in cutting and binding and problems in the availability of materials. For example, the printing house may run out of a certain paper. The availability related issues are not negotiable; on the contrary they might be the reason to change the supplier. Table IV illustrates the customer deployment chart of the magazine publishing.

Printing houses offer solutions for the customer instead of just putting four colours on the paper. For example, they offer consulting in selecting the paper, as well as training in prepress activities. They are willing to take as large a part of the customership as possible. Nowadays customers usually deliver the material in PDF-format and, thus, the printer's role in the beginning of the process has been diminished. However, the printing houses are paying more attention to process and quality control.

Printing house has rather an important role, when a paper brand is selected for the magazine title. In Finland, the publisher defines the paper properties, even the paper brand, but the printing house consults the customer and also buys the paper. The deployment of quality characteristics of magazine printing is presented in Table V.

Table V: Quality characteristics deployment chart of magazine printing

1st level	2nd level
Customer relationships	- Customer relationship management - Printing house offerings
Workflow in the printing house	- Workflow of the content - Production control - Line of business
Print quality	- Definition of quality - Printer's tools in print quality formation - Colour control
Selecting the paper	- General criteria - Selecting the paper brand - Paper properties
Special features	- Technical solutions

With QFD the correlations between publisher needs and printer means were estimated and the most important means in customer's point of view were identified. The most important properties are:

- Customer delivers the material in PDF-format,
- Printing house checks the PDF,
- Quality control is rather systematic in printing house,
- Automatic colour control system,
- Quality controls stripe is used to guarantee that process is running smoothly,
- Print quality controlled with on-line spectrophotometer,
- Closed register control,
- Quality tolerances are agreed beforehand,
- Printer decides the acceptable deviation in print quality,
- Control of grey balance,
- Target density is based on printer's experience,
- ICC profile of the printing house has been delivered to the customer,
- Publisher decides the paper,
- Printer consults in selecting the paper,
- Tools in selecting the paper: paper samples, printed sample books, dummy magazines,
- Pilot printing,
- Printing house offers its basic paper selection,
- Covers or covering sheet in different paper.

4. Discussion

Earlier studies on customer needs in paper industry have concentrated either on the customer's side [7] or on the paper company's side [8, 9]. In our study we are focusing on linking these two sides together

with the requirement analysis method. The requirement analysis presented in this paper is an application of existing methods in a new area. The method is verified with high-quality magazines in Finland. It is typical for method verification that some simplifications are needed, for example in this case the interviews are limited to Finland and the magazine's quality level is specified. However, the method is applicable to other products as well. The requirement analysis method is considered as the initial step in paper development process. Thus, even more focusing would be appropriate in order to achieve detailed information on customer needs concerning a particular product.

The data gathering process with interviews is rather time consuming and requires careful planning. Selecting the interviewees has to be considered thoroughly. In this case the interviewees were professionals in their field and they had a possibility to influence on the decisions concerning co-operation with other parts of the value chain, for example printing and paper. However, they were not the persons making the final decisions. These criteria were selected in order to get a fresh and simultaneously realistic look on the area. Using different criteria in selecting the interviewees might have influenced the data.

In the requirement analysis the Quality Function Deployment method is applied in quite an untraditional manner. Traditionally the analyzing of the relationships between customer demands and product characteristics starts with the quality of each component and continues to the quality of each process. In our case the components are the properties that the publisher offers to advertisers and the final part is linking the customer requirements throughout the value chain with paper properties. In addition, traditionally the product characteristics are technical properties, but in this case they could be also immaterial goods. This requires interpretation of the data. Due to the application, the QFD matrix and the following conclusions could vary quite a lot depending on the persons constructing the matrix. QFD has been used already earlier in paper industry, for example Jernström [7] used it in competitor comparison. In our approach QFD is used in finding new paper properties that are relevant for the customers.

According to the results, the services offered to the customer are highly valuated throughout the value chain. However, the role of paper in the service part, especially when we consider magazine as a service for advertisers and readers, remain unclear. "*Paper is selected based on the magazine's brand.*" What does this statement mean in real life? The definitions in the magazine's brand are related to images of the product and the reader. These are quite far from the definitions of a paper brand, which are mainly the technical properties of the paper. For a paper producer it would be important to know what kind of images are related to their papers, and further, how these images can be developed. Further research in this field is required.

5. Conclusions

Requirement analysis is a useful method for taking the customer perspective into account in the paper development process. With requirement analysis, the paper producer gains more knowledge on the customers' business throughout the products value chain and enables the link between customer requirements and paper properties. The requirement analysis can be utilized to help the paper producer offer a suitable paper for a certain end product, as well as producing linking information for the paper development process.

The requirements set to the magazine's quality are different in different parts of the value chain. Advertisers' needs concentrate on the target group and the media environment offered. They describe paper through senses and images that they awake. Based on the advertisers' needs, the magazine concept can be divided into a service part and a physical product. Service means information on readers, their reading habits, values and attitudes. Service means also the definition of the media environment including the magazine's brand, content and image. Physical product includes the

appearance as well as the technical production. Publishers' needs are related to the magazine's quality and smooth co-operation with the printing house. Publishers describe papers through their visual properties and overall appearance. Also paper's effects on costs, e.g. paper price and delivery costs, are important for the publisher. Printers appreciate punctuality in the delivery of the content and also technical competence in preparation of the content for printing. Printer's role has changed towards consulting the customer in material preparation as well as in paper-related issues. The most important paper properties for the printers are related to the paper's technical performance on the printing press.

Paper has an important role in communicating the magazine's brand. Customer needs for the end product are valuable information for paper producers in order for them to understand the issues that are valued in the magazine's value chain and should be linked with paper. The challenge in linking customer needs with paper properties is the lack of appropriate knowledge on images related to paper. Also the correlations between measurable paper properties and images are not studied in a comprehensive manner.

References

1. Pönni, V., (2006), *Suomalaisen painoalan kilpailukyky, Turku School of Economics and Business Administration, Business Research and Development Centre, B3/2006, 280 p.*
2. Anon., (2006), *Paperiteollisuus - toimialan tilanne ja tulevaisuuden haasteet, Paperiteollisuuden tulevaisuustyöryhmän raportti, 31.5.2006, 97 p.* URL: http://www.metsateollisuus.fi/files/newsletter/Paperiteollisuus_loppuraportti_31-05-2006FINAL.pdf 14.6.2006
3. Hirsjärvi, S. & Hurme, H., (1980), *Tutkimushaastattelu. Teemahaastattelun teoria ja käytäntö. Yliopistopaino Helsinki, pp. 41-48*
4. Karjalainen, E. E., (2004), *QFD - Asiakaslähtöinen suunnittelu. December 4-5, 2004, Espoo. 106 p*
5. Mitsufuji, Y., Uchida, T. & et al, (1990) *Using and Promoting Quality Charts. Quality Function Deployment. Integrating Customer Requirements into Product Design, Y. Akao (Ed.). Productivity Press, pp. 53-81*
6. ReVelle, J. B., Moran, J. W. & Cox, C. A., (1998), *The QFD Handbook. John Wiley & Sons, 410 p*
7. Jernström, E., (2000), *Assessing the technical competitiveness of printing paper. Doctoral Thesis. Acta Universitatis Lappeenrantaensis 95. Lappeenrannan Teknillinen Korkeakoulu, 156 p*
8. Haarla, A., (2003), *Product differentiation: Does it provide competitive advantage for a printing paper company? Helsinki University of Technology, Laboratory of Paper Technology, Reports. Series A17, 238 p*
9. Kalela, E., (2005), *New business opportunities for printed media: Coated paper for coldset printing, Helsinki University of Technology, Laboratory of Paper Technology, Reports, Series A24, 55 p*

Separation of publishing and printing production in daily newspapers

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1. Introduction

Ifra commissioned the Québec Institute of Graphic Communications (QIGC) to conduct a survey on the separation of printing and publishing in the daily newspaper market. The project was initiated by Mr Manfred Werfel, Research Director and Deputy CEO, and Mr Jochen Dieckow, Business and New Media Research, both from Ifra.

The newspaper publisher as an "all in one" company that includes all of the organisational units necessary to create and produce a newspaper, while still predominant, is no longer the rule. More and more publishers are examining their organisation's set-up to analyze and redefine their core competence. This process is increasingly leading to the separation of print production from the publishing business. This separation takes place in different ways, but the main variants are:

- establishment of a profit centre that is owned by the publisher and acts on its behalf,
- creation of a joint venture production company bringing together different newspaper publishers,
- outsourcing of print production to a third party.

This trend is strengthened by market and external factors. Publishers' revenues are under pressure and investment in production facilities is very expensive. Besides the issue of new investments, economic pressure forces many publishers to reduce their operating costs and slim down their organisations. One option is therefore to change the organisational set up of print production.

If the core newspaper product does not achieve a sufficient level of printing capacity usage, then it becomes even more important to consider a different approach to production. Improved performance of printing presses combined with more favourable conditions for marketing concepts (such as distributed printing) will also influence the re-think of how production should be organised in the future.

The newsprint medium is dynamic. Due to the demands of both readers and advertising customers, as well as new technical developments, the newspaper as a product is changing. Format changes, lower page counts, shrinking circulation, late editorial deadlines, and more colour requirements (almost magazine-like) newspapers are the most prominent trends defining the new requirements for production workflow at many newspapers.

2. Objective

This study is dedicated to investment strategies. It focuses on the efficiency of the various models and technologies needed to achieve objectives related to the printing strategy.

This research aims to identify the distinctive features of the current best performing printing strategies. The results should provide guidance for a decision-maker facing this difficult choice (the separation of printing and publishing). Finally, it should also help newspaper publishers in developing effective business printing strategies best suited to their specific needs and markets.

3. Research method

A case-study approach was chosen. Two representative cases were selected for each of the following business printing models studied (see figure 1):

- Cost centre, integrated print production: Publishing company keeps production operations internally to print owned titles (status quo),
- Profit centre: Publishing company organizes its production facilities into a fully-owned, profit-oriented company, which has to refinance itself to a large extent on the market,
- Joint venture: Different newspaper publishers own and operate a joint production facility,
- Outsourcing: A third party prints the newspaper.

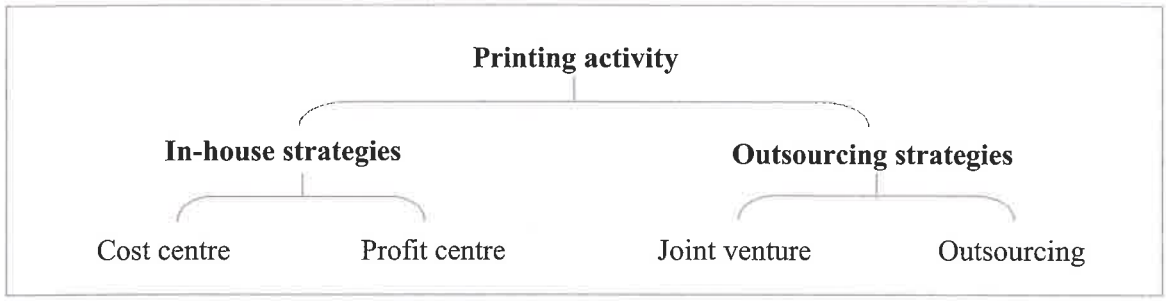


Figure 1: Four alternative printing strategies were defined

3.1 Methodology

Data was collected via two separate means:

- A written questionnaire was first sent to each participant. It was split into 4 sections to collect factual data. It was designed for the general manager or vice-president of operations of publishing companies, or any other person heavily involved in the project.
- An interview was conducted to supplement the questionnaire. *When necessary, both technical and business executives were interviewed to collect as much relevant data as possible.*

Ifra created a working group composed of Ifra and QIGC members, together with representatives from some of the selected cases from the publishing or the printing side.

A first meeting aimed to specify the mandate and define the main objectives, methodology, deliverables and time frame of the study. Two other working sessions also took place to share objectives and methodology with participants, review the written questionnaire, and present a preliminary report to the working group.

3.2 Case selection

The selection of the case studies ensured that they were comparable in terms of circulation and age of equipment. A number of criteria were determined to choose the case studies:

- Minimum circulation of 100,000 copies,
- Similar page count,

- Major investments within the last 3 to 8 years (maximum 10 years) in the printing pressroom,
- Remote printing excluded.

The following cases were studied:

- Cost centres
  - St Galler Tagblatt (Switzerland),
  - The Chicago Tribune (United States).
- Profit centres
  - Bonnier Group (Sweden),
  - Westcountry Publications (England).
- Joint ventures
  - Politiken and Berlingske (Denmark),
  - DZO Druck Oetwill am See AG (Switzerland).
- Outsourcing models
  - La Presse (Canada),
  - The Globe and Mail (Canada).

3.3 Presentation of the results and analysis

Data gathered from both the interviews and the questionnaire was analyzed from a publisher's point of view, and structured by topic. For some sections and when relevant details were available, the results are commented on separately by strategy. The stories of the case studies illustrate the analysis.

An overall conclusion brings together the specific conclusions. The differences between the strategies are highlighted and commented upon.

4. Comparison of business strategies - analysis and synthesis

4.1 Definitions and main challenges of the business models studied (Table I)

Table I: Definitions and main challenges of the business strategies studied

Model	Definition	Main challenges
Cost centre	Integrated print production: the printing activity is a service to the newspaper, which incurs expenses, but does not generate revenue directly. The objective is to control costs. *A publisher tries to minimize total costs with incidental revenues (generated by external printing contracts).*	Press utilization and union agreement: ▪ A cost centre operates to fulfill newspaper's needs. ▪ Employees' versatility is limited and may be a source of conflict. The production department can significantly influence variable costs. The challenge is to set fixed and variable costs properly.
Profit centre	Production facilities organized as publisher-owned, profit-orientated companies: a distinct business entity enabling revenues from external customers and expenses to be determined to measure profitability.	Challenge: Loss of control over print capacities and schedules. Benefit: Better overview and understanding of profitability, better economic control over each different part of the business. *Separation allows for full advantage to be taken of printing capacity and skills, and helps to discipline editors or production facilities, which have never had to deal with external customers before.*
Joint venture	A contractual agreement joining together two or more parties for printing: all parties agree to share in profits and losses of the enterprise.	To find an agreement defining the principles co-operation. *Faced with a more industrialized printing culture, publishers become closer and choose to share investment, risk and expertise. This model enables them to decrease investment requirements and to increase press capacity usage while reducing total press capacity on the market.*
Outsourcing	Management and/or day-to-day execution of an entire business function by a third party service provider: in our study, it consists more particularly of delegating non-core operations previously performed in-house to an outside provider specialized in that operation.	To transfer to the supplier a significant amount of management control, to establish a considerable degree of two-way information exchange, co-ordination and trust. *Outsourcing is a business decision that can be made for quality or financial reasons. In our study, publishers subcontracted their printing activity to a printer, which built a new plant. Investment and economic risks are therefore transferred to the printer in the event of project delays or inefficiencies.*

Publishing companies face challenges such as decreasing circulation and more demanding advertisers. Publishers have therefore had to undergo either technical or social modernization with different focuses in mind: achievement of better print quality, of the ability to print in full colour and the opportunity to become more profitable by increasing press time usage and sales to external customers.

4.2 Reasons for considering a change

All of the publishers interviewed considered a change because of the age of the presses and market requirements in terms of quality and delivery (colour, pagination, time to market, or circulation).

Profit centre cases are the only ones in which a decision to change business model does not coincide with an upgrade of the printing equipment. On the one hand, the main reasons for investing in new printing equipment were the age of the presses, poor print quality, and insufficient speed to satisfy circulation requirements. For Bonnier, a key reason was the downtown location of the plant. On the other hand, the key factors leading to the separation of printing and publishing were introduced differently to both profit centres, but are quite similar in the end. Bonnier basically wanted to move away from the cost centre model because of management and financial issues. For Westcountry Publications, the separation was part of a rationalization process. The final purpose of both publishers was similar and consisted in gaining third party contract business to improve press capacity utilization and profitability.

For the joint venture cases, the decision to change business model also coincides with the publishers' desire to reorganize their production activities and increase press capacity usage.

One specific reason for outsourcing is to face up to competition. The outsourcing model effectively allows for the achievement of a higher level of sophistication that the publishers may not have been able to achieve in another way. Differentiation from the competition was the main focus. In the case of La Presse, for example, Transcontinental created a working group looking for innovations, new finishing options, and customizations.

4.3 Technical and management objectives

Major technical objectives were defined to ensure that the constraints forcing them to react were satisfied, such as increasing colour availability, meeting advertiser's and reader's expectations in terms of colour and quality, and diversifying newspaper activity, editorial form and content. Other important technical objectives relate to production lead-time (meeting delivery deadlines and controlling the distribution process).

The typical technical objectives for cost centres are controlling the printing process, maintaining expertise in printing and being independent. These objectives confirm the major reasons why a publisher may decide not to change its business model. Both cases had great expertise in printing. The Chicago Tribune for example had already invested heavily in assets in the plant. Both publishers then had good experiences with the cost centre model. It allows for control of the printing process and without depending on an outsourcer or supplier.

In the case of outsourcing, the decision to outsource was strongly linked to the publishers' respective problems with unions. In the case of The Globe and Mail, the observation was made that union problems would not be a concern anymore. *La Presse* considered outsourcing its printing activity once the unions rejected the initial project proposed by the publisher, which consisted of building a new plant. Moreover, when outsourcing its printing business, a publisher wishes to gain flexibility, while benefiting from technical improvements and customized products. These objectives were shared with the respective printer.

The main management objectives relate to costs: controlling and reducing costs or staying competitive in terms of costs. For cost and profit centres, publishers want to stay competitive in terms of quality. Increasing ROI (Return On Investment) is quite an atypical goal for this model and even contradicts the definition of a cost centre. The least important objective for profit centres is to "concentrate on core business", which confirms for both publishers that printing is not part of their core business. The Bonnier Group, for example, saw the separation of the printing activity as an opportunity to discipline the newspaper's workflow and establish customer relationships between publishers and printers within the same group.

For the joint venture cases, main management objectives result from the main purposes of the joint venture strategy, i.e. sharing investment and financial risks to reduce costs and the risk of obsolescence. The only objective not related to cost consists of concentrating on the core business. It confirms that printing was only part of their core business or did not form part of it at all.

In the case of outsourcing, whereas controlling costs is very important for all of the other strategies, here it seems to be subordinate to the quality of the end product. Both publishers were probably looking for an outsourcer to gain dynamism and necessary specific expertise. Their purpose was ultimately to satisfy customer expectations. This means that one of the most critical management objectives is to remain competitive or gain competitive advantage in terms of quality and time to market. Another critical management objective is to concentrate on core business. Both publishers see outsourcing as an opportunity to concentrate on their mission, which is to be a good publisher.

4.4 Risk assessment

The following graphs (figure 2) illustrate the loss related to an undesirable result versus the probability of undesirable results, as identified by the publishers[1]. On both axes, a higher score corresponds respectively to a higher probability of either an element or a loss. Graphs were generated from the replies to the questionnaire and from the answers issued from the interviews.

The most risky elements are defined as the most probable risks with the highest probability of related loss, and are located in the top right corner of the graph below (surrounded with a red circle). The least risky elements are in the bottom left corner (surrounded with a grey circle).

Table II: Common and specific risks of the four business strategies considered

Model	Cost Centre	Profit Centre	Joint Venture	Outsourcing
Specific feature	Essential ability to coordinate operations and monitor costs	Limited self confidence in internal performance and print market	Reduction of additional costs through risk "sharing"	Transfer to printers of the additional responsibility for costs in terms of maintenance, transition and project management
Specific risks	- Investment risk - Implementation difficulties - Production costs	Satisfaction of customers' needs	Maintenance costs	- Satisfaction of customers' needs - "Relative" loss of control over the printing activity - Equipment choice
Common risks	- Equipment choice - Unforeseen costs - Equipment obsolescence in the long term		- Loss of control over implementation and production costs - Contractual agreement, contract - Capital available for strategic decision rather than for production - Union issues	
	Inability to fulfil needs in terms of deadlines and increase in customer complaints			

[1] 1 = not probable at all, 2 = far from probable, 3 = quite probable, 4 = probable, 5 = extremely probable

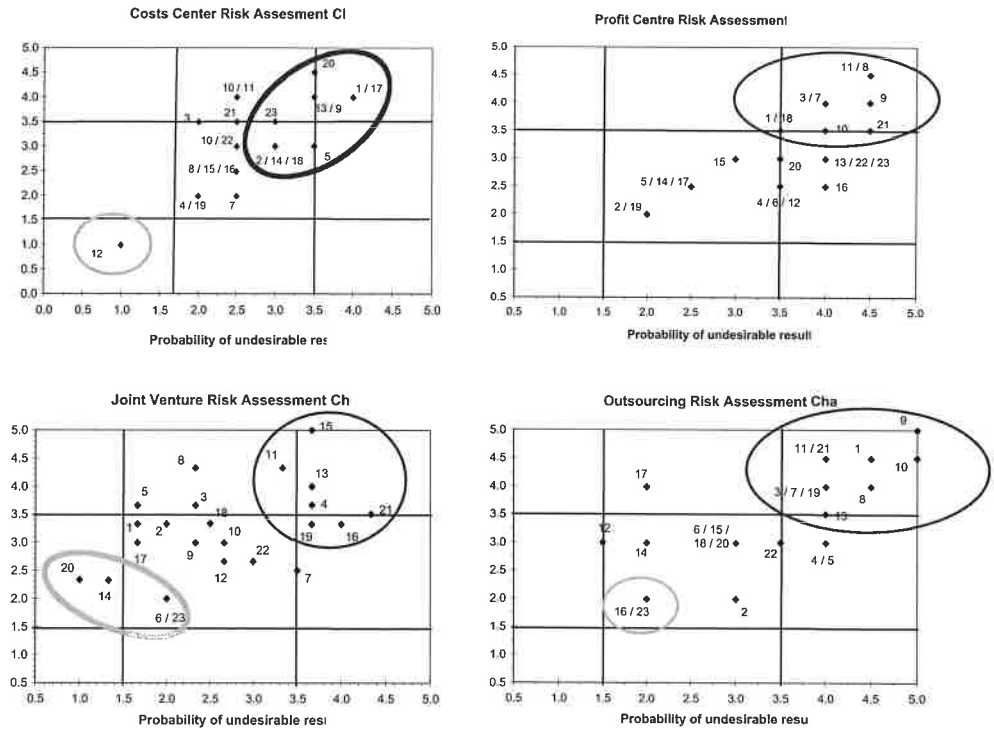


Figure 2: Risks charts for each individual strategy

Caption: (1) Choose the wrong equipment, (2) Conflicts and litigation with the supplier, (3) Decline in quality, (4) Employee resistance to change, (5) Equipment obsolescence, (6) Hidden costs, (7) Image deterioration, (8) Inability to deliver the exact number of copies, (9) Inability to fulfil needs in terms of deadline, (10) Inability to fulfil needs in terms of product requirement, (11) Increased client complaints, (12) Increased coordination and monitoring costs, (13) Increased production costs, (14) Incurring costs related to change of supplier, (15) Lack of employee motivation, (16) Lose control of maintenance costs, (17) Loss of organizational skills, (18) Penalty costs and costs due to contract renegotiation with the supplier, (19) Problems with unions, (20) Put company in difficult financial position, (21) Total implementation costs, (22) Underestimated project costs, (23) Unpredictable costs related to the transition and project management.

All of the relevant risk management strategies and control mechanisms were put in place to reduce undesirable results and the related losses.

4.4.1 Comments on cost centres

To control and minimize the impact of implementation risks (second series of risk factors) and to limit disruption, the Chicago Tribune assigned a full time person to manage the implementation phase and coordinate press vendors to meet internal requirements.

The least risky point confirms the publisher's ability to coordinate operations and monitor costs, which is essential for cost centres.

4.4.2 Comments on profit centres

The main group of risks (3, 7, 8, 9, 11 + 10) is related to meeting and satisfying customers' needs. In the case of Bonnier in particular, the publisher separated printing and publishing to make its printing shops more competitive. But, internally, the publishers (belonging to the Bonnier group) have the

choice to outsource. Some uncertainty concerning the quality of the end product could also be caused by the loss of control over the printing process. This may be the case for The Express & Echo, which has now outsourced printing activity to Northcliffe Press.

Peripheral risks are linked to equipment choice (1) and unforeseen costs (18, 21). These confirm the fears of the publishers, which have lost control over the process.

4.4.3 Comments on joint ventures

The averages are less representative than for the other printing strategies.

Some of them are specific to the Berlingske/Politiken case. The two publishers faced many issues with unions, trying to make two powerful unions work together. For them, the main risks were related to the lack of employee motivation (15), employee resistance to change (4) and problems with unions (19). Union conflicts did not constitute a risk for DZO.

The costs of implementation (21), printing production (13) and maintenance (16) are important risks for both cases and especially for DZO. Outsourcing printing activity to a joint company may indeed represent a sort of loss of control over the whole process.

The least risky elements are all related to hidden (6), unpredictable (23), or additional (14) costs, which could potentially put the company in a difficult position (20). The purpose of embarking on a joint venture is precisely to reduce additional costs by sharing financial risks. These elements identify what are probably the main reasons why the interviewed publishers chose this strategy.

4.4.4 Comments on outsourcing

The Globe and Mail systematically gave lower probability to elements identified by *La Presse*. This is *La Presse's* first outsourcing experience, whereas *The Globe and Mail* started to outsource its regional editions to local printers in the 1980s and had good outsourcing experiences with its national print sites.

The most likely risks are linked to the "relative" loss of control over the printing activity, which is now managed by an external provider. On the publisher's side, a newspaper has to be published daily. Although the publishers have priority on the press that they financed through a long-term contract, they are nevertheless dependent on their respective printers, who own the press, and control the majority of operational details.

The least risky elements are related to additional or unpredictable costs in terms of maintenance (16), transition and project management (23). These two risks actually become two advantages that justify outsourcing the printing activity, as they are no longer the publishers' responsibility. The printers are now in charge of cost control.

4.5 Investment assessment

With regard to project evaluation, the publishers in every case assessed their decision positively. They all agree on the adaptability of the chosen strategy to future needs, except for the profit centres, and that they have better control over deadlines. The latter was first identified as a risk but in the end has proved to be an advantage, except for the cost centres. The cost centre configuration seems rather to provide flexibility with regard to the finished product and control over quality and variable costs.

By definition, the outsourcing and joint venture models reduce levels of fixed costs, but also the risk of obsolescence. In the case of a joint venture, the risks and costs are split between at least two publishers. For the publishers, respective initial projects are thus currently being developed to meet the needs of both the publishers and the market. In the case of outsourcing, despite the "relative" loss of control over operations, the publishers felt that control over quality is far better. Moreover, there is almost no limit, barring financial limits, or restriction on the development and customization of the product.

One key success factor common to all four strategies was the ability to select the right implementation and management team to run the project. Planning was the most common critical step. The cost centres pointed out the importance of choosing the right printing plant location versus the distribution network. At different levels, the preparation and drafting of the contract were a key success factor specific to the joint venture and outsourcing cases. For the joint venture cases, the partners had to agree on the principles of co-operation, while the outsourcing contract needs to clearly express the publisher's requirements. Then, for the joint venture cases, the joint distribution company was a major key success factor. Finally, the outsourcing cases particularly stressed different important points from the other models, namely their ability to select the right partner and determine the length of the contract.

There was consensus on the biggest challenge, which was staying within budget and on schedule. Cost and profit centres are the only cases for which the ability to define future needs and trends was critical as the printing activity remains within the company. This means that a wrong decision may affect the whole company. Specifically for the joint venture cases, one big challenge was to minimize conflicts with unions. In the case of outsourcing, the biggest challenges were the choice of the right outsourcer and negotiations with them. The drafting of the contract was critical for both joint venture and outsourcing cases, as two or more parties have to find an agreement. The perceived level of difficulty was however a lot higher for printers adopting profit centre, joint venture and outsourcing strategies. Pressure seems to be transferred to the printers.

With regard to financial criteria, all of the enterprises emphasised the level of investment required, except the joint venture cases. The impact of manpower was not a significant criterion in the case of the profit centres. The English case, which had no union within the company, may have lowered the rate. Finally, the length of the project and delays from initial production time were of great consequence only for the outsourcing cases because of unions (pressroom employee redundancies).

4.5.1 Case-specific features: the cost centre model

For The Chicago Tribune the project is not yet complete. Its goals are to tighten up its process and improve quality. The publisher is also in the process of reviewing every section of the newspaper title based on feedback from advertisers/readers (St. Galler Tagblatt remodelled the newspaper in this way before investing. It was actually one of the main reasons why they chose to invest, to do justice to all the editorial effort). A lot of investment had already been made in prepress to achieve greater accuracy and automate processes.

4.5.2 Case-specific features: the profit centre model

For Bonnier/Bold, both the publisher and the printer agree that the model did not meet the publisher's expectations. However, Bonnier feels that the key factor for success is not the way the printing business is organized, but rather managers' skills at key levels. And because of the price competition on the Swedish market, Bonnier could not force publishers to print internally if outsourcing is cheaper and of better print quality. The printer's point of view is interesting. Bold is the only company that runs printing plants within Bonnier, and reaching an understanding is sometimes difficult. According to Bold, it would have been much easier to solve and manage most of the problems they experienced if

Bold had been independent. Internal customers quite often interfere with Bold's management and most of the decisions are political. However, great progress was made in 2005.

For Westcountry/Northcliffe, the assessment is very positive, as significant savings were made. Quality and flexibility improved in terms of deadlines, reliability, pagination, speed and colour. The publisher has also seen an increased advertising income. The printer only tempered this assessment slightly by pointing out that the project was very demanding in terms of manpower, training and planning. According to Westcountry publications, it has gained production efficiency with faster inserting, pre-printing most of the supplements and production flexibility. For instance, it sometimes allows some advertisers an extra day for submission of copies.

4.5.3 Case-specific features: the joint venture model

Both Berlingske and Politiken assessed the project similarly. It was a success as far as time and budget are concerned. They succeeded in decreasing investment requirements and optimizing press time usage. Both companies have seen strategic and economic improvements. However, the project is not finished yet. The printing plant is still experiencing technical problems such as delays, poor consistency, lack of press stability and issues regarding human issues, which are all not related to the chosen buisiness model. But the Danish market has been turbulent from time to time for many years in terms of regularity and delays. The union conflict should have been solved before and the mailroom's needs were underestimated.

"The current challenge for Danish publishers is to change the printing culture from the way it has been for the past century to a more industrial approach." *Tom Jorgensen, Berlingske.*

At DZO, the joint plant met the publishers' expectations mainly thanks to its flexibility for satisfying the various newspapers' needs. Publishers have achieved a kind of synergy with a common layout and subscription system. This assessment was only slightly tempered by the feeling that not enough time was planned for the implementation stage. The fine-tuning period set aside for each newspaper should have been slightly longer before full production began.

The initial projects will be continued to develop the model. In the case of Berlingske/Politiken, as technical and human problems are increasing with time, the publishers have appointed an external consultancy firm to carry out an audit and give recommendations. The mailroom will be extended as it was at DZO. For DZO, the contract will also be amended following recent investments.

4.5.4 Case-specific features: the outsourcing model

The greatest advantage of the outsourcing strategy is that there is almost no limit, barring financial restrictions, to its development and progress. Both publishers agree that outsourcing is adaptable to future needs whilst reducing the risk of obsolescence and is flexible to allow the product to be developed or customized without technical restrictions thanks to the customer/supplier relationship. There is always room for improvement or investment in exchange for some contract alterations. On the other hand, the supplier puts a lot of effort into developing customer loyalty. For example, Transcontinental created a unit to proactively develop customized products that publishers can offer their own customers.

Outsourcing gives publishers the benefit of having access to new presses without owning them.

The Globe and Mail has maintained control and expertise despite the outsourcing model and its expected "loss of control". The publisher regularly pushes the print quality standards even higher. Six years after the end of the project, they moved the strategy on and proposed a five-year extension contract to the printer in exchange for investment in equipment updates to meet increased colour and pagination requirements. The aim was to sell more adverts and dominate the market.

Outsourcing printing was an opportunity for *La Presse* to redesign the newspaper and rethink the way articles are written. It also brought more discipline. However, *La Presse*'s expectations have still not been met in terms of quality. Both parties (La Presse and Transcontinental) are working together to improve this. Some operational details should have been changed; in particular, specific validation processes should have been put in place during the transition period before full production began.

Whereas controlling costs seemed to be less important at the beginning, both publishers are today increasing their cost control. Most of quality objectives have been reached and the cost models may have to be revised. *La Presse* aims to review the contract to reduce the price list as the model planned initially has been exceeded with increased usage of colour, longer press runs and an increase in both inserts and editorial colour pages. A new quality model will be put in place (currently under development) to define more stringent quality requirements and responsibility in the event of problems with the equipment and to determine financial penalties.

5. Conclusion

The current challenging and evolving global context is forcing publishers to consider new business models. This study aimed to analyze the efficiency of various existing models and technologies needed to achieve objectives related to printing strategy. It also aimed to identify potential distinctive features of the best performing printing strategies in given environments.

The publishers only had to consider a change, for most of the strategies, when the time came to replace their printing presses. In all cases, except those relating to the profit centre, the decision to change the business model coincided with an upgrade in printing equipment (internally or through an external partner). Of the reasons to change press equipment, recurring arguments are the age of the presses and the increasing need for the newspaper to be printed in full colour.

The main objectives, whatever the business model chosen, were increasing colour availability and meeting advertisers' expectations in terms of colour and quality. These two objectives aim to fulfil the requirements forcing publishers to consider a change. The common management objective was to control the delivery cost of the finished product, which is the only cost the publisher is still in charge of whatever the strategy considered. For the profit centres and outsourcing cases for example, controlling the production costs of the finished product by the publisher is not a major issue anymore, as it has become the printer's responsibility.

For the cost and profit centre models, the main customers are from the parent company and remain the main focus of operations. The objectives are therefore similar, i.e. control without risk. The specific objectives of the cost centre model are controlling the printing process, maintaining expertise in printing and independence. For the profit centres, staying competitive is of great importance in terms of cost but also in terms of quality and time to market.

The management objectives of the joint venture cases are more central than for the previous strategies. The decision results above all from the strategy's potential to share costs and risks, thus reducing initial investment and the risk of obsolescence.

In the case of outsourcing, whereas controlling costs is essential for all of the other strategies, it appears to be subordinate to product quality. The focus was ultimately, more than for the other models, to satisfy customer expectations through the outsourcer's dynamism and expertise, and stay competitive in terms of quality and time to market. Unlike the other case studies, staying competitive in terms of cost and reducing printing or distribution costs were not critical management objectives.

What distinguished the strategies considered and led to the final decision is interrelated with the perceived strategic value of the printing activity for the company. Cost centres only consider the in-house printing option, as investment has already been made in developing assets internally.

The joint venture option was never considered initially, even in the joint venture cases. This alternative was only considered when a possible partner had been identified. For the cases studied, there was a true collaborative opportunity with a competitor that had the capacity to take responsibility for printing. The specific feature is that the partners had already developed a business relationship through other activities, namely a joint distribution company.

The profit centres' decision to separate publishing from printing was mainly related to cost minimization, either to save on maintenance and equipment non-productive time costs or on mismanagement and non-efficiency costs. The unavailability of reliable printing plants was a major driving force behind the separation of the two activities, and even surely the main reason why they were not able to outsource printing totally.

The outsourcing model was chosen as the most cost-effective solution to meet the publishers' exacting requirements and to concentrate on their core business, i.e. on their mission, which is to be a good publisher. This alternative was considered because potential printing plants were available.

Joint venture and outsourcing were the only strategies for which unions played a critical role as reorganizations and redundancies are often inevitable in such projects. For the outsourcing cases, for example, the change of strategy was seen as an opportunity to solve union problems.

So, the main reasons that progressively eliminated the alternative strategies were mostly financial; in addition, other solutions were often unfeasible due to lack of opportunities, partners or available printing plants. Finally, unions were regularly quoted as a key decision-making factor.

The risks identified by those interviewed reveal common trends. The main common risks, except for cost centres, were the inability to fulfil needs in terms of deadlines and an increase in customer complaints. For the publisher, a newspaper has to be published and produced well in time daily. Furthermore, such complex projects may cause some disruption or irregularity.

For cost centres, the main risks are related to the choice and cost of the equipment, implementation difficulties, the unforeseen related costs that are to be expected in such complex projects, and the production costs, as the printing business side directly affects the whole company.

For the profit centre and outsourcing cases, the major expected risks are more related to meeting customers' needs because of the necessary loss of control, in these two business configurations, over the whole process and thus over the quality of the end product.

For the joint venture (one case only) and outsourcing cases, unions constituted a significant risk such as potential customer complaints that could result from union issues. Both stressed also the importance of the contract. Each element of the contract with the printer has to be worked out in detail and clearly expressed; the contract must also deal with who has to bear each specific risk.

It is interesting to note that, in all of the cases studied, all of the relevant risk management strategies and control mechanisms were put in place to reduce undesirable results and the related losses.

Concerning the evaluation of the projects, whatever the business model, the adaptability to future needs (except for profit centres) and better control over deadlines seem to be the main advantages. Moreover, the outsourcing and joint venture models reduce, by definition, levels of fixed costs, but also the risk of obsolescence. One common key success factor for all four strategies was the ability to select the right implementation and management team. Specifically, contract drafting was a key factor for the joint venture and outsourcing cases. Everyone agreed that staying within budget and on schedule was the biggest challenge. Moreover, the ability to define future needs and trends was essential for cost and profit

centres as the printing activity remains within the company. Minimizing conflicts with unions was challenging for the joint venture case, whereas the outsourcing cases highlighted the choice of the right partner and negotiations.

Drawing some non-exhaustive conclusions on the cases studied by strategy, for both cost centre cases, the chosen model is profitable, which is quite contradictory with the definition of a cost centre.

For profit centres, the main financial objective should have been to refinance themselves on the market but seems to have been cost reduction, which is a defensive strategy that doesn't deal with profit maximizing.

The joint venture model seems to be the configuration with the most significant impact on the publishers' ways of working. In one case, the layout and subscription systems were standardized to achieve more flexibility for all partners. In the other case, employee and technical issues made this configuration very difficult to operate afterwards. Even those issues that are about to be resolved had quite a substantial impact on the publishers.

In the case of outsourcing, whereas controlling costs was initially seemingly of secondary importance compared to the quality of the end product, both publishers are now strengthening their cost controls.

Finally, drawing some specific conclusions from a global point of view, the profit centre model seems to be the right model for publishers looking to reduce their production and printing costs. Printing centralization appears to be an integral part of the change in strategy, before or after separating printing from publishing. Some print shops will necessarily be closed and others extended or new ones built. A typical trait is the wish to outsource, which is unfortunately not feasible due to a lack of available and competent partners.

A joint venture is made up of companies in strong positions with some interest in sharing operations and risks. The availability and open-mindedness of future partners with similar needs, evolving in a very competitive context, are so many opportunities for joint ventures.

The change to an outsourcing strategy is brought about by the needs for more in-depth expertise. This model enables publishers to benefit from a higher level of sophistication than they might have been able to achieve any other way. More than for the other strategies, the main focus is on differentiation from the competition, and customer satisfaction comes first. The quality of the end product prevails over cost to some extent. For this business strategy, Canada is something of a trailblazer, with relatively important international printing companies such as Transcontinental and Quebecor compared with its demographic significance.

Choosing a business strategy is mainly driven by the company's philosophy and financial considerations or working culture, and the state of the printing business within the country.

Whatever the selected business model, publishers and printers will sooner or later have to face up to the press overcapacity on the market and fight against even tougher competition. This explains why most of the publishers plan to develop the initial model and adjust it to enhance either requirements or operational details.

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Break-even analyses gravure vs. web-offset a new approach!

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Abstract

The objective of this paper is to determine what factors are important when a particular printing method is chosen. In 1985-86, a study of the European publication printing industry was carried out by the European Rotogravure Association (ERA) in Munich, and contemporary industry leaders considered that study to be one of the most comprehensive ever made in the publication printing industry. This paper deals with an important part of an ongoing survey of the European Publication Printing Industry - and highlights the development in recent years of the break-even level between gravure and commercial web-offset printing. These studies were the first of their kind and comparable studies have, to the author's knowledge, never been reported.

In 1986, the summary showed that commercial web-offset printing was very competitive when printing signatures with 16 or 32 pages, and that gravure printing was very competitive from 48 pages signatures upwards, even though the manufacturing costs in the bindery for gathering together a number of smaller signatures in web-offset were not included. Further, the data collected also showed that for those gravure printers who were engraving cylinders directly from digital data without having to proof the cylinders, the break-even level even for a 32 page signature became very competitive.

About 15 years ago, some commercial web-offset press manufacturers were redesigning the commercial web-offset press, and the Sunday press concept was launched by Harris (later taken over by Heidelberg, now Goss) in 1993/94. Within a few years, a completely new breed of commercial presses was presented for the publication printing markets; not only the traditional 16-32 pages (in short grain), but also larger and wider presses capable of printing 48 to 64 pages on a single web. There was not only an increase in the signature pagination but also a significant leap in web speed. Automation of plate processing (CTP-technology), plate mounting and other press variables led to a sharp increase in productivity and print quality. Web-speed and productivity in web-offset became close to or in some instances even higher than in gravure printing. Recently, some indicators have shown that during the last decade gravure has lost its previous market dominance to web-offset printing, and recent investments in new printing capacity in commercial web-offset have outnumbered gravure by 4:1.

These recent developments made it clear that a new survey comparing printing costs, lead-time and quality for printing was needed. During 2005/2006, interviews have been conducted with a substantial number of printers - both gravure and web-offset printers - using the same kind of Questionnaire as in 1985-86. Data from internationally renowned printers using gravure and/or commercial web-offset have been collected and analyzed in order to determine the relevant break-even level. A similar non-disclosure agreement as in 1985 has been used to ensure that confidential data will not be disclosed, and that it will not be possible to identify any single printer. For the first time, a scientific methodology has been used to compare the printing costs of a few well-defined signatures.

In 1986, the following hypotheses were formulated concerning the important and decisive factors of a customer's choice:

- the economy (printing costs and market pricing),
- the required lead-time (process speed and productivity),
- the market requirements of the product (format and print quality).

In 2006, the hypotheses have been adapted to the present market situation (chapter 3).

Keywords

Automatic make-ready, break-even, commercial web-offset printing, long grain printing, publication gravure printing, short grain printing, short runs in gravure

1. Introduction

In 1985, the European Rotogravure Association (ERA) published a study on gravure and web-offset "Separating the facts from the myths" [Bjurstedt 1986]. The investigation included in-depth interviews with the leading industry managers, and the costs of producing various signatures (paginations from 16 to 96 pages) for each individual company were investigated. The figures were given to the author under a non-disclosure agreement, so that it would not be possible to identify any individual company. However, as part of the investigation, each participating company was given its relative position in the study. Subsequently, the data containing some 500 files was processed, and a summary of the findings was presented at the 1985 Annual Meeting of the Association. Later, in the fall of 1986, an official ERA report was presented by the author at the G.R.I. (Gravure Research Institute) Conference in Fort Lauderdale, Florida.

The study conducted by ERA in 1985-86 was one of the first of its kind; it was very comprehensive and included a number of companies in Scandinavia, the UK and Central Europe. Some of the companies participating in 1985 are still in operation, and they also consented to participate in the present study. However, others have merged, changed ownership or structure and in some cases gone out of business. During 2005, interviews (with a similar non-disclosure agreement) have been conducted with a large number of printers - both gravure and/or web-offset printers.

This time, however, in-depth discussions with the leading suppliers of both CTP technology, engraving systems and press manufacturers have been included in the study, as technical developments are progressing very rapidly. Web-offset printers have profited greatly from the new CTP (Computer-to-Plate) technology and new offset plate technology, which have matured during the last decade. The new technologies have lowered the entry level for the web-offset industry, improved the print quality and made longer runs possible. The gravure industry has been slow to respond to the challenge, but recently new technical solutions have been available in the engraving area, concerning both the traditional electro-mechanical engraving heads and the new laser-engraving units. Now the question is whether similar developments are going on in the press room in order to improve the production rates and shorten the lead-time in gravure printing technology.

2. Methodology

2.1 Important areas of research and methods

Media and communications studies have developed a variety of analytical procedures and designs; drawing on the social sciences as well as on the humanities. Scientific approaches and social implications are studied in the quantitative research process [cited in Bruhn Jensen 2002, p. 206]. Quantitative studies are covered both in terms of their basic categories and operations; and with reference to the relevance of survey, experiment, and content analysis. Qualitative studies are presented, similarly, in terms of the systematic processes of interviewing, observation, and textual research, including issues of data collection and data analysis. The complementarity of qualitative and quantitative research is to examine references to both concrete examples and to classical problems in the philosophy of science.

2.2 Quantitative approach

Quantitative research is primarily concerned with demonstrating cause-effect relationships and any research project begins by setting up a hypothesis or a research question. A hypothesis is a proposition to be tested, or a tentative statement of a relationship between two variables. Whilst hypothesis testing is not unique to quantitative research, it is one the fundamental elements, and almost a required aspect of quantitative academic research. In this case, the hypothesis is that the relationship between gravure and commercial web-offset has changed dramatically with regard to printing costs for a predetermined signature containing 48, 64 or 96 pages in A4 format.

The first step in the quantitative research was to create a survey and the main problem was to find a sufficiently descriptive survey. In this particular case, a questionnaire was created already in 1985 and the main question has been whether or not the old questionnaire can still be used. In this case the same questionnaire has been used for the new survey, but the forms used have been updated using the latest available digital forms technology.

According to Siegel and Hodge from 1968 [cited in Bruhn Jensen 2002], there are two fundamental issues in any academic research project, viz. the reliability and the validity of the results Reliability concerns the dependability and consistency of the relationship between two variables or in the score obtained and a single variable at more than one point in time. Reliability can be established by carrying out repeated tests of phenomena and the relationships between phenomena, and by repeating such tests among different groups. Validity and concurrent validity mean that a measure is associated with another indicator that has already been shown to be valid.

The companies interviewed have been selected according to a special cluster sampling. The only way of obtaining access to them was that they belonged to the ERA as the major European association in publication printing and thus belong to the cluster of important gravure printers and/or web-offset printers. In 1985, the questionnaire was sent by mail to the contact persons at each company. Most of questions/issues were also debated and discussed during a number of meetings held during the autumn of 1984 and 1985; hence the relevance of the survey was certified. It can be assumed, in addition, that almost all the respondents understood the background and the meaning of the questions; hence it can be assumed that both the reliability and the validity of the answers to the industry in general can be assured.

2.3 Comparison between the investigations made in 1985/86 and today

In 1985/86, the investigation of the printing costs was very confidential. In this context, about 20 of the leading companies (and/or their contact persons and managers) belonging to the European Rotogravure Association (ERA) were approached. The participating companies sent their assessments directly to the author personally, and the information was kept strictly confidential. Before the request for information was distributed, the content and structure was discussed and decided upon by a project group, which comprised managers of the leading European publication printers at the time. Some of the basic data (non-confidential) and findings were also discussed within this group, and two separate reports were published by the ERA in 1985 and 1986. These are still available to-day. The survey in 1985/86 can be regarded as a quantitative analysis, which was supported to some degree by direct interviews. It has been possible to retrieve the basic empirical data (from my personal archive), and reformat it to modern PC office software.

The 2005/2006 survey, however, was planned having a broader target group, and the main emphasis has been on both a quantitative and a qualitative approach extended with personal interviews. The interviewees have been selected among the most important supplier companies in Europe. There are only a few suppliers to the industry (gravure cylinder processing and press equipment manufacturers). Almost the same number of printers has been involved in submitting the information, although there have been some very important changes in the industry:

- Many companies in the first study have merged, changed ownership or gone out of business,
- Many of the leading managers are no longer in the business; they left the industry, retired or are no longer available,
- New structures have emerged in the industry in Europe.

The reason for including the suppliers this time is that most of the research in developing new technology and/or production processes is now concentrated to the suppliers. In the past, important work in this area was done by the publication printers (users) themselves. One major difference, although it is not significant, is that today all communication is by e-mail and the Internet. One major challenge was that some of companies interviewed are not members (or are no longer members) of ERA, and this could have a significant impact on the quality of the answers. The main emphasis has been to interview these managers personally, and so far none no one has declined to participate.

3. Hypotheses

In the ERA study of 1985-86, it was stated, that the break-even between gravure and web-offset was very dependent on the pagination of the signature. In the investigation, the worst case for gravure was chosen, namely a standard A4 format for all signatures because most web-offset presses for the European market were designed (with a fixed cut-off) for this format. Gravure presses, on the other hand, were basically designed for a variable cut-off offering a much larger flexibility for the customers.

In 1985/86, it was found that gravure printing was indeed competitive when printing signatures from 48 pages or larger. It could also be said that even from 32 pages, gravure printing was competitive when cylinders were digitally engraved and no wet proofs were made.

Based on a general interpolation of the current market situation, the hypothesis is that the current relations are still much in favour of web-offset printing and that the previous signature size has increased substantially during recent years. There has been a tremendous investment boom in the European commercial web-offset industry with the introduction of more advanced CTP-systems, offset plates with extended service life and new modern web-offset press designs. It is here generally believed that break-even can now only be achieved when printing a signature of 64 pages or more (in a standard A4). This is a quite significant change in competitiveness compared with 1985/86. This investigation will determine whether this hypothesis is verified or falsified.

Another field of interest for gravure printers is the question of the quality achievable when printing on uncoated stock - SC magazine paper grades. In the beginning of the 1980's, British publishers persuaded some Nordic paper-makers to develop paper grades similar to SC (super-calendered) for commercial web-offset. The new paper grade was called HSWOP (Heat-Set-Web-Offset Paper) and initially had a great success, particularly in the UK. It was then suggested that the print quality produced in commercial web-offset printing using HSWOP grades was comparable to what achieved with gravure.

During recent years, however, it has been suggested by many print buyers that in order to achieve a print quality comparable to that obtained with gravure printing on SC grades, commercial web-offset printers have to use a coated stock., such as LWC or similar grades. Hence, the second hypothesis is that, in order to achieve a print quality comparable to gravure on SC grades (56 g/m^2), commercial web-offset printers have to use a coated stock - but at a slightly lower grammage (54 g/m^2).

4. Printing technology in 1985-86

In 1985, the gravure presses used in the European publication printing industry were still rather small with narrow webs and moderate speeds. However, the scatter among gravure printers was huge, and

many aged presses were still in use and operated mainly manually or with semi-automation of the press functions. By the end of 1970's, the so called 40 000 generation of gravure presses was introduced in the Europe, which meant that the presses were capable of printing 40 000 cylinder revolutions (or more) per hour; equal to about 10-12 m/second. Web width was up to 2.4 but the majority of the new presses were still around 2.0 m.

Commercial web-offset presses were very successful in the North American markets and were achieving running longer runs than in Europe. The pagination was still limited to signatures of 16 or 32 pages. In North America, commercial web-offset printers were printers only, and were subject to fierce competition, but of some the reasons for the success were the demands from the American publishers and print buyers such as:

- Increase in demographic split of editions - large editions were subdivided into many smaller runs,
- Flexibility in pagination and colour content,
- Bindery operations were outsourced and rather cheap (non-union and mostly non-white operators).

Due to the fierce competition, the North American commercial web-offset companies were running their presses flat out during a rather short period of time. After a cycle of only 5-6 years, new improved presses were installed, which led to a high level of technical development in the commercial web-offset business. And it must not be forgotten that web-offset printing technology was, to a large extent, developed in North America - an American process.

From the end of the 1960's, an increasingly large number of web-offset presses designed by American manufacturers were installed in Europe. Hence, in the middle of the 1980's, commercial web-offset presses in the European markets were seldom more than 5-10 year old, and new presses were installed in quite a large number [source: ERA List of Presses - 1986].

American publication gravure printers, on the other hand, were relying on European equipment and process knowledge. Although some of the larger printers (like Donnelley's and World Color Press) were printers only, others were fully or partly owned by publishers (Burda-Meredith and others). The gravure presses installed in the American market (there were and are no publication gravure presses in Canada) were partly very old, with fixed formats and they were rather inflexible.

The working hours in the European press room were about 102 - 144 hrs a week. However, most of the gravure printers were faced with very strong union demands, which made it virtually impossible to run 24/7, i.e. 24 hours a day, seven days a week. They were forced to accept a moderate-to-low utilization of the printing presses. Commercial web-offset printers were faced with stiff competition, not only from gravure printers, but also from other web-offset printers, and they had to be much more flexible and adapt to the needs of the customer. Hence, commercial web-offset printers did not have to carry the same heavy load of infrastructure, such as large prepress and/or post-press operations, as did many gravure printers, but could concentrate on their core business, the printing operations (and plate making).

4.1 Prepress technology

In 1985, the methods in the prepress area were mainly manual with the extensive use of graphic films in both printing processes [Bjurstedt 2006]. Most publication gravure printers had large prepress departments, where customer's pages - text composition, images scanned and pages assembled - were processed. Halftone separations were already an established procedure in the gravure prepress activities, and this made it possible to use commercial available preproofs, such as Matchprint and Cromalin, although the colour gamut match in many instances was questionable.

In 1985, most European publication printers had abandoned the old etching technique and switched to the mechanical engraving method. A few were engraving using digital data, whilst the majority were

using halftone Opalines and real-time scanning during engraving. Opaline was both an expensive material and rather slow in processing. Web-offset plate-making was also a manual process with stripping of pages and using light boxes for plate exposure. Both negative and positive films were used, depending on the market. In the US most web-offset printers were using negatives, whereas in central Europe most printers used positives [Bjurstedt 2005]. The service life of the offset plates was limited to about 100 000 copies (without heat treatment).

4.2 Publication gravure printing

The basic format for gravure publications was DIN A4 size or close. The majority of the recently installed gravure presses were running landscape-size products (or short grain) [Bjurstedt 2006]. The recently established standard for publication gravure presses of the time - first introduced by the large German publisher/printer Axel Springer AG in the beginning of the 1980s - was of the 40 000 generation with a web width of 2.40-2.60 metres, capable of printing 64/96 pages in A4 format. The press with its variable folder with grippers could run in excess of 40 000 revs/hour or 10-12 m/s.

4.3 Commercial web-offset printing

Most commercial web-offset presses were, however, limited to 16 or 32 pages, in long grain configuration (portrait size) with a fixed cut-off [Bjurstedt 2006]. Gravure presses, on the other hand, were basically designed for a variable cut-off offering a much larger flexibility for the customers. Nevertheless, the untrimmed press format was smaller in gravure because all web-offset folders were using pins and not grippers (as in gravure folders).

Pin-folders used in commercial web-offset caused almost 4% more trim waste than in gravure printing. There were however, some installations in the UK with a narrow cut-off of 1220 mm, for a product size slightly smaller than A4. There were only two sizes of commercial web-offset presses available; 16 or 32 page presses. Both were single width - max 98 cm - and had single or double round plate/blanket cylinders respectively. The press speed was limited to about 18-20 000 revs/hour (32 page press) with a web speed of 5-6 m/s.

The long grain concept had some obvious drawbacks with, because it was considered to limit the possible press speed to about 7-8 m/s. Cross-fold (or chopper folding) techniques had been used for a long time in narrow gravure presses, but they were abandoned for that very reason at the end of 1970's.

Some attempts were made to design short-grain web-offset presses to overcome the speed limitations, but short-grain presses in web-offset had another problem; in the post-press operation of perfect binding with hot-melt glue. The low moisture content in the paper made the spine prone to wrinkles causing customers to complain; particularly with low grammage papers (this phenomenon was not present in gravure). Short-grain products were, however, very suitable for stitched magazines.

5. Contemporary technologies

The extremely fast progress of digital technology in the 1990's had a great impact on the printing industry, in particular in the prepress area. New software packages for editorial and image manipulation were quickly accepted by the publishing industry, and the previous analogue technology was soon abandoned [Bjurstedt 2005]. All these new techniques created a dramatic change in the way the industry had worked, because the customer suddenly gained complete control of the prepress work and indeed of the work flow. Previously, the publication printing industry processed all the pages and controlled both the prepress work and most of the entire work-flow.

The working hours have changed too. Today almost all printers, gravure and web-offset, are running 24/7 shift systems in order to maintain their competitiveness and shorter lead-times. This became possible during the first recession in the beginning of the 1990's, when the weaker position of the print unions made this change possible.

About 15 years ago, some commercial web-offset press manufacturers started to redesign their presses. The first commercial concept was the Sunday Press from Harris (Harris was later taken over by Heidelberg and recently by Goss International). A huge leap in web speed became possible when a new design of the blanket and plate cylinders produced a much narrow gap than before. Within a few years a completely new breed of commercial presses was presented for the publication printing markets, and not only the traditional 16-32 pages (in short grain), but also larger and wider presses capable of printing 48-64 pages in a single web. Not only was there an increase in the signature size but also a significant leap in web speed.

Only in the beginning of the 1970's, when the renowned European publishers/printers Burda and Ringier entered the American market, were variable and more flexible European gravure presses from Albert-Frankenthal (today KBA) and Cerutti installed. By the end of the 1980's, however, American publishers shed their interests in the printing business and became publishers only. The structural changes in the North American gravure market has now gone so far that there are only three huge companies left, Donnelley's, Quebecor World and Quad Graphics. (Both Donnelley's and Quebecor World have many subsidiaries and have also very important subsidiaries in Europe).

New plate technology with extended service life, automation of plate mounting, and other press variables led to a sharp increase in productivity and print quality. Web-speed and productivity in web-offset came close to or in some instances even exceeded that in gravure printing. Recently, some indicators have shown that during the last decade gravure has lost its previous dominance in the market to web-offset printing, and recent investments in new printing capacity using commercial web-offset have outnumbered gravure capacity by 4:1.

5.1 Prepress technology

New screening technologies have improved the print quality of lithography, but the film material limited the potential of these new technologies. A new technology, exposing the offset plate directly from the digital files was needed, and it was called Computer-to-Plate - CTP. The common opinion in the graphic art industry is that plate-making and new plates for offset have made dramatic progress during the last few years, and many technical solutions have been developed with the emerging Computer-to-Plate technology.

CTP technology has quickly matured and became accepted by the offset printers. Another contributing factor was of course the PDF-technology which made digital prepress affordable for all customers. Then many of the prepress companies were marketing larger size CTP-devices suitable for web-offset plates in 48 or even 80 page press formats. Heat-treatment (baking) has given a service life of up to a million copies [Kipphan 2000]. Recent developments, with faster laser diodes and with many different plates available on the market, have made CTP-technology and plate marketing extremely competitive.

All the European gravure publication cylinders have been engraved digitally for many years. Recently, more advanced products have also been developed in plating the cylinders with copper and chromium [Bjurstedt 2005]. These products allow the user full automation including loading/unloading with a minimum of staff comparable almost to the CTP operations in web-offset.

5.2 Publication gravure presses

The format for publication printing now being used in the industry is still DIN A4 size or close to it. The trend in publication gravure presses has gone from 64/96 pages in the mid-1980's to 96/144 pages; although there is one installation in Germany with two super-wide presses running 112/168 pages in A4 (two other gravure printers will be installing similar presses later in 2006/2007) [Bjurstedt 2006]. (The larger signature can be printed with cylinders with 6 pages around). When using cylinders larger than 3.0 m face width, all cylinders-loading is done automatically with no manual intervention. The cylinders are mostly moved automatically from the cylinder storage or department to the press department and loaded to cylinder loading device. The web width is typically 3.6 - 3.8 metres and the speed is approaching 15 - 16 m/s, The newly designed variable folders may run up to 58 - 60 000 revs/hour, although tests are being done with even higher speeds.

5.3 Commercial web-offset printing

Commercial web-offset presses redesigned in the middle of the 1990's incorporated two features which are both necessary for high speed printing; a smaller overlap (a precise overlap is mandatory for all post-press operations) using gripper folders (as in gravure), and the mini-gap on blanket and plate cylinders [Bjurstedt 2006]. Some manufacturers are using a sleeve type of blanket to reduce the vibrations in the units, but these have not yet gained wide acceptance in Europe. There are many alternative press configurations available for the potential buyer, and the average format is today either 48 (either long-grain or short-grain) or 64 pages (long-grain) [Kipphan 2000].

There is no standard configuration in commercial web-offset operations; because it depends very much on the market in which the printer is working [Bjurstedt 2006]. The maximum web-width is presently about 2.00 cm for the 64 page alternative in portrait size, although there are a few presses running 72 or even 80 pages, albeit smaller than A4 in size.

The sleeve blankets are quite expensive and very bulky to transport compared to the traditional flat blanket. The dryer capacity has been improved, but dryers are today very long. The length of the dryer is about 1 m per 1 m/s web speed, which means that the longest dryers are close to 17 - 18 metres. The former drawback using cross folders [Kipphan 2000] has been overcome, and the commercial web-offset presses can operate flat out also in portrait size, even though there are still some constraints concerning grammage and page count.

6. Analysis of data from 1985-86

The 1986 study assumed, however, that the preparation costs of text and images (prepress) prior to cylinder and plate processing were approximately the same for both processes. The publication printing industry used halftone separations, manual stripping and planning (or in the case of many gravure printers, colour page make-up systems) and preproofing of the current standard. Most of gravure printers did all this work in-house, in contrast to many web-offset printers who were receiving plate-ready film separations from the customer and/or trade house.

The Questionnaire asked the participants for their best estimate of the printing costs (no pricing information) on the following product (-s):

- Print run - 350 000 copies,
- 4+4 colours,
- 16, 32, 48, 64 and 96 pages,
- Format - standard A4 (210 x 297 mm after post-press trimming),
- Paper - standard SC Magazine paper - 60 g/m^2,

- One gravure wet proof (per cylinder set),
- "Normal" ink coverage for magazine production.

It was also assumed that the calculations should not include post-press operations for either gravure printers or web-offset printers. After some initial discussion, a more comprehensive study was made on the new standard of recently installed gravure presses capable of printing 64 or 96 pages with web (250 - 260 cm web-width). Commercial web-offset printers were using either 16 page or 32 page presses. In the following diagrams, break-even is shown for each signature size in gravure, except for the 16 page, in comparison with the 32 page web-offset press.

Generally speaking, web-offset printing was cheaper when printing signatures from 16 to 32 pages in A4 format. However, this was only true when the worst scenario gravure was used - standard offset size A4, one or two gravure wet proofs etc. The project concluded, nevertheless, that the gravure printing process was rather competitive from 32pp signatures, but very competitive when printing 48 pages and above, if the best practice and technology were used [Bjurstedt 1986]. The results of the 1985-86 study can be found in the following diagrams:

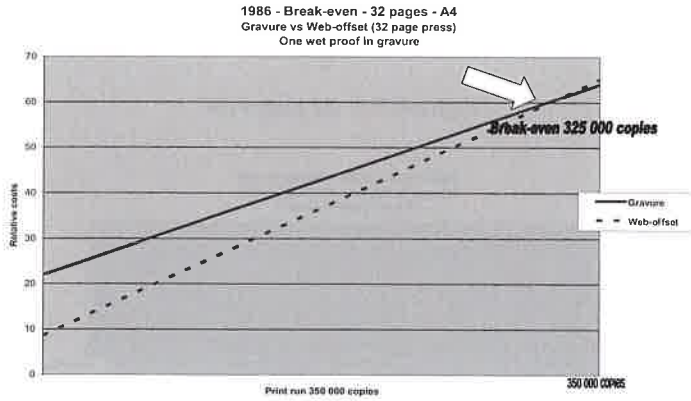


Diagram 6.1: 32 pages A4

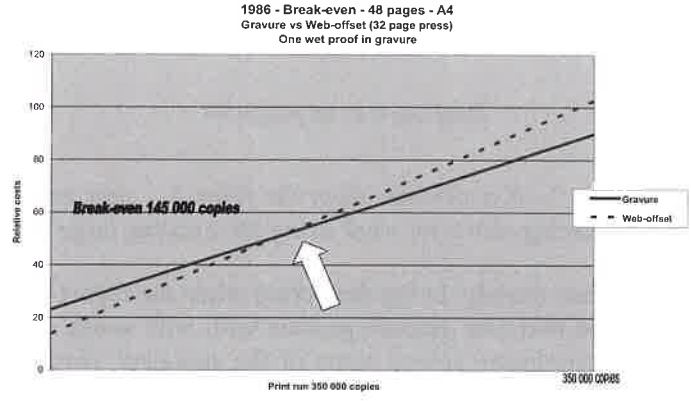


Diagram 6.2: 48 pages A4

In the final report [Bjurstedt 1986], several suggestions were made for improvements to the gravure process:

- One of the most important suggestions was digital engraving, i.e. engraving directly from digital data (rather than scanning Opalines) which would save both costs and lead times in the process,
- Another suggestions was to dispense with gravure wet proofing and go directly from chromium plating to the press room,

- The 64/96 page press (paper width 250-260 cm) was suggested to become the standard European press configuration,
- Presetting or automation of folder and colour register settings when changing formats was suggested to improve the make ready process,
- Reduction of waste during the acceleration (from make ready speed to production speed).

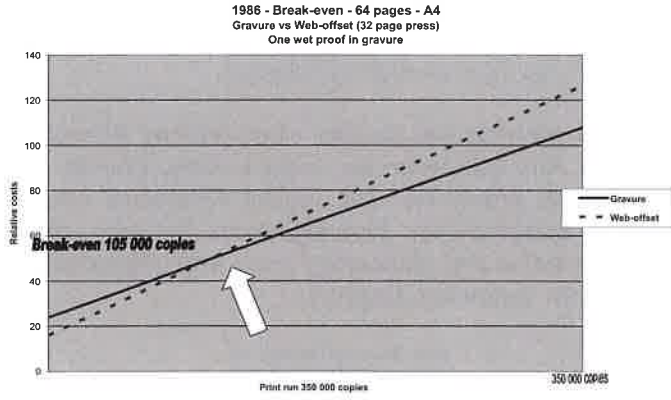


Diagram 6.3: 64 pages A4

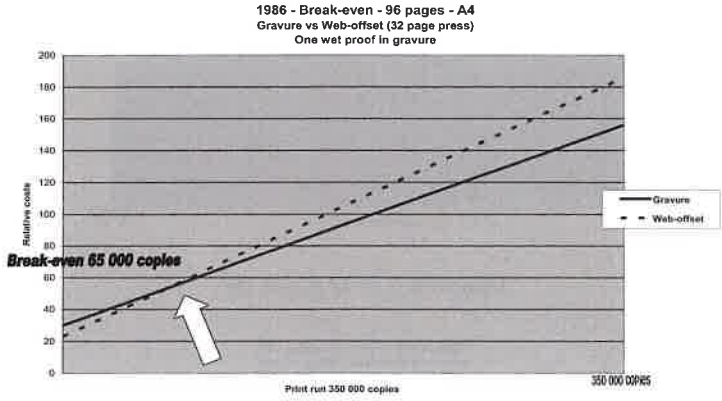


Diagram 6.4: 96 pages A4

It was also stated in the report *"...it is obvious from the figures... that gravure is uncompetitive on lower paginations when considering short run work using the existing large presses."*

It should be noticed however that, already during the period when the report was being compiled, Bauer Druck in Cologne had installed two new gravure presses with web width of 3.0 m. The three-metre-wide-web stirred considerable confusion among some of the suppliers, particularly the paper industry. The logistics of serving Bauer Druck with 3 m wide paper reels was not an easy task to solve.

Chapter 8 includes a more thorough analysis of the different options for short run gravure.

7. Analysis of data from 2005 and 2006

7.1 Break-even levels

During the winter of 2005 and spring 2006, further interviews have been conducted with a substantial number of printers - both gravure and/or web-offset printers - using the same technique as in 1985-86.

A similar non-disclosure agreement as in 1985 has been used. The scatter among the European gravure printers is indeed very large, and the statistics show, that the cost of producing smaller signatures is high in comparison with web-offset. The data obtained are shown in the following diagrams. However, there are many more combinations, particularly on different sizes of commercial web-offset presses, and only some of these are shown here:

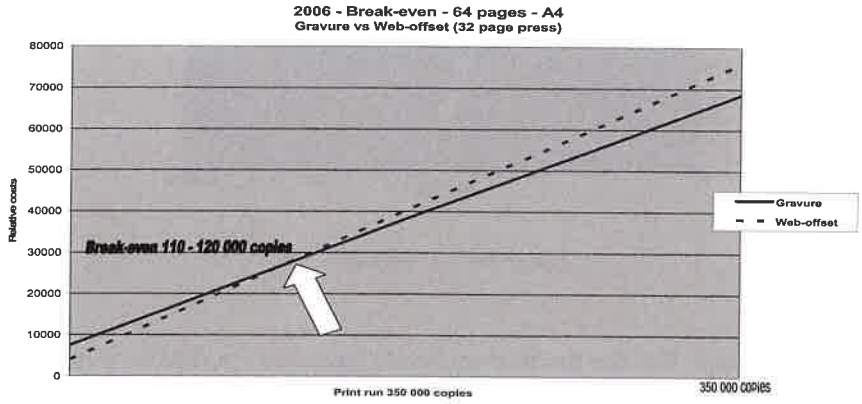


Diagram 7.1: 64 pages A4

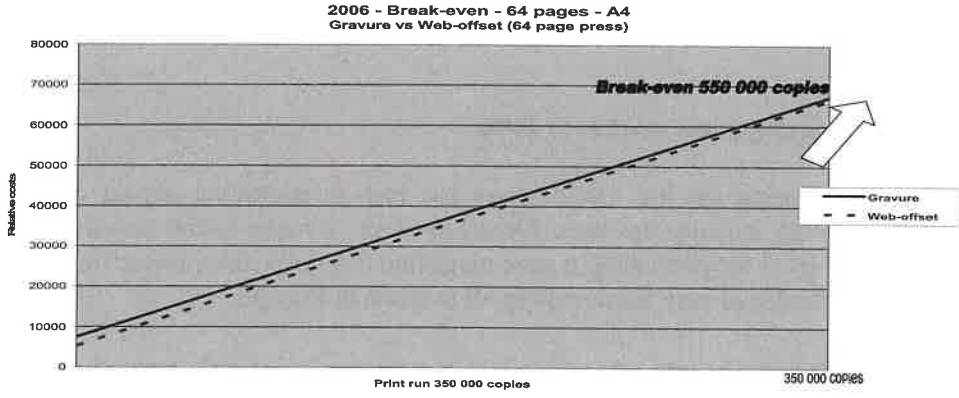


Diagram 7.2: 64 pages A4

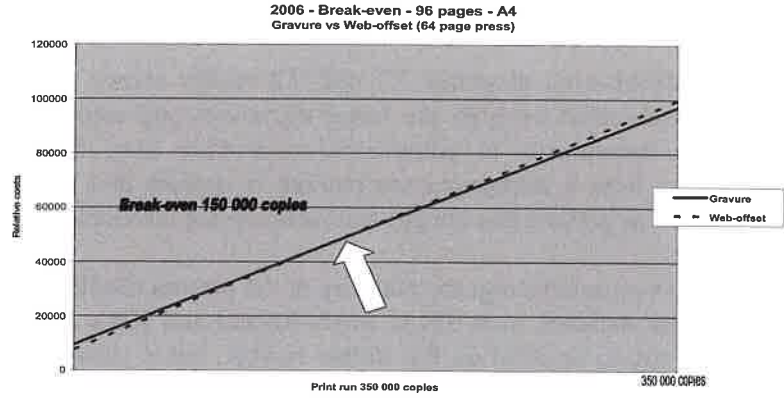


Diagram 7.3: 96 pages A4

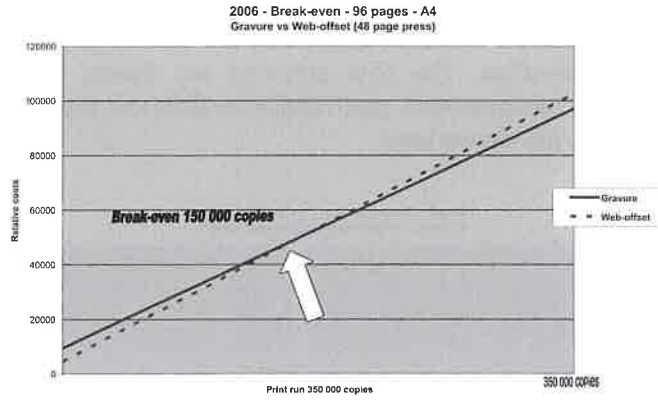


Diagram 7.4: 96 pages A4

These diagrams clearly show that the break-even levels have been pushed to a much higher level than they were at twenty years ago. Producing a 64 page signature with a brand new 64 page commercial web-offset press is indeed very competitive against any of the gravure alternatives. Only the 32 page web-offset alternative is not very competitive, even though no post press operations are included. When comparison is done on the 96 page alternatives, gravure is clearly very competitive from about 150 000 copies or more, although the break-even level is not quite clear cut. It should also be mentioned that the scatter among all participating printers is much smaller today than it was 20 years ago.

7.2 The European printing press market in 2006

The technology shift during the last 10-15 years has had an enormous impact on the publishing industry, and the printing industry has been forced to close or move to the customer most prepress operations. The entry level for publishing a new magazine has never been lower than it is today, and new titles are being introduced very frequently in all markets in Europe.

The previous technology was quite expensive and complicated, and only trained operators were in control of the technology, but these processes have now been simplified to such level that it has become everybody's standard procedure. Hence, the proliferation of the prepress technology has made it much easier for even very small printing companies to handle these processes. During the last decade, the development of CTP-technology and web-offset plate-making has undergone tremendous progress. Today there is hardly any web-offset printer who does not use CTP-technology.

Table I together with the break-even diagrams 7.1 and 7.2 clearly shows that gravure has lost its previous dominance over web-offset on both the larger signatures and medium size runs. It is also quite remarkable that the investments in commercial web-offset have been extremely high in Germany, which has always been a strong gravure market. It appears that gravure has at last been challenged at its core market, as gravure has always been dominating the German publication market.

The situation in Italy is also very interesting; the majority of the presses installed are very large presses - 64 pages or larger. Recent statistics from ERA, MAN-Roland and KBA are included in Table I. Gravure has always had a strong position on the Italian market, but it seems that commercial web-offset is rapidly taking over that position. Investments in the Nordic markets have been quite large with the exception of Sweden. The trend towards larger web-offset presses has been quite obvious since 2000, and the majority has been installed in the UK, Germany and Italy.

Table I

COMMERCIAL HEATSET WEB-OFFSET PRESSES INSTALLED 2000-2005								
Country	**Pages**	**16**	**24**	**32**	**48**	**64**	**> 64**	**Total**
Austria		2	3	1	4	1	0	**11**
Belgium		5	2	4	4	1	0	**16**
Denmark		3	2	1	3	0	1	**10**
Finland		6	0	0	1	2	1	**10**
France		22	3	1	10	2	0	**38**
Germany		50	6	18	18	9	5	**106**
Great Britain		28	1	0	8	9	5	**51**
Italy		10	2	1	7	14	8	**42**
Netherlands		4	2	2	0	0	0	**8**
Spain		13	2	1	8	1	2	**27**
Sweden		1	0	1	0	0	0	**2**
Switzerland		8	0	0	2	0	0	**10**
Subtotal		**152**	**23**	**30**	**65**	**39**	**22**	**331**

It has been estimated by web-offset press manufacturers that the investment volume in commercial web-offset during the years 2000-2005 was around 2 billion Euro (€). During the same period investments in new gravure printing capacity have been estimated to be about 0.6 billion Euro or around 20% of the total press investments. It seems that the renewal, and indeed also the installation, of new larger presses is more frequent among commercial web-offset printers. Consequently, gravure printers with low volumes and small-to-medium sized presses have high costs and will face strong competition from modern web-offset printers. With signatures of 16 to 48 pages the total printing costs are very high in comparison with modern web-offset.

During Drupa 2004, a series of in-depth interviews were conducted with many top managers in the industry. Web-offset technology was seen almost everywhere in the exhibition and made a strong impact on most visitors. The web-offset printer has, however, the choice of installing new capacity in 16 page increments, which might be less risky. Any printer contemplating such an investment needs control of the supply and demand on his market.

7.3 Hypotheses testing

One should, however, look at the results shown in Table 7.1-7.4 with some caution. A sensitivity analyses made on the break-even computations show that even a small change (5-10%) on either the fixed or variable costs constitutes a larger change on the break-even level. The diagrams shown should be regarded as trends rather than absolute figures, but it can be stated with sufficient validity that:

- The hypothesis that gravure printing is competitive from 64 pages is falsified (comparing the most modern web-offset presses with a capacity of 64 pages).

The result from the Questionnaire regarding gravure print quality on SC grades (uncoated stock) vs. HSWOP was that the majority of the respondents were supportive; the remainder did not know or were indecisive:

- The hypothesis that gravure print quality on uncoated stock is considered to be superior is supported.

8. A new concept for small and medium sized gravure printers

8.1 Sensitivity analysis of present data

The above mentioned diagrams are drawn from data and formula with a rather high sensitivity. A sensitivity analysis shows that even a small change in the fixed or variable costs for any of the web-offset or gravure alternatives, may lead to a quite dramatic change in the break-even level. This sensitivity suggests that a considerable amount of caution should be applied, and one may note if the fixed costs in gravure approaching those of web-offset, these changes may become quite large. The fixed costs in gravure are, to a very large degree, dependent on the cylinder-processing costs, and any sudden progress in cylinder processing will have a dramatic effect on the competitiveness of gravure printing. Any printer should use its own data when computing break-even levels and use the results in this report only as indicative. This is, of course, also relevant for any supplier of printing presses and/or cylinder- and plate processing.

8.2 Cylinder processing costs

Although direct digital engraving has been the standard procedure for almost all European gravure printers since the beginning of the 1990's, the process of producing gravure cylinders has not progressed until the last few years. One important advance, however, is that today there is no need for gravure proofs for magazine publication work. In 1986, it was not uncommon that certain gravure companies were proofing their cylinders up to three or four times, particularly for the most demanding advertising pages on the reverse side or inside of a cover or a demanding mail order catalogue signature. Between each proofing process there were also many hours of manual corrections.

This has changed during the last few years, and very few gravure printers are still offering gravure proofs and/or corrections. Some claim, nevertheless, that they retain these procedures, but that the customer has to pay for any use of the facilities. The majority, however, have no or little capacity (or competence) to do these manual operations. Other printers suggest that it is economically better and faster to carry out the necessary changes in the digital data and re-engrave the cylinder set. However, with the recent fast progress on new preproofing devices (more sophisticated software); the emulation of a gravure print is approaching a near perfect level. Corrections on cylinders may then only be necessary because of some malfunctions in the engraving cycle; hence a remake may be the only solution. The former skill of the trained craftsman is vanishing very rapidly.

Substantial investments in new gravure cylinder technology have, however, been implemented by some of the larger companies in Europe. Again, one must not forget the impact from the customers, demanding higher reliability, high quality and short lead times. Fully automated engraving and plating lines with a minimum of staffing have made the cylinder process much more efficient. Even if the investments in new technology in the cylinder processing department are large, the unit costs can be very competitive compared with web-offset plate-making, provided that the volume of cylinders is sufficiently high [Bjurstedt 2005].

8.3 A new approach

Already in the final report from 1986 [Bjurstedt 1986], some ideas were put forward as to how to improve the situation for the small and medium sized gravure printers. The concepts of short-run gravure and/or smaller paginations have also been investigated by Puri [Puri 2003]. His suggestion, however, was that all the narrow cylinder processing should be outsourced to a local packaging company or Trade service house [Puri 2003]. This suggestion might be possible in the North American

market, but would probably not work in Europe, because the market demands very short lead times. Notwithstanding, there is one example in Germany where the gravure printer has outsourced the cylinder processing to one of the leading trade-houses (for packaging gravure cylinders). Nevertheless, in this case, the cylinders are still processed in-house on the printer's premises. Puri also suggests that all PONY presses in Germany and Switzerland have been dismantled. This is not quite correct, because the presses in Germany (and in the US) are still in operation [ERA List of Presses 2005 and other sources].

Short runs in gravure was also discussed in the final report from 1986 [Bjurstedt 1896]. Unfortunately, there is no detailed definition available about short runs. A short run on a large market in Germany or North America might be considered to be a long run on a smaller market in Scandinavia, such as Finland or Denmark. I would like to suggest the following definition of short runs < 200 000 copies combined with the pagination of the signature printed, for example:

- Small pagination - < 32 pages
- Medium pagination - 48 - 96 pages
- Larger pagination - > 128 pages

When one considers the circumstances any printer is facing, running the press room on a 24/7 schedule, it quite easy to compute the annual consumption of paper (grades from 50-65 g/m2) in the European magazine markets according to this definition:

- Short runs - small pagination < 10 000 tons annually
- Short runs - medium pagination 10 - 18 000 tons annually
- Short runs - large pagination > 18 000 tons annually

It is quite easy to compute the press size which each of these volumes would fit. The standard press of 1986 updated to the 2006 level in automation and speed (the same web width) would probably consume about 24-28 000 tons annually, assuming a medium pagination and medium runs. Hence, the standard 2006 gravure press would consume some 50% more (50% wider web) or 36 - 42 000 tons. It is easily recognized that not only the investment but also the demand from the market have to be taken into account.

A narrow gravure press (web width about 2.0 m) would still, with the above mentioned constraints, consume about 18 - 22 000 tons. So, how about an even narrower presses? In 1985, it was suggested that the high speed narrow press concept should be investigated, but it was, after lengthy discussions in the project group, "*decided not to proceed with the cost examination of the high-speed narrow press option, because of the relative high initial costs in cylinder making for short run work. The cylinder costs are not linear with the face width of the cylinders although Tandem-engraving is an established procedure.....there is no advantage to be had in the capital investment required.*"

Recent investigations in modern cylinder processing equipment [Bjurstedt 2005] confirm the above statement. The linearity of investments vis-a-vi the cylinder face width is unfortunately for the small size gravure printer very weak.

8.4 The DE (Double Ender) concept

The DE concept will allow smaller or medium sized gravure printers to enjoy an entry level similar to that of a commercial web-offset printer, but more versatile and competitive. Preliminary figures collected in the new investigation shows that gravure can be competitive from signatures of 32 pages onwards. The concept is based on the previously mentioned suggestions from the 1986 report [Bjurstedt 1986] called the PONY press design, although the press manufacturers today prefer a Double Ender or DE for short - see Diagram 8.1 - 8.3.

It was suggested in the report that *"The PONY-alternative, where only 4 cylinders are produced, appeared to have more attraction for this type of work, and press room costs and efficiency were computed from known and existing installations."*

Further in the 1986 report it was stated that *"A PONY press is a press consisting of only four units, where half the cylinder width is used to print the recto side, then turning the web to go back to print the verso on the other half of the cylinder.... The proposed press is designed only for PONY-printing..."*

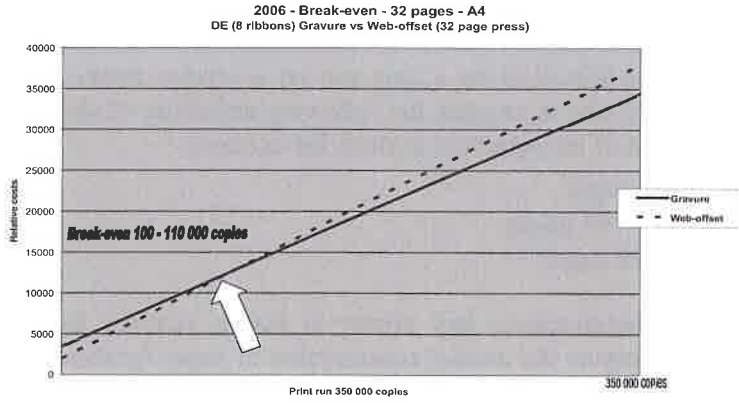


Diagram 8.1: 32 page A4 - DE gravure press - 32 page web-offset press

In order to improve the situation for the smaller or medium sized gravure printers, a new concept has been discussed in cooperation with the major gravure press manufacturers. With modern design, web control and press automation there is no doubt that a new DE press has a performance which is similar to or very close to a standard 8 unit straight gravure press, and this assumption has been confirmed by one of the leading gravure press manufacturers.

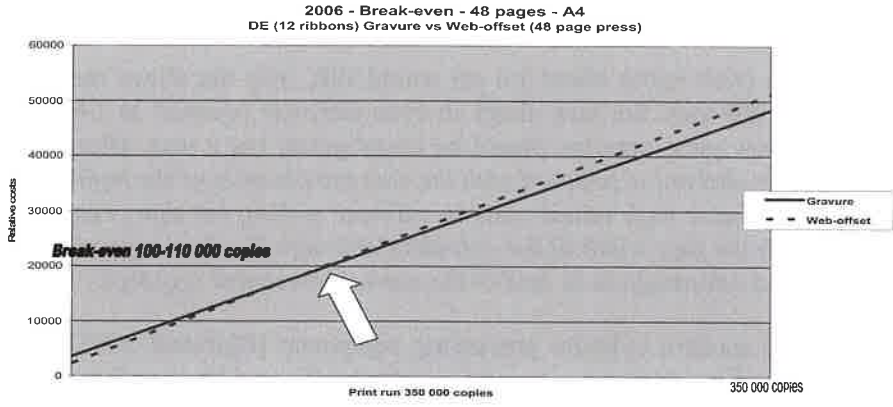


Diagram 8.2: 48 page A4 - DE gravure press - 48 page web-offset press

In diagrams 8.1, 8.2 and 8.3, the break-even levels for a 32, 48 and a 64 page signature are shown using the data computed from 2006. It should be noted, however, that the gravure figures are taken partly from synthetic data (estimations of the press room hourly costs) as there are only rather old presses installed. Other data, such as cylinder-making costs, press room performance etc., are taken from the new database. In these diagrams, the break-even levels between a modern DE press and a 32, 48 or 64 page commercial web-offset press are shown. Such a press would fit into the brackets of short runs with medium and/or large paginations, all depending on the product mix.

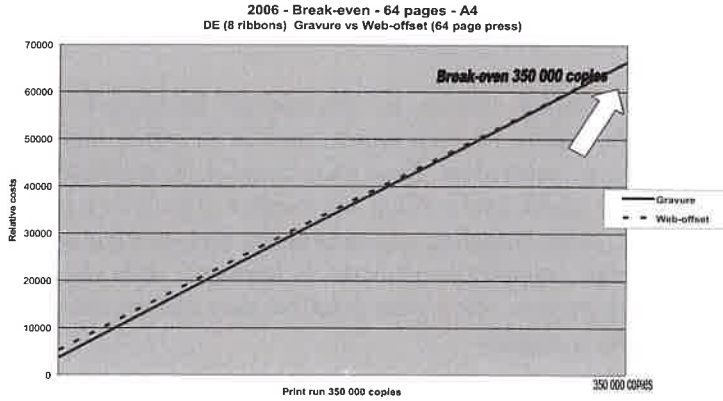


Diagram 8.3: 64 pages A4 - DE gravure press - 64 p web-offset press

The number of ribbons mentioned in the diagrams is equivalent to a straight 8 unit press, but in the DE-alternatives only half of the number produces the signature. It should be mentioned, however, that a 64 page signature can only be printed on a DE with 8 ribbons and 8 pages around (8U). (The DE with 12 ribbons may print 72 pages in 6 pages around (6U)). The lead-time of engraving cylinders in 8U is roughly twice the normal engraving time, and should for this very reason be avoided for printing jobs with the demand of short lead-times, diagram 8.3. In any case, the break-even level is also less advantageous for gravure.

Any publication gravure printer contemplating a DE gravure press has to make is own calculations based on the product mix and the annual volume to be printed. A DE press for 32 - 64 pages would process about 10 - 12 000 tons of paper annually depending on the product mix (pagination and print runs) and paper grades. A wider DE press suitable for 48-96 pages would process about 50% more. The initial investigation has shown some very interesting facts:

- A DE gravure press for 32 to 48 pages (web-width 250 - 260 cm) is similar to a 48 page commercial web-offset press with regard to capital investment,
- A DE gravure press has a very small foot-print (smallest press room area even with an automated cylinder loading/unloading) - about 12 x 18 metres,
- The same paper reels can be used for printing 16 pages up to 64 pages (8U) but using different cylinder circumferences,
- Combined with the most modern cylinder processing equipment, the time to market, or the lead time calculated from the receipt of digital data until the press produces acceptable copies, is probably shorter (< 3 hrs) than that of a standard 48 or 64 page commercial web-offset press (3 - 4 hrs),
- It should be possible to run a DE press with lower staffing than a 8-unit press, regardless of the web width,
- A DE press has the same flexibility of format as the normal gravure process,
- A DE press has the same colour gamut and excellent print quality also an uncoated stock - superior to web-offset,
- A DE press uses less paper for a given size and circulation compared with commercial web-offset - less printed waste and trimmings.

It is important for the future of the gravure process that there is a close cooperation and understanding between the gravure press and the cylinder equipment manufacturers, for example for press manufacturers to understand the economics of gravure cylinder processing. An internal paper from ERA published in 1987, written by Ms Ann Wilkinson *(Break-even zones presses - presses for short runs & low paginations)*, can unfortunately no longer be retrieved from the ERA archives. Nevertheless, one

copy was recently found in my archive, and the following statement from this paper is still valid and possibly of great interest for smaller gravure printers:

"Should a gravure cylinder-making system be devised or developed which had a cost linear relationship with cylinder face widths, or even pages, such as in offset, than the Pony (DE) principle would have far more economical constraints. Even then, there is the additional fact that the price of a press is also not linear with the width, and halving the number of units in a press cuts investment costs more than halving the width, even including the additional web-turning and alignment features. In those cases where only a small capacity in gravure is required, then the DE machine is the most economical investment. It also permits the lowest possible next investment step that is, retrofitting to u-units when the extra capacity is needed."

9. Conclusions

In the present investigation, the first hypothesis about the current break-even level of 64 pages is falsified. The current relations are still much in favour of web-offset printing and the previous signature size has increased substantially during recent years. One the reasons is that there has been a tremendous investment boom in the European web-offset industry with the introduction both of more advanced CTP-systems and new modern web-offset press designs. Break-even in gravure can now be achieved only when printing a signature of 96 pages or more (in a standard A4). This is a quite a significant change in competitiveness compared with 1985/86.

Nevertheless, it has been shown that gravure print quality on uncoated stock is still superior to that of commercial web-offset. Although some of the previous advantages for gravure printers, a cheaper sheet (then about 50 € per tonne) and less printed waste and trimmings, have been reduced to only - namely about $1/3^{rd}$ to $1/4^{th}$ less printed waste according to reliable sources. There is still some economic advantage to print on SC uncoated grades in gravure in comparison to commercial web-offset on LWC grades, even if a slightly lighter grade could be used.

What can be done for the short run gravure concept? If these advantages of the DE concept can be scientifically established, why has this concept never been a commercial success? There were some initial installations of new DE presses in Germany and Switzerland in the middle of the 1980's, but after these there have been no developments in this field. The German installations are producing covers (4 page products sometimes with gate folds and other special features etc.) and some very special low pagination work in superb gravure quality. Maybe the reasons are quite simple:

- Gravure is dominated by two large markets - Germany and North America,
- Gravure printers operating on those markets are used to the biggest customers, long runs and high pagination work,
- Gravure equipment manufacturers have no product management - contrary to commercial web-offset equipment manufacturers - and rely on input from their large customers in Germany and North America,
- Neither ERA (European Rotogravure Association) nor GAA (Gravure Association of America) have hardly any smaller printer as member. In the US market, there are only three big groups, each having a number of gravure printing plants. In the past ERA, however, had many small or medium sized gravure printers as Active Members, but many of these have been merged by other printers or gone out of business. During recent years, only one printer (previously in web-offset) has started a completely new green site in publication gravure.

It can be concluded that the key for future success for shorter runs in gravure lies in the cylinder-making process. One may add not only is a lower investment cost solution necessary, but more importantly, a technical solution which is highly automated (less staffing than before), high reliability, predictability

and repeatability. Such a solution would also enable the smaller and/or medium sized gravure printers to process gravure cylinders almost as cheaply as web-offset plates, provided that the volume is there.

The DE concept is worth exploring not only for the small and medium sized printers but also as a complement to larger groups to meet the demand for smaller signatures, covers or other speciality products printed in gravure.

In 1986, the working group concluded by saying that *"These figures obviously prove that there is large untapped market available to gravure printers, provided they are prepared to organize themselves to attack these sectors.*

We have shown that gravure can be cost competitive for short print runs, but in addition we should not forget that gravure gives the print buyers other advantages."

10. Acknowledgement

I would like to thank all those companies who have actively taken part in this study, particularly extending all the gravure and web-offset printers who have calculated their internal costs with great interest and commitment. Without their work, it would never have been possible to write this paper.

Finally many thanks go to the representatives of Hell Gravure Systems GmbH, Max Dätwyler AG, KBA Albert-Frankenthal AG and Officine Meccaniche Giovanni Cerutti Sp.A., Italy; for their most valuable input and comments as well as in-depth technical discussions.

References

1. Bjurstedt, Anders 1986. *Gravure vs. web-offset - separating the facts from the myths*. Gravure Research Institute - Report No M-351, Fla, USA, 1986
2. Bjurstedt, Anders, 2005: *Converging technologies in the Prepress*. TAGA Conference Proceedings, Toronto, Canada 2005
3. Bjurstedt, Anders, 2005. *Benchmarking gravure cylinders vs. Web-offset plates.* IARIGAI Conference Proceedings, Porvoo, Finland 2005
4. Bjurstedt, Anders, 2006. *Market Conditions and Product Requirements.* TAGA Conference Proceedings, Vancouver, Canada 2006
5. Bruhn Jensen, Klaus 2002. *A handbook of Media and communication research - Qualitative and Quantitative Metholodogies.* Routledge, Taylor & Francis Group, New York
6. Gravure Education Foundation and Gravure Association of America 2003: *Gravure - Process and Technology.* GEF/GAA, Rochester, USA 2003
7. Kipphan, Helmut 2000: *Handbook of Printed Media; Springer-Verlag, Berlin, Germany 2000*
8. Puri, K. K. 2003: *Cost-Competitive, Short-Run, Narrow-Web Rotogravure for Publications*; *TAGA Conference Proceedings 2003*
9. Merriam-Webster OnLine 2005. *www.merriam-webster.com*. 2005-08-24



Reorganisation of the media industry and the personnel

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Summary

The structural changes are strong in the media industry, since the entire production and the end products are in digital form and the globalisation accelerates the needs for decentralising the processes. The traditional vertical structure of the printing industry is turning into a horizontal one, where the companies specialise on given segments and sub-processes. This requires networking and operating together with focusing.

The total media consumption will not increase significantly. The circulations of the newspapers slowly decrease in Finland like in most western countries. In commercial printing the number of items is increasing, but the number of pages and editions are reduced. Flexibility becomes the ace in competition. In small family enterprises there is an obvious risk for passing at the change of generation. In printing production the number of employees will decrease and part of the prepress jobs will disappear. Also the traditional first line supervisors may disappear, as work processes are reorganised.

The changes bring new demands on skill for the employees. There is an increased need for managing totalities, complex processes and information technology. In addition to matters related to production tasks and equipment, the importance of quality management, customer orientation and understanding of business aspects will increase in all forms of production and on all levels in the organisation.

The changes will offer new challenges, development opportunities and more diversified work tasks. On the other hand, in the increased competition in the aggraded and networked organisations there is a risk for a higher work and time pressure. The main question is how the changes are carried out in practise.

The best results are obtained, when the members of the work community are offered responsibility and learning is supported with good introduction and training. To control the changes it is also important to create suitable routines for co-operation and to form teams of individuals representing different knowledge, different amount of experience and different ages.

1. Introduction

The scope of the study [Lindqvist & al., 2006] was to clarify the structural changes in the printing industry, their impact on the working environment and the wellbeing of the workers. The impact of the structural changes in printing production, de-centralisation and outsourcing of production, on working conditions were analysed together with resulting disadvantages for the workers and new demands on skills, demands and possibilities.

2. Methods

In the first step of the study the structural changes in the media processes were analysed in a time perspective of ten years ahead. This was made utilising earlier research results [Juhola & al., 2002], and interviewing the strategic management in different printing companies. The future value chains, production processes and organisation of printed production were described. Special emphasis was given to the new worker profiles needed, disappearing professions and the future need for training and experience.

After this, different personnel groups were interviewed and tested in three printing plants, the production processes were studied and their demand on human functionality was analysed. From these findings the potential impact of work on the wellbeing of the workers was evaluated. In addition, subjective impressions of work management, skills and need for training was studied with a questionnaire.

Finally the possibilities to support wellbeing during the restructuring have been evaluated. Different ways of performing reorganisation of work have been studied, utilising experiences from earlier changes. Recommendations for how to carry out a better controlled restructuring were developed.

3. Results and discussion

The total media consumption will not increase, but the position of printed and electronic media is difficult to predict. The media companies are converting from a vertical to a horizontal organisation, where each process stage can be decentralised and outsourced [Lindqvist & Siivonen, 2002]. At the same time a clear overcapacity in printing has been discovered.

The circulations of newspapers are slowly decreasing, and will fall by 20 per cent in the next decade. The share of electronic newspapers will be about 10 per cent of the total turnover of the newspaper companies. In commercial printing segmentation will lead to smaller editions and page numbers. Even if the number of items printed may rise, the total volume does not increase any more. Flexibility becomes the most important competition edge. Many small family printing plants will obviously close down at the next generation shift.

In the companies studied here approximately 20 per cent of the skilled workers in printing production will lose their jobs in the next ten years. The number of employees has decreased dramatically since the recession in the early Nineties (see figure 1). The same reduction in labour power will also occur in the mailroom. However, the most dramatic changes are foreseen in reproduction and plate production, where two thirds of the employment will disappear.

The service functions get more important, as automation develops, printing speed increases and delivery times are reduced. Service of core functions must be kept in house at least in big media companies, although many other functions may be outsourced. The future printing teams should also manage ICT technology. Multiply skills are valuated, and will become the best guarantee for workers to keep their employment. Also persons working in production must have abilities for customer service.

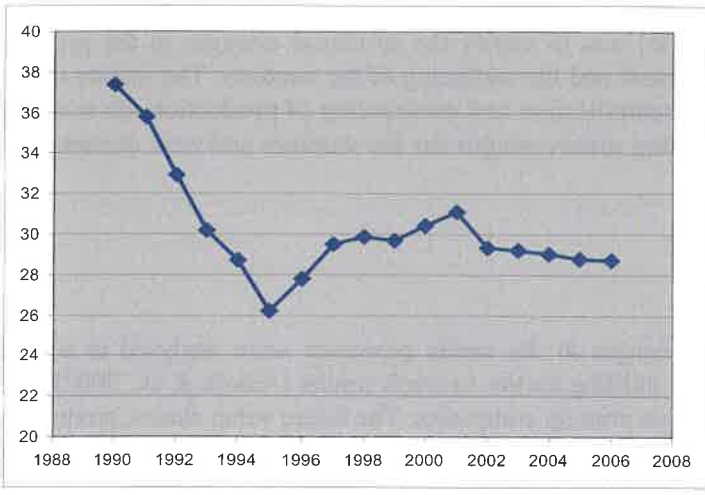


Figure 1:
The number of persons working in the Finnish printing industry (in thousands) has declined dramatically partly because of the recession in the early Nineties, partly because of outsourcing the distribution of newspapers. In Finland newspapers are delivered to your home early in the morning

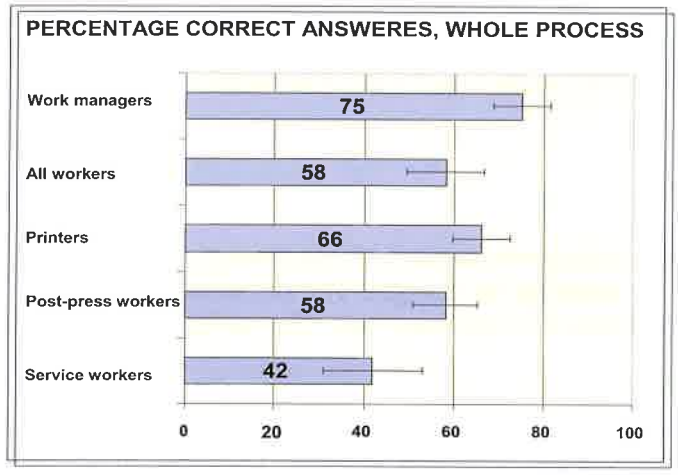


Figure 2: The conceptual mastery of the total printing process (in percentage of correct answers given in average and standard deviations) among different occupational groups

For this reason, the total process skill of the workers in different apartments was tested with a questionnaire in one big printing plant. It turned out that the over-all process knowledge was on a rather high level, i.e. 58 per cent managed the whole process (see figure 2). The task managers scored the highest ranking (75 per cent), in good competition with the printers (scoring 66 per cent). The poorest knowledge about the entire process was among the factory service people.

Figure 3 gives the conceptual mastery of the total printing process found in a diagnostic test of all the workers in one company. Production planning, the mailroom processes and labour protection turned out to be best mastered by all the workers, whereas service functions were poorly mastered.

The traditional work leaders will disappear, as organisations are flatted. Instead teamwork, co-operation and networking will be emphasized. There is an obvious risk that the new organisation will increase the amount of work and stress.

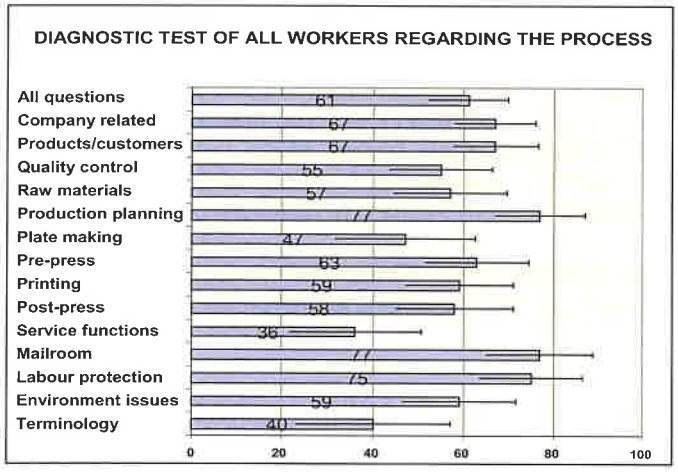


Figure 3: The conceptual mastery of the total printing process (in percentage of correct answers given in average and standard deviations) among different occupational groups

On the other hand, the new organisations also offer the personnel many advantages in form of a cleaner work environment, more diversified work tasks and challenges, and abilities to develop and

advance. New opportunities for both companies and personnel will be found in ambient environment, printed electronics and hybrid media [Lindqvist & Siivonen, 2005]. Multiple skills will, of course, also increase the market value of the workers and make them more attractive on the labour market.

4. Conclusions

In the restructuring of the media processes it is of importance to manage both the functions of the new processes and the way of operating the changes. The restructuring can be a long process, where also social and human sub-processes are important parts. The managing of these processes is a prerequisite for efficiency.

The combination of different knowledge, experience and values gives a social capital that enables economic results, innovations and wellbeing at work. The need for co-operation between different generations is emphasized in a situation of changes.

The future printing process is networked. The structure of the networked process requires well co-ordinated co-operation, well planned and strict time schedules and a flexible exchange of information. The process is sensitive to disturbances, since operations are not controlled from one point.

Teamwork and the responsibility of the team become important. On the other hand, individuals should learn more than one work task and to manage entire processes and systems. The company and the team should support the individuals by giving them responsibility and possibilities to further training. Last not least, each work and each organisation needs its own rules and forms for co-operation.

The new organisations offer their workers a cleaner work environment, more diversified work tasks and new abilities to develop and advance in compensation for higher demands on skill and flexibility. The impact on workers' wellbeing is summarised in the appendix. In total, the positive effects are estimated to be far stronger than the negative ones.

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References

1. Juhola, H., Lindqvist, U., Siivonen, T., (2002), *Media Technology Outlook; VTT Information Technology, Research Report TTE4-2002-27. Espoo, 2002. 67 s*
http://virtual.vtt.fi/inf/julkaisut/muut/2002/Media_Technology_Outlook.pdf
2. Lindqvist, U., Siivonen, T., (2002), *Integration and convergence in the media field; 29th IARIGAI Conference, Lake of Lucerne, Switzerland, 2002. 22 p*
http://virtual.vtt.fi/inf/julkaisut/muut/2002/iarigai2002.pdf

3. Lindqvist, U., Siivonen, T., (2005), *The media industry as a catalyst for economic growth; 32nd IARIGAI Conference, Porvoo, Finland, 2005. 8 p*
http://virtual.vtt.fi/inf/julkaisut/muut/2005/iarigai2005.pdf
4. Lindqvist, U., Siivonen, T., Seppälä, P., Klemola, S., Huuhtanen, P., Leppänen, A., (2006), *Painotoiminnan muutokset ja niiden vaikutukset henkilöstöön; VTT Tietotekniikan ja TTL:n tutkimusraportti 2005-6, Espoo 2006, 113 p. In Finnish with English summary*
http://virtual.vtt.fi/inf/julkaisut/muut/2005/PsykoMedia.pdf

Appendix: Summary of the changes in parameters affecting wellbeing

Working environment caractersistics	Changes in the company function and environment	Expected changes in wellbeing
Work load, stress and strain	Increasing factors: - Harder competition, shorter deli-very times, faster customer service, reduced personnel, decentralised and networked production, less hierarchy in organisations, larger job descriptions, continuous changes and increased demand an skills. Compensating factors: - Technical development and auto-mation, improvement in skills and flexibility.	Mental stress: - Increases or remain constant, can be positive or negative (if too wide work tasks and stress). Physical stress: - Less energetic strain, - Positional stress increases or remain constant.
Working environment, risk factors and health hazards	Increasing factors: - New technologies and materials, new risks? Compensating factors: - Automation, better equipment, labour protection.	Chemical risks and hazards: - Less. Noise exposure and physical damages: - Less.
Organisation of work, content of work and development	Factors improving possibilities for individual development: - Less hierarchy, teamwork, larger job descriptions, IT technology, multi-skills, improved skills and training. Factors reducing possibilities for individual development: - Subcontracting and outsourcing of work to customers.	Content and versatility of work: - Improved in general, - May be more restricted in some cases. Possibilities for individual development: - Improved in general.
Possibilities to influence work and independence	Factors improving possibilities to influence work: -IT development, automation, less hierarchy, teamwork, improved skills. Factors reducing possibilities to influence work: - Shorter delivery times, subcon-tracting and increased dependence.	- Possibilities to influence on organisation of work improved in general. - Stronger dependence on time schedules.
Social interactions	Factors improving interaction: - Process thinking, teamwork and enhancing of co-operation. - Factors reducing interaction: - Automation and reduction of peronnel, solo work	- More co-operation at work. -Nature of contact changes: Less face-to-face and more electronic communication.

Adoption of interactive media news services among young people in the Nordic countries

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Abstract

This paper studies adoption of interactive media news services among young people in the Nordic countries, focusing on Sweden. The paper aims to reflect the courses of events in terms of usage as the services are established on the market.

Using statistics and survey data concerning four contemporary media technology based news services selected to reflect different levels of available interactivity - on-line newspaper editions, web TV, news podcasting and news blogs - this paper analyzes some of the adoption characteristics of the services.

The new technological platforms as well as the presentation of content for the four analyzed news services can be compared to specific precursors, thus the S-curve and the five adopter categories suggested in diffusion theory can to some extent be used when forecasting the diffusion of the new services.

1. Introduction

According to statistics from the Mediebarometer 2004, a Swedish study of media use [Nordicom-Sverige, 2005], in 2004, 35% percent of the Swedish population used the Internet every day. On the Internet, different types of interactive news services such as on-line news editions, web TV, news podcasting and news blogs are becoming popular and accepted by the audience. However, continued use of contemporary new media technology services, such as interactive services, may to a higher degree than for traditional media services depend on critical mass of users to be interesting for the audience.

In Rogers' theories on diffusion of innovations, using the S-curve and adoption categories to describe the rate of adoption for innovations in a social system, communication channels constitute one of the dependent variables for the diffusion process to take place [Rogers, 2003]. The S-curve and the five adopter categories; innovators, early adopters, early majority, late majority and laggards constitute one of several highly accepted theories in research and trend reports predicting the rate of adoption, or as Lennstrand (1999) describes it "used in the context of sales forecasting" of new media technology.

In this study, in order to investigate adoption and use of four selected new media services, a survey was performed focusing on the four new media news services: on-line news editions, web TV, news podcasting and news blogs. The sample of the survey consisted of Media Technology students at the Royal Institute of Technology in Stockholm, Sweden, aged from 19-34 years old.

The selected news services are in some form all used for news content distribution and have to a certain extent been proposed to be competitors to the traditional news media, such as the printed newspaper. According to statistics from the World Association of Newspapers [Tidningsutgivarna, 2005], the Nordic countries are among the most newspaper dense areas in the world, which further contributes to making the market interesting for the study of the diffusion of interactive media news services.

2. Objectives

The aim of this paper is to investigate adoption of new interactive media news services as they are establishing themselves on the market and the complex of challenges when using the theories of diffusion on the converging technological development. The technology services have been chosen with respect to their level of interactive and personalization possibilities.

The adoption of the new media services is to be considered from a meta perspective as services analyzed are to some extent the same communication channels used in the diffusion process for spreading information about their own existence.

3. Methodology

As described by Carey and Elton (1996) new information services poses a special problem since they have no track record. In order to evaluate usage for the four chosen new media news services a combination of quantitative and qualitative methods have been used.

Available statistics both sales and usage for the four new media news services have been analyzed. A survey has been carried out during May 2006, with students from all the four levels of the Media Technology Master's Degree program at the Royal Institute of Technology, Stockholm, Sweden.

Furthermore literature on diffusion theory, new media and survey techniques have been studied in order to map the area for relevant theories, models and definitions and finding comparable studies to the selected services.

3.1 Internet based surveys

According to Solomon (2001) the popularity of Internet based surveys is growing continuously as they reduce time and cost compared to traditional phone or mail based surveys. Statistical surveys usually consist of four parts: planning, data collection, analysis and presentation [Blom, 1989].

Response rates for Internet based surveys tend however to be lower than for the traditional survey methods. Those who do not respond to a survey contributes to the non-response bias of the survey. However, the severity of the non-response rate bias can be reduced by comparing the results from the survey to known values in the population. [Grossnickle, 2001]

3.2 The survey instrument

The survey consisted of seven parts and was created in the software tool Bilda[1], mainly used for education purposes. The first part contained questions both open-ended and multiple options, with the purpose to get background information about the participants and find out more about their general view on new media. The following four sections all contained four-point Likert-scales, open-ended questions and multiple option questions. The purpose of these four sections were to find deeper knowledge about the adoption and usage of the four selected new media services; on-line newspapers, web TV, podcasting and blogs. Furthermore, in the four new media specific sections the respondents were asked about the importance of the content in the respective services. The sixth part concerned different forms of m-learning using new media services and contained four-point Likert scales and open-ended questions. This section is outside of

[1] www.bilda.kth.se, 2006-06-22.

the scope of this paper. The last section offered the respondents the possibility to add their e-mail address in order to participate in further surveys and a section for comments in general to the researchers. It was not possible to answer the survey several times, and the participants had to log into the system, thus avoiding people from outside of the sample to participate in the survey.

3.3 Procedures

All the participants of the survey were Media Technology Master's Degree students who attended a comprehensive course for all students at the Media Technology Program. The course list of spring 2006 consisted of 273 students from all four levels of the Media Technology Master's Degree Program at the Royal Institute of Technology, Stockholm Sweden. The list of e-mail addresses to the students was used with the permission of the course leader and the course examiner. Each student received an e-mail cover letter from the course leader encouraging him or her to participate in the survey. Further, the e-mail cover letter contained instructions on how to reach the survey and log on to it. The data was stored anonymously for each question. However, the names of the students that had answered the survey were available to the researchers in a separate data file. In the introduction of the survey, the participants were informed about their anonymity. Furthermore the participants were informed that an incentive of a lottery ticket to the national "Trisslott" lottery was offered each participant having completed the survey in a week's time from the first invitation e-mail.

3.4 Sample

The sample used for the survey was a convenience sample. All the participants in the study were all the students attending the same University program. The sample for the survey can be considered as early users of the new media news services, and the purpose of the survey was to explore usage of the services such as why adoption took place, at what time and to what extent usage take place, what role interactivity has for the usage and to what extent the personalization is important for the decision to adopt and to maintain usage of the service.

A total of 103 students logged into the system. Of these, 86 students responded to the entire survey. The response rate of the survey was however therefore 31% (86 of 273). The respondents ranged in age from 19 to 62 years old. However, only one respondent indicated that he was 62 years old, which was false. Excluding this person would give a range of ages between 19 to 34, with an average age of 23. 36% of the respondents were female and 64% male.

4. New media services and definitions

The following sections discuss definitions used in the paper and background to the four analyzed new media services.

4.1 On-line newspaper editions

Newspapers were among the early news organizations to move to the Web [Garrison, 2000, p. 6]. Boczkowski (2002) describes how newspaper companies have experimented with various alternatives to newsprint such as the phone based newspaper, radio based facsimile editions and videotex editions. Nordic newspaper companies are no exception in venturing in such new publishing channels, often referred to as "test projects".

Hedman (2004) claims that today, most newspapers with "self-respect" provide some sort of spin-off from the printed edition, an on-line edition. Boczkowski (2002) reviews previous research on on-line newspapers pointing out that early initiatives with for example "teletext" and "videotex" editions for computers and TVs primarily were made to cut printing and distribution costs, however also because of the new possibilities to create greater depth of the content compared to the printed newspapers.

Today, there are several market models for online newspapers, such as the national/international model, the regional model, the local-community model and the specialized or niche-model [Garrison, 2006]. In a review of revenue models for on-line newspapers, Mings and White (2000) exemplifies four basic revenue models: subscription, which in turn consists of several different models of subscription; advertising, where it often has been pointed out that classified advertisements are particularly well suited for the on-line editions; transactional, where "market spaces" are created between newspapers, consumers and advertisers; bundled model, where newspapers form partnerships with other content providers or for example, Internet access providers.

As Scandinavians are top ranked with regard to news reading, Engebretsen (2006, p. 3) argues that Scandinavian online journalism therefore is of interest especially as an indicator of European tendencies in this area. Engebretsen (2006) further describes how printed newspapers are limited in terms of space for storage and presentation of news content whereas online newspapers have no such limits. Furthermore Engebretsen claims that on the web, the potential of the on-line media is far from utilized by the newspaper companies in terms of using rich media or in-depth coverage. Instead news sites use a narrow and static design, focusing on downscaled still pictures and text presented in a traditional linear style.

In this paper, on-line newspapers are defined as daily and evening newspapers available on the Internet.

4.2 Web TV

Hjelsvold et al (2001) argues that the world wide web offers service quality features that traditional television cannot match, such as availability of the information any time the viewer wants to watch, interactivity with hyperlinks and other tools of interactions, personalization as the viewers can choose their content to a larger extent than they can with traditional TV, and possibilities for the audience to publish their own content even though they are not professionals. On-line newspapers often provide such web TV services on their web sites, such as Swedish newspapers Aftonbladet, Norrköping Tidningar and Dagens Industri [Appelgren, 2005]. However, according to a study of Nordic online news stories made by Engebretsen (2006) only 14 of the 95 examined stories contained video clips.

Beckman (2005) identifies three alternatives for web TV for newspapers:

1) Web TV as an additional function to the web site, updated sparsely,
2) Highly prioritized web TV, integrated with the on-line newspaper, updated with content when the type of news is especially well suited for the web TV channel,
3) A new TV channel, developed side by side with the on-line newspaper but with the same identity in terms of alignment as the newspaper.

Web-TV is in this paper defined as moving photographic images available at websites such as on-line newspapers.

4.3 News podcasting

A podcast is a radio show created by anyone who owns a computer and a microphone. It can be downloaded onto listeners' computers or portable music players [Fischer, 2005, para 2]. Podcasts can

also be described as time-shifted broadcasts over the web [Chan and Lee, 2005, p. 65]. Chan and Lee further describes how audio content via podcasting is downloaded to a computer and listened to directly from the computer or transferred to a portable media player such as an Ipod for later use when convenient for the owner of the media player. As podcasting is subscription-based it is therefore not subject to unsolicited material like spam [Chan and Lee, 2005]. Shandle and Swaniga (2005), quoting Curry describes podcasting as "the new 'old radio' in that the tools needed for broadcast are simple and for free". With the aid of RSS feeds, anytime the user logs on to the Internet, the software reaches out and automatically downloads newly posted podcasts to which the user have subscribed [Kreider Eash, 2006]. In an article in Wired, podcast content is described as anything from spoken-word programs by bloggers to shows made by professional radio organizations [Jardin, 2005] According to the Washington Post [Fischer, 2005] the few broadcast stations that so far have started to produce podcasts are mainly news stations. Kreider Eash describes podcast content as music, speaking, as a creative mix of voice, music and sounds, video or photos. The variety of available content is wide-ranging from radio shows to university lectures, news updates, bands' newest music or individuals' views of a political issues [Kreider Eash, 2006].

The definition chosen for podcasting in this paper denotes podcasting as several forms of subscriptions for audio files for automatic downloading to handheld devices such as mp3-players, hand held computers and mobile phones. Video files are excluded from the definition although it is currently often included in general definitions of podcasting.

4.4 News blogs

Herring et al [2004, p. 11] defines weblogs (blogs) as frequently modified web pages in which dated entries are listed in reverse chronological order. Furthermore, they argue that "the blog is neither fundamentally new or unique, but that it - along with other emergent genres driven by interactive web technologies - occupies a new position in the Internet genre ecology". Matheson [2004, p. 445] describes the weblog as "a form of writing that is unique to the web, reliant on what is arguably its key characteristic: the hyperlink". Andrews [2003, p. 63] claims that "the majority of blogs are personal Web sites, posted because blogging software automates much of the HTML coding needed for Web publication". Of the news blogs Andrews further claim that many of the blogs focus on niche content and that the news blogs to a large extent contain links to other blogs or in many cases print journalism. Matheson (2004) discusses Blood's division of weblogs into those, which emphasize the diary aspects and those, which emphasize hyperlinking [Blood quoted in Matheson, 2004, p. 449] and gives some examples of different types of news blogs, such as:

1. Blogs similar to electronic newsletters or e-zines with the purpose to inform and organize a particular community,
2. Blogs containing static collections of links, similar to links or metapages,
3. Blogs containing personal commentary from staff employed at media content companies,
4. Blogs that are event-specific weblogs from news organizations,
5. Blogs that are independent news weblogs.

Enlund (2005) describes blogs as a typical "pull" media, where the readers actively and on a regular basis have to seek the blog and look for newly updated content by themselves. However, Enlund argues that once the blog reader decides to use an RSS-service forming a subscription to the updates of the blog, it turns the blog into a push-medium as the reader is notified with hyperlinks and summaries from the last post as soon as the blog is updated.

In this paper, blogs are defined as web pages containing either text, images or audio content, presented as entries or so called posts written or created by the owner or several owners of the blog.

5. Theory

In this section theories concerning diffusion and adoption of new media and the uses and gratification theory are discussed.

5.1 Uses and gratifications theory

According to Katz et al (1974), studies have shown that audience gratifications originate from the media content, exposure to the media and the social context in which a person is exposed to a certain type of media. Stafford and Stafford claim that the use of media in general can be described as dichotomous, meaning that the audience consumes media either based on preferred media content versus enjoying the experience of media usage [Stafford and Stafford, 1996, in Stafford and Stafford, 2001].

Studies of audiences and their media usage thus often involve the theory of uses and gratifications [Perry, 2001]. The uses and gratifications approach involves (1) the social and psychological origins of (2) needs, which generate (3) expectations of (4) the mass media or other sources, which lead to (5) differential patterns of media exposure (or engagements in other activities), resulting in (6) need gratifications and (7) other consequences, perhaps mostly unintended ones [Katz et al, 1974, p. 510].

5.2 Diffusion and adoption theory

Cited in Stafford and Stafford (2001), McGuire (1974) claims that it is of less importance to know why a user came to a medium compared to how a medium could hold a user. However, in the theory of diffusion and adoption, why a user came to a medium is crucial. The base of diffusion studies is formed by the process where an innovation (1) is communicated (2) over a number of channels (3) over time (4) among the members of a social system [Rogers, 2003]. According to Rogers (2003), if an idea is perceived as new for the individual, it is an innovation. The newness of the innovation does however not only need to depend on that the individual knows about the existence of the idea; the individual can also have known about the idea for some time and built a positive or negative opinion about it, chosen to adopt the idea or to reject it. The newness of an innovation can therefore be expressed in knowledge, persuasion or a decision to adopt a new idea. The decision to adopt an innovation is part of a process that according to Rogers can be described in the following manner: Knowing an innovation exists creates uncertainty concerning the consequences the innovation could have for the individual in terms of whether the innovation could make life easier for the individual or not. This uncertainty makes the individual search for more information about the innovation in order to make an adoption decision. The main questions asked at this stage of the innovation-decision process concerns what kind of innovation it is, how it works, why it works, what consequences it might bring and what advantages or disadvantages that might follow if the individual will use the innovation. As the individual gathers more knowledge about the innovation, an opinion can be created. The decision to adopt or reject takes place, and after that the implementation and usage of the innovation can start. At this stage, the individual needs some sort of confirmation from the process in order to make yet another decision to further adopt or reject the idea. [Rogers, 2003]

Individuals tend to trust subjective opinions of other individuals that are similar to themselves. According to Rogers, mass media channels are efficient ways to inform the audience of the existence of an innovation, however so called inter-personal channels, involving face-to-face communication, are even more efficient in persuading an individual to adopt or reject and innovation.

The time it takes for an individual to go through all the stages of the innovation-decision process is called the innovation-decision process period. As individuals are different, the process will not have

the same period for all individuals. The rate of innovativeness denotes how early an individual chooses to adopt an innovation compared to other members of a social system. To compare the innovativeness between individuals, Rogers have created the five adoption categories: innovators, early adopters, early majority, late majority and laggards. The adoption rate is the relative speed at which an innovation is accepted by the members of a social system. When it is plotted in a diagram it takes the form of an S-curve. In the first stage of the curve, only a few members have adopted the innovation; the innovators. The more members of the social system that accept the innovation, the more the curve takes off and finally when there are very few individuals that are left to accept the innovation, growth slows down. The gradient further varies from innovation to innovation and also depends on the different social systems. [Rogers, 2003]

6. Media usage

In following sections, media usage is discussed based on available statistics from the Nordic countries and Sweden in particular.

6.1 Media usage in the Nordic countries

In the Nordic countries, especially in Sweden and Iceland, more than 80% use computers and the Internet. The lowest rate of Internet use in Europe can be found in Greece with 25%[2]. [Demunter, 2005]

According to statistics from Eurostat (2005), in 2004, 43% of all the households in Europe had Internet connection in their homes. Furthermore, the Nordic countries were well above the average (11.8) concerning the broadband penetration rate in the OECD (Organisation for Economic Co-operation and Development) countries with for example Sweden having 16.5 and Denmark 21.8 broadband subscriptions per 100 inhabitants [June 2005] [Norden, 2005]. There are also other ways to access Internet than from the home such as work school and public places. The highest proportion of accessing Internet at work can be found in Denmark with 70%. Furthermore, in all of Europe, 20% access the Internet using neighbours', friends' or relatives' Internet connection. [Demunter, 2005]

As this study concerns users aged from 19 to 34, the two age groups 16-24 and 25-34 is of interest. According to statistics of Nordic Internet use [Norden, 2005] the following percentage of individuals use the internet on a daily basis (Table I).

Table I: Daily users of the Internet in the last 3 months. 2005, the data from Finland was from 2004. [Norden, 2005, p. 42]

Age	Denmark	Finland	Iceland	Norway	Sweden
16-24	70 %	63 %	77 %	60 %	73 %
25-34	68 %	67 %	80 %	60 %	69 %

Statistics from Statistisk sentralbyrå in Norway 2005, shows that the Norwegian Internet users spend 44 minutes on the Internet on the average day, that is 10% of the time they consume media on an average day [Vaage, 2006].

According to statistics from Finland, young people in Finland use the Internet in considerably more varied ways than elderly people do. Six out of ten under 30 years old had at least eight purposes of

[2] Use in this case, means use in the three months preceeding the interviews carried out with the respondents.

use, compared to one out of seven 60 to 74 year olds. [Norden, 2005, p. 36] According to the Nordic Council of Ministers [Norden, 2005], the most popular activities on the Internet in the Nordic countries were sending and receiving e-mails, finding information about goods or services, reading or downloading online newspapers and news magazines, and internet banking. Listening to web radios and watching web television were also among the top 15 activities, however not as popular as reading newspapers on-line.

6.2 Media usage in Sweden

As the study performed in this paper is set in Sweden and concerns 19-34 year olds, specific statistics available concerning such Swedish users have been reviewed in more detail. Some of the statistics and topics presented in the previous section 2.4 will therefore to some extent be overlapping the statistics compiled in this section.

Morning newspapers: Statistics from 2003 [Carlsson and Facht, 2004] show that on the average day, 63% of the 15-24 year olds and 72% of the 25-44 years old in Sweden read a morning newspaper. The total number for readership of morning newspapers of readers aged 9-79 in Sweden was the same year 73%. The 15-24 year olds spend 19 minutes and the 25-44 year olds spend 23 minutes reading a morning newspaper on the average day. The total average reading time for readers aged 9-79 was 31 minutes.

Radio: In the year 2003 79% of the Swedish population aged 9-79, 75% of the 15-24 year olds and 79% of the 25-44 years old listened to radio on the average day. The total time spent listening was 148 minutes for the 9-79 year olds, 115 minutes for the 15-24 years old and 154 minutes for the 25-44 years old. [Carlsson and Facht, 2004]

TV: In 2003, 87% of the Swedish population aged 9-79, 86% of the 15-24 year olds and 84% of the 25-44 years old watched TV on the average day. The time spent watching TV was 122 minutes for the entire population, 131 minutes for the 15-24 year olds and 116 minutes for the 25-44 year olds. [Carlsson and Facht, 2004].

Table II: Purposes for using the Internet among the Swedish population aged from 16-74 January - Mars 2003 [SCB in Carlsson, 2004, p. 215]

Activity	Age 16-24	Age 25-34	Total (age 16-74)
Send and receive e-mail	86	82	66
Search for information about goods and services	76	79	64
Get information from homepages of authorities	35	53	41
Use internet bank services	35	58	38
Read newspapers or electronic magazines	36	38	30
Travel and lodging services	29	35	29
Listen to music or downloading music and games	64	37	27
Buy/order goods/services	32	34	23
Download forms from authorities	18	31	23
Other types of communication, such as chat	52	23	18
Listen to radio/watch TV	28	20	15
Send forms to authorities	10	15	12
Financial services such as shares	6	9	7
Attend formal education such as school, university etc.	14	6	6
Sell goods and services such as via auctions	7	7	5
IP-telephony/video conferencing	5	6	3
Attend general courses	3	4	3
Attend vocational training	5	4	3

Internet: Among those that have used the Internet during the past year (2002), 69% of the 15-30 year olds say they read a newspaper on the Internet [Hedman and Bergström in Carlson and Facht, 2004]. The purposes for using Internet in the year 2003 of those aged between 16-24 and 25-34 that are using internet every week are as can be seen in Table II. In the age group 16-24, 36% and in the age group 25-34, 38% state that they read Internet newspapers and electronic magazines. This is considerably lower than the number for those that stated they had used the Internet during the past year.

According to a survey made by RUAB in Carlsson (2004) 11% of the people aged 20-34 listened to live radio on the Internet on an average week in 2003. Table II also confirms that watching TV or listen to radio on the Internet is one of the 15 most popular purposes for the age group in question.

6.2.1 Access to different types of media

Table III shows the access to five types of media related to those types of media that have been investigated in the survey of the paper among the Swedish population's aged 15-44. As can be seen, access to computers with Internet access and having access to a mobile phone are almost compulsory, subscribing to a newspaper is common while owning a hand held computer is less common.

Table III: Percent of the population aged 15-44 that have access to different media in their homes 2004 [Nordicom, 2005]

Have in their homes access to	Age 15-24	Age 25-44
Subscription of newspaper	63	62
Computer with access to Internet	84	83
Hand held computer	9	9
Mp3-player	39	26
Mobile telephone	98	98

7. Results

In the following sections, results from the survey are presented, such as internet connection, what new media is to the respondents, what type of user the respondents consider themselves to be and media usage for the four analyzed new media services.

7.1 Internet connection

All of the respondents have access to high speed Internet connection at the Royal Institute of Technology. Furthermore, the majority of the respondents, 95% all have broadband connection to the Internet in their homes, of these 5% indicated that they surf for free on unprotected wireless LAN owned by their neighbours. Two percent use dial-up modem from their homes. Three percent indicated that they have no other Internet access than at the Royal Institute of Technology and the last 1% did not answer the question.

Apart from having access to Internet at home or at the University, 39% of all the students indicated that they have broadband Internet access at their part time work, 5% use wireless connections at coffee houses, airports and hotel, and 11% access the Internet via the 3G or GSM network using their mobile phone.

7.2 What is new media?

For the four services, on-line newspapers, web TV, podcasting and blogs, the respondents were asked to indicate which ones of these they find to be new media. It was possible to select several alternatives

or none of the listed alternatives and to give additional comments. 22% indicated that on-line newspapers where new media, 59% that web TV were new media, 74% podcasting, 50% blogs and 10% indicated that none of the listed services were new media (Figure 1). Some comments were made regarding online newspapers, which these respondents not considered to be new at all. A few of the respondents had never heard about podcasting, furthermore some respondents indicated that blogs were less serious than other media and therefore not should be denoted as new media at all.

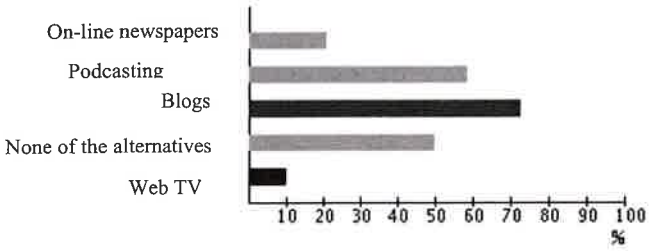


Figure 1: What is new media? (N = 86)

7.3 What type of new media user are you?

As the sample for the survey consisted of media technology students, they were considered to be fairly familiar with the adoption categories suggested by Rogers (2003): innovators, early adopters, early majority, late majority and laggards. However, for those that were not familiar with the concepts a brief explanation was given. The explanation is not the official definition of the categories, but served more as a guide for the respondents in order to estimate which category they believed they belong to.

The result can be seen in Figure 2 and shows that the majority of the respondents believe they are in the early adopter category (36%) or the early majority category (39%). 20% of the respondents considered themselves to be in the late majority when adopting new media, 1% in the innovator category and 2% in the laggard category.

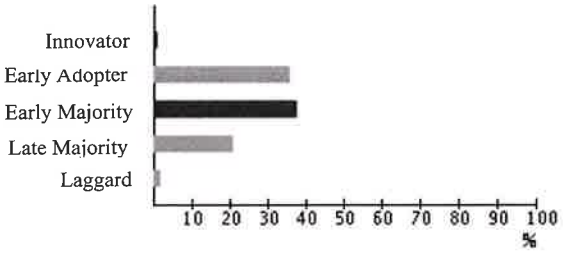


Figure 2:
Perceived type of new media user (N = 86)

Within this question, the respondents also had the opportunity to add comments. Many of the comments concerned economic issues related to adoption. The respondents behind these comments stated that they would like to be innovators and are aware of the new media trends, but can't afford to try out new trends themselves at the moment. The main reason for that they cannot adopt is simply that the new technology is too expensive and that if they have to choose between food and new technology, food comes first.

7.5 Total media usage

As can be seen in Figure 3, 42% of the respondents did not listen to radio at all on the average day. Only 5% listened for two hours or more. Figure 4, shows minutes spent watching TV on an average day, where 8% did not watch TV at all, while the other extreme, 2% watched TV more than 400 minutes a day.

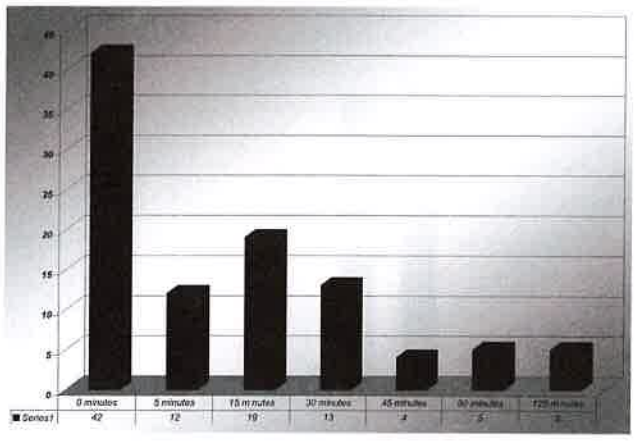


Figure 3: Radio listening on an average day (N = 83)

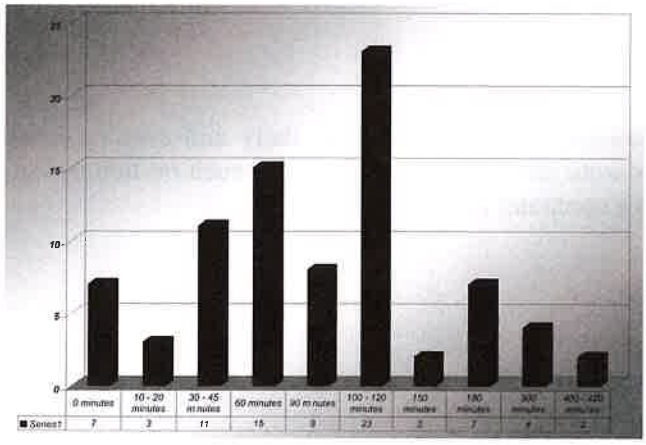


Figure 4: Minutes spent watching TV on an average day (N = 86)

Figure 5 shows minutes spent reading a morning newspaper on an average day. 41% indicated that they never read a morning newspaper and about 3% said they read morning newspapers for 60 minutes on an average day. In Figure 6, the minutes spent using the Internet has been plotted. Here, the majority of the respondents use the Internet at least for one hour up to four hours a day.

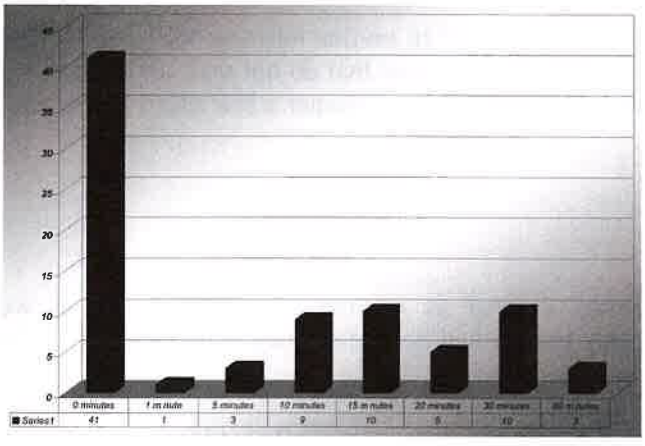


Figure 5: Morning newspaper reading on an average day (N = 82)

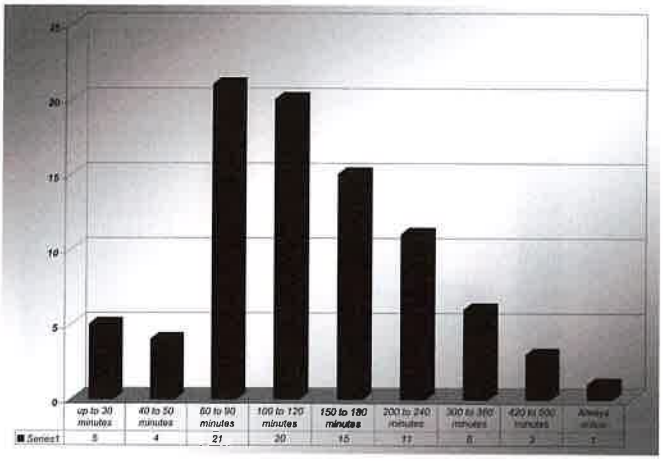


Figure 6: Minutes spent using the Internet on an average day (N = 86)

7.5.1 On-line newspapers

In the survey, on-line newspapers were defined as daily and evening newspapers available on the Internet. The respondents were asked how often they visit such on-line newspapers on the average day when they have access to a computer (Figure 7).

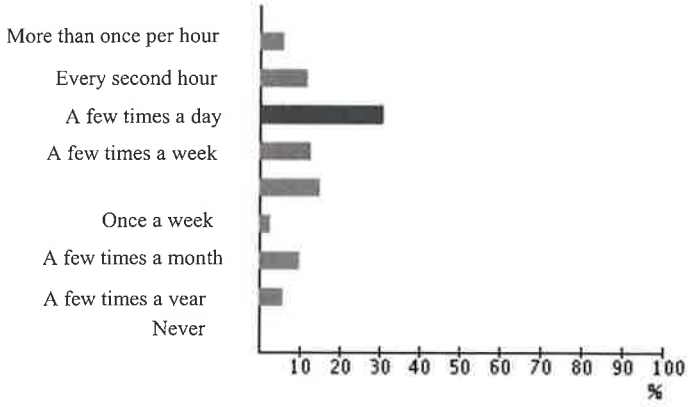


Figure 7:
How often do you visit an on-line newspaper on the average day when you are nearby a computer and have access to it (N = 85)

The majority responded that they visited an on-line newspaper at least a few times a day, where 5% visited more than once per hour. Among those that do not visit on-line newspapers on a regular basis, 5% indicated that they only visit an on-line newspaper a few times a year and one percent never visits on-line newspapers at all.

7.5.2 Web TV

Web-TV was in the survey defined as moving images available at websites such as on-line newspapers. The respondents were asked how often they watch web-TV, when they have access to a computer (Figure 8).

6% responded that they watch web-TV at least once a day. 13% at least once a week, 22% a few times e a month and 22% a few times a year. 31% stated that they never watch web-TV.

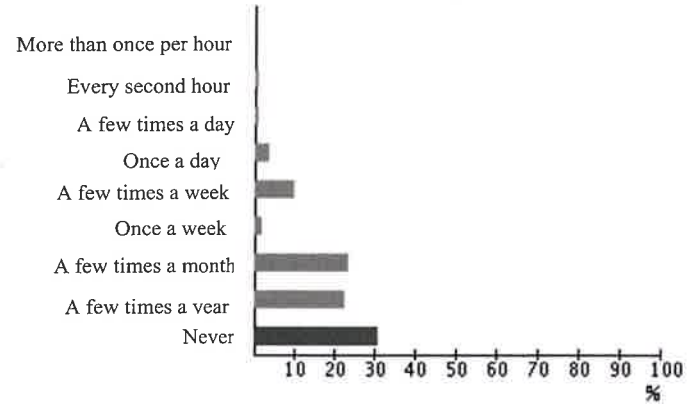


Figure 8:
How often do you watch web-TV on the average day (N = 85)

7.5.3 Podcasting

The definition chosen for podcasting in the survey denoted podcasting as several forms of subscriptions for audio files for automatic downloading to handheld devices such as mp3-players, hand held computers and mobile phones. In the survey, video files where excluded from the definition although it is currently often included in general definitions of podcasting. The respondents (N = 85) were however first asked if they own a device suitable for podcasting. 11% stated that they own a device that can download podcasts for both audio and video material. 28% stated that the device they own, only could receive audio podcasts. 55% stated that they do not own a device suitable for podcasting and 4% answered that they do not know. Further, the respondents were asked if they rather choose to consume podcasting services in their computer than downloading it to a hand held device (N = 83). Here, 28% stated that they rather download podcasts to their computers while 4% rather download the services to their hand held devices. 55% stated that they do not consume podcasting services at all, and 10% answered that they did not know. The usage of the podcasting services can be seen in figure 9 where 77% responded that they never use podcasting services. Of those that do use podcasting services this occurs only a few times a year.

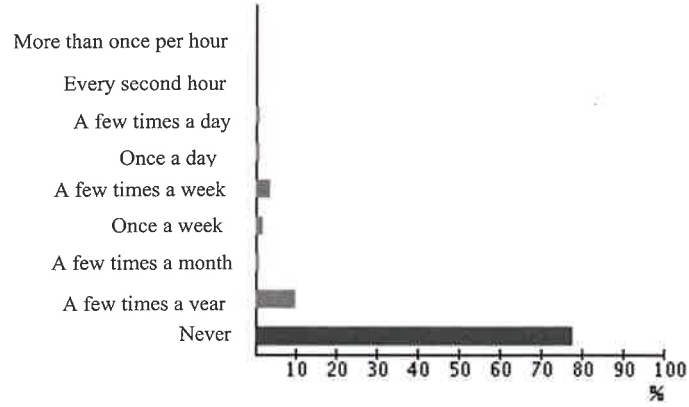


Figure 9:
How often do you watch web-TV on the average day (N = 84)

7.5.4 Blogs

Blogs were in the survey described as a phenomenon that recently has been highly exposed in the media. The respondents were presented to this section of the survey with information on that blogs are available in a variety of areas, ranging from highly considered news blogs to personal diaries. Furthermore, respondents were informed that the blog format is used for project and courses in schools and universities. In the survey, blogs were defined as web pages containing either text, images or

audio content, presented as entries or so called posts written or created by the owner or several owners of the blog. The posts can be commented and often contain links to other web sites or blogs as well as previous posts created by the owner of the blog.

The respondents were asked if they currently are keeping or have previously kept a blog of their own. 21% answered yes, and 78% answered no (N = 85). Of these, 25% updated their blog a few times a week, 6% once a week, 6% a few times a month, 31% a few times per year and 31% responded never. To view comments in their own blogs, 6% visit their blogs a few times a day, 6% once a day, 12% a few times a week, 12% once a week, 6% a few times a month and 12% a few times a year. 43% responded never.

Those of the respondents that visit blogs but do not keep a blog of their own, were asked about their reasons for not keeping a blog. Reasons given were that they have nothing interesting to write about, didn't want to expose their private life on the internet, that nobody would be interested to read about them, or that it was too much work to keep a blog. Many of the comments were strong such as "blogging is ridiculous", "I hate blogging", "I don't think I have anything more to add to what thirtysixthousandfourhundredtwelve idiots already are saying", "I don't wan't to keep my own blog it is too much hype around it" and "..blogging smells of unseriousness, navel-gazing and exhibitionism".

7.6 Adoption

7.6.1 First visit to an on-line newspaper

When asked about the first time the respondents visited an on-line newspaper the majority answered some time during the end of the 90's as can be seen in Figure 10.

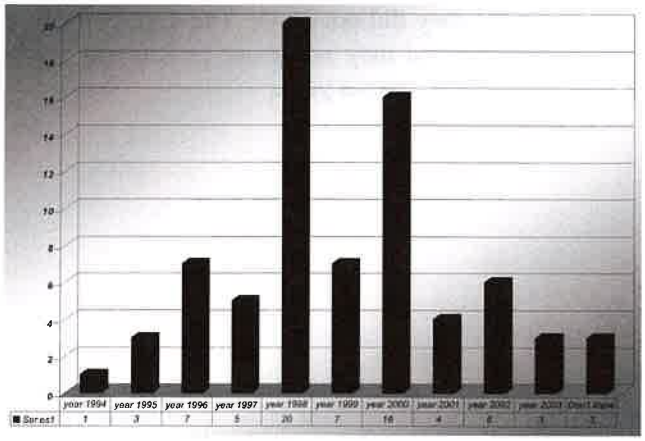


Figure 10: When did you first visit an on-line newspaper (N = 77)

7.6.2 Regular visits to on-line newspapers

The respondents where then asked about when they recall that they started to visit on-line newspapers more regularly (Figure 11). Here it is notable that 8% of the respondents still do not visit on-line newspapers on a regular basis. While 14% started visit on-line newspapers on a regular basis already in 2002.

Of those that responded they do not read on-line newspapers on a regular basis (7%), the main reason was that they prefer to read the printed edition. These respondents further indicated that they would

start reading on-line newspapers on a regular basis if the on-line newspapers were easier to navigate, had less copy-and-paste material from the printed edition, or if they started having breakfast in front of their computer.

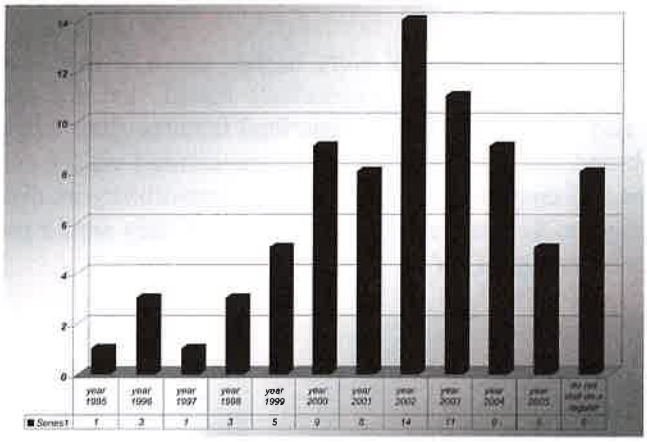


Figure 11: When did you recall that you started visit on-line newspapers on a regular basis (N = 77)

7.6.3 First time watching web-TV

Only 44 of the respondents indicated that they have watched web-TV. Of these, 14% watched web-TV for the first time during the year 2004, and one percent as early as 1998 (Figure 12).

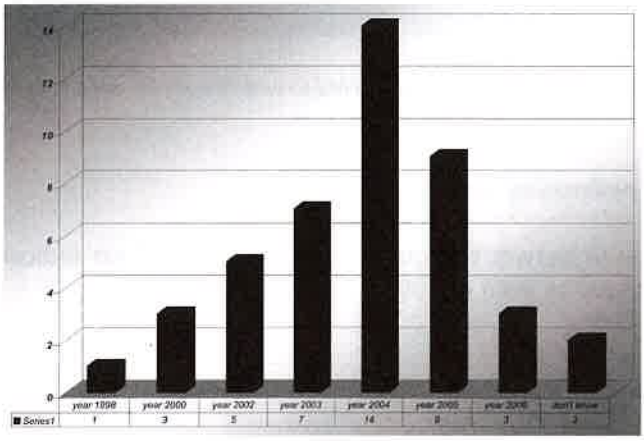


Figure 12: When was the first time you watched web-TV (N = 44)

7.6.4 Watching web-TV on a regular basis

17% watch web TV on a regular basis and most of them started watching around year 2005. 11% of those that answered the question indicated that they do not watch web TV on a regular basis (Figure 13). The rest indicated before entering this question that they didn't watch web-TV at all, and therefore continued to another part of the survey. These respondents were instead asked to indicate why they don't watch web-TV. The main reason was that the quality of image and sound were considered to be too low. Furthermore, the respondents prefer watching TV in the sofa and not in front of the computer. Some indicated that their computer wasn't compatible or didn't have the necessary plug-ins. Many of the respondents stated that they do not have a need for web TV or that they are too lazy to start watching it, as there are too many obstacles to overcome before they can reach the actual content.

Another reason for not watching web-TV was that the content isn't interesting enough and that it is much easier to find interesting content by downloading it from p2p-networks. One respondent further indicated that the feel of web-TV is that it is "created by amateurs compared to traditional broadcast TV shows".

The respondents that did not watch web-TV were further asked if there was something that could make them start watching web-TV. Most respondents stated that the quality had to be higher concerning video, audio and the content. Some described features they wished for, that would make web-TV into traditional broadcast TV, only that it was transmitted via the Internet. Others stated that Web TV has to be for free and easy to access in terms of compatibility on different operative systems, web readers and media players. Several respondents stated that they would probably watch web-TV if they didn't have access to a traditional TV.

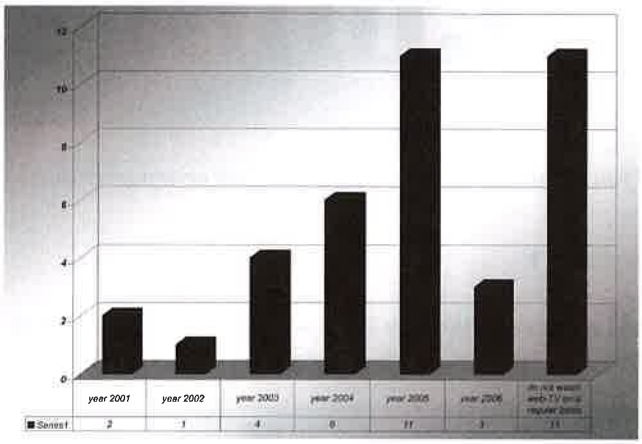


Figure 13: When did you recall that you started to watch web-TV on a regular basis? (N = 38)

7.6.5 First time to use a podcasting service

Only 8 respondents chose to answer this question. These respondents indicated that they first used a podcasting service in the year of 2005 or 2006.

7.6.6 Subscribing to podcasting services

The same respondents indicated that they started subscribing at the same time as they tried the service, during the years 2005 and 2006.

The 75 respondents not using podcasting services were asked to comment on why they are not subscribing. The main reasons were that podcasting isn't perceived as an interesting service, that they didn't see a need for the service, that they didn't know what it was or had not enough knowledge about it, or that they do not own a device that they can download the services to. Some of the respondents stated that it was too expensive and that it was much easier to download files for free, using p2p-technology than subscribe to podcasts.

These respondents, not using podcasting services were also asked if something could make them start subscribing. The answers revealed the same issues as why they do not use podcasting services such as: if they would purchase of a portable device such as an ipod, if there was interesting and free content, and furthermore if it was easy to access the content.

7.6.7 First time visiting a blog

As can be seen in figure 14, the first visit to a blog among most of the respondents took place around year 2004 and 2005.

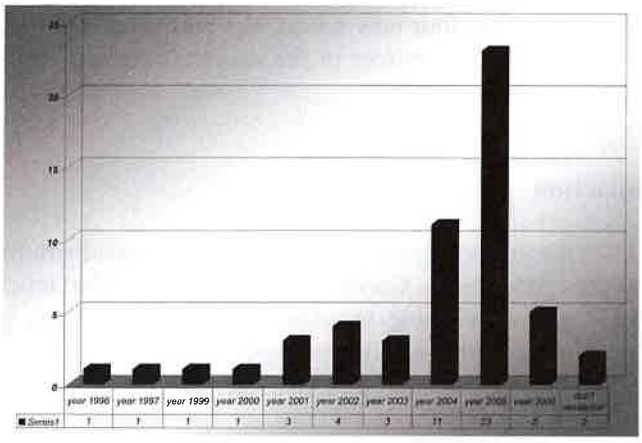


Figure 14: When was the first time you visited a blog (N = 55)

7.6.8 Visiting blogs on a regular basis

The year that the most of the respondents started to visit blogs regularly was in 2005 (Figure 15). 3% (N = 62) of the respondents further stated that they comment in blogs a few times a week, 4% once a week, 14% a few times a month, 25% a few times a year and 51% responded that they never comment in blogs.

The respondents that do not read blogs on a regular basis, were asked about why they do not read blogs and what could make them start to read blogs. Many comments seemed to be written in anger, as also have been stated previously in section 5.3.5 concerning why they are not keeping a blog of their own. The comments describe how blogs is seen as a waste of time with uninteresting low quality content. The respondents further stated that they would consider to read blogs if someone else encouraged them to, if they knew someone that kept a blog or if they found a blog interesting enough to read.

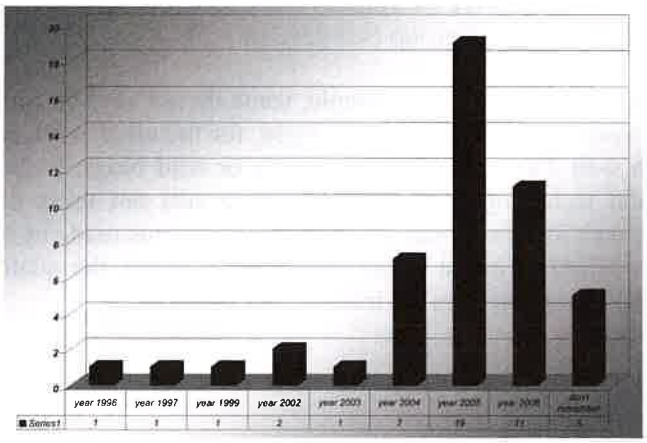


Figure 15: When did you recall that you started visit blogs on a regular basis (N = 50)

8. Discussion

The results obtained from the survey can at this point not be used to draw accurate conclusions from. The sample is too small, it is a snap shot and not based on longitudinal data, and it is not at all reflecting the population in general. However, it can still be used to discuss opinions, views and aspects considering media usage of the four new media services. The following sections will therefore briefly discuss the media usage of these services in the sample compared to the available statistics on the Swedish population of the same age group.

8.1 Media usage - a comparison

According to Carlsson (2004) the younger generation of today is in good command of media technology in all aspects compared to other generations. Carlsson therefore claims that much of the content available in newer media technology is not available to older generations, as this group of people are not comfortable with, and thus not using the new technology. When examining newer forms of media, a relevant group to focus on at this stage can therefore be a sample from the younger generation.

Comparing the answers from the sample of the survey, to the corresponding statistics of the Swedish population shows that there are differences in terms of media usage on the average day. These differences can be due to that the sample used for the survey are persons interested particularly in media technology as they are studying for a master's degree in the area. Furthermore, they sample consisted of University students, which also is a group that may differ from the rest of the population in for example interests, time, habits and economy.

As was seen in Figure 5, 50% of the respondents indicated that they do not read a morning newspaper at all on the average day. The average time spent reading a morning newspaper were 20 minutes, which is fairly the same as for the statistics for the Swedish population, (See section 5.2).

92% of the respondents watched TV on the average day, which is higher than the statistics for the Swedish population in the same age group (see section 5.2) the average time spent watching was however slightly lower than the average time spent watching TV for the Swedish population.

All the students had access to Internet at the university and most of them at home, and they therefore spent more time on the Internet than the Swedish population in the same age group.

Concerning radio listening, 42% of the sample stated that they never listen to radio, and of those who do, the average time spent listening were 31 minutes which is considerably lower than the statistics for the Swedish population in the same age group (see section 5.2).

Reading on-line newspapers varied across the sample, some do not read on-line newspapers at all while others have been regular visitors since 1998. Surprisingly, for the other services, few of the respondents indicated that they watch web TV, subscribe to podcasts or read blogs. Even though the students are highly interested in media technology, many of them are still not users of the above listed three technologies. The main reason for this as was stated in the comments made by the respondents had to do with that they cannot yet afford to invest in the technology needed, the quality of the services or the content is too low and that the content does not interest them enough.

8.2 Adoption categories

In the survey, the respondents were asked to indicate what adoption category they believed they belonged to concerning adoption of new media. However, is it possible to decide by oneself what

category one belongs to? The majority of the respondents indicated that they either belonged to the early adopters and early majority. Rogers [2003, pp. 283-284] describes these two groups as ideal types (here shortened and summarized):
Early adopters are a more integrated part of the local social system than are innovators. They are localites and function as opinion leaders in most social systems. Potential adopters look to early adopters for advice and information about an innovation. The early adopter is respected among his or her peers and his or her use of new ideas is successful and discrete. The early adopters put their stamp of approval on a new idea by adopting it, thus conveying a subjective evaluation of the innovation to near peers through interpersonal networks.

The early majority adopts new ideas just before the average member of a system. The early majority deliberate for some time before completely adopting a new idea. They are seldom opinion leaders in a social system.

To name just a few of the generalizations Rogers makes based on past research, earlier adopters tend to have higher social status than later adopters, more years of formal education, greater intelligence, a more favourable attitude toward science, greater exposure to mass media channels and greater knowledge of innovations than do later adopters [Rogers, 2003, p. 298].

In the case of the chosen sample for the survey, the respondents were all media technology students, thus highly aware of new media technology and innovations in the area. They had completed many years of formal education and studied in a highly challenging tempo at the Royal Institute of Technology in Stockholm, Sweden. This would thus indicate that they might belong to the earlier adopter categories, at least in terms of the above-described characteristics. However, as students' economy tends to be poor, this factor might be the most influential concerning their adoption category. Even if they would like to try a new media service, they might not afford to buy the equipment needed. Furthermore, they might not have the time to consume media to the same extent as other young people that were not studying at university level. It is not possible, due to the lack of longitudinal data on usage of the four analyzed media services to decide what category the respondents actually belong to. However, the results indicate that they are among the early adopters and the early majority.

8.3 New media and the meta perspective

Van Dijk (2004) claims that new media or contemporary new media seldom is completely "new" but rather combined characteristics of old media. Bolter and Grusin (2001) discuss new media by suggesting the concept of re-mediation to be "the formal logic by which new media refashion prior media forms". As Rogers (2003) suggest that an innovation is an idea, habit or an object that is perceived as new by an individual. The actual newness of the idea, measured objectively in time, is of minor importance for the individuals' reactions to the idea.

As can be seen in the sections of chapter 7, 77% of the respondents indicated that they never use podcasting services and 74% of the respondents in the survey further indicated that podcasting was considered as new media. This can be compared to on-line newspapers that were denoted as new media only by 22% of the respondents. Online newspapers were visited regularly by 92% of the respondents, thus a service they were familiar with. Web TV was considered as new media by 59% of the respondents and blogs by 50%. Furthermore, 10% believed that none of the four services could be denoted as new media.

As has been described previously in this paper, mass media are often efficiently used to spread information about a new innovation. All of the four analyzed services are thus to be considered from a meta perspective. The services analyzed are to some extent the same communication channels used in the diffusion process for spreading information about their own existence. Another common way to

introduce new media channels is to use cross-promotion in order to draw attention to the new publishing channel. In this manner, one media channel is used to promote another, for example when a TV program or a TV channel together with a newspaper promote each other starting from their common content [Appelgren, 2005].

9. Future research

The presented graphs on adoption in the paper have due to the lack of time, not been analyzed cumulatively. It would thus be interesting to further investigate the shape of the curves and compare them to the S-curve, when the data concerning adoption has been plotted cumulatively.

It is necessary to follow up the results from this study with deep interviews with newspaper company experts of the respective new media services. The purpose of the interviews will be to relate the available statistics of usage and the results from the survey to the strategies of the newspaper companies when launching, venturing and producing the new media news services in order to find if they correspond to each other. An analysis of critical mass of users in order to use the interactive services was during this study not possible to make and would be interesting to perform in the future.

Some parts of the collected survey data were outside of the scope of this paper, such as the respondents view on interactivity, personalization and content in the four analyzed media services. Therefore, this paper will be followed up by a deeper analysis of what kind of content that was perceived as best suitable for the different types of media. Furthermore, a deeper analysis will be made concerning who influenced the respondents into taking the decision to start using the four types of media services and what types of media is possible to use and consume simultaneously.

Acknowledgements

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References

1. Andrews, P., (2003), "Is Blogging Journalism? A blogger and a journalist finds no easy answer, but he discovers connections." *Nieman Reports*, Fall 2003, pp 63-64
2. Appelgren, E., (2005), "The influence of media convergence on strategies in newspaper production." Thesis for the degree of Technologie Licentiate at The Royal Institute of Technology, Sweden, Media technology and Graphic Arts
3. Beckman, K., (2005), "What is going on at di.se?", Thesis for the degree of Master of Technology at The Royal Institute of Technology, Sweden, Media technology and Graphic Arts
4. Blom, G., (1989), "Sannolikhetsteori och statistikteori med tillämpningar - C" (In Swedish), Lund, Sweden: Studentlitteratur
5. Boczkowski, P., (2002), "The Development and Use of Online Newspapers: What Research Tells Us and What We Might Want to Know", in Liewrouw, L and Livingstone, S. (eds.) The Handbook of New Media, Sage Publications
6. Bolter, J. and Grusin, R., (2001), Remediation, understanding New Media, The MIT Press
7. Carey, J. and Elton, M., (1996), "Forecasting Demand for New Consumer Services: Challanges and Alternatives". In Dholakia, Mundorf & Dholakia, eds.: *New Infotainment Technologies in the Home*. Lawrence Erlbaum Associates, pp. 35-58
8. Carlsson, U., and Facht, U., (eds), (2004), "Mediesverige 2004 - Statistik och Analys", Nordicom - Sverige, Göteborgs Universitet

9. Chan A., and Lee, M., (2005), "An mp3 a day keeps the worries away: exploring the use of podcasting to address preconceptions and alleviate pre-class anxiety amongst undergraduate information technology students", In: Dirk HR Spennemann & Leslie Burr (eds), Good Practice in Practice. Proceedings of the Student Experience Conference 5- 7th September '05. Wagga Wagga, NSW, Australia: Charles Stuart University, pp. 59-71
10. Demunter, C., (2005), "The digital divide in Europe", *Statistics in focus*, 38/2005, Eurostat, European Communities
11. Engebretsen, M., (2006), Shallow and Static or Deep and Dynamic? Studying the State of Online Journalism in Scandinavia. *Nordicom Review* 27 1, pp. 3-16
12. Enlund, N., (2005) "Bloggosfären - en arena för journalistik, debatt eller exhibitionism?" (The blogosphere - an arena for journalism, debate or exhibitionism?" in Swedish), *17. Nordiske Medieforskerkonference*, Aalborg, Denmark, 12 p
13. Fischer, M., (2005), "Podcasting: A Made-to-Order Change for Listeners - and Perhaps Stations, Too", Washintonpost.com, 4/12/2005, [Available online]: http://www.washingtonpost.com/wp-dyn/articles/A37405-2005Apr8.html, retrieved 2006-06-14
14. Garrison, B., "Online Newspapers" in Salwen, M., (ed), (2004), Online News and the Public. Mahwah, NJ, USA: Lawrence Erlbaum Associates Inc. [Available at Ebrary]: Retrieved: 2006-06-15
15. Grossnickle, J., (2001), "Handbook of Online Marketing Research", Blacknick, OH, USA: The McGraw-Hill Companies, p. 109. [Available at Ebrary]: Retrieved: 2006-05-22
16. Hedman, L., (2004), "Dagstidningar på nätet", in Carlsson, U. and Facht, U,. *Medie Sverige 2004, Statistik och analys,* Nordicom-Sverige, Göteborgs Universitet
17. Herring, S.C et al, (2004), "Bridging the Gap: A Genre Analysis of Weblogs", System Sciences, 2004. Proceedings of the 37th Annual Hawaii International Conference on Publication, Date: 5-8 Jan
18. Hjelsvold, R. et al, (2001) "Web-based Personalization and Management of Interactive Video", Proc. of 10th World Wide Web Conf. (WWW10), Hong Kong
19. Jardin, X., (2005) "Podcasting killed the radio star", *Wired News*, April 27. [Avalable online]: http://www.wired.com/news/digiwood/0,1412,67344,00.html, retrieved 2006-06-14
20. Katz, E. et al. (1973-1974), "Uses and gratifications research", *The Public Opinion Quarterly*, Vol 37, No.4. (Winter, 1973-1974), pp. 509-523, p. 510
21. Kreider Esch, E., (2006) "Podcasting 101 for K-12 Librarians" *Infotoday.com*, Vol. 26, No. 4 - April 2006. [Avalable online]: http://www.infotoday.com/cilmag/apr06/Eash.shtml, 2006-06-16
22. Lennstrand, B., (1999), "Diffusion Models - Tools for Forecasting or Self-fulfilling Metaphors?", 19th International Symposium on Forecasting, Washington DC, June 27th - 30th
23. Matheson, D., (2004), "Weblogs and the epistemology of the news: some trends in online journalism", *New Media & Society*, Vol6(4), SAGE Publications, London, pp. 443-468
24. Mings, S.M. and White P.B., (2000), *Profiting from Online News: The Search for Viable Business Models,* in Varian, H.R., (Ed.) Internet Publishing & Beoynd: The Economics of Digital Information & Intellectual. Cambridge, MA, USA: MIT Press, pp. 62-90
25. Norden, Nordic Council of Ministers, (2005), "Nordic Information Society Statistics 2005", TemaNord 2005:562, Copenhagen
26. Nordicom - Sverige, (2005), Mediebarometer 2004, NORDICOM - Sverige, Göteborgs universitet, Nr. 1
27. Perry, D., K., (2001), "Theory and Research in Mass Communication: Context and Consequences". Mahwah, NJ, USA: Lawrence Erlbaum Associaties, Inc., 2001
28. Rogers, E. (2003), "Diffusion of innovations". Fifth edition. New York, NY: The Free Press
29. Shandle, D. and Swanigan, M., (2005), "Podcasting for Dollars: Contextual Analysis, The digital Thinktank, October 2005, [Available online]: http://www.digitalthinktank.org/text.php, retrieved 2006-06-14
30. Solomon, D.J. (2006) "Conducting Web-Based Surveys", *Practical Assessment, Research & Evaluation*, 7 (19). Retreived May 26, 2006 from http://PAREonline.net/getvn.asp?v=7&n=19

31. Stafford, T.F., and Stafford, M.R., (1996), Mechanical commercial avoidance: A uses and gratifications perspective. *Journal of Current Issues and Research in Advertising*, 18(Fall), 27-38
32. Stafford, T.F., and Stafford, M.R., (2001), "Investigating Social Motivations for Internet Use". In Lee, O. (Ed.), Internet Marketing Research: Theory and Practice. Hershey, PA, USA: Idea Group Publishing. [Available at Ebrary]: Retrieved 2006-06-01
33. Vaage, O.F., (2006), "Norsk mediebarometer 2005", Statistisk sentralbyrå - Statistics Norway, Oslo-Kongsvinger
34. van Dijk, J. (2004), Digital Media in The SAGE Handbook of Media Studies, Downing, J. D. H, McQuail

Roadmap on printed functionality and hybrid media

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1. Introduction

Printed functionality means adding new functionalities into flexible substrate, typically paper and plastic, in addition to regular graphical properties by using printing methods. Functionality can be on the surface of the substrate or within it, or both. Printed functionality can be codes containing links to additional information. Such codes include one- and two-dimensional bar codes as well as invisible, reactive and electronic codes. Furthermore, printed functionality can be visual effects and images, multi-layer structures, electronics, optics and displays as well as sensors and indicators. Table I summarizes different areas of printed functionality.

Table I: Different areas of printed functionality

Main areas	Sub-areas
Optical codes	Linear bar codes (1D bar codes) Two-dimensional bar codes Reactive codes
Hidden or embedded codes	Invisible codes Digital watermarks Microtext Magnetic codes
Electronic codes	RFID tags
Visual effects	Holograms, kinegrams
Multi-layer structures	
Electronics	Passive components Conductors Circuit boards
Optics	Light guides Micro lenses
Displays	OLED LCD Thermochromic
Sensors and indicators	Temperature, moisture, oxygen, chemical compounds

Digital watermarks are information hidden in digital medias such as images by modifying the digital content. The difference between sensors and indicators is that sensors are read instrumentally and indicators by using human senses.

Hybrid media is closely related to printed functionality. Figure 1 shows how printed media, digital media, printed functionality and hybrid media connect to each other. In the figure printed means that every part of the certain component is made by using printing methods. Printed/attached means that some parts of the component can be done by other means besides printing methods. One example is printed RFID tag where the antenna is printed and the chip attached to the printed antenna by other means.

Hybrid media is defined as the integration of different medias, contents and functionalities - especially convergence between fiber-based products and digital media. Electronic paper or e-paper belongs to the same context, even if the substrate here is plastics rather than fibre-based materials. One example

of hybrid media applications is using printed two-dimensional bar codes as a link to digital media [Hakola et al., 2005]. A code printed on a publication or a package can be imaged with a camera phone that has software for decoding the information in the code. The decoded information can contain a link to a website which the user can access with the network connection in his mobile phone. One example of such an application is presented in Figure 2.

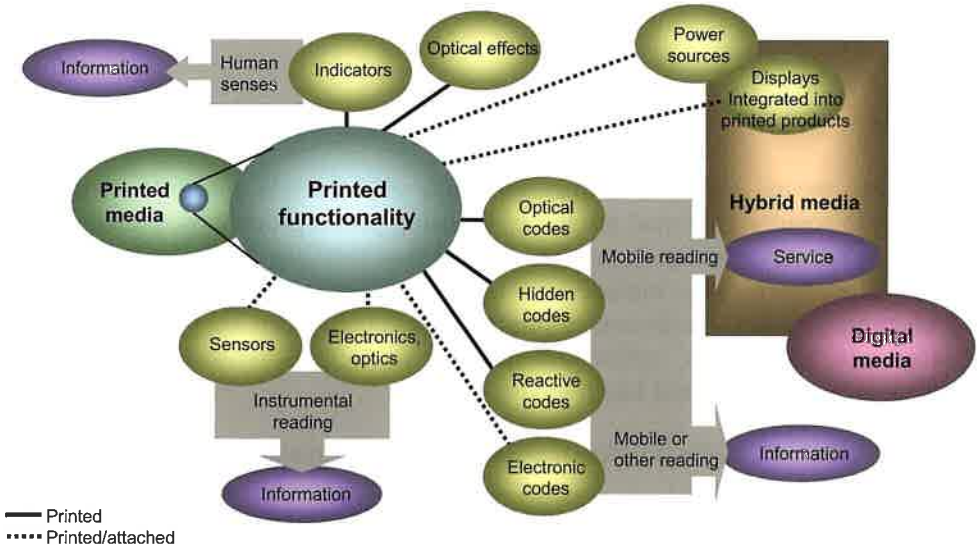


Figure 1: The definition of printed functionality and hybrid media



Figure 2: An example of a hybrid media application.
A camera phone is used for imaging a two-dimensional bar code for accessing a website

The objective of a research project at VTT was to create technology and business roadmaps on printed functionality and hybrid media [Södergård et al., 2005]. The objective was also to bring together the knowledge on printed functionality scattered around VTT. The work combined knowledge on media and printing technologies, electronics and optics as well as diagnostic packaging to be able to estimate future turnover and applications in this area. The results will serve as a base for future research projects.

Besides research organisations also industrial companies have started to show interest in topics related to printed functionality and many companies are working together with research institutes. The business potential in this area is big, because the media and package industries are constantly striving to add new functions in their products and, at the same time, develop their processes. Other branches, such as electronics, ICT and food industry, look at printing as a cheap method for mass production which also opens new applications and opportunities.

There is a border area between the ICT and forest clusters with a lot of business potential in particular for new knowledge-intensive small and middle-sized enterprises (SMEs). Utilisation of this potential

demands the forming of a permanent network between SMEs, traditional ICT and forest companies, and universities and research institutes. From an international perspective, Finland has every possibility of taking a leading role in this sector, because both forest and ICT clusters are strong in Finland.

2. Methods

The work was done by gathering all research groups at VTT active in the area of printed functionality into three workshops. At first mapping of global and VTT's excellence in printed functionality was done. Global excellence on printed functionality was divided into sub-categories of research organisations, equipment manufacturers, material manufacturers, companies selling technology, end-product producers, displays and printed electronics. Global excellence in hybrid media was covered as a separate category.

Both technology and business roadmaps for a time span of 2005 to 2015 were implemented in the areas of materials and manufacturing, displays, sensors, hybrid media and e-paper as well as packaging. Technology roadmaps show when certain technologies will emerge. The whole value chain of each sector was defined in technology roadmaps i.e. application areas, enabling technologies, components and devices, manufacturing processes and tools as well as relevant materials. Each business roadmap was presented in a scale of VTT, Finland, Europe and global each consisting of turnover, personnel, market share and companies.

3. Results

3.1 Technology roadmap

The results presented here focus on the technology and business roadmap on hybrid media and e-paper. The vision for technology roadmap for hybrid media and e-paper is that electronic and magnetic inks, as well as mobile devices with RFID and touch readers will become more common. This will promote the shift from the static, optical codes currently used in hybrid media applications to active, updateable, electronic codes. Electronic paper will further enable hybrid media applications that won't require a separate reading device. Table II shows the technology roadmap on hybrid media.

Table II: Technology roadmap on hybrid media

	2005	2008	2010	2015
Application area	-Information -Visit cards -Logistics	-Shopping -Booking -Games -Active posters	-Aid for disabled and elderly	
Enabling technologies	-Plain paper -Functionality in coating -2D codes -Invisible codes	-Coded paper -Tailored 2D codes -Embedded 2D codes -2D codes with graphics-microscopic -Electronic codes	-Functionality in fiber -Electronic paper -Reactive codes -3D codes -Position codes -Holograms	-O-ROM -Dynamic information
Components/ devices	-Mobile with camera -Small displays -PDA	-Mobile with RFID reader -Speakers -Touch reader	-Paper-like displays	-Displays everywhere
Manufacturing processes and tools	-Conventional printing -Digital printing		-Surface modification	-Wireless printing
Relevant materials (existing)	-Paper -IR/UV inks	-Electronic inks -Magnetic inks		

There are at least three different scenarios of what will happen in the field of hybrid media technologies during next ten years. The first scenario is that electronic codes will eventually replace optical codes, because their offer more functionality and become as cheap as optical codes. The second scenario is that both technologies will co-exist. This is especially possible if the prices of the electronic and magnetic inks don't come down enough from their current price level. In this scenario the optical codes will be used in inexpensive and mass volume applications and electronic codes in more sophisticated and expensive applications. The third scenario is that prices will come down, but all three technologies - optical codes, electronic codes and e-paper - will co-exist and their use will depend on applications, preferences and products. Other technologies, such as reactive codes, functionality in fibres and holograms as well as improved mobile device reading functions will further broaden the field of applications.

Plastic Logic [Burns, 2005] has estimated that A4 size greyscale electronic paper with 150 ppi will become reality in 2006-2007 and A5 size colour electronic paper with 100 ppi will be realized in 2007. According to the same roadmap fast updating of the electronic paper content will be possible in 2008. The forecast by Plastic Logic is more optimistic than the one presented in this paper. However, the forecast by Plastic Logic defines when certain technologies will be demonstrated, but the roadmap presented in this paper talks about commercial use.

PolyIC [Clemens, 2005] claims that prototypes of printed RFID tags will be realized in 2006 and the first products will emerge in 2007. This estimation supports ours since we have forecasted that the use of electronic codes will emerge in 2008.

3.2 Business roadmap

Table III presents the business roadmap on hybrid media. It should be noted that VTT's figures are included in Finland's figures, Finland's in Europe's and Europe's in the global figures. The business roadmap shows a significant growth in hybrid media and e-paper activities during ten years, for example turnover in Finland will become hundred times bigger and also global turnover will become over forty times bigger. Currently Europe's market share is only 20% of the global markets since hybrid media applications are already widely used in Japan. It is, however, expected that Europe's market share will grow in the next ten years to 35% since the technology is already at the piloting stage in Europe. It is expected that Finland will have a large market share of 10-20% in Europe since Finland is strong in mobile technology. Also Finland has already had research activities on hybrid media for several years and several hybrid media pilots have been done in Finland especially during last two years.

*Table III: Business roadmap on hybrid media [*my = man years (the number of persons involved in the activities are 2-3 times higher), **the turnover of Finnish mass media 2003 was 3,7 B€, ***the break-through of e-papers is expected to come 2010-2012, ****includes the hybrid media research of VTT]*

GLOBAL	2005	2008	2010	2015
TURNOVER	230 M€	500 M€	1.500 M€	10.000 M€
PERSONNEL	750 my *	1.200 my	5.000 my	23.000 my
MARKET SHARE	100%	100%	100%	100%
COMPANIES	< 30	< 100	< 300	< 500

EUROPE	2005	2008	2010	2015
TURNOVER	45 M€	120 M€	500 M€	3.500 M€
PERSONNEL	150 my	300 my	2.000 my	8.000 my
MARKET SHARE	20%	25%	30%	35%
COMPANIES	~ 10	~ 25	~ 100	~ 400

FINLAND	2005	2008	2010	2015
TURNOVER	5 M€ **	25 M€	65 M€ ***	500 M€
PERSONNEL	~ 20 my	80 my	200 my	1.200 my
MARKET SHARE/EU	10%	20%	15%	15%
COMPANIES	~ 3	~ 5	~ 20	~ 50

VTT	2005	2008	2010	2015
TURNOVER	1 M€	2 M€	3 M€	3 M€
PERSONNEL	10 my	20 my	30 my	30 my
MARKET SHARE/FINLAND	20%	8%	5%	0,6%

Besides hybrid media and electronic paper also the other sectors of printed functionality show considerable growth potential. Figure 3 summarizes all business roadmaps made in this study. The total global turnover is estimated to be about 2500 M€ 2005 and will in 10 years grow 28 times to 70 000 M€. The OLED displays are currently the most important sector, whereas materials and manufacturing of other components (including low-quality OLED displays) is the second. The other sectors are currently still of small volume. OLED displays will retain a significant growth rate 10 years ahead, but will be surpassed a bit by the total sum of materials and manufacturing of other electronic components. Printable sensor will grow rapidly the next years to come, but a slight saturation will take place after 2010. Hybrid media has an exponential growth accelerated by the deployment of electronic paper around 2012. Visual indicators on packages have a similar growth curve as hybrid media, but the volume is about the half.

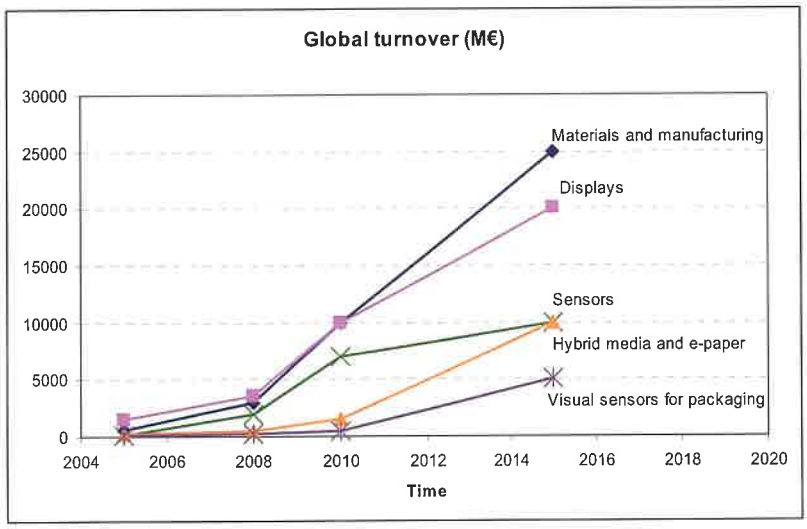


Figure 3: Expected growth of printed functionality in different sectors

NanoMarkets [Gasman, 2005] has estimated that the biggest growth areas in 2005-2010 in printed electronics will be RFID (cumulative sales 3000 M$), OLED displays (2900 M$), backplanes (1700 M$), memories (900 M€), photovoltaics (850 M$), smart cards (500 M$) and sensors (300 M$). Compared to our forecast NanoMarkets has estimated that sensors won't be as big. However, NanoMarkets agrees with us that OLED displays will be one of the most important areas.

For Finland, the corresponding trends are given in Figure 4. From a marginal volume today, especially OLED displays as well as hybrid media and e-paper will grow very rapidly. Altogether, the sectors will generate 1500 M€ turnover year 2015 and employ about 5000 man years. In hybrid-media and e-paper, Finland will gain 5% of the global market, in other sectors significantly less.

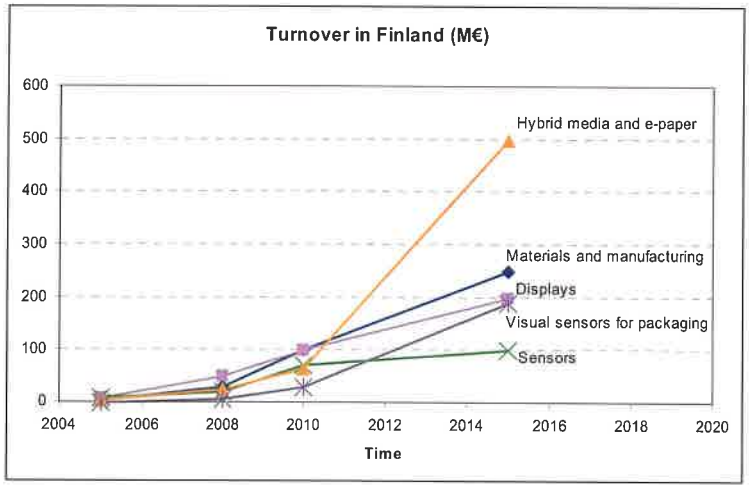


Figure 4: Expected growth of printed functionality turnover for Finland

3.3 Mapping of excellence

Based on mapping of excellence 16 research organisations, 8 manufacturers of printing presses and printheads, 28 material manufacturers, 19 technology sellers and 18 producers of end-user products currently active in the printed functionality were found. Specifically, 13 companies active on hybrid media were found. This study was done in summer 2005, but since then especially in Finland even more active players in hybrid media have emerged.

4. Conclusions

According to technology roadmaps the first area of printed functionality to be commercialized will be roll-to-roll and inkjet printing of flexible electronic components and low-quality displays around 2008-2010. Printable RFID tags will be used in logistics around 2008 and in product packages around 2013-2015. Electronic paper will make a breakthrough on the market around 2012 and spread rapidly.

According to business roadmaps hybrid media will have an exponential growth that will be accelerated by the deployment of electronic paper around 2012. Fast improvement of mobile device properties and reading capabilities will be one of the reasons for rapid growth of hybrid media. As a conclusion, printed functionality and hybrid media is a fast-growing technology area in which Finland has a good chance to gain a significant role globally, especially in areas related to the current forest industry.

5. List of abbreviations

IR	InfraRed
LCD	Liquid Crystal Display
OLED	Organic Light Emitting Diode
O-ROM	Optical Read Only Memory

PDA	Personal Digital Assistant
RFID	Radio Frequency IDentification
UV	UltraViolet

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References

1. Burns, S., *Commercialising printed thin film transistors (TFTs) for flexible active matrix displays, Pira Printed Electronics Conference, London, UK, 2005*
2. Clemens, W., *With printed Electronics toward low cost RFID, Pira Printed Electronics Conference, London, UK, 2005*
3. Gasman, L., *A Roadmap for Printable Electronics, IMI's 4h Annual Printable Electronics and Displays Conference & Trade Fair, Las Vegas, USA, 2005*
4. Hakola, L.; Linna, H., *Detection of printed codes with a camera phone. Proceedings of the 32nd IARIGAI research conference, Porvoo, Finland, 2005, p. 355-361*
5. Södergård, C.; Alastalo, A.; Erho, T.; Hakola, L.; Hurme, E.; Jussila, S.; Kaukoniemi, O-V.; Kopola, H.; Lindqvist, U.; Linna, H.; Maaninen, A.; Mäkelä, T.; Petäjä, J.; Qvintus-Leino, P.; Seppä, H.; Siivonen, T.; Smolander, M., *Key Technology Action Roadmap - Internal VTT Report, 2005, p. 51*



2

Non impact, security and special printing

Modeling of screening elements in stochastic multi-color reproduction

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Keywords

Individualized graphics, screening cell programming, stochastic screening

1. Introduction

Digital reproduction is spreading as to methods and application in many printing business areas in a new way: in graphics make ready, reproduction photography, production of printing forms, digital and conventional printing. Theory in the screening element and screening cell area is spreading to forms that have not been researched nor applied yet. The need for new screening systems is prominent in the security product applied production, large format design, and in new material use. Stochastic screening has yielded positive results in printing that integrates process and spot inks, improving thus the problems of moire and digital defining of screening cell coverage. There is need for finishing in the digital stochastic screening area because the coverage behavior in border areas has been leftwithout definition. Numerous issues in the „dot gain", transparency and digital printing application area have been opened. This paper will investigate the interconnection of the digital screening cell, multi-color covering of the image element area together with new screening element definition experimenting. Graphics to be applied in the area of high security should be individualized. The paper investigates imitations of hand-made lines known from times when images were designed with the help of graving techniques. Line graphics had the advancement of direction in accordance with drawing details. This paper will demonstrate the algorithm of constant screening element angle change according to parts marked in the image.

2. New screening forms

Application of new screening forms is possible in digital printing outside the contemporary area of experimental graphic reproduction. It is possible to carry out parametric determining of the screening cell angle, line and form in stochastic screening. In multi-color graphic make ready and printing it is possible to expand the application of new digital screening while determining the periodicity in the moire area. The theme of mutual interdependency between the volume and the screening cell coverage is expanded in the theoretical „dot gain" area, and is proved through the application of new screening element forms. It will be proven that there is an area of completely different screenings in respect to amplitude and frequency modulating, with application in places where conventional screening does not yield satisfactory results.

The goal is to encourage application of new ways in designing and reproduction, investigate border areas that would not only be used in special security printing but in general when designing a large-scale graphic product. New information will be gained on graphic production as a whole and on the graphic reproduction parameter interdependency. Such insight will make way for additional knowledge in upgrading the graphic branch of business standards. Criticism on the screening proposal will be given with positive and negative reviews along with testing interpretation. The goal is to determine and apply screening in printing reproduction in a new and different manner. „The new way" is further applied to image element and screening cell interdependency in a non-periodical scheme, using direct generating of

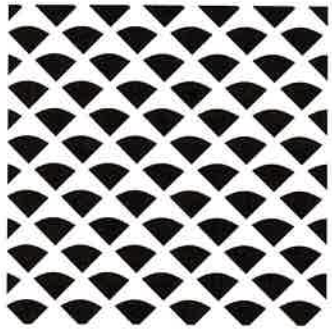
random values during the calculation of the following parameters: screening dot stochastic arrangement; stochastic lines; the image element interpreted with the help of the stochastic screening element.

Preliminary investigation was performed through eight tests of multi-color reproduction with stochastic screening arrangement, with new forms for screening cell design. Part of the results was published during world conferences. The ones published during IARIGAI 2003. [*1, IARIGAI 1998. *2, *3] when the results of single-color pixel and vector graphics reproduced with various screening element design were exhibited are singled out here. Preliminary investigation was carried out as to the relation of asymmetric screening cells parameter sensitivity in respect to the exit of forms outside the cell 3D area. Borderline cases are corrected visually before transformation into PostScript form in order to avoid reproduction execution blocking in a photographic unit for film making or printing forms. Investigation methods include screening element dissipation measuring in various printing techniques. More extensive testing and measuring will be carried out for large size digital prints because it is expected that the implementation will be greater in this printing segment than in the reproduction of magazines or books.

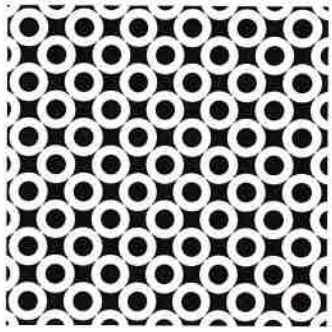
Reproduction photography uses digital procedures in constructing screening elements. PostScript has enabled programming of its own solutions, but in practice „verified", „safe" and „guaranteed as to good quality" graphic forms are applied. However, the step has been taken in modeling forms with digital design; those that existed in analog hand-made versions. Testing, coverage and dissipation measuring have been carried out for several new models and research of possibilities for production and application. Methods have been set on the manner of designing the software of new screening elements, building into the existing graphic programs and exploitation. The existing base with new digital screening has already justified the goals of the planned investigation through a variety of applications in designing some ten securities, in security document design and the design of large format graphic products. Testing to date has proved that there are unexplored areas in defining the screening element algorithm as well as in wider application of graphic reproduction.



Picture 1: Waves



Picture 2: Cake



Picture3: Negativ ring

PostScript of raster elements:

```
/r15 {neg exch 1.1 add 1 exch div add 10 div abs 1 exch sub} bind def
/r16 {neg exch dup mul add 2 div abs 1 exch sub} bind def
/ring { dup mul exch dup mul add 1 mul sqrt 120 mul sin abs 1 exch sub} bind def
/ringNeg { dup mul exch dup mul add 1 mul sqrt  120 mul sin abs} bind def
```

Special attention is paid to digital models that change the screening element angle depending on the image contents. Application is in portrait reproduction. The image is first made as a three-dimensional object. Lines are carried out in two ways. The first is in the form of verticals gradient in respect to

height change within the image depending on the solutions expected in the reproduction of the nose or chin in the portrait. The second realization of line angle advancement is the object height in the image. This detail is designed in the form of eyes, the ear and bulges. In any case, the area of individual designs is isolated manually. This manner of reproduction is digital imitation of artistic graving techniques that are found in documents and security graphics.

3. Treatise on the and reproduction

The raster element choice, angle of progress and raster layout liniature are a sufficient number of parameters for programming an individual, unique reproduction solution. We are introducing interdependency of these three parameters in order to interpret pixel blackening in a special manner. We are introducing a new image named as the having the same number of pixels as the image that is reproduced. This may be the source of information on raster element choice, or on the other two parameters: the angle or liniature.

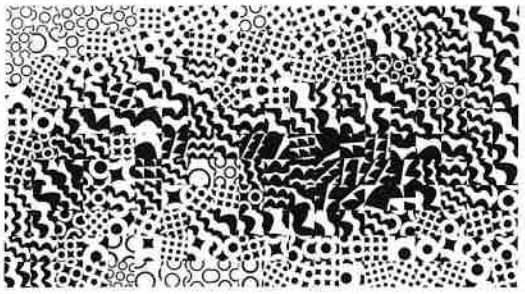
We are giving example no. 1 for the beginning of the discussion: pixel blackening in the determines the raster type choice. If we have, for example, four raster forms with the help of which to cover the reproduction, then we could solve the blueprint channel in such a way that pixel blackening below 20% determines the choice of the first raster element in the blueprint channel in the same pixel position as in the . Blackening above 80% determines the choice of the fourth raster element form in the same manner of and channel joining as in the image to be reproduced.

Solution of chose raster through blackening:

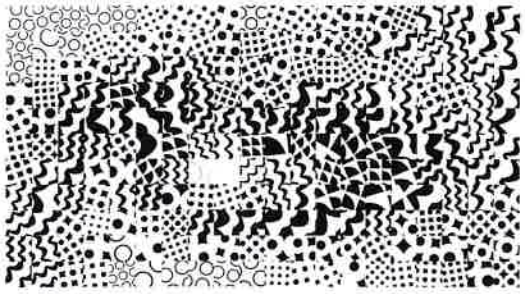
```
0 1 dy 1 sub {/k exch def /i k dx mul def
gsave
  i 1 i dx 1 sub add {/j exch def
maska j 1 getinterval 0 get /nivosivogpixla exch def
nivosivogpixla 63 le
{/indexrastera 0 def }
{
nivosivogpixla 127 le  {/indexrastera 1 def }
{nivosivogpixla 191  le  {/indexrastera 2 def } {/indexrastera 3 def } ifelse  }
ifelse
}
ifelse
 L K ros indexrastera  get  bind setscreen % l=linijatura K=kut
  1 1 8
  [dpixl 0 0 dpixl 0 0]
  {grga j 1 getinterval}
  image
  pixl 0 translate
  } for
grestore
0 pixl neg translate
} for
```

The same as in example no. 1, joining may occur with the liniature too. Example no. 2 would describe mutual dependence of raster liniatures inside the pixel as the dependency on the pixel blackening information in the same position.

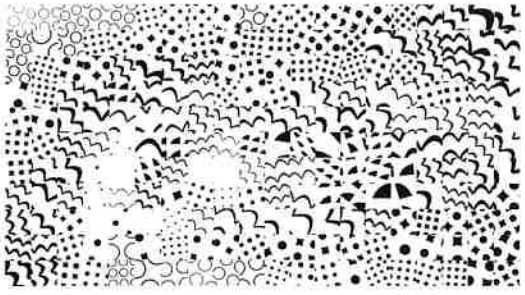
The raster angle choice could be more complex. Depending on the ink channel (C, M, Y, K) we will add an angle correction for each channel separately, for instance Ky is 15 degrees away from the blueprint channel. In such situations some type of classical layout of the raster element angle interdependency between the channels may be accepted.



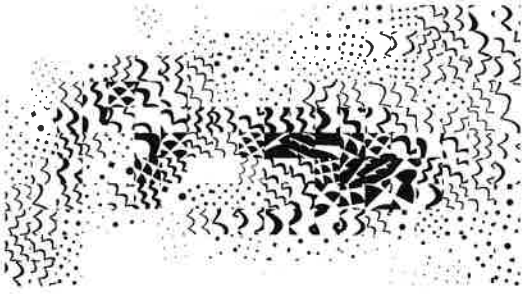
Picture 4: Cyan of the eye



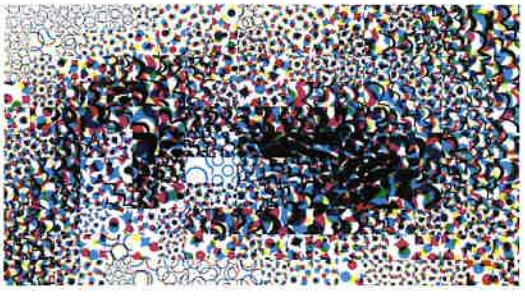
Picture 5: Magenta of the eye



Picture 6: Yellow of the eye



Picture 7: Black of the eye



Picture 8: 4 color process of eye

The has also been created on basis of the image according to the first proposal. This could be the image created as a gray channel of the whole image to be reproduced. A more important application would be if

the er channel were to be created from a set image of an independent blackening form under the condition that the pixel number is identical to the pixel number of the image to be reproduced.

4. Treatise on stochastic joining

In previous works we have generated random numbers from existing PostScript functions rand, srand with modul 2exp31-1. Such application was scarce in cases of setting separate chains of random number sequences for each ink color channel separately or for independent control of stochastic lineation setting or raster angle for determining the reproduction of individual pixels. We are introducing external setting of parameters in the congruency method creating several random number generators (in our application - three). We are setting the multiplier and the module on fixed values and we control the initial seed for each generator separately. In our application we are setting the following values for: aa multiplier, m1 module, sr1 first generator seed:

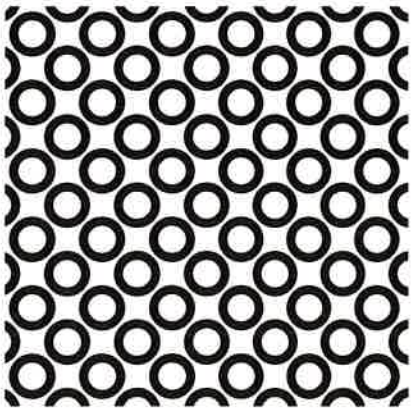
```
/aa 433 def /m1 3452879  def
/sr1 1452658 def /sr2 1325667 def /sr3 1812946 def
/r1 {aa sr1 mul  m1  mod  dup  /sr1  exch def m1 div} def
/r2 {aa sr2 mul  m1  mod  dup  /sr2  exch def m1 div} def
/r3 {aa sr3 mul  m1  mod  dup  /sr3  exch def m1 div} def
```

The set parameters were tested as to the uniformity of random chain generating and no anomaly has been noticed.

5. Discussion on the raster dot form

In previous works some ten raster forms were given. Now we are offering four new forms with the following names: ring, cake, waves and negativ ring (picture 1, 2, 3 and 9). Their algorithms and blackening forms are given in the following relations:

We have included the ring raster because we are forcing dotgain testing even though this is not the content matter of this paper. A ring raster has the characteristic that the raster element shell is always equal in length for all coverage values. Due to the fact that it has the interior as well as the exterior circular line, their lenghths compensate each other. The wider the exterior line - the smaller the interior line. Excerpts are given in previous works [*4].



Picture 9: Ring raster

6. Software solutions

The enclosed examples elaborate part of a portrait: the eye. The image of the eye from the portrait was used for stochastic rastering interpretation. For the sake of clearness we used the eye image having only 20 x 11 pixels (in total 220 pixels for the whole image). Each channel gave the impression as if it were a case of a much bigger number of pixels. The authentic code is enclosed in order to check these experiments. In practice, especially in portrait security printing, a much larger number of pixels are applied. We have made a software solution for such practice but it is not the subject of this paper. The talon is the grey channel of the same image. Cyan is the initial activating of the random chain choice with generator No. 1. The program is given below:

```
20 11 8
[1 0 0 1 neg 0 3]
{<2A31353538434A484747474E5A656E74818A8D8F35394247545E605D61646161
6A747B7F878F8D8D414C5D6C7884857E706964697178848F9294928E53687D8B
919085736962606F7E878D919798969266819A978E868CA2A59185879BB2AEA1
9B999793718FAD9C7B9FB7ACA2E3C0B9BFC2BFBEB4A49D967A94B48D74B48436
37C1E7D7D0C3BEC0BBA8978F809EB37189997962658AC0B5B6C2C0B5A18D7F7C
849F9856715B6981949DA3A5A8A0917B726F6D718493855A4F4A4E57676F7077
73665953555E666C848474543F38383B444843494743434647515E67
>}
{<1C22212024303B3B3D3E3C444F595E64676C6B6D242831364247484F5A5D5859
60656A74716A68662F38505E727E7E8273645C5F5F5959616365636540517496
A7A3907768707880847C6C605B5B5E5F4F6999AAA08F8A97918F96A2ACA69184
7368605B5B67927E609B96624D9696959AA39E9E9482746767628862489B6800
00545856909F9FA0A08D77676A6888406C977250424E797A9EA39A978C776765
6D6E5F285E4B6D8B92929D9B9588746764636268767353363534C43494E545E5E
5C544D4B525A6269756E5D3F2D2A27242A35313A3B3C40444A55646B
>}
{<1B1D1D2020282F2E30312E363E474C525A626263202128 2D373D3A4047494546
4C51565A5C5D5C5F2831414E5C57464A4741424544463E39434F58593542535A
583D2E2B2626323C3B383A3530363C483D434C3D1C243C3E2E38433D3631333C
3C38363C3D41452A0C3A4E23152F686B59523F323B4040444A393F170F5E3300
00072E2D3A615F4B3E474B4E5539300C25371A1F19182A32414C57544E504F53
59452C070D020D1E2830393A3D464A4F504E4D555E5D3F1B191C25282B2B393F
3E3E3B3B3E464C54635C4E352825201A1D28272D302F313236404D54>}
{<00000000000000000000000002081218212D3E3D450000000000005060913140E0E
16202A353B3E3B3A000109183C4E464524150E101415171F2A323636030D2E6A
8E6D3D1F0F0E1526302A221B1A1E242B0A20617740315166505E6B757D60483F
2F25212012265E370D78954F2E7DE1E2C5B785635743322A2222551B17B15800
0019535488D7D5A46F52382E2B294509436F22221D1D444D799BA58959372626
32352302130007273C45605B574C38241E1B1A223F411C0000010203080C1215
120B0503080F172041351A020000000000000000000000002091620
>}
```

Program No. 1 data for test picture of eye

Individuality is obtained by choosing the first random number. This number may be in the function of some personal piece of information (date of birth, for example, or the product of some quantitative value from the protected area).

A new solution for the reproduction follows the choice of some other seed value.

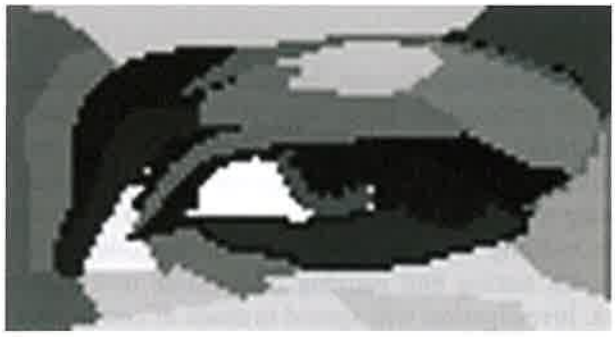
7. Vector image interpretation

In the artistic design area today uniform level surfaces are stressed with vector defined surfaces. Color is printed either as spot color or in the cmyk system. We have applied combinations with a wide palette of variables choice. The raster element type is the element mostly altered in all solutions

because it is most effective in giving the impression of a new original interpretation. The same reproduction had also in some of its parts a rough lineation all the way up to the raster element's visibility. Raster elements selected at random were joined with the same color in accordance with the original positioning of the image in grey pixel interpretation. Thus we joined a pixel and vector graphic image. Pixel information was used to determine the raster element choice in filling in a part of the image that had been recorded as a vector graphic image. The software solution required that the vector graphic image be preliminarily translated into a pixel graphic image in order to use the method of exploiting double records: the ern and certain image channels. This combination of mixing ideas; stochastic in choice of lineation, angle and raster element was applied in designing jumbo posters requiring „news"in graphic interpretation.



Picture 10: Color of art interpretation after transform in piksels structure



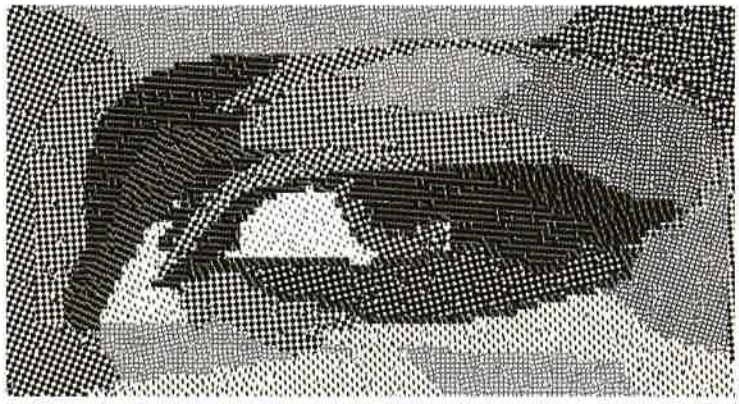
Picture 11: Gray eye

A vector image with spot colors was rastered in the cmyk ink system and afterwards we applied stochastic parameter joining that determines raster interpretation. Such solutions give an individualized image interpretation that had been created in vector graphics. Mean algorithms enabling further research work is enclosed herewith. It should be stressed that for professional work these algorithms should be integrated into a separate program with a graphic interface that would automate work on a level adequate for the designer who is not trained well enough for coded forms. Our programs have automated production of hexadecimal notations following DCS.eps separation and choosing the linking of stochastic parameters. This paper is concentrated on code authenticity in order to check and continue with all investigation parts in stochastic rastering and application of different raster element forms in the same image.

```
/line {dup 2 exp 3 1 roll sub abs 2 div add 1 exch sub } def
/beatle {dup 2 index 3 exp sub abs sqrt 3 1 roll 3 exp sub abs sqrt exch sub abs 1
exch sub} def
/ring { dup mul exch dup mul add 1 mul sqrt  120 mul   sin abs} bind def
```

```
/dot {dup mul exch dup mul add 1 exch sub} bind def       %kruzni
/romb {abs exch abs add 2 div 1 exch sub} bind def
/ros [ {ring} {dot} {romb} {beatle} {line} ] def
/L  {5 1 r1 mul add } def
/K  {0 90 r2 mul add } def    %angle between 0 and 90
/R {4 r3 mul} def
/IR {R  round cvi } def

Program: raster elements IR, stochastic of resolution L, angle K
```



Picture 12: Rasterisation in stochastic chosing of raster, angle and resolution

8. Conclusion

The paper is expansion of the screening element definition theory in stochastic arrangement of multi-color reproduction. Stochastic parameters have been introduced for lines, screening element form, angle of coverage arrangement for each image element separately. Such research work and application have not been carried out till now because special program tools are needed for this type of stochastic reproduction. New screening elements have been presented, methods for their modeling and the procedure for testing their validity and applicability. The reproductions will dissipate in bit-map structure in order to carry out testing and proving of possible new screening with the help of the existing printing equipment. Investigation will spread to cases of continuous screening angle change in the form of images, blackening advancements or breaks and color tone change. The listed results are interesting in security printing. In contemporary practice the line screening for which follow up is requested as to characteristic forms in the image is carried out manually. The paper sets the algorithm and models of angle and line screening change depending on the image element structure.

References

1. Vilko Žiljak, Klaudio Pap, (1999.), *Mathematical model of stochastic curves in digital printing, 26th International Research Conference of IARIGAI, Munchen*
2. Vilko Žiljak, Klaudio Pap, (1999.), *The investigation of document and securaty digital printing procedures, 26th International Research Conference of IARIGAI, Munchen*
3. Ivana Žiljak, Vesna Vančina, Darko Agić, Jana Žiljak, Klaudio Pap, (2003.), *New screening elements in multi-colour printing for special purposes, 30th International Research Conference of IARIAGI, Dubrovnik, Croatia, ISBN 953-96276-6-4*
4. Jana Žiljak Vujić: *Multicolor graphic picture with original ring raster element, International Design Conference - DESIGN 2006, Dubrovnik - Croatia, May 15-18, 2006. / Design of digital systems in printing, ISBN 953-6313-81-2, Volume 3*

Measuring printed special-effect colours
First experiences with the MultiFX10 spectrophotometer

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1. Introduction

The printing industry is burdened with price battles and overcapacity. This leads to improvement of the infrastructure and cost reduction on the one hand and introducing new technologies and services on the other hand. To achieve sustained success it is advantageous to introduce new technologies to stand out of the crowd. A new technology, which has been integrated lately, is the printing of special-effect colours such as interference colours.

These kinds of colours are better known in other industries, especially in the automobile industry. Body paintings of cars mostly show metallic effects or a change in colour addicted to the viewing angle as a result of interference. There is a standardisation and different measuring devices to control the quality are established.

For the printing process this proceedings have not taken place jet. Neither the physical background of printed special-effect colours and its interaction with absorption colours nor the possibilities to measure this kind of colours were researched. That is why today no measurement device to measure printed special-effect colours is available. Still, to assess this kind of colours modern printers only have the possibility of a visible inspection, which makes an industrial printing process impossible.

In order to find a remedy it is purpose of this paper to make a technology transfer from measuring devices of the automobile industry to the requirements of the printing industry. For this, a description of measuring device for measuring special-effect colours and the requirements of printing are given fist. Subsequently the multi-angle spectrophotometer Multi FX10 and its attributes are studied. In consequence of this, an adjustment process, using different apertures, occurs with the aim to reach aperture sizes similar to the requirements of the printing industry.

2. Preliminary considerations

2.1 Measuring special-effect colours

The conventionally used inks like Cyan, Magenta, Yellow and Black consist of absorption pigments. These pigments absorb (or "swallow") a particular wavelength of the oncoming light, Figure 1 left. The colour impression is the remaining part of the white light (complementary colour). Because of their irregular shapes, absorption pigments only show one colour and have no iridescent properties [Merck, 2005]. That is why colour measurement instruments only need one illumination/viewing angle (normally 45°/0° or 0°/45°) to measure these colours.

Metallic inks consist of very thin metallic flakes that act as miniature mirrors, Figure 1 middle. The intensity of these inks changes according to the angle from which they are viewed. Maximum light intensity is achieved near the "gloss" - the angle at which incident light is reflected. Minimum is experienced for an angle far away from the gloss. Factors affecting this flip-flop effect are the shape

and the size of the pigment particles and the way they are laid down within the paint [Rodrigues, 1995; Huber, 2000]. To assess the flip-flop effect it is necessary to measure by different viewing or illumination angles. Since the metallic-effect pigments are very often used for automobile varnishes, standardisation process for the illumination and viewing angles takes place in this industry first (DIN 6175-Teil 2).

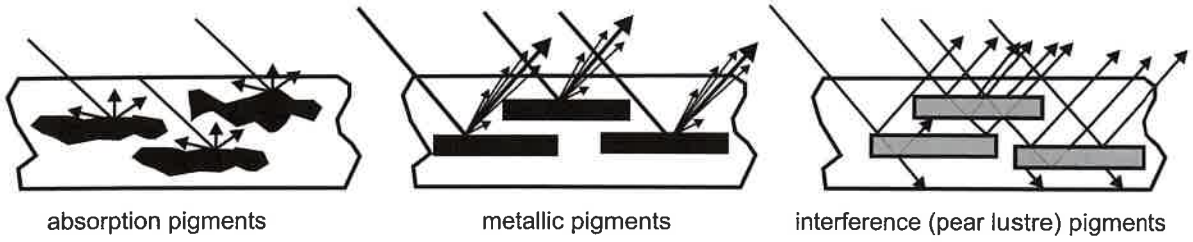


Figure 1: The three different classes of pigments [Maisch, 1991]

Interference pigments represent the third class of pigments. In contrary to the other two classes, these pigments are transparent and acquire the colour effects through interference with little or no absorption. The most requested kind of these effect pigments is basically a mica flake coated with single or multiple thin layers of metal-oxide, like TiO_2 [Rodrigues, 1995; Huber, 2000], shown in Figure 2 on the left. White light impinging on this type of pigments is partially reflected at its TiO_2 surface. The remainder passes (with refraction) through the TiO_2 layer until it encounters the surface of the mica. Here it is partially reflected again. This reflected light leaves the pigment parallel to the first reflected light component, but with a shift in the wave compared to the light reflected on the TIO_2 surface. A wave peak coinciding with another wave peak will produce a magnified wave, while a wave trough on another wave trough will give a flatter wave. In the simplified interference formula, the resultant reflection colour is a function of the layer thickness of the TiO_2, of its refractive index and of the angle from which light impinges [Cramer, 1999]. As the thickness of the layer (TiO_2) increases the colour of the pigment changes from silver-white, through yellow, red and blue to green (Figure 2 right) [Cramer, 2001].

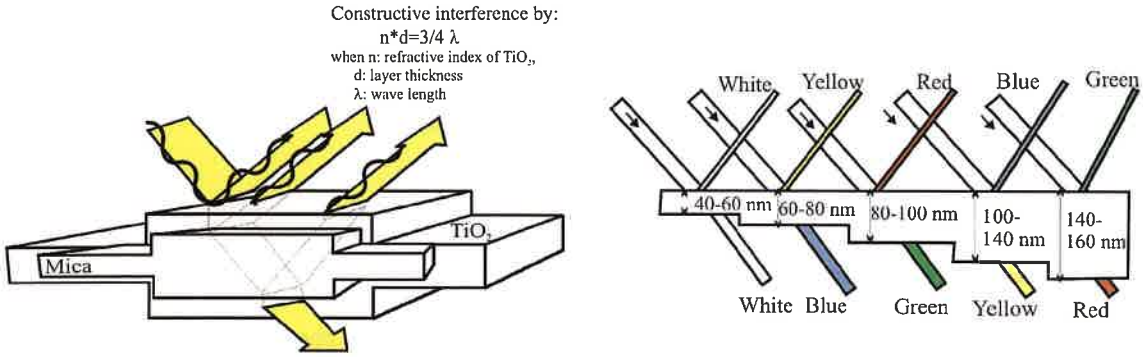


Figure 2: left: Schematic cross-section through a mica flake pearl lustre pigment [Maisch, 1991] right: Changes in the colour, with respect to the thickness of the TiO_2 layer [Maisch, 1991]

The interference formula expresses the reflection colour as a function of light incidence. Examinations of Cramer and Gabel [Cramer, 2001] have demonstrated that the interference pigments show a marked colour flip-flop effect dependent on the illumination and observation angle. They indicate two discernible fundamental colour shifts of interference pigments. The first is the shift produced by varying the illumination angle and keeping the aspecular angle constant (interference shift). The second is when the illumination angle is kept constant and the aspecular angle is varied (aspecular

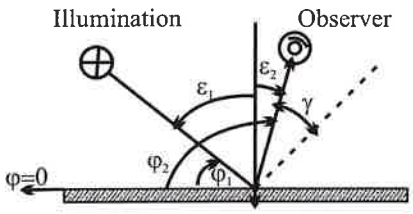
shift). This leads to the knowledge that a colour measurement system has to provide different illumination and varying viewing angles to measure interference pigment colours [Cramer, 2001].

Recapitulate it could be said, that for measuring the absorption colours only one illumination/viewing angle is necessary. For measuring metallic effect colours a higher effort is needed, so that at least either the illumination or the viewing angle has to be variable. The measurement of interference colours shows the maximum complexity. For this colours varying illumination angle as well as a varying viewing angle are essential.

2.2 Measuring instruments for metallic and interference colours, state of the art

Different manufactures and standardisation commissions endeavour the design and development of measuring devices for measuring metallic effect and newly as well for interference colours. In effort of the automobile industry a standardisation process for measuring metallic effect colours took place. The standardisation DIN 6175-2 defines the viewing and illumination angles to be used for measuring this kind of colours.

Figure 3 demonstrates the definition of these angles (ε_1 illumination angle, ε_2 viewing angle) in this standardisation. However, there is still a discussion about the naming of the angles [Rösler, 2005]. Manufactures and researchers often use the definition of the aspecular angle[1], corresponding to the working group ASTM E-12.12 [Rodrigues, 1996]. Others, like Datacolor, count the angles from the horizontal line (φ_1 illumination angle, φ_2 viewing angle), see Figure 3.



DIN 6175-2			counted from horizontal	
illumination angle	viewing angle	aspecular angle	illumination angle	viewing angle
ε_1	ε_2	γ	φ_1	φ_2
45°	-20°	25°	45°	110°
45°	0°	45°	45°	90°
45°	30°	75°	45°	60°
45°	65°	110°	45°	25°

Figure 3: Different possibilities of illumination and viewing angles for measuring Metalic - effect colours [Datacolor, 2006]

In the following, except for the next two tables (Table I and Table II), the nomenclature of Datacolor, counting the angle from horizontal line (φ_1/φ_2), is used. Table I shows an overview of different portable measuring instruments for measuring metallic effect colours. All these measuring instruments have in common that the illumination angle changes and the viewing angle is fixed or vice versa. The used angles are according to the angles given in DIN 6275-2.

Table I: Overview of different measuring instruments to measure metallic effect colours, according to DIN 6275-2 [Minolta, 2006; Gretag Macbeth, 2006; Xrite, 2006]

Instrument (Name, Manufacturers)	Illumination angle(s)	Aspecular angle or viewing angle	Light source	Aperture size
CM-512m3, Minolta	ε_1 = 25°, 45°, 75°	ε_2 =0°	Circumferential pulsed xenon light	∅12 mm
ColorEye 640 & 740, GretagMacbeth	ε_1 = 45°	γ = 15°, 45°, 75°, 110°	Pulsed xenon light	∅14 mm
MA48 and MA 68II Xrite	ε_1 = 45°	γ = 15°, 45°, 75°, 110°	Tungsten lamp 4000°K	∅12 mm

[1] Aspecular angle γ: Viewing angle measured from the specular direction to observer [Rodrigues, 1996]

Since these measuring instruments only give the possibility to measure metallic effect colours, different devices, providing varying illumination and changeable viewing angles, were developed. An incomplete overview of measuring instruments providing changeable illumination and viewing angles is given in Table II.

Table II: Measuring instruments with changeable illumination and viewing angles, giving the opportunity to measure interference colours [Instrument Systems, 2006; Phyma System, 2006; Murakami, 2006; Gerlinger, 1990; Datacolor, 2006]

Instrument (Name, Manufacturers)	Illumination angles	Viewing angles	Aperture size
GON 360, Instrument Systems	ε_1 = 0° to 360° Infinitely variable	ε_2 = -7° to 187° Infinitely variable	∅10 mm
WICO 5&5, Phyma System	ε_1 = 22,5°, 45° (from perpendicular)	ε_2 = 22,5°; 0°; -22,5°; -45°; -67,5°	∅14 mm
GCMS-3, Murakami	ε_1 = 16° to 180° in 1° steps	ε_2 up to 196° (transmission measurement)	----
GK 311/M, Zeiss	ε_1 = 25° to 155° in 5° steps	Difference angles ε_2 -ε_1 0° to 110°	∅15 mm
Multi FX10, Datacolor	φ_1/φ_2: 25°/170°; 25°/140°; 45°/150°; 45°/120°; 75°/120°; 75°/90°; 45°/110°; 45°/90°; 45°/60°; 45°/25°		69x22 mm (length x width)

As seen before in Table I and Table II, all measuring instruments according to DIN 6275-2 and all of the devices with changeable illumination and viewing angles have aperture (sample port) sizes grater than the requirements of printing (diameter 3 mm to 4 mm). By this reason, it was looked for the best alternative measuring device, which furthermore could possibly be adjusted to the requirements of printing. For the aim to measure metallic colours as well as interference colours, it is necessary to provide different illumination and viewing angles. That is why all measuring devices providing either a changing illumination or a varying viewing angle can be excluded. The devices of Instrument Systems, Murakami and Zeiss, which allow to illuminate and view in small or rather infinitely variable steps have problems to assure the same illumination/viewing conditions each time of measurement. Beyond this, the Zeiss GK 311/M is not commercially available any longer. For the remaining measuring devices the Multi FX10 presents the best opportunities because of the good repeatability properties, due to the assigned illumination/viewing conditions and the ten sets of illumination/viewing angles. By the reason of the major number of illumination/viewing conditions compared to the WICO 5&5 of Phyma System, the Datacolor Multi FX10 gives the best opportunities to rate interference colours.

2.3 Description of Datacolor Multi FX10

The MultiFX10 is equipped with ten sets of illumination/viewing angles which are arranged pair wise on a movable half pipe. The half pipe is associated with a light coupling system connecting a single tungsten halogen lamp with the illuminator optics and the receiver optics to a single spectral analyser, Figure 4 right.

Only one set of optics is active at a given time, by moving the half pipe, and thereby the active illumination/viewing optic, to a position under the sample port. Since only the half pipe moves the angles are always the same and the repeatability is very high. The rectangular sample port is located on the top of the instrument, Figure 4 left. The dimensions of this sample port (aperture) are 69 mm in length and 22 mm width.

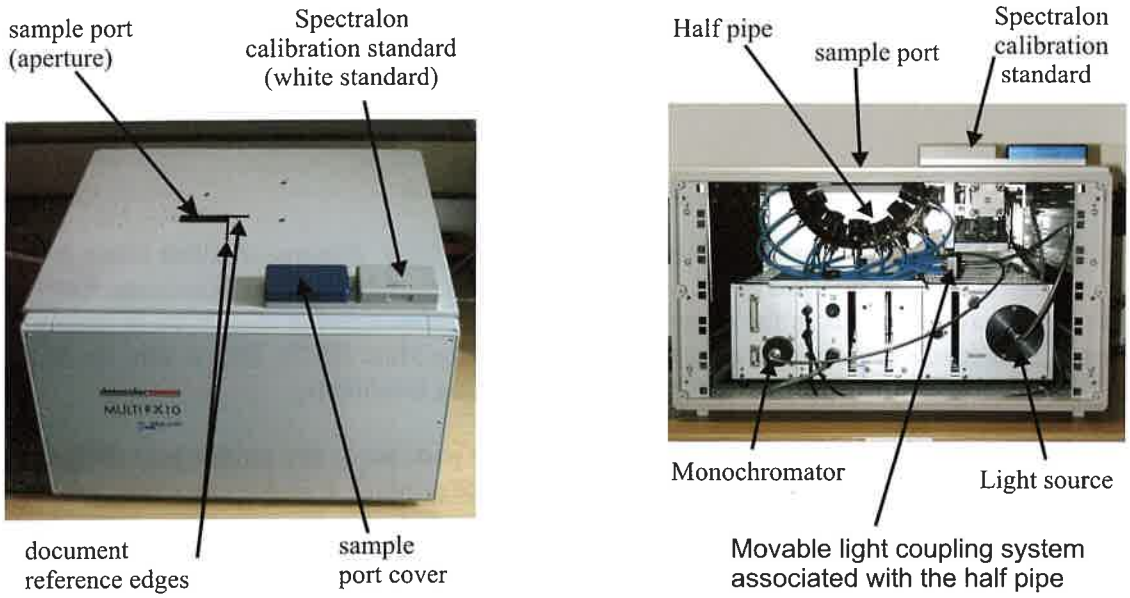


Figure 4: left: View on the top of the measurement instrument Multi FX10 and declaration of the document reference edges right: View of the device with open front panel

Figure 4 additionally gives a determination for the document reference edges used in the following. In the right edge of the instrument a sample port cover and the Spectralon calibration standard (white standard) are placed [Datacolor, 2006].

The MultiFX10 is mainly built for labs in the automobile, textile, and colour recipe calculation industry, which is shown by the dimensions of the measuring instrument (530 mm wide, 470 mm deep and 320 mm high) and the sample port (69 mm long, 22 mm wide).

2.4 Demands of the printing industry

Today the printing industry uses generally absorption pigment colours. That is why standardisation of colour measurement, given in DIN ISO 13655, specifies only an illumination/viewing angle of 45°/0° or rather 0°/45°. Special-effect colours like metallic or interference colours are not considered in this standardisation.

Besides this, the printing process places special claims for the size of the measuring fields. On multicolour presses, the application of ink in each printing unit must be monitored and adjusted individually. The fact that several colours have to be printed together in halftone images makes both visual assessment and measurement of the individual inks in the image relatively difficult. The measuring accuracy is limited because the measuring signal is partly superimposed by other inks. Printing so-called colour control bars with measurement patches for the individual colours in the trim-off alongside the image has proven good practise. Colour control bars of this kind are usually printed over the entire sheet width, and the individual patches are positioned so that they are assigned to the ink zones of the ink fountain. This enables targeted adjustment or control of the colour/ink flow [Kipphan, 2001]. Control bars are not a sellable part of the printing product, because they are rarely a part of the image. That is why they have to be as small as possible to reduce waste. Normally they are rarely bigger than 5 mm squared. This leads to the exigencies of ISO 5-4 concerning aperture sizes. This standardisation demands a 0.5 mm to 1 mm bigger measuring field at all edges than the aperture size. Consequentially the outcome of this is a requirement of a maximum aperture size of 3 mm to 4 mm squared or diameter, for measuring printed colours.

Since only the measurability provides the possibility for objective and, to a certain extent, automated quality control in printing, it is necessary to provide a measuring device, which is capable to measure in control bars and allows to rate special effect colours.

3. Methods

The comparison of the different measuring devices available today, demonstrates that many device are only built for measuring metallic effect colours. Other devices, which allow to measure interference colours either have problems in the repetition of the illumination/viewing conditions or supply a less number of illumination/viewing conditions than the Datacolor Multi FX10. That is why the Datacolor Multi FX10 is chosen to try the technology transfer to printing conditions.

Main point of this transfer is the dimension of the sample port. Since the sample port dimensions of the Multi FX10 are oversized alluded to the requirements of printing, it is purpose of the following to use a smaller area of the given sample port. In view of the fact, that the measuring device is a new technology and a detailed examination of this instrument is not existing, different preliminary examinations of the measuring device itself are necessary. Especially for the adaptation process to smaller sample port sizes (apertures), it is essential to get further information about how the unmodified sample port of the Multi FX10 is used during the measurement process. Afterwards the actual efforts to adapt the sample port using different apertures of diverse materials and sizes took place. The individual steps and used methods are described consecutively.

3.1 Preliminary examinations

For the preliminary examinations following topics were purpose of the research:

- Repeatability of Multi FX10 measurements,
- Allocation of light inside the sample port,
- Location of the centre of illumination and sensor observing,
- Spectral distribution and ratio of luminance in the sample port.

The preliminary examination of the device was based on the appraisal of the accuracy of the measuring results. In order to this, the repeatability was proven. Considering the reference manual, the repeatability has to be tested by measuring the Spectralon calibration standard for 20 times. Thereby the deviation in ΔE^*_{ab}[2] should be less than 0.15 ($\Delta E^*_{ab} < 0.15$) (Datacolor, 2006). To get a statistically firm impression of the metering precision, the repeatability test procedure itself was proven five times.

In the next step the sample port got a closer inspection. As mentioned before the sample port holds a rectangular shape with dimensions of 69 mm length and 22 mm width. The different illumination and viewing angles were realised by moving the half pipe to a given position below the sample port. Since the illumination and sensor optics are positioned on the half pipe along a semicircle, it comes to different illumination/viewing areas, Figure 5.

Figure 5 illustrates exemplary for two different illumination/viewing angles the size of the overlapping area of the optical paths from the illuminant and the sensor. As it could be seen easily that the sizes of overlapping areas are highly dependent on the angles. For the flat angle 25°/170°, the overlapping area is very large. For the steep angle 75°/90°, the smallest overlapping area could be seen. In the operation manual of the Multi FX10 this overlapping area is called effective measuring area. For the angle 25°/170° the effective measuring area is given with 41 mm x 15 mm (length x width), for the angle 75°/90° with

[2] The maximum is declared as CIE 1976 L*a*b* colour difference: $\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$

17 mm x 17 mm. Both declared effective area and schematically acquired overlapping areas are almost equal. However, since the locations of these effective measuring areas are unknown, a further examination of the real illumination and sensoring conditions is needed. To clarify the location of the highest ratio of luminance a contour drawing of all illumination angles was made, Figure 6 In consequence of overlapping the different contours, the area of the highest ratio of illumination was determined. Outcome is the designation of the centre for the area with the highest ratio of luminance. Furthermore, the statements of the operation manual concerning the real effective illumination area were checked.

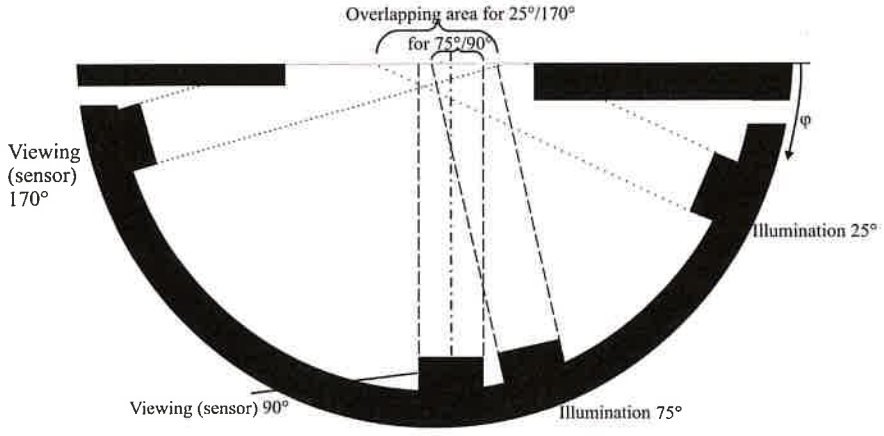
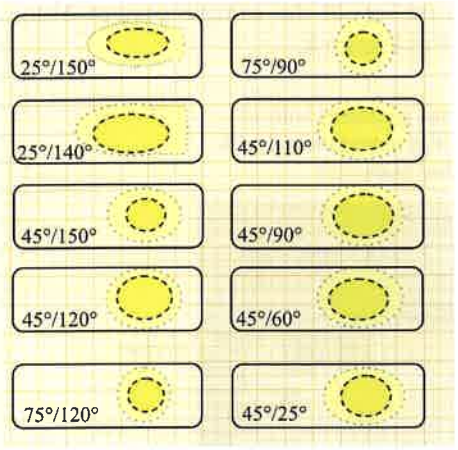
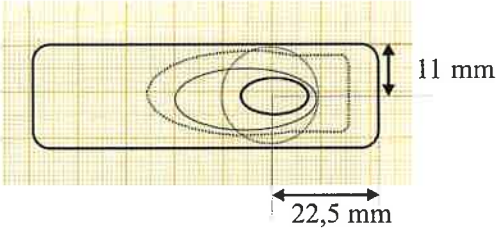


Figure 5: Shematic illustration of the overlapping areas of illumination and the viewing (sensor), using the model of optical paths



Areas marked with the dotted lines illustrate regions with lower light intensity, areas marked with dashed lines describe the areas of higher intensity.

Overlapping of all illumination conditions inside the aperture



Maximum size of illumination area (dotted line) around the point 22,5mm/11mm with an overweight to the left:
length: 42 mm
width: 20 mm

Figure 6: left: Illumination conditions inside the aperture of the MultiFX10 right: Overlapping of all illumination conditions and determination of the centre

Since the area observed by the sensor is not observable, the location of the "sensor centre" has to be found by measuring. For this a 5 mm wide strip of white paper in front of a black background was moved to the different positions shown in Figure 7 The positions with the highest remission ratio appropriate the area of the highest sensor sensitivity and therewith the centre of the measuring area.

By combining the different centres of illumination and sensor observing it is possible to accumulate a point inside the sample port, in which the middle of a sample has to be located to get the best measuring results.

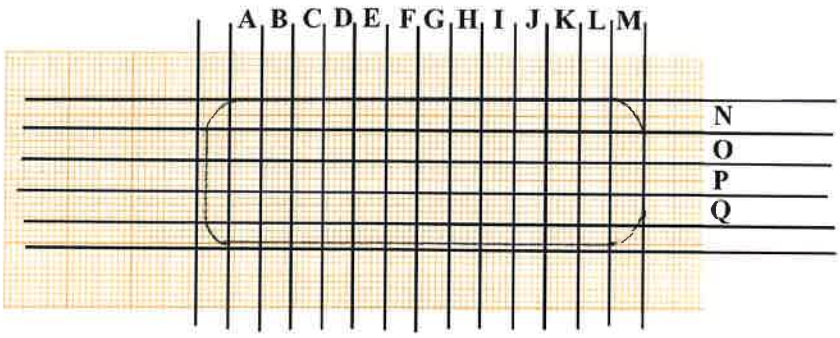


Figure 7: Positions to find the optimum measurement area inside the aperture

Besides this, to get a better impression of the measurement device and the illumination conditions the spectral distribution and the illumination ratio of the light were measured in the beforehand acquired location, Figure 6 left. For this examination, the spectrophotometer EyeOne Beamer of Gretag Macbeth and the light measuring instrument MiniLux of MX-Electronic were used.

3.2 Adapting process for the sample port of Multi FX10

After the preliminary examinations and with the knowledge of the location for the centre of illumination and sensor observing inside the sample port or rather the centre of the aperture, the actual adjustment process took place. For this different apertures were built using different materials and varying the hole sizes of the apertures. Exemplary an on top of the sample port of Multi FX10 fix aperture as well as diverse other apertures are illustrated in Figure 8.

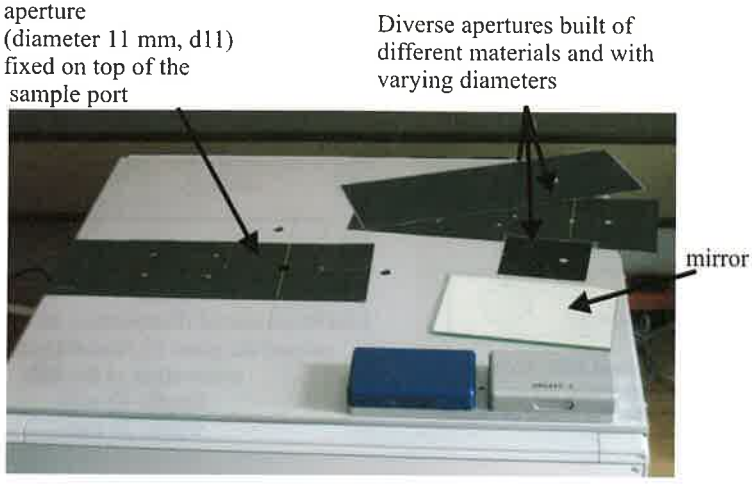


Figure 8: Illustration of the modified sample port of Multi FX10 with an aperture (size diameter 11) and examples for other apertures

The sizes of the apertures varied from the size of the overlapping area of illumination found before to typically used sizes in the different industries, diameter 3 mm for printing and diameter 8 mm and 12 mm for the automobile industry. In the following "d" is been used for the abbreviation of the diameter.

Following researches to adapt the sample port of Multi FX10 to printing conditions, described in detail subsequently, were done:

- Influence of the calibration method,
- Influence on the measuring results of absorption and interference colours by attaching different black-paper apertures on the sample port,
- Comparison of the measuring results of Multi FX10 with unmodified and adapted sample port with other measuring instruments,
- Adapting the sample port using a mirror as aperture.

The influence of the apertures cohesive the calibration and the results measuring the calibration standard were considered first. For measuring colour, it is necessary to calibrate the measuring instrument first. In this coherence, a 100%-reflection calculation is used. This means that the outcome of measuring the white standard during the calibration process is set to 100% at all wavelengths. In a CIELAB assessment the result for an ideal white standard has to be L* = 100, a* = 0 and b* = 0. By the reason of this knowledge, it is easy to get a first impression of the impact using apertures to reduce the size of the sample port. If here a huge influence on the measuring results is established, this way of adjusting the size of the sample port could be excluded. In the next step, the measuring results of different print substrates and printed absorption and interference colours were regarded. For this, different black paper apertures were fixed on top of the sample port with the centre of the aperture at the location found before. For sample two different papers (LumiArt of Stora Enso and a paper for copier), the absorption colours "Cyan", "Magenta", "Yellow" and "Black" as well as the interference colours "LithoYellow", "LithoRed", "LithoBlue", "LithoLilac" and "LithoGreen" were consulted. The samples for the absorption colours were taken from the colour compendium IRIODIN® /IRIODINBRONZE® [Merck, 1993]. The samples for the interference colours derived from the IRODIN®/AFFFLAIF® Offset colour effects fan of Merck [Merck, 2006], Figure 9. The measuring results of these colours, determined using different apertures, were compared.



Figure 9: Used samples for absortion and interference colours

To improve the quality of the Multi FX10 and adjustment process, a comparison with measuring results of other measurement devices were made. For this, commonly used measuring instruments of different industries, such as the printing and the automobile industry, were used, given below:

- Techkon Spectrodens, a common used portable spectrophotometer for the printing industry, with a sample port of diameter 3 mm and (φ_1/φ_2) 45°/90°- Geometry [Techkon, 2006],
- Minolta CM-2600d, a portable spectrophotometer, mostly used in the automobile and textile industry, with a sample port of diameter 8 mm or 12 mm and a diffuse illumination [Minolta, 2006],
- Minolta CM512-m3, a portable multi-geometry spectrophotometer, for measuring especially automobile metallic colors, with geometries of (φ_1/φ_2) 45°/90°, 45°/110° and 45°/60° [Minolta, 2006].

The outcome of this comparison is the appraisal of the possibilities of reducing the sample port of Datacolor Multi FX10.

After the comparison a new adaptation process, this time using a mirror as aperture, occurred. In the first step of this process, the effectiveness of measuring a mirror with Multi FX10 unmodified sample port was tested. After that, the absorption and interference colours were measured using different sizes of mirror-apertures.

4. Results

4.1 Results of the preparatory examinations

As told before, the repeatability of the Multi FX10 was tested first. Based on 20 reads of the Spectralons calibration standard, the deviation has to be smaller than $\Delta E^*_{ab} < 0.15$ [Datacolor, 2006]. The accomplished repeatability test, repeated five times, indicates that 3.5% of all measurements were outside the maximum range of $\Delta E^*_{ab} < 0.15$. These errors predominantly occur for the illumination/viewing angles of 45°/60° and 45°/25°. In consequence, it was necessary to take more than one measurement in the present work to exclude the measurement errors and calculate the average.

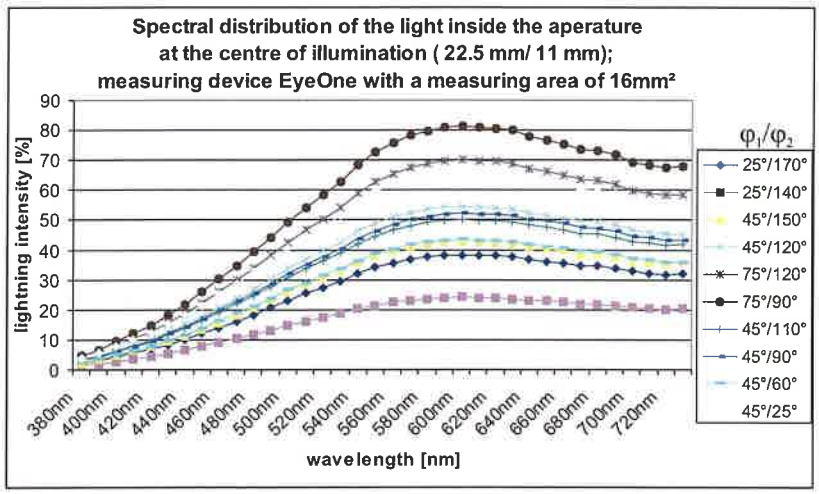
Figure 6 illustrates the contour drawings of the distribution of light inside the sample port. As it could be seen, the illuminations areas of highest ratio of illuminance for the varying angles have almost the same size as predicted by the operation manual and the theoretical considerations out of the optical paths. For example, the illumination area by an illuminant at the angle 25°/170 (φ_1/φ_2) should theoretically have a length of 46 mm and a width of 19 mm. The contour draw exhibits the dimensions for the illumination area with highest ratio of luminance of 38 mm x 13 mm (length x width) and a bigger area (43 mm x 18 mm) included regions of lower intensity. Thus the theoretical considerations can not include the different allocation of the light intensity, but gives a good appraisal for the covered area. Similar circumstances established for the other illumination angles. By overlapping all illumination areas of highest intensity a centre at the point 22.5 mm from the right edge of the sample port and 11 mm from the upper edge of the sample port is found, Figure 6 right. Besides this results a maximum illumination area of 42 mm length and 20 mm width, located around the centre, by measuring the length and the width of the overlapped counter draw.

The following search of the "sensor centre" confirms the assumption of the centre located in the area around the same point like the centre of illumination (22.5 mm / 11 mm). Between the vertical positions "I" and "J", as well as between the horizontal positions "O" and "P" (Figure 7, the maximum of remission is located.

Subsequently, the precise illumination conditions in the centre of illumination, found before, were studied. Since the operation manual does not give any details on the illumination ratio and the spectral distribution, this data was acquired next. For this measurement, the sample port abides unmodified. Concerning the different measurement devices and their aperture sizes, used to measure the illumination ratio and the spectral distribution, the acquired areas of light around the centre of illumination of the sample port (22.5 mm / 11 mm) were different. Figure 10 left shows the measured spectral distribution of the light in the centre of illumination inside the aperture. The table in the same figure right illustrates the different illumination ratios for the different illumination/viewing angles in the same point.

For the illumination angle of $\varphi = 75°$ the highest ratio of illumination exists. For the very flat illumination angle of $\varphi = 25°$ the illumination ratio decreases to 30%. As expected, because of the light coupling of all illuminator optics with the halogen lamp in the half pipe, the spectral distribution for all illumination/viewing angles shows the same tendencies. Only the illumination intensity decreases in the

same way as the ratio of illumination. The distributions show a high share in the green-red sector and a very low intensity in the blue sector. Looking at the colour temperature, not illustrated in the figure, the measurement shows a colour temperature of approximately 3560 K for all angle combinations.



Illumination/ viewing angle (φ_1/φ_2)	MiniLux measured area 95 mm² Illumination ratio [lux]
25°/170°	1530
25°/140°	1240
45°/150°	2240
45°/120°	2970
75°/120°	3530
75°/90°	5370
45°/110°	2790
45°/90°	2860
45°/60°	2730
45°/25°	4340

Figure 10: left: Spectral distribution of the light inside the aperture at the "optimum" position right: Ratio of illumination at the different illumination/viewing angles measured at the "optimum" position

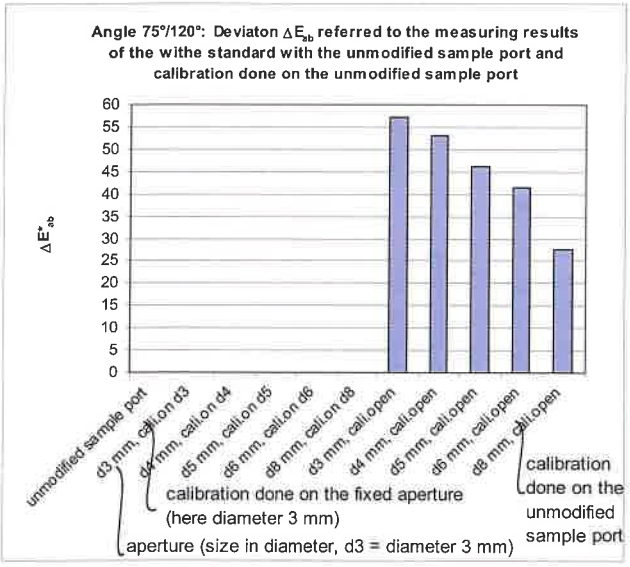
4.2 Results of adapting the sample port to measurement conditions of printing

With the different apertures of black paper, fixed on top of the sample port (Figure 8), the illumination conditions were checked again. For this the centre of the apertures was located on the position of the centre of highest illumination ratio (22.5 mm / 11 mm). The results, Figure 10, indicate a reduction in the illumination ratio of 75% in all illumination/viewing angles with respect to the open unmodified sample port by using an aperture of diameter 3 mm. By enlarging the aperture size, the illumination ratio gets higher again. For an aperture size of 15 mm x 15 mm the same lightning conditions could be measured as within the unmodified sample port. Meanwhile, the reduction of the aperture size does not influence the spectral distribution. With the knowledge of the aperture size influence on the illumination conditions, it is of interest, if the different apertures influence the colour measurement in the same way.

Figure 11 illustrates, on the example of black paper apertures for the illumination/viewing angle of 75°/120°, the influence of different aperture sizes while calibration is done on the unmodified sample port or on the aperture.

If the calibration is done on the open aperture, huge colour differences ΔE^*_{ab} appear. The colour differences between the different aperture sizes become greater by smaller aperture sizes. It almost shows a linear tendency. If calibration is done on the apertures and the calibration standard is measured again, the colour difference ΔE^*_{ab} is very small, almost zero. Therefore, it was determined for the following to calibrate directly on the corresponding aperture.

Since the measuring results of the white standard, after calibration is done on the aperture, match the measured values acquired by the unmodified sample port, the adaptation process was continued. This time different printing substrates, absorption and interference colours were measured with the different apertures. The measurements of two different papers (LumiArt of Stora Enso and a Copy paper) strengthened the conclusion that measurements will have the same result as measurements on the unmodified sample port.



measurement	L*	a*	b*	ΔE^*_{ab}
unmodified sample port	100,08	-0,01	0,00	
d3 mm, cali.on d3	100,01	0,01	-0,01	0,07
d4 mm, cali.on d4	99,98	-0,01	0,03	0,10
d5 mm, cali.on d5	99,99	-0,02	0,04	0,09
d6 mm, cali.on d6	99,99	0,01	0,00	0,09
d8 mm, cali.on d8	100,01	0,00	0,02	0,07
d3 mm, cali.open	42,83	0,30	-0,33	57,25
d4 mm, cali.open	46,92	0,51	0,25	53,16
d5 mm, cali.open	53,86	0,34	0,24	46,22
d6 mm, cali.open	58,55	0,03	-0,36	41,53
d8 mm, cali.open	72,41	-0,10	-0,27	27,67

Figure 11: Visualisation and table of ΔE_{ab} for different black paer apertures influenced by the calibration; "cali on" stands for measuring and calibrating on an aperture, "cali open" stands for measurering on an aperture but calibration on the unmodified sample port. ΔE_{ab} refers to the measurement measured and calibrated on the unmodified sample port

Figure 12 and Figure 13 illustrate the remission curves of the absorption colour "Yellow" and the interference colour "LithoYellow" for two different illumination/viewing angles. This remission curves were measured firstly on the unmodified sample port and secondly with different apertures. Other absorption and interference colours were measured for all illumination/viewing angles as well and show the same attitude. The diverse apertures were built of different papers with different sizes. Depending on the used paper, the thickness and the colour of the aperture the shape and attitude of the remission curves change. The curves with the rhomb show the measuring results of unmodified sample port. They mark the reference for rating the quality of the adjustment. As it could be seen, the remission curves show different behaviours in dependence to the aperture size and the illumination/ viewing angle. The absorption colours have the same remission curves for all illumination/viewing angles measured on the unmodified sample port tendentious, only the intensity for the very flat angle is lower. Thus, the measurement with the unmodified sample port demonstrates the independency of the illumination/viewing angle of the absorption colours. On the other hand, the influence on the colour impression of interference colours can be seen in Figure 13. As during a visual inspection, the interference colour "LithoYellow" exhibits a yellow colour impression for very flat angles, Figure 13 left. For angle combinations according to DIN 6175-2 with aspecular angles greater than ± 15°, as illustrated in Figure 13 right, the impression of the interference colour gets more colourless and even white.

As shown in Figure 12, the remission curves of absorption colours measured with apertures feature higher intensities. This behaviour does not change according to the illumination/viewing angle. Contrary to this, the interference colours change their behaviour with the illumination/viewing angle if apertures are used. For flat angles the measured curves with reduced aperture sizes lay below the remission curve measured with the unmodified sample port. As the illumination angle gets steeper, the remission curves of interference colours will lay above the remission curve of the open aperture. Besides, it could be seen that the differences between the diverse remission curves decrease with steeper illumination angles.

Beside the illustration of the remission curves, the software of MultiFX10 gives the possibility to compare two different measurements for all illumination/viewing angles in one CIELAB colour space

diagram. In Figure 14 the differences of the measuring results using the aperture (diameter 3 mm) compared to the unmodified sample port are easily visible. As the behaviour of a visual inspection, the measurements by the unmodified sample port designate a colour flop from a red impression near the specular angle (light violet for the very flat angle 25°/170° through pure light red, 45°/150°) to alight the yellowish impression far away from the specular angle. The measurements with the reduced aperture size however assign an even lighter (whiter) colour impression.

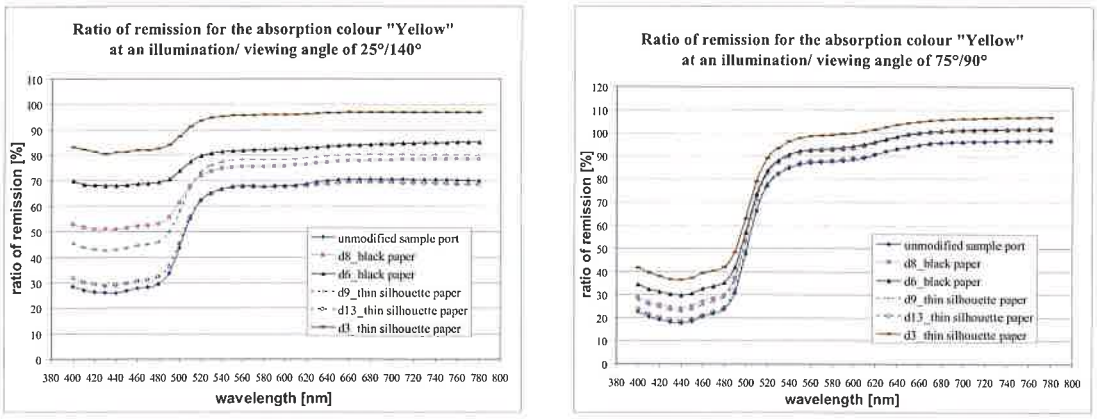


Figure 12: Remission curves of the printed absorption colour "Yellow" for two different illumination/viewing angles (φ_1/φ_2); left: 25°/140°; right: 75°/90°

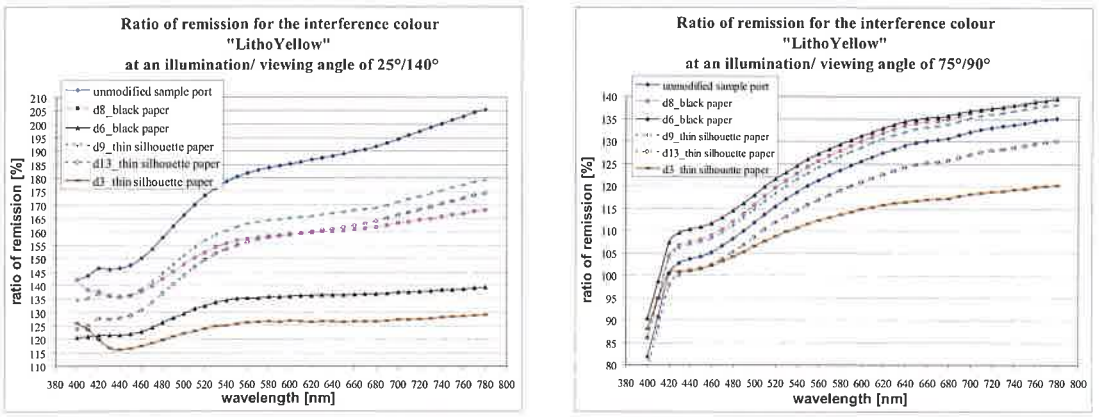


Figure 13: Remission curves of the printed interference colour "LithoYellow" for two different illumination/viewing angles (φ_1/φ_2); left: 25°/140°; right: 75°/90°

Another possibility to demonstrate the differences between the diverse aperture sizes is the CIELAB colour difference ΔE^*_{ab}. Table III gives the achievement for the colour differences of the measuring results using apertures versus the measuring results of the unmodified sample port. Displayed are the colour differences for the absorption colour "Cyan" and the interference colour "LithoGreen" and the two aperture sizes diameter 8 mm and 3 mm. The colour difference of both colours is higher if the aperture size is reduced. For the absorption colour, this effect is heightened.

Table III: Colour differences ΔE^*_{ab} of the measuring instrument MultiFX10 referred to the open aperture

	Absorption colour: "Cyan"	Interference colour „LithoGreen"
Unmodified sample port	reference	reference
d8 mm	4,9	2,25
d3 mm	14,39	7,4

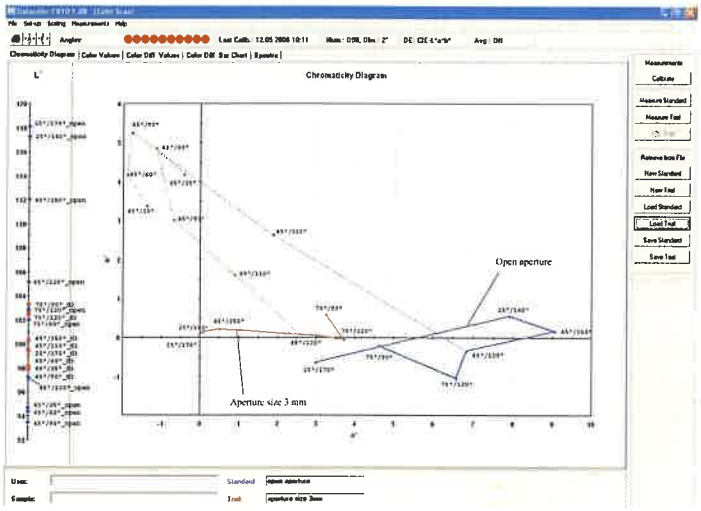


Figure 14: Comparison in the CIELAB colour space of the measuring results for the interference colour "LithoRed", measured by the unmodified aperture and a black paper aperture with the size diameter 3 mm

Further, a comparison with measuring results of other measuring instruments took place. For this, the CIELAB colour space and the colour differences ΔE^*_{ab} (D65 and 2° observer) are used. Table IV and Tabel V show the results for the absorption colour "Cyan" and the interference colour "LithoGreen". For this comparison, the measuring results of the unmodified sample port and for an aperture diameter 3 mm were consulted. The table indicates colour differences between the different measuring devises referred to the measuring results of Techkon Spectrodens. This device is taken as a reference, because it represents a device of the printing industry.

Table IV: Comparison of the measuring results of different measuring instruments [Datacolor: MultiFX10 with open aperture; Techkon: Spectrodens; Minolta: CM-2600d; Minolta: CM-512m3]; measured colour "Cyan"

	Absorption colour "Cyan"				
L*, a*, b* (illumination/ viewing angle); (φ_1/φ_2	Spectro-dens Techkon	Unmodified sample port Multi FX 10 Datacolor	aperture d3 for Multi FX 10 Data-color	Cm-2600d Minolta (exclu-ding glance)	CM-512m3 Minolta
L (45°/90°)	82,66	82,08	91,95	82,37	81,1
a (45°/90°)	-14,37	-14,62	-6,08	-14,63	-14,06
b (45°/90°)	-11,17	-10,74	-4,67	-9,88	-12,7
L (45°/110°)	----------	86,71	94,12	----------	82,88
a (45°/110°)	----------	-12,7	-4,57	----------	-14,16
b (45°/110°)	----------	-9,21	-3,39	----------	-12,56
L (45°/60°)	----------	79,79	87,47	----------	84,5
a (45°/60°)	----------	-14,62	-11,01	----------	-13,76
b (45°/60°)	----------	-12,28	-8,03	----------	-12,74
ΔL^* (45°/90°)		**-0,58**	**9,29**	**-0,29**	**-1,56**
Δa^* (45°/90°)		**-0,25**	**8,29**	**-0,26**	**0,31**
Δb^* (45°/90°)		**0,43**	**6,5**	**1,29**	**-1,53**
ΔE^*_{ab} (45°/90°)		**0,76**	**14,04**	**1,34**	**2,20**

Table V: Comparison of the measuring results of different measuring instruments [Datacolor: MultiFX10 with open aperture; Techkon: Spectrodens; Minolta: CM-2600d; Minolta: CM-512m3]; measured colour "LithoGreen"

	Interference colour "LithoGreen"				
L*, a*, b* (illumination/ viewing angle); (φ_1/φ_2	Spectro-dens Techkon	Unmodified sample port Multi FX 10 Datacolor	aperture d3 for Multi FX 10 Data-color	Cm-2600d Minolta (exclu-ding glance)	CM-512m3 Minolta
L (45°/90°)	93,09	93,03	92,9	93,64	91,25
a (45°/90°)	0,3	0,23	0,05	-1,21	0,23
b (45°/90°)	1,67	2,66	2,96	4,31	0,08
L (45°/110°)	---------	98,28	98,14	----------	95,53
a (45°/110°)	---------	-2,26	-2,23	----------	-1,4
b (45°/110°)	---------	3,93	4,32	----------	1,27
L (45°/60°)	---------	93,88	93,34	----------	94,61
a (45°/60°)	---------	1,06	0,35	----------	0,08
b (45°/60°)	---------	1,74	3,11	----------	0,3
ΔL^* (45°/90°)		**-0,06**	**-0,19**	**0,55**	**-1,84**
Δa^* (45°/90°)		**-0,07**	**-0,25**	**-1,51**	**-0,07**
Δb^* (45°/90°)		**0,99**	**1,29**	**2,64**	**-1,59**
ΔE^*_{ab} (45°/90°)		**0,99**	**1,32**	**3,09**	**2,43**

For the absorption colour Cyan the measuring results measured with the aperture diameter 3 mm applied on the sample port of the Multi FX10, the greatest colour differences ΔE^*_{ab} could be identified. For the interference colour however the difference between the measuring result of Techkon Spektrodens and the applied aperture on Multi FX10 is within the range of normal measurement device tolerances ($\Delta E^*_{ab} \leq 1.2$); [Dolezalek, 2005]. This could be explained by the measuring geometry. Since the Techkon device only measures with an illumination/viewing angle of 45°/90°, the change in interference colours could not been seen. For this, the other illumination/viewing conditions are necessary. For absorption colours in contrast, a reduction of illumination intensity caused by the aperture for every illumination/viewing condition affects the remission curves and thereby the colour difference a lot.

Furthermore the table demonstrates the influence of the measurement geometry for the other measurement devices. The multi-angle spectrophotometer Minolta CM 512m3 has the greatest colour difference compared with the Techkon device for the absorption colour. Especially for the interference colour, the Minolta CM 2600d shows a high colour difference compared with the Techkon device. This could be explained by the diffuse illumination and the measurement excluding glance, which plays a big roll in the case of interference colours.

The adjustment process using black paper apertures of different sizes and exhibit a huge influence on the measuring results. Since the absorption colours and the interference colours show different behaviours for the different illumination/viewing angles, further examination was done with a mirror as aperture. Characteristic of a mirror is the reflexion in specular direction only. Since all illumination/viewing angles of the MultiFX10 are positioned not in specular direction the remission of the mirror has to be zero for all illumination/viewing angles. To prove this statement a measurement of the mirror is done for all illumination/viewing angles, see Figure 15. The highest intensity of the

measured remission occurred for an angle of 45°/150°. Since the intensity of remission is very low, almost zero, the assumption is proven.

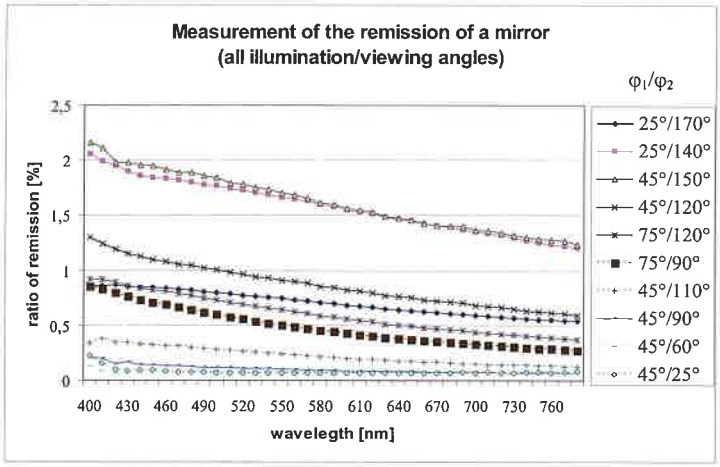


Figure 15: Results of the measurement of a mirror for all illumination/viewing conditions

In the next step it was looked for the smallest possible size of the aperture when using a mirror. The upper part of Figure 16 left illustrates the results of the measurement by different aperture sizes for the absorption colour "Cyan" and right for the interference colour "LithoRed".

In the lower part of the figure the accumulated quotient based on the results of the measurement with unmodified sample port is shown for both colours. It could be seen that for aperture sizes greater than 15 x 15 mm the results based on the unmodified sample port almost coincide. For aperture sizes smaller than 15 x 15 mm a relation to the remission curve measured by an unmodified sample port size could be seen, but they do not give the same outcome. For a better validation the quotient based on the remission curve for the unmodified sample port was accumulated, see equation 1.1.

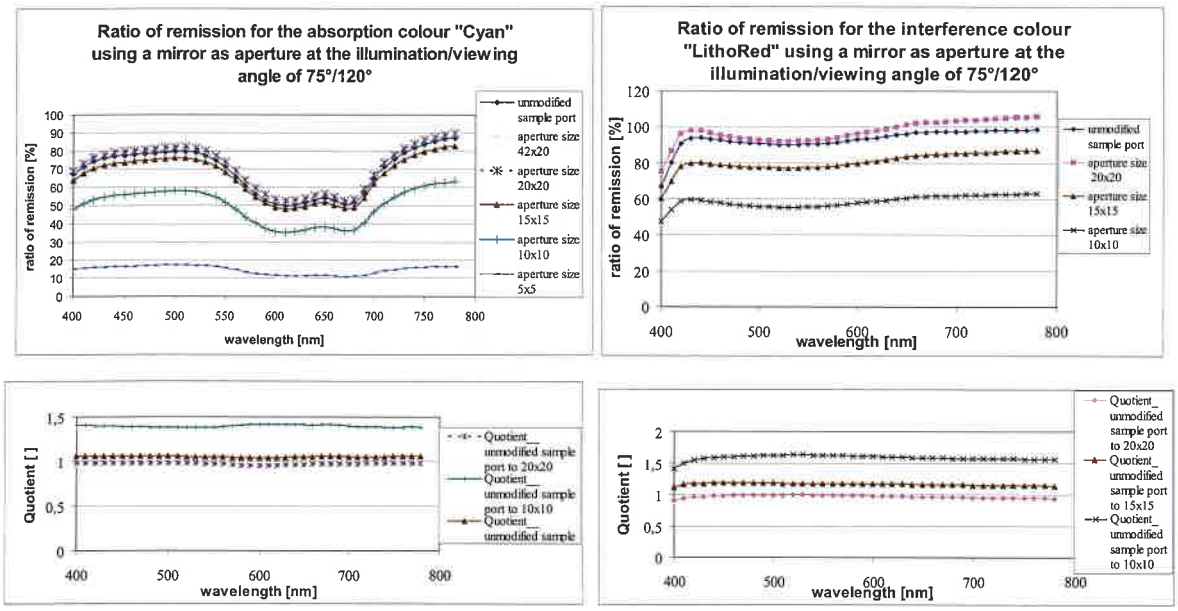


Figure 16: Measured ratio of remission for the angle 75°/120° using a mirror as aperture upper part left: Ratio of remission for the absorption colour "Cyan"; right: Ratio of remission for the interference colour "LithoRed" lower part: Accumulated quotient of the ratio of remission unmodified sample port and the mirror-apertures for both colours

$$Quotient = \frac{remission\ curve\ measured\ by\ unmodified\ sample\ port}{remission\ curve\ measured\ by\ mirror - aperture} \tag{1.1}$$

Looking at this quotient for all different illumination/viewing angles it can be seen that this quotient is almost equal for all measured colours (absorption and interference colours) for aperture sizes greater or equal 15 x 15 mm. For smaller apertures no relation between the measuring results of the unmodified sample port and the apertures could be found.

5. Conclusion

Multi FX10 offers a device for measuring metallic and interference colours. Since this measuring instrument is not developed for the printing industry, the sample port of this device is not suitable for measuring in print control bars. The researches describe the process of adapting the sample port to demand measurement conditions of the printing industry.

In detail, addict following results:

- Multi FX10 shows in context of the repeatability test bigger uncertainties than given in the operation manual. That is why die measurement results have to be proven each time assiduously. As best way for statistically firm measurement results is to repeat each measurement at least three times and accumulate the average.
- The distribution of light inside the sample port of Multi FX10 is addicted to the illumination angle and the size of the illuminator optics. Furthermore it does not show a consistent distribution of light intensities.
- Inside the sample port a centre of the illumination and the sensoring was found and accumulate the centre of the adapting apertures.
- The comparison between the different measuring instruments on absorption colours demonstrate that the measuring results measured with the MultiFX10 (unmodified sample port) are within normal tolerances of $\Delta E^*_{ab} \approx 1.2$. Hence, the measuring results of this instrument achieved by an unmodified sample port can be used as reference.
- The adaptation using black paper apertures of different sizes was dissatisfactory, because the measured colour values (L*, a*, b*) as well as the remission curves are highly dependent on the aperture size and differ intense to the measured values of the unmodified sample port. Also no uniform tendencies (increase or decrease of the remission curve) respectively a conversion factor significant for absorption colours as well as for interference colours could be found.
- The adaptations with the mirror apertures in contrast show better results. With this it was possible to reduce the size of the aperture to 15 x 15 mm. Smaller sizes of apertures are not possible because no quotient valid for both absorption and interference colours could be found. Since the measuring results by the unmodified sample port of MultiFX10 and the mirror aperture do not coincide, a factor was found to randomize the measuring results. The dimension of this factor depends on the illumination/viewing condition.

In conclusion, this paper shows that it is not feasible to adjust the aperture size for measuring fields in print control bars (diameter 3 mm). Since the printing process has difficulties to print huge solid patch with constant film thickness the adaptation of the sample port using a mirror aperture with a size of 15 x 15 mm nevertheless gives advantages in measuring printed interference colours.

References

1. *Cramer (1999), M*agical Mixtures, Paint & Coatings Journal 9, 72
2. *Cramer, Gabel, (2001),* Measuring Special Effects, Paint & Coatings Journal 7-8, 36-42
3. *Cramer, Gabel (2001),* Effektvolles messen, Farbe & Lack 104, 42-49
4. *Cramer, Gabel, (2003),* Das gewisse Etwas Dreiecksbeziehungen aus Bunt-, Aluminium- und Interferenzpigmenten, Farbe & Lack 109, 78-84
5. *Datacolor (2006)* MultiFX10 Operation Manual
6. DIN ISO 13655, (2000), *Spektrale Messung und farbmetrische Berechnung für graphische Objekte*
7. DIN 4512-Teil10,(1993), *Photographische Sensitometrie Teil 10: Geometrische Bedingungen für Messungen bei Reflexion*
8. *DIN 6175-Teil2, (2001),* Farbtoleranzen für Automobillackierungen Teil 2: Effektlackierungen
9. *Dolezalek, Kraushaar, (2005),* Korrektur von Messfehlern bei Farbmessgeräten, Fogra Bericht Nr. 52.034, München, FOGRA
10. *Gerlinger, (1990),* Color Measurement of Pearlecent Paints for the Nineties, Die Farbe 37, 123-135
11. *Gretag Macbeth, (2006),* information about measuring instruments, May 2006 http://www.gretagmacbeth.com/indx/products/products_color-measurement.htm
12. *Huber, (2000),* Effektpigmente in Lacken, Phänomen Farbe 7+8
13. *Instrument Systems, (2006),* Information about measuring instruments, May 2006 http://www.instrumentsystems.de/accessories/accmaingeneral.htm
14. *Kipphan, (2001),* Handbook of Print Media, Springer, Heidelberg
15. *Maisch, Weigand, (1991),* Perlglanzpigmente Bd. 56, Verlag Moderne Industrie, Landsberg/Lech
16. *Merck, (1993),* Color Compendium IRODIN®/ IRIODINBRONZE®, Darmstadt
17. *Merck, (2005),* World of Effects, Brochure of Merck KGaA Pigments Division, Darmstadt
18. *Merck, (2006),* IRODIN®/ AFFLAIR® Offset Color Effects with Pantone Colors, Darmstadt
19. *Minolta, (2006),* Information about measuring instruments, May 2006 http://www.konicaminoltaeurope.com/de/products/industrial_products/ueberblick/farbmessung
20. *Murakami, (2006),* Information about measuring instruments, May 2006 http://www.mcrl.co.jp/english/GCMS3B.html
21. *Phyma System (2006),* Information about measuring instruments, May 2006
22. http://www.phyma-colourvisin.com/wico10_htm_d.htm
23. *Rodrigues, J.,(1995*), Color and Appearance Measurement of Metallic and Pearlecent Finishes, ASTM Standardisation News
24. *Rodrigues, Steenhoek., (1996*), ASTM E-12.12: Measurement of Metallic and Pearlecent Colors, Die Farbe 42, 151-158
25. *Rösler, (2005),* Presentation of Arbeitsgruppe Multigeometrie Farbmessung at DfWG-Jahrestagung, Berlin
26. *Techkon (2006),* Information about measuring instruments, May 2006; http://www.techkon.de
27. *XRite(2006), Information about measuring instruments, May 2006, http://www.xrite.de/produc_guide.aspx?Industry=4&Segment=8*

Magnetic printing for the packaging industry: methods and feasibility

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Keywords:

Anti-counterfeiting, magnetic inks, packaging, sensor

1. Introduction

The Pulp & Paper industry is facing new challenges. From an industry focused primarily on cost reduction, the Pulp & Paper industry is forced to show innovative solutions as an answer to the threat that other industries represent. For packaging e.g., new ways of making communicative packages are developed. The idea is to let the package support information about the climatic history (temperature or humidity logs), traceability or authenticity, cf Heiniö and Smolander (2006).

Forgery of packaging is a growing business. Many solutions borrowed from bank notes development are available to reduce this. Unfortunatly, these solutions can not be directly implemented on paperboard, as the surface properties and the printing methodsused are not the same as for money paper. Corrugated boards e.g. show an important waviness of the surface which introduces characteristic printing problems for this substrate, e.g. washboarding, cf Hallberg et al (2006).

Printing with magnetic inks is nowadays a well-known technology to ensure security of documents like bank notes or checks. Black iron oxide (Fe_3O_4) is used in black magnetic inks because it is a semi hard magnetic material. van Renesse (2005) reports that Canadian bank notes, which are printed with this material, are easily machine read and counterfeits made on colour copiers can be easily detected at the sorting system. This is a convenient, easy to use and secure method, but van Renesse (2005) admits that this protection method does not give full security, as a wrinkled bank note might not pass the authenticity test.

In this paper, an anti-counterfeiting technology based on magnetic pigments incorporated in inks is presented. The feasibility of an implementation of this method is studied. The requirements for the coating layer, the magnetic particles and the detection device are evaluated. The quality of a detection signal given by a magnetic sensor is evaluated. Finally some guidelines to implement the described technology are given.

2. Materials and methods

2.1 Magnetic inks and fluorescence pigments

Mixing inks with particles with magnetic properties produces magnetic inks. Many substances can be magnetised, temporarily or permanently. Two important parameters to characterise the properties of these substances are remanence and coercivity. Remanence is the magnetisation left behind in a medium after an external magnetic field is removed. Coercivity is the intensity of the applied magnetic field required to reduce the magnetisation of a material to zero after the magnetisation of the sample

has been driven to saturation. Substances that possess intermediate coercivities are referred to as semi hard magnetic. For the testing purposes, two different ferromagnetic materials were used: Magnetite (Fe_3O_4) and Hematite (Fe_2O_3) with particle sizes bellow 5 µm. These materials were mixed into a flexographic printing colour, which was diluted to a working viscosity. Three different mix with concentrations corresponding to 5, 15 and 30% of dried printing colour were tested. It should be pointed out that it is hard to buy pre-mixed magnetic inks for flexography, which is the reason why the preparation of the ink was made on site.

The success of anti-counterfeiting relies on the ability to implement different security tags and techniques to discourage the counterfeiters. While magnetic printing was the main subject here, the possibility of incorporating UV-sensitive pigments into a coating layer for use for the production of paperboard was also investigated as an extra feature. Four fluorescence pigments (Xirallic T 50-10 Crystal Silver, Miraval 5411 Magic White, Solarflair Muster and Iriodin 320 Bright Gold Pearl, Merck & Co, Sweden) were mixed with a $CaCO_3$ based coating to a quantity of 1 pph.

2.2 Coatings and substrates

A commercial wood-free copy paper from StoraEnso with a grammage of 80 g/m^2 and commercial transparency films were used as substrates for an opacity study. Kaolin clay (Brazilian fine-particle clay, Capim DG, supplied as slurry by Imerys, USA) and ground calcium carbonate with broad particle size distribution (Hydrocarb 90, provided as a slurry by Omya AG, Switzerland) were used as pigments. A carboxylated styrene-butadiene latex (P6115, Eka Polymer latex, Finland) with a glass transition temperature (T_g) of 8°C was used for both pigments types. All the coating colours contained a small amount of CMC (Finnfix 10, Noviant Oy, Finland).

2.3 Methods

2.3.1 Coatings

A sheet was designed with different patterns and different colour levels (100, 75, 50 and 25% colour) to evaluate the difference in visibility when coating and coating thickness are change. The image depicted on Fig. 1 was then printed using a desktop laser printer. The patterns were printed with black and red colours. This choice was dictated by the colour of the magnetic materials available commercially. The patterns were coloured rectangles, bar codes, squares of different sizes and squares together with circles and small bars, in order to compare if the visual perception of these patterns was different depending on the pattern.

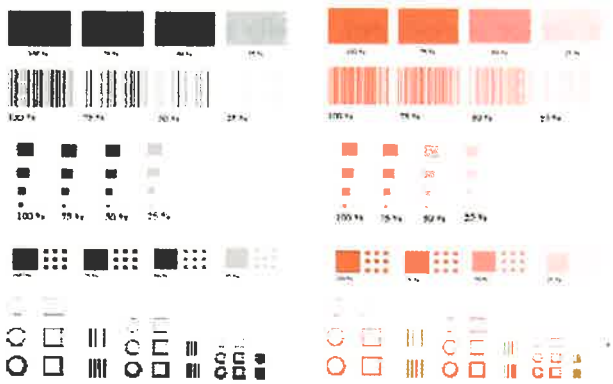


Fig. 1: Pattern printed for the evaluation of the coverage potential of the coatings

The papers and plastic films were coated with a laboratory coater from RK Print-Coat Instruments Ltd, Royston, England. Different bars were used to achieve different coating thicknesses reported in Table I together with the corresponding coat weight.

Table I: Thickness and coat weight of the coating layers

Bar	Clay thickness (µm)	Coat weight	GCC thickness (µm)	Coat weight
3	11	18.2	9	17.3
6	28	43.7	-	-
8	48	76.9	44	73.5
8+2	53	88.7	-	-
8+3	59	92.1	52	99.6
8+5	74	112.2	-	-

The samples were also calendered. Coated products are often calendered to gain higher gloss and printing quality. Due to more compact substance, the opacity of the coated surface decreases when calendering is performed. This is an unwanted effect when it comes to hidden printing and the opacity before and after calendering is therefore important to evaluate. According to Larsson et al. (2006) the clay coating should be more compressed than the GCC coating due to the shape of the pigments. Calendering was performed for one of each coated paper and plastic films with a load of 300 kN/m and a temperature of 95°C.

The reflectance was then measured on a Spectrophotometer (Minolta CM-3630) for the different coating thicknesses, at the wavelengths 460 and 540 nm (SCAN-G 5:03). The measurement was performed on the coated plastic films to avoid errors from light scattering in paper. Two measurements were performed for each wavelength. The results were then used to calculate the opacity of the coating layers before and after calendering, according to:

$$Opacity = \frac{R_0}{R_\infty} \tag{1}$$

where R_0 is the reflectance from one single surface on a black background, and R_∞ is the reflectance from a infinite pile of surfaces. R_∞ is given by

$$R_\infty = a - \left(a^2 - 1\right)^{\frac{1}{2}} \tag{2}$$

$$a = \frac{1}{2} \cdot \frac{\left(R_{gw} - R_{gs}\right)\left(1 + R_w R_s\right) - \left(R_w - R_s\right)\left(1 + R_{gw} R_{gs}\right)}{R_s R_{gw} - R_w R_{gs}} \tag{3}$$

where R_{gs} is the reflectance factor of the black background, R_{gw} is the reflectance factor of a white background, R_w is the reflectance factor of one single surface against R_{gw} and R_s is equal to R_0 in Eq 1.

2.3.2 Evaluation sets

To evaluate objectively the coverage potential of the different layers, a grey image of each picture was scanned using a desktop flat bed scanner. The averaged grey level at the printed areas was evaluated using an imaging software (Adobe Photoshop 7). A subjective evaluation was also performed. The coated and uncalendered plastic films containing GCC draw downs 3, 8 and 8+3 and clay draw downs 3, 8, 8+2 and 8+3 (cf Table I) were placed, in covers shown in Fig. 2. The printed area shown in Fig. 2. was visible and the other areas were masked using cardboard covers.

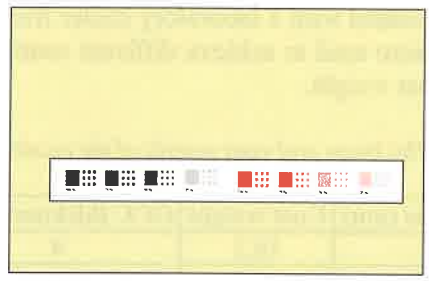


Fig. 2: The cover and the displayed patterns that were used in the subjective test

Eighteen persons were asked to fill in a questionnaire while looking at the covers. They were asked to evaluate if the patterns were "clear", "less clear", "indistinct" or "not visible at all". They were also asked to judge if a visibility difference could be detected between the black and the red patterns, and between the different red half tone patterns. Finally they were asked to rank the covers in aspects of clearness. In the first part of the test this was carried out with just the cardboard, (reflectance 27.9% at 540 nm) as background to the plastic films. In the second part the procedure was repeated with a white background (reflectance 83.3% at 540 nm).

2.3.3 Evaluation of the magnetic properties

Another part of this analysis concerned the possible use of specific magnetic pigments for applications in the packaging industry. Flexographic prints were produced using an IGT F1 printability tester with paperboard as substrate. The ink formulations described in the material section were used. The tone values used were 30% or 100%. The magnetic properties of the printed samples were investigated using a DAST (Document Authentication Security Technology) sensor. In short, this is an in-field sensor used by applying a magnetic field while measuring the sample's response. The sensor measures the vertical component of the field above the tested surface. This component of the field is only present at the edges or any place of discontinuity. A new type of sensors, giant magnetoresistive (GMR) and Spin-Dependent tunnelling (SDT) sensors described by Smith and Schneider (2003) offers a high sensitivity and the properties of this type of sensors have been evaluated.

3. Results and discussion

3.1 Hiding patterns

Despite the low concentration of the UV-sensitive pigments, a clear and simple detection was possible. This matter might be the subject of a subsequent study and has not been investigated further.

The opacity measurements are presented in Fig. 3. The clay based coating shows a clear difference in opacity before and after calendering but the difference decreases with increasing grammage. The curves for CaCO3 showed the same result, but with a lower opacity than the clay coatings.

According to Larsson et al. (2006), the opacity of the clay is higher than GCC, and the GCC opacity does not change much after calendering. Even if clay and GCC have relatively similar pore size distribution the particles are of different shapes. Clay is disc shaped and GCC is more spherical, and this microstructure gives the clay coating a higher opacity. When the structures are calendered, the clay particles are pressed down to a more horizontal position, and the clay coating layer is therefore more compressed than the GCC. The structure of the GCC coating does not change much after

calendering, and because of this the reflectances R_0 and R_∞ in Eq. 1 are not affected in any higher grade. When a clay coating is calendered, R_0 decreases more than R_∞, which leads to a lower opacity.

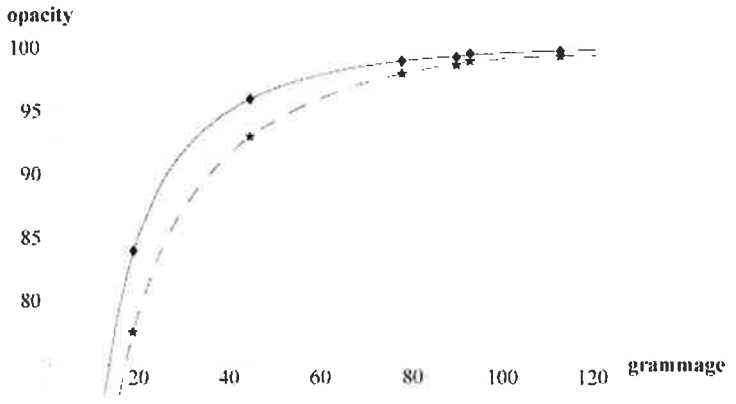


Fig. 3: Variation of the opacity of a clay based coating film with the coat weight (___ uncalendered, _ _ _ calendered)

The gray scale measurements are reported in Fig. 4 for a clay coating on a plastic film. The full tone patterns are more visible after the coated plastic films have been calendered. The same measurements made on a red full tone showed lower values than the black ones when the coating layer is thin but the trend remains the same. As the coating layer becomes thicker, the difference in detection potential of red and black full tone becomes smaller. The difference between the visibility of the calendered and the uncalendered coating layer, on the other hand, is constant. The greatest difference in visibility lies among the thinnest coating layers. The thicker the coating is, the flatter the curve becomes. Hence, there is an optimal coating weight for which the patterns are covered enough without reducing the possibility of detection with a magnetic sensor. This matter is treated in next chapter.

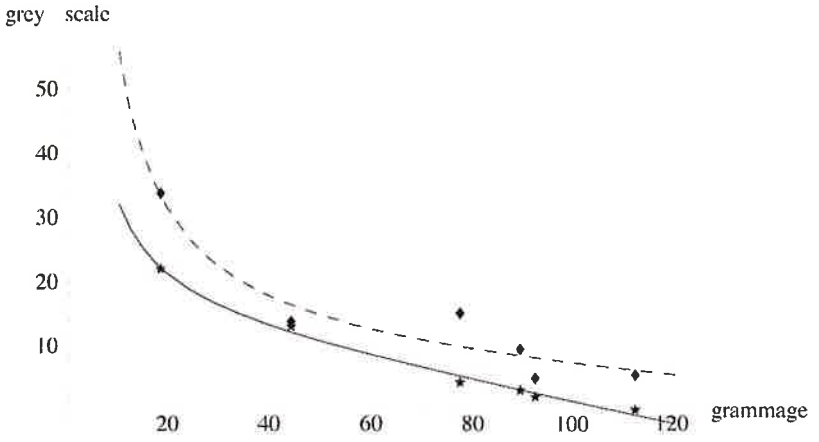


Fig. 4: Grey scale measurements for a black printed area (100% black) covered with a clay based coating on a plastic film (___ uncalendered, _ _ _ calendered)

Fig. 5 shows the grey scale measurement of the different colour levels field. There is almost no difference between paper and plastic film when it comes to visibility and hence only the results for the plastic film are depicted here. The figure show that the visual difference between the colour levels decreases when the coating layer becomes thicker. Hence there should be no point in reducing the amount of magnetic pigment in a colour in order to hide it better.

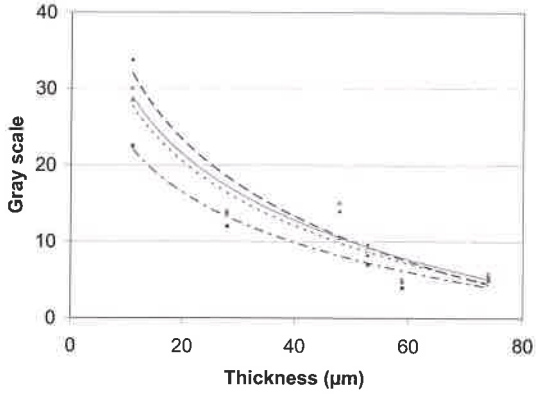


Fig. 5: Gray scale measurement of the four different levels (_ _ 100%, __ 75%, ... 50%, _ . _ 25%)

Fig. 6 shows the ranking in terms of visibility of different coatings. It is clear that clay coatings give a better coverage than GCC coated plastic films with equal coating weights.

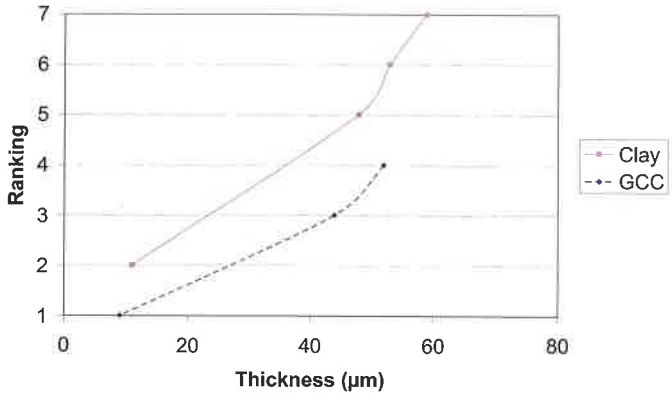


Fig. 6: Visibility of the coated patterns and their ranking in the subjective test. 1 = most visible; and 7 = least visible

3.2 Characterisation of the magnetic ink

The samples printed with a magnetic ink were tested regarding the detection possibility. A magnetisation loop was registered. Fig. 7 shows a typical curve for Fe_3O_4 with a magnetic pigment concentration of 30% and a tone value of 30%.

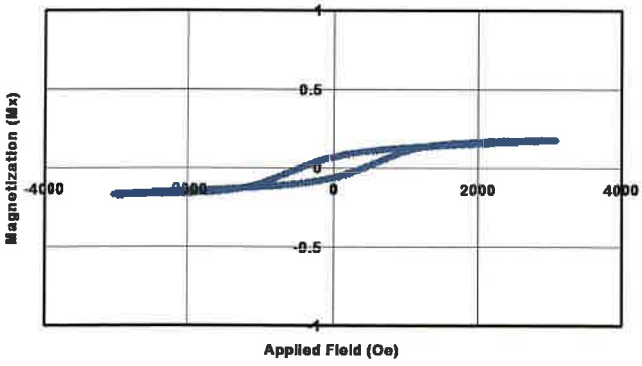


Fig. 7: Magnetisation curve for a printed sample (Fe_3O_4)

The concentration of the magnetic materials is very low. Hence, the signal from a loop system is also low. For some concentrations the same measurement was repeated in order to obtain a significant detection signal. Nevertheless, the materials tested were detectable and showed expected magnetic properties.

Fig. 8 shows the output signal measured when a strip printed with the three different mix with concentrations corresponding to 5, 15 and 30% of dried printing colour is registered. It is clear that the output voltage is directly coupled to the amount of magnetic pigment in the ink. By varying this amount (using different concentrations or different tone values) the amplitude of the signal can be changed and hence a simple code can be built.

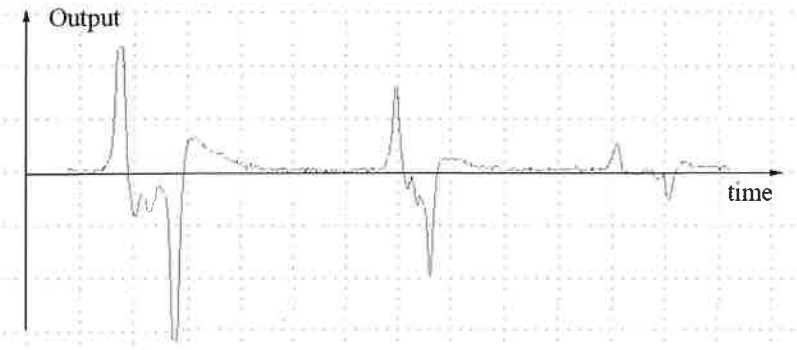


Fig. 8: Output from a magnetic measurement with inks containing 5, 15 and 30% of magnetic pigments

3.3 Interaction coating-magnetic ink

Fig. 9 shows the variation of the output signal as a pattern is moved farther away from the sensor. (NVE Corp, USA). Combining this curve with the opacity measurement, we can obtain the output/opacity curve, as depicted on fig 10.

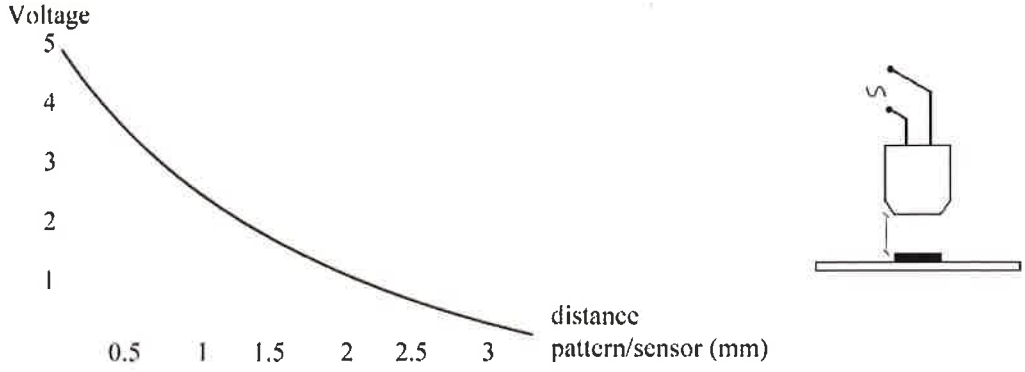


Fig. 9: Variation of the output signal of a sensor with the distance between the magnetic media and the sensor

This type of curve can be used differently depending on the application. the output signal of magnetic sensors is strongly dependent on the distance between the magnetic particles and the sensor head. Increasing the thickness of the coating layer will certainly provide better coverage but will also increase the distance between the sensor and the magnetic particles, hence resulting in a bad detection. A comparison between Fig 10. and Fig 8. shows that the reduction due to the thickness of the coating layer is not as critical as a reduction of the output signal because of a change in the concentration of the magnetic pigments.

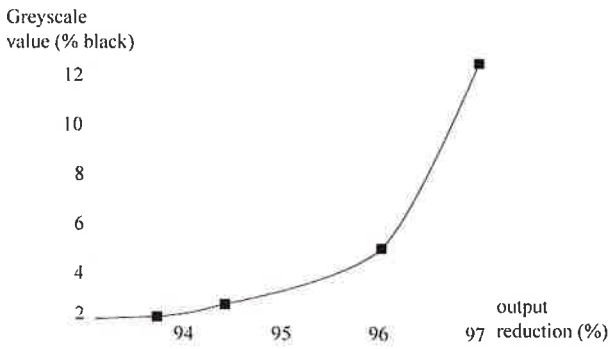


Fig. 10: relation between the output reduction (%) of a magnetic sensor and the coverage potential of a coating layer (expressed as greyscale value, a low value gives a good coverage)

4. Conclusions

This work shows promising results for implementing a technique used in protection of bank to the packaging industry. This would offer new possibilities regarding the anti-counterfeiting aspects and show that it is possible to enhance packages with printing.

The feasibility of the implementation of this new technology adding value against counterfeiting of packaging has been studied in details. Magnetic inks used in the banknote industry for a long time have been used and the detection possibility of these inks has been studied. Patterns were hidden under a coating layer and the coverage potential of the coatings has been studied to ensure a better security. The feasibility of the detection using a magnetic sensor has been performed. The study shows encouraging results about the possibility of hiding information under coatings without jeopardising the detection possibility. The printed samples with magnetic inks were evaluated regarding the detection possibilities and showed a response strong enough for a further use in commercial packages. The solution of hiding prints behind a coating layer was remarkably good and exhibited very promising properties. Designing a two-dimensional pattern in order to apply a large amount of data onto a package could tremendously enhance this solution. This feature is still under development.

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References

1. Hallberg E, Lestelius M and Rättö P., 2006, Dynamic measurements of nip force variations during post-printing of corrugated board, Nordic Pulp&Paper Research Journal, 21(1) pp 111-114
2. Heiniö, R-L and Smolander, M., 2006, "Sensory aspects of intelligent packagings", Nordic Workshop in Sensory Science: Focus on the Nordic Consumer. Ski, Norway, 3 - 5 May 2006
3. Larsson, M., Vidal, D., Engström, G. and Zou, X. 2006, "Compression of Coating Structures During Calendering", TAPPI Coating and Graphic Arts Conference, Feb 8-10, Turku, Finland, pp. 373-384
4. van Renesse R.L., 2005, Optical Document Security, Third Edition. Artech House Publishers, USA, ISBN 1-58053-258-6
5. Smith CH and Schneider RW, 2003, "Very Dense Magnetic Sensor Arrays for Precision Measurement and Detection" Sensors EXPO, June 3, 2003, Chicago

Gravure printing: formulation and characterisation of polymer conductive inks

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1. Context and objectives of the study

The field of organic electronics has progressed enormously during the past few years as a result of worldwide activity in numerous research centres. Advances have been made in the fields of device science and fabrication as well as in chemical, physical and material sciences. The technology of plastic electronics is believed to open a new field in low-cost electronics with numerous innovating applications. For cost reasons, plastic electronics need to rely on printing technologies such as roll-to roll printing. The necessary materials for printed electronics are readily available and appropriate printing methods are being developed for their production. It appears that the formulation of such specific inks can be based on parameters from conventional printing but the process has to be adapted every tile according to the needs. (Substrates, conductive particles ...)

This study is composed of two parts:

- first of all we explain how printing of conductive inks, formulated with two polythiophene derivative dispersions for gravure printing technology, is prepared;
- then we compare the electric performances of these printed films as well as those ones coming from samples obtained with silver pigment ink.

The objectives are slightly different from those of standard printing; the fidelity of the reproduction is still important but the final purpose is quite divergent. The visual aspect of the product is not essential, only the electrical characteristics of the printed components have to be linked up to the physical and chemical attributes of the process; the required ink viscosity and the surface tension is determined by the substrate surface properties thus ensuring a good wetting and adhesion on the surface. Finally, the process parameters (printing pressure, speed, ink quantities ...) should be optimised.

2. Research method

Polythiophene and its derivatives are among the most popular conductive polymers in the field of printed electronic because of their good air stability, the possibility of specific function chains addition and the relatively high conductivity of formed films when a polyalcohol co-solvent is added.

Nevertheless, the physico-chemical properties of the commercial polythiophene dispersions (Baytron P from Bayer AG) do not allow direct printing. Most importantly, the viscosity and the surface tension are not adapted to the gravure printing technology. The first step is to modify the ink characteristics by evaporation followed by a surfactant addition.

2.1 Viscosity and surface tension adjustment

The typical operating viscosity of gravure inks ranges from 10 to 80 mPa.s, depending on the speed and the pressure applied during printing. The surface tension of the water-based solution has to be controlled so as to be under the substrate surface energy.

A classical formulation of Baytron P was used at first but a more conductive solution was chosen to be used in the immediate future (Baytron P HS); the solid content and the viscosity of the latest version being higher than the previous one.

The viscosity adjustment is not a very important problem; the first dispersion has just to be adapted to the gravure printing specifications.

Ink viscosities are measured on a rotational TA instrument rheometer with a cone plane geometry.

Table I shows the viscosity of the different Baytron P solutions.

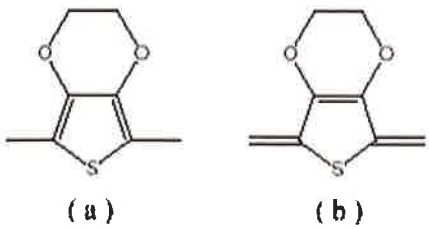
Table I

	Baytron P	Baytron P modified	Baytron P HS
Viscosity (mPa.s)	50	180	150

In order to obtain a good surface tension, two different surfactants are employed (Tween 80 and Dynol 604). The determination of the critical micellisation concentration (CMC) in water and then in Baytron P is determined using a Kruss tensiometer and the "Du Noüy ring" method.

2.2 Increase of films conductivity

Recently, it has been observed that by addition of poly-alcohols (alcohols with more than two OH groups on each molecule) to a PEDOT:PSS solution the conductivity of the formed film can be enhanced by over 100-folds [Ouyang J. 2005]. The mechanism for this conductivity enhancement was studied and a new mechanism was proposed. Raman spectroscopy indicates an effect of the liquid additive on the chemical structure of PEDOT chains, which suggests a conformational change of PEDOT chains in the film. Two kinds of resonant structures, the benzoid and the quinoid structures, have been proposed for PEDOT (schema 1).



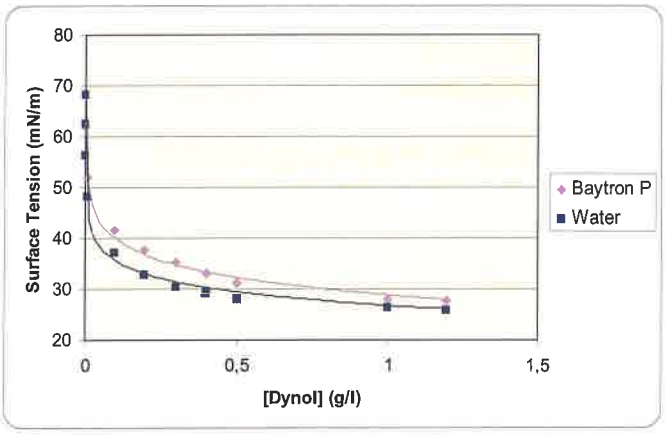
Schema 1:
a) benzoid and b) quinoid structures of PEDOT

In our study Baytron is modified with two co-solvents: Ethylene Glycol and Glycerol.

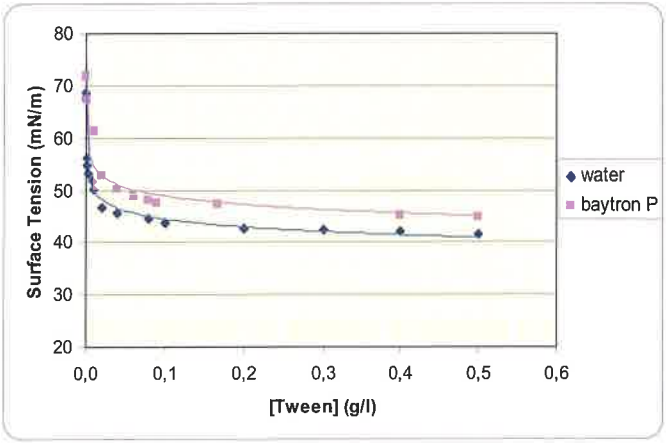
3. Experimental results

3.1 Determination of CMC in water and in Baytron

The graphs 1 and 2 represent the evolution of the surface tension of water and Baytron P solution in function of the two surfactant concentrations. Graph 1 represents the evolution with Dynol 604 and Graph 2 with Tween 80.



Graph 1

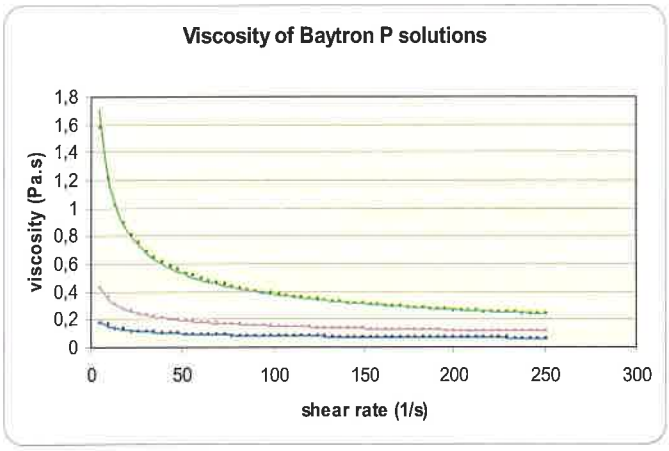


Graph 2

Dynol 604 seems to be more efficient than Tween 80 in static mode. The major advantage of the Dynol is its high efficient both in static and dynamic mode. Surface tension of our gravure ink has to be around 30 mN/m for a good wetting of polymer substrates.

3.2 Adjustment of the Baytron P viscosity

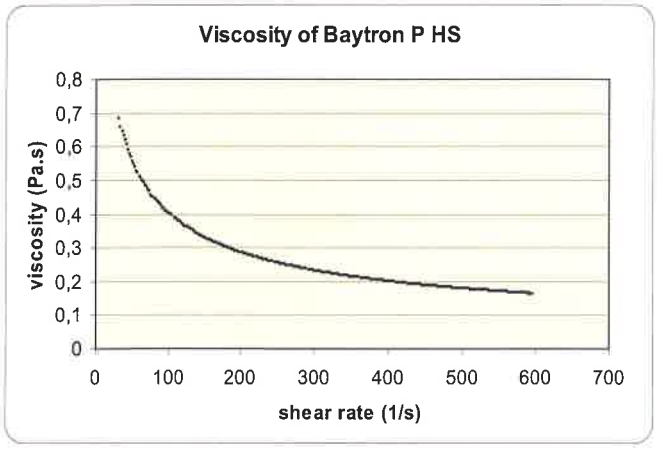
The graphs 3 and 4 present the evolution of the viscosity in function of the shear rate for three solutions of Baytron P and for Baytron P HS solution:



Graph 3

S5-1 a solution of pure Baytron P is represented in blue.
S5-2 an evaporated solution (20% in volume) is represented in pink.
S5-3 an evaporated solution (40% in volume) is represented in green.

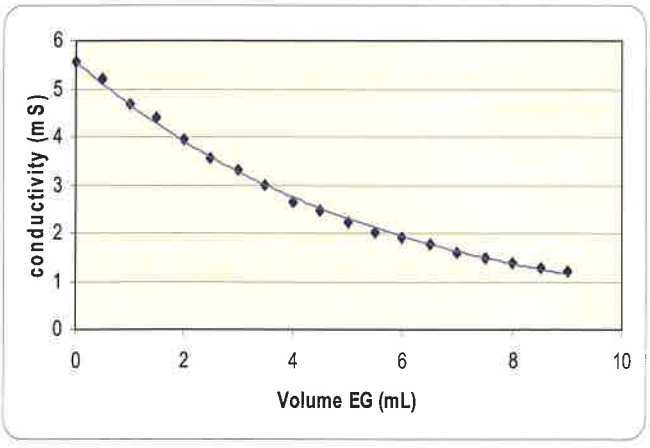
The viscosity of the solution S5-3 is 220 mPa.s; it is well adapted for gravure printing ink.



Graph 4

3.3 Enhancement of Baytron P film conductivity

The first step consists in measuring the conductivity of a Baytron P solution in function of ethylene glycol percentage added so as to determine when the conformational change is done. The graph 5 represents the evolution of the solution conductivity respect to ethylene glycol volume. The initial volume is 20 mL of Baytron P HS.



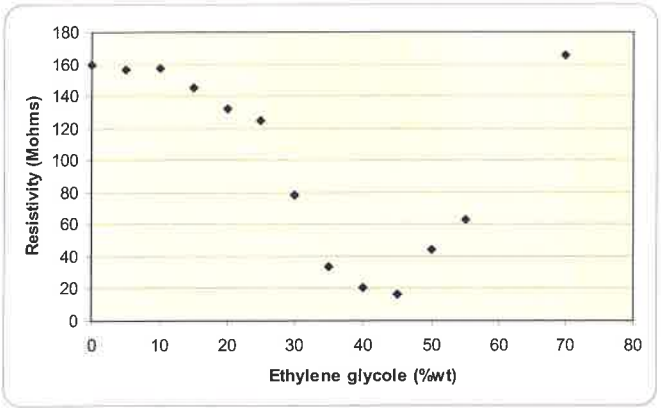
Graph 5

After each addition, the solution was shaking during 2 minutes and then agitation was stop during 5 minutes; the conductivity was measure again. No differences were found.

We concluded that no conformational changes were done in the solution with the co-solvent addition.

The determination of the optimum concentration in ethylene glycol of the solution has been realised in function of the film conductivity. We measured the conductivity of dry films.

Graph 6 represents the evolution of the film conductivity in function of the ethylene glycol concentration.



Graph 6

The optimal ethylene concentration for Baytron p HS solution is between 35 and 45% in weight. Similar study was made with Baytron P by *S. Ashizawa*[1]. This author found that the optimal percentage is 20% in weight. We can explain the difference with the concentration in PEDOT in the two solutions. Baytron P solution is two times less concentrate in PEDOT than Baytron P HS solution.

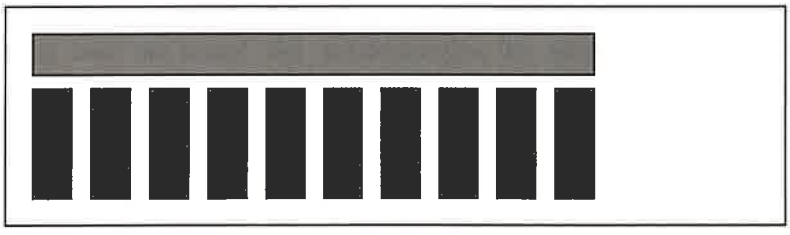
We have demonstrated that the enhancement of the conductivity is not realised directly in solution; so we could expect that it is during the drying.

Today the most serious explanation is a conformational change of some monomer group in the polymer chain.

To confirm this hypothesis we could firstly analyse dry films with a Raman spectrometer because quinoïd and benzoïd ring have not the same reaction to vibrations. Then we could determine the quantity of free radicals with a RPE spectrometer.

3.4 Comparison of metallic and polymer printings

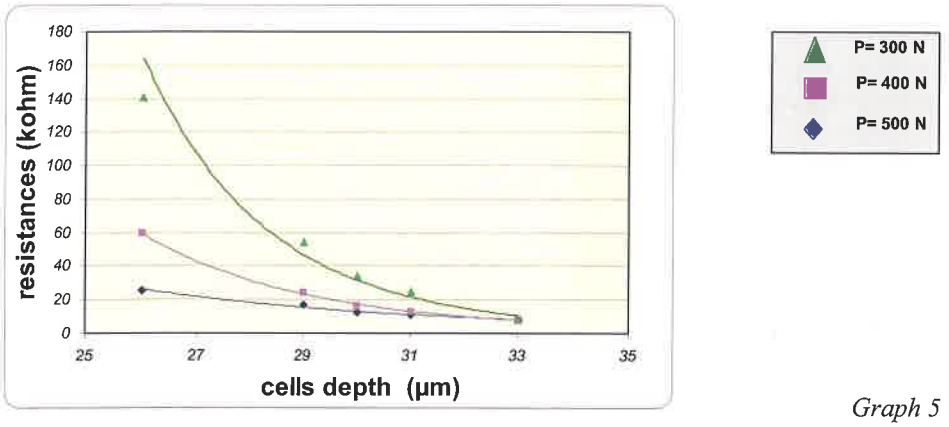
The printings are realized with an IGT F1 in gravure mode. We used an IGT gravure test form, (reference: 402 153 432), composed of ten engraving cells (33 to 11 µm in depth); the resolution is 70 l/cm (IGT website).



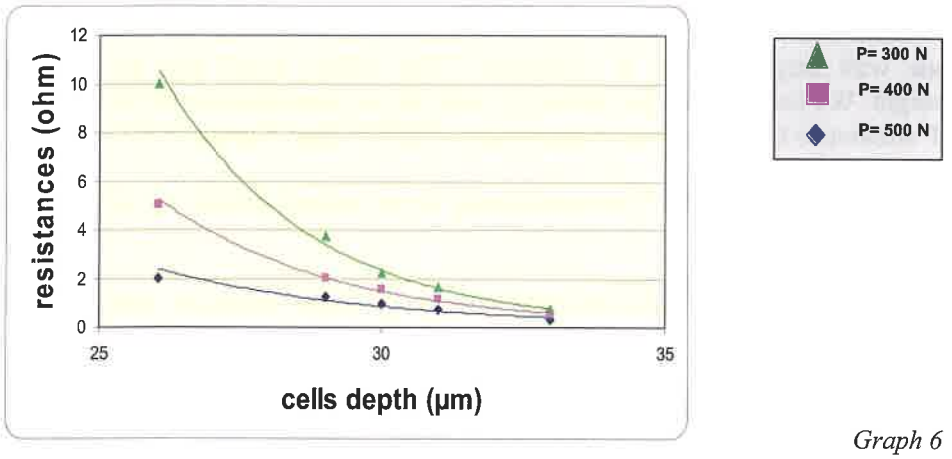
The metallic pigments ink is from Xink. (Viscosity: 0,50 Pa.s and surface tension: 39,7 mN/m).

The graphs 5 and 6 represent the evolution of the printing resistance in function of the engraving cells depth for a solution of Baytron P (S5-3 with Tween 80 and 20% wt of Ethylene glycol) and the metallic pigment Xink ink.

[1] S. Ashizawa, R. Horikawa, H. Okuzaki: Effects of solvent on carrier transport in poly (3,4-ethylenedioxythiophene) / poly(4-styrenesulfonate), Synthetics Metals 153, p. 5-8, 2005



Graph 5



Graph 6

We observe that printed layer resistance decrease with respect to the increase of the cells' depth. Indeed, the deeper is the cell the thicker is the layer. The pressure is an important parameter in the ink transfer; here it influences the resistance layer. For an equivalent depth, the resistance decreases with the pressure growth.

4. Conclusions

This paper presents the formulation of polythiophene ink based on two grads of commercial dispersion. The "Du Noüy ring" method permits to determine the influence of two surfactants on the surface tension. The formulated ink is finally compared to a metallic pigment ink. Chemical analysis should confirm the conformational change of PEDOT molecule.

Development of active power devices using the printing method

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Abstract

Organic solar cells are active power devices that may be fabricated using the printing methods. We report initial results involving the formation of micron scale dye aggregates using a two-step ink jet printing process. 4,5,4',5'-Dibenzo-3,3'-diethyl-9-methyl-thiacarbocyanine bromide (DTCB), 1,1'-Diethyl-2,2'-carbocyanine chloride (DCC), Euriochrome Cyanine R and 5-(4-(dimethylamino) benzylidene) rhodanial dyes have been selected and shown to produce micron-sized J and H aggregates in the presence of an aggregate promoter. These J and H aggregates, of uniform size and placement, will serve to function as the charge separation medium in our organic solar cell. The aggregate promoter was selected to optimize and control the crystallization conditions. Ionic strength and polarity changes are being investigated as the mechanism of aggregate promotion. Ionic strength was investigated using mono- and multi-valent salts. Surfactants were also investigated as a means to vary the solution polarity to promote aggregate formation. Albumin protein solutions, however, were shown to be the most promising promoter for producing micron-sized aggregates by taking advantage of the confined non-polar region of the protein core. A specially designed ink jet printer, capable of delivering sub-microliter droplets of controlled timing, placement and volume was developed and used in the study.

As our solar cell device will require conductive electrode contacts or pads, we report our progress in the printing of conductive inks on non-woven and synthetic substrates using the gravure printing method. A gravure cylinder was mechanically engraved with a test form comprising electrode pads of increasing screen density from 65 to 100%, gradients, antenna and line art structures ranging in resolution from 100 to 200 LPI. Cell depth was also varied on this form. Silver-based ink formulations have been used to produce conductive elements with resolutions of 165 LPI, much higher than that capable using flexography. The 180 LPI form failed to produce a useful electrode element. Low transfer efficiency and dynamic ink viscosity changes are discussed.

1. Introduction

The printing industry is enjoying a rebirth with the growing need to produce smaller electronic devices. Gravure, flexography and digital printing methods, such as ink jet printing, have been used to produce high quality electronic devices and sensors on a production scale [Rigney, 2004]. Printed radio frequency identification (RFID) circuits, for example, have been identified as the 21st century version of the packaging barcode [Frenzel, 2005]. Active devices, however, are going to require power. Therefore, the RIT Print Science Laboratory focuses on leveraging the printing method as a means to produce efficient power sources for emerging nano-devices.

Photovoltaic devices would be the power source of choice given their portability and renewable attributes. The generalized design of a photovoltaic cell is illustrated in Figure 1.

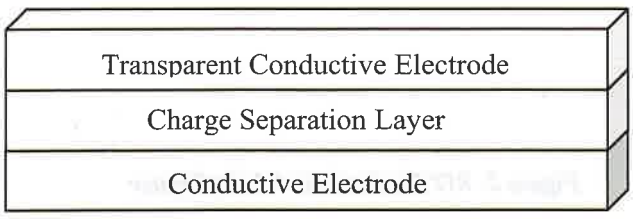


Figure 1: Photovoltaic device

Dye-sensitized solar cells, such as the Graetzel cell, have been demonstrated, but often suffer from low conversion efficiency [Hara, 2003]. Alternative dye-based designs would involve the fabrication of a charge separation layer using the inherent electronic properties of the dye material rather than relying on coupled electrochemical processes. We choose to fabricate a charge separation layer leveraging the delocalized π electronic character of the polymethine dye (PMD) aggregates.

PMD aggregate properties have been extensively studied and reported in the literature [Tani, 1995; Hoeben, 2005]. These aggregates have also been used as the charge separation layer in photovoltaic devices with limted success [Sayama, 2002; Adams, 2003]. We believe that one reason, for the limited efficiencies, results from the fabrication method. In most cases, dye aggregates are precipitated onto a TiO_2 electrode surface using bulk phase dye solutions. This would result in an inhomogeneous aggregate distribution of varied structure and electronic character. Our approach is to control the synthesis, and therefore the structure of the PMD aggregate, using a two-step ink jet method. In this method, an aggregate of uniform size and structure can be crystallized via the addition of an aggregate promoter.

Aggregate formation would depend on the thermodynamic decrease of the dye solubility constant for a chosen solvent. Ionic strength, polarity and surface absorption, for example, are typically used for this purpose [Tani, 1995]. In order to minimize the onset of corrosion of the ink jet printing head, we have selected to focus our efforts on using polarity changes; although, we do report some results using ionic strength effects. Mixed solvent applications have been reported for polymethine dye systems [Tatikolov, 2000]. Our approach, however, is a novel application of using water-soluble protein structures for three main reasons. One, an aqueous soluble promoter provides the upper limit in solvent polarity. Two, a protein necessarily has to polar domains in aqueous solution - a polar outer surface and a non-polar inner core. Lastly, the protein tertiary structure is small and confined. Our idea was to promote aggregate formation by intercalating a hydrophobic dye into the protein core. The organic solvent, used to dissolve the dye, would denature the protein transforming this aggregate promoter into a binder for surface adhesion and protection.

The program objective is to fully print a solar cell device; therefore, we must also investigate the best methods for printing the conductive electrodes and lead contacts. As illustrated in Figure 1, solar cell electrodes typically have special properties. One contact must necessarily be both transparent and conductive. This electrode is commonly called a transparent conductive electrode (TCE) and is often a composite metalloid compound such as indium titanium oxide evaporated onto a synthetic or glass support. The other electrode can be any metal as long as there is a difference in the workfunction between the two electrodes. This difference establishes an electric field across the charge separation layer and is critical for current flow.

2. Experimental approach

2.1 Ink Jet printer

A two-nozzel ink jet printer was developed in our laboratory and shown in Figure 2.

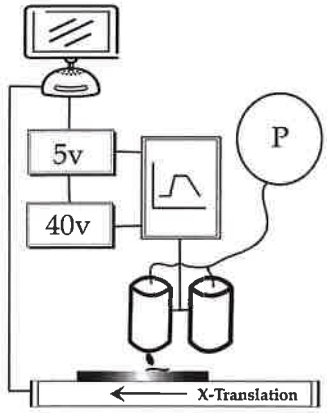


Figure 2: RIT Dual-nozzle Ink Jet Printer

Two Lee VHS-M/2 microdispensing values, capable of 40 nl droplet formation, are driven by a Lee spike and hold controller (Lee Co.). The dispensing value was fitted with a 0.005" sapphire nozzle. The spike and hold controller is supplied using a 24V spike and 5V hold potential using a BK Precision 1672 Triple DC output power supply. The printing frequency is controlled using a Beckman function generator set with a 3V (P-to-P) square wave function of variable gate and delay. Compressed nitrogen (P) at 10 psi was used to apply a valve head pressure. Motion control of the substrate, under the nozzle, was achieved using an Arrick X-18 linear stage driven by a MD-2 controlled stepper motor (Arrick Robotics Ind.).

2.2 Dye and aggregate promoter preparation

We have selected four dye candidates in our initial survey phase of this project. 4,5,4',5'-Dibenzo-3,3'-diethyl-9-methyl-thiacarbocyanine bromide (DTCB) and 1,1'-Diethyl-2,2'-carbocyanine chloride (DCC), Euriochrome Cyanine R and 5-(4-(dimethylamino)benzylidene) rhodanial dyes were chosen for their propensity to form J and H type aggregates in the presence of a promoter. DTCB was prepared at a 250mM concentration in distilled water. The DTCB aggregate promoter was sodium chloride prepared at a 23mM stock concentration. DCC was prepared at a 10mM concentration in ethanol. The DCC aggregate promoter was 0.2M sodium dodecyl sulfate (SDS) in distilled water. When a protein was selected as the aggregate promoter, a one (1) mg/ml aqueous solution of Albumin (Aldrich) was prepared. At the time of this proceedings report, the other dye systems were beginning to be investigated. Typical dye concentrations were in the one to 10 millimolar range.

2.3 Spectral measurements

Soution spectral measurements were obtained using a Cary 100 Spectrophotometer configured with one (1) nm bandpass resolution. Reflective spectral measurements were obtained using an Edmund Scientific bifurcated fiber optic collection system integrated onto a BRC111A CCD array spectrometer. The effective spectral resolution of this system was one nanometer.

2.4 Conductive ink printing trials

Silver-based conductive inks were used to prepare the conductive solar cell contacts or pads. A SPAZ1-033L UHF aqueous-based silver composition was provided by Xink, Incorporated. The ink viscosity was measured at 63 seconds with a #3 Zahn Cup that equated to 900 cp. This composition was printed using the gravure method. A 32" long hollow core gravure cylinder with a 21" repeat area was engraved with 25 mm square electrode contacts screened from 55 to 100% at a resolution of 100 to 200 LPI. Cell depths ranged from 67 to 24 microns, respectively. The image impressions were made on a Heaford HA3 Single Cylinder proofing press using a single 45 degree bevel doctor blade and 600 kilograms of impression pressure.

3. Results

3.1 Dye-aggregate charge separation media

DTCB J-aggregate formation, in the presence of increasing NaCl concentration, has been well documented in the literature. Figure 3a illustrates the spectral differences between the monomer and J-aggregate form of DTCB. We found, however, that there was a significant temporal dependence on aggregate formation that may be linked to the solvation rate of reactant species.

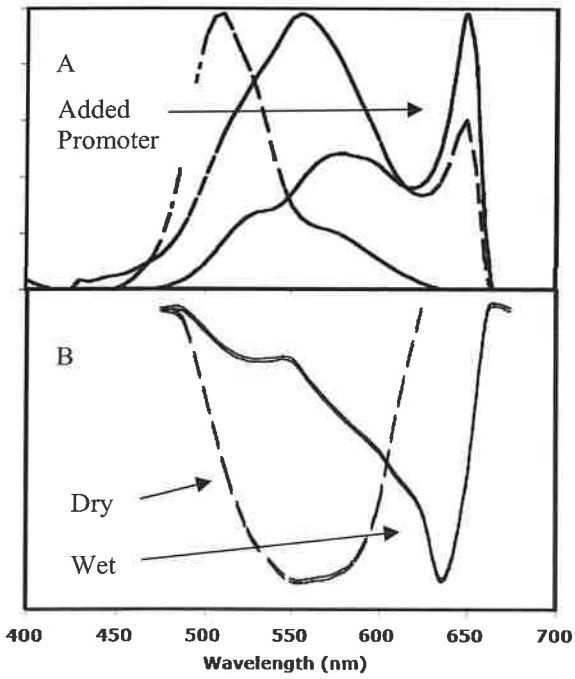


Figure 3:
250mM DTCB in water with (A) increasing concentration of NaCl promoter added dropwise into three milliliters of dye solution, and (B) reflective transmission measurements of a printed dot in the order promoter followed by dye solution. The dry promoter curve corresponds to allowing a one hour time delay between overprinting sequence to allow for sufficient drying

We first printed the DTCB solution onto an office grade uncoated bond stock. The reflectance spectrum of the dried dye mark, in the absence of promoter, was consistent with DTCB in the monomer form. We followed by overprinting the DTCB dye with the NaCl promoter by introducing a time-delay between the two marks. Figure 3b (dashed line) illustrates that only the monomer species was present when we allowed the promoter mark time to dry before overprinting with DTCB. By overprinting wet-on-wet, or directly (less than a one second delay) overprinting each mark, J-aggregate formation appeared (Figure 3b, solid line).

H-aggregate formation was achieved using DCC dye with an SDS promoter. As with DTCB, H-aggregate formation occurred when two components were overprinted wet-on-wet with little intermittent time delay. Figure 4 shows a light micrograph (480x magnification) surfactant-promoted aggregate. The approximate aggregate size was measured, in this experiment, to be approximately 600 x 50 μm.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 4:
DCC H-aggregate in the presence of SDS

Smaller, more uniformly distributed, aggregates were formed when we used a protein as the aggregate promoter. As shown in Figure 5, when Euriochrome cyanine R (in ethanol) was brought into direct contact with a one mg/ml aqueous solution of Albumin, J-aggregates on the order of a few microns long by less than a micro wide were obtained.



Figure 5:
Eurochrome Cyanine R J-aggregates Using an Albumin Promoter. These crystals were grown in bulk phase solution. SEM micrograph was obtained at a magnification of 5000X

These crystals were grown in bulk phase solution. Ink jet printing trials are planned in order to study and control the behavior of aggregate formation.

3.2 Electrode printing trials

Silver-based conductive ink, optimized for flexography, was printed onto a coated gravure paper stock in an initial trial. The ink was about a factor of nine times more viscous than would be optimal for gravure printing. Gravure optimized inks are currently being formulated; however for the purpose of a trial to generate some conductive electrode pads, a printing trial via gravure was conducted. A conductive pad was a 25 x 25 mm square produced using varying tint levels from 55 to 100%. Flexography trials were also conducted, but the data was not analyzed in time for disclosure in this report.

These conductive pads were printed up to a line screen of 165 LPI. Line screens higher than 165 LPI did not yield a conductive pad even at a 100% tint. Figure 6 illustrates that the conductivity, measured in Ohms/cm, onsets abruptly at tints starting at 90% and higher.

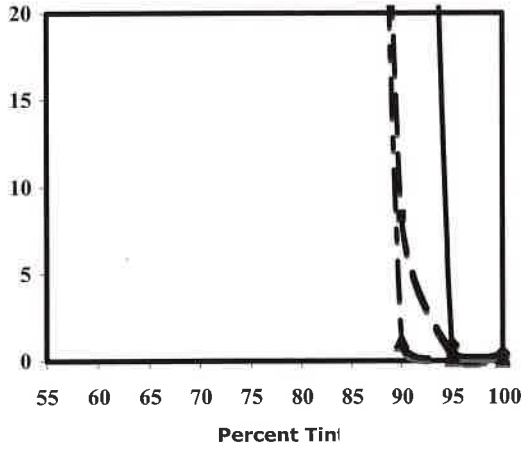


Figure 6: Conductivity in Ohms/cm as a function of percent tint. 100 LPI (solid line, diamond), 150 LPI (dash line, squares) and 165 LPI (alternate dash, triangles) printed tints were measured from 55 to 100%. Conductivity was measured to be infinite for all tints lower than 90 percent

We anticipated that the onset of conductivity might vary more gradually; that is, the 100 LPI screen image set might yield conductive pads at tints much lower than 90%. As the screening value increased from 100 LPI, we expected that the conductivity range would correspondingly narrow as less ink would be delivered to the substrate. As shown in Figure 6, however, the higher screen image sets yielded a more gradual conductivity onset than that found with the lower screen specification.

Another apparent anomaly was observed when the coat weights were compared between the various screen image sets. A 80% tint at 100 LPI screen did not yield a conductive pad. The coat weight for this printing condition was measured to be 80 gsm. The 100% screen at 165 LPI did yield a conductive pad with a measured coat weight of 80 gsm. n order to understand why two nearly identical coat weights would yield different conductivity results, we looked at the printed image using an SEM.

Figure 7 shows the 80% tint at 100 LPI (Figure 7A) and the 100% tint images at 165 LPI (Figure 7B). The 80% tint shows a non-continuous film interrupted by large sections of missing ink material. These missing regions correspond to the gravure cylinder cell locations. The 100% tint image would be expected for a proper gravure impression, but there is still material missing in the non-image area; that

is, a continuous film was not obtained. The silver-based ink used did exhibit an apparent shear thickening under the force exerted by gravure printing.

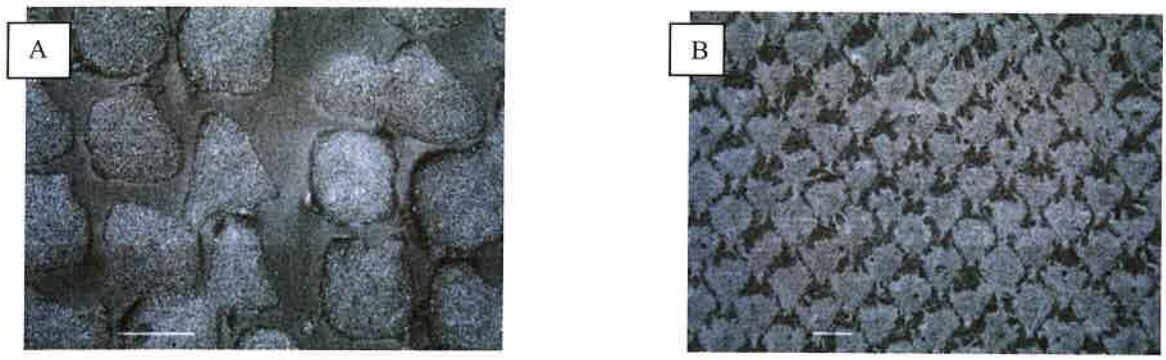


Figure 7: SEM micrograph of (A) a 80% tint at 100 LPI and (B) a 100% tint at 165 LPI

4. Conclusion

According the Fisk's second law of diffusion, the rate of crystal growth is directly proportional to diffusion-controlled collision, volume and dye concentration terms. Solution phase crystallization of nanoparticles, in bulk or macroscopic volumes, is typically achieved by favoring collision processes through stop-flow type mixing procedures. There still exists, however, a distribution of microenvironments, within any macroscopic volume region, that will result in a corresponding heterogeneous distribution of crystal structures. Our ink jet printing approach is to minimize the volume parameter, which is often the rate-limiting term, by conducting the experiment in sub-microliter volumes further minimized by rapid solvent evaporation rates on the order of the crystallization rate. Since we can control the concentration term, we are left with designing crystal structures based on the time-dependent diffusion processes that control crystallization. The ink jet method also provides a mechanism for accurate placement of an aggregate at a pre-determined location on an electrode surface.

Our early experimental results indicated that there appears to be a significant influence of the solvation rate on aggregate formation. At sub-microliter reaction volumes printed onto an absorptive paper support, we can control the promoter concentration by using an overprint time delay. If there is minimal time delay, wet-on-wet overprinting, the crystallization reaction proceeded to a stage whereby aggregates with larger than desired dimensions (see Figure 4) were obtained. Likewise, when the time delay supported drying before the placement of the subsequent dye drop, no aggregates were detected. This result suggests that the aggregate formation rate depends on the re-solvation and diffusion rate of the promoter printed mark.

To further minimize the volume-dependent processes in aggregate formation, we experimented with using an Albumin protein as an aggregate promoter. The protein structure will act as a confined cage with a hydrophobic core. The experiment was to mix an alcohol soluble dye with an aqueous phase protein solution. Upon mixing, the dye would intercalate and concentrate inside the protein core supporting aggregate formation in the confined space. As the aggregate forms, the protein tertiary structure would be disrupted by the organic solvent causing the protein to denature and act as a binder for the aggregate on the electrode surface. Since each of these processes are time-dependent, our research continues to focus on the timing issues related to the introduction of promoter and dye to the electrode surface.

In order for an aggregate to function as an effective charge separation medium, the crystal structure must be devoid of defects. A single crystal defect, in the aggregate, can quench electron transfer processes necessary for photovoltaic function. Bulk phase preparation methods would result in a distribution of

structures of varying efficiency. The low conversion efficiencies may result from a limited number of aggregates with the optimal structure to support the charge separation process. Our approach is to first learn how to homogenize and control the structure of these aggregates; and then, study the conversion efficiency as a function of size and composition.

As the objective is to completely print the solar cell, we are also investigating the best printing conditions, using either gravure or flexography, to print the electrode compositions. When we conducted our initial experiments using a silver-based conductive ink using gravure, we obtained some unexpected results. Upon printing, we noticed that there was significant shear thickening that occurred under the stress of gravure printing. At line screens higher than 165 LPI, the ink would shear thicken to the point that it would skip under the doctor blade. When an impression was completed, apparent de-wetting of the ink components, at the nip areas of the press, was apparent. Similar results were observed at the anilox region on the flexography press, but those results are still being analyzed. This shear thickening may explain the apparent "back trapping" observed in the image of the 80% tint at 100 LPI. The transfer efficiency for this image was calculated to be about 7% - far too inefficient to be useful. High dynamic viscosity and extensive shear thickening combine to keep most of the ink on the cylinder. If a significant amount of ink is transferred, the shear thickening caused ink to break away from the substrate, similar to back trapping in offset lithography, and voids would appear in the conductive film. Smaller volumes of ink would transfer with the higher screens, but the film produced still contained void defects from low transfer efficiencies. We continue to experiment with conductive ink formulations, developed in our laboratory, which might overcome the problems observed with these silver-based systems.

References

1. Adams, David, et.al., (2003), "Charge Transfer on the Nanoscale: Current Status", J. Phys. Chem. B, 107, 6668-6697
2. Frenzel, L.E., (2005), "Tag It!" Electronic Design, 53:10, 43
3. Hara, Kohjiro and Arakawa, Hironori, Handbook of Photovoltaic Science and Engineering (Wiley (2003)), pg. 663
4. Hoeben, F.J.M., et. al., (2005) "About Supramolecular Assemblies of p-Conjugated Systems", Chem. Rev., 105, 1491-1546
5. Sayama, Kazuhiro, et.al., (2002), "Photochemical Properties of J Aggregates of Benzothiazole Merocyanine Dyes on a Nanostructured TiO_2 Film", J. Phys. Chem. B, 106, 1363-1371
6. Tani, Tadaaki, Photographic Sensitivity: Theory and Mechanisms, (Oxford 1995), pg. 111
7. Tatikolov, A.S., Ponterini, G. and Krasnaya, Zh.A., (2000) Aggregation of Cationic-Anionic and Related Polymethine Dyes, International Journal of Photoenergy, Vol 2, 125



Optimization of electrophotographic photoreceptors

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Abstract

The object of the work is to optimize the organic electrophotographic photoreceptor parameters in order to achieve a maximal magnitude of the development electric field that is the most important factor determining the quality of final image. Therewith most attention is concentrated on the investigation of the quantum yield of free charge photogeneration in dependence on electric field changing in maximal wide limits. The experimental photoinduced discharge curve (PIDC) has come to an agreement with the estimated optimized curve.

1. Introduction

At present in the majority of electrophotographic devices, organic photoreceptors in the dual layer configuration are used. They consist of the support, the charge-generation layer (CGL) and the charge-transport layer (CTL). The fundamental image-forming step in electrophotography is the creation of an electrostatic latent image on the surface of CTL. Latent image formation involves the photoinduced discharge of a corona-charged photoreceptor by an image-wise exposure. The exposure creates free charge carriers, a fraction of which is displaced to the photoreceptor surface. The surface charge is dissipated in the exposed regions and an electrostatic charge pattern is created that corresponds to the image that is to be reproduced. In digital electrophotography, the same technology is used, but the electrostatic latent image is created by sequentially exposing a large number of image elements {pixels), using an job file and exposing laser pulses.

The process of the free charge carrier generation in CGL is considered, based on the Onsager theory (Borsenberger, 1998). On the first stage of the process, light quantum is absorbed by the dye molecule with formation of a bound electron-hole pair with a quantum yield η_0 and a distance between electron and hole r_0. On the final stage, the pair of the bound charges dissociates into free charge carriers with the probability φ or recombines with the probability 1 - φ. The free charge photo-generation efficiency is expressed as $\eta = \eta_0 \times \varphi$. The calculation of η were performed using the formula [Frankevich, 2002]:

$$\eta = \eta_0 \cdot \exp\left[-\frac{e^2}{4\pi\varepsilon\varepsilon_0 kTr_0} \exp\left(-4\pi\varepsilon\varepsilon_0 F \frac{r_0^2}{e} \right) \right] \quad (1)$$

The formula approximates well the Onsager equation in terms of infinite series. Here, k - Boltzmann constant, $k = 1{,}38 \times 10^{-23}$ J/K; T - temperature, K; r_0, cm; F - electric field in the photoreceptor layer, V/cm, $F = V/l$, V - surface potential of photoreceptor, l - photoreceptor thickness, cm; ε - dielectric constant of photoreceptor; $\varepsilon_0 = 8{,}846 \times 10^{-14}$ F/cm.

Figure 1 demonstrates the electric field dependence of quantum yield at different values of r_0 calculated from equation 1. As seen, the free charge generation efficiency increases with the growth of electric field.

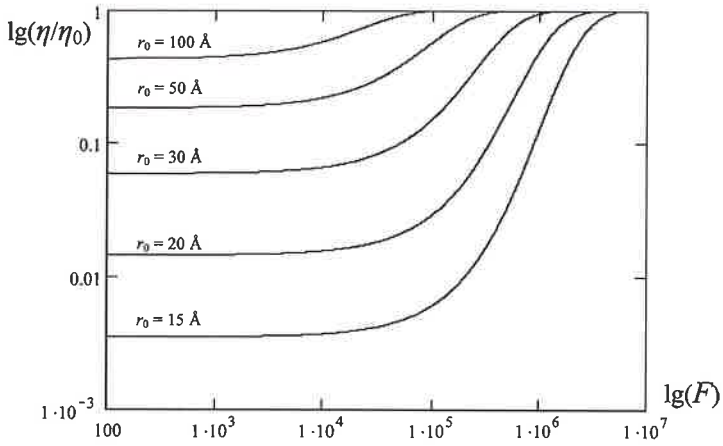


Figure 1: The probability of the electron-hole pair dissociation into free carriers in dependence on electric field. Plots are found from (1) using several values of r_0

It was found that the dependence of r_0 on wavelength of exposure light λ (nm) for CGL from Se and some organic photoconductors could be expressed by the empiric expression:

$$r_0 = A\exp(b\lambda) \tag{2}$$

A and b - experimental coefficients, $A = 3.677 \times 10^{-5}$ cm, $b = -9{,}895 \times 10^{-3}$ nm^{-1}.

One of the major parameters of digital electrophotographic process is the difference of normal components of the development electric field E_z above picture elements (pixels) and background ones. The greater is this difference, the more stable is process of development and the more qualitative is the final image on the hard carrier [Pai, 1975]. For the line image formation on the photoreceptor charged to V_0, the magnitude of E_z is given by expression [Scharfe, 1984]:

$$E_z = (f_0 + p(z)f_k)\frac{\Delta V}{2}, \tag{3}$$

Where

$$f_0 = \frac{1}{\frac{\varepsilon_d}{\varepsilon}l + d}, \tag{3a}$$

$$p(z) = \frac{\cosh[k\cdot(d-z)]}{\cosh(kd)}, \tag{3b}$$

$$f_k = \frac{1}{l\left(\frac{\varepsilon_d}{\varepsilon} + \frac{\tanh(kd)}{\tanh(kl)}\right)} \tag{3c}$$

Here, as shown in Figure 2, l - photoreceptor thickness, d - zone development thickness; ε_d - dielectric constant of developer; $k = 2\pi/s$; s - line width; z - coordinate normal to photoreceptor surface; V - residual potential. For latent electrostatic image (LEI), V_0 applies to lines, V - to blanks, electrostatic contrast $\Delta V = V_0 - V$. As $V_0 >> V$, it is valid to assume that $\Delta V = V_0$.

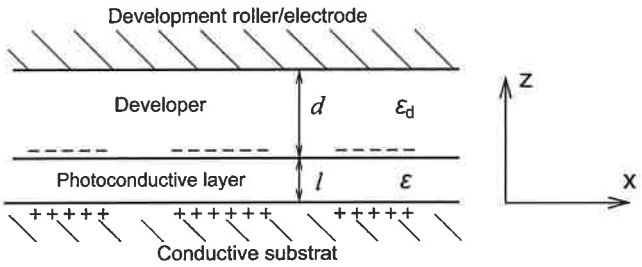


Figure 2: Slab model of the photoreceptor and developer system

In the above expression (3), it is ΔV that is of first importance. Electrostatic contrast is governed by many factors and primarily by photoreceptor charging potential, photoreceptor sensitivity and exposure used. With organic polymeric photoreceptors commonly in use today, the exposure time is much shorter than the transit time of photo-generated carriers through CTL, because of the low carrier mobility of the order of 10^{-6} cm^2/Vsec [Vannikov, 1994]. The transit time is of the order of a few msec at a field of 5×10^5 V/cm for a 25 μm thick CTL and becomes longer as the field decreases. In digital electrophotography, the exposure time for each spot is of the order 100 nsec or shorter. Therefore, the photoinduced discharge is limited by carrier transit time. On condition that all photo-generated carriers have achieved the photoreceptor surface, the electrostatic contrast for electrophotographical devices may be calculated by the equation:

$$\Delta V = \frac{A_\lambda \cdot l \cdot e \cdot \eta \cdot H \cdot \lambda}{\varepsilon\varepsilon_0 \cdot hc} \qquad (4)$$

Here A_λ - spectral absorption coefficient; $e = 1{,}6 \times 10^{-19}$, C, electron charge; H - exposure, J/cm^2; h - Planck's constant, $h = 6{,}63 \times 10^{-34}$ J×sec; c - velocity of light.

It is easy to check that a number of photons is in direct proportion to wavelength of light for fixed exposure. Notice also that only those magnitudes of ΔV are physically meaningful which are located in an interval from 0 to V_0 (V_0 is a photoreceptor charging potential). From above equations it is possible to obtain a final expression for the normal component of the development electric field:

$$E_z = \left[\frac{1}{\frac{\varepsilon_d}{\varepsilon} l + d} + \frac{\cosh[k(d-z)]}{\cosh(kd)} \cdot \frac{1}{l\left(\frac{\varepsilon_d}{\varepsilon} + \frac{\tanh(kd)}{\tanh(kl)} \right)} \right] \frac{A_\lambda l e \eta H \lambda}{2\varepsilon\varepsilon_0 hc} \qquad (5)$$

It should be emphasized that E_z is directly proportional to the electrostatic contrast value: $E_z \sim \Delta V$.

3. Results and discussion

Figures 3 - 6 demonstrate the E_z dependences on the most important parameters of photoreceptor calculated using equation 5 for the following values of parameters typical for the current electrophotographic devices provided that the parameter in question is not a variable quantity:

Photoreceptor thickness: $l = 5 \times 10^{-4}$ cm;
Development zone thickness: $d = 10^{-3}$ cm; $10^{-4} < d < 10^{-2}$ cm;
Photoreceptor dielectric constant: $\varepsilon = 2{,}5$;

Developer dielectric constant: $\varepsilon_d = 5$;
Charging potential: $V_0 = 700$ V;
Exposure: $H = 10^{-7}$ J/cm^2;
Exposing light wavelength: $\lambda = 450$ nm;

As seen in Figure 3, the normal components of the development electric field E_z has no extremum in dependence on photoreceptor thickness and resembles the electric field dependences of quantum yield in Figure 1. The similarity is not accidentally as V_0 appears in the equation 5 by way of photo-generation efficiency expressed by equation 1.

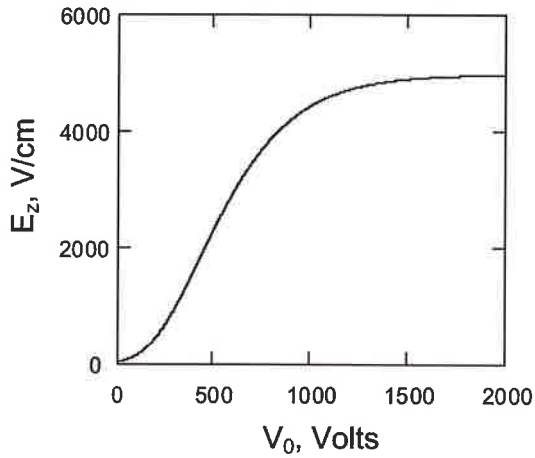


Figure 3: The normal component of development field dependence on surface potential of photoreceptor

Well-defined maximum of the E_z dependence on photoreceptor thickness, presented in Figure 4, is due to two competitive processes, namely, the ΔV increase (H = const, η = const at high F) and the η decrease with F (at low F) when photoreceptor thickness increases. The E_z dependence on wavelength of exposing light, given in Figure 5, characterizes the spectral sensitivity of photoreceptor. Here also there are two competitive processes: 1) a number of photons is directly proportional to λ (H = const) and increases when λ grows, 2) distance between electron and hole r_0 in the photo-generated pair, as mentioned above (equation 2), decreases with increasing λ resulting in the photo-generation efficiency decrease as follows from equation 1. Variable ε appears in equation 5 by complex way, in particularly, through photo-generation efficiency of free charge carriers expressed by equation 1. When ε increases, the expression in brackets of equation 5 also increases becoming asymptotic to some value, whereas ΔV tends to zero. Superposition of two factors produces the characteristic feature of the curve with a clearly defined maximum.

The extremal character of some parameters allows to assume that E_z has a maximal magnitude at some values of parameters.

The optimization of photoreceptor to obtain a maximal magnitude of E_z was carried out using a computer MATLAB program. The list of parameters to be optimized and their bound values are given below:

Photoreceptor thickness: $10^{-4} \le l \le 0{,}01$ cm;
Development zone thickness: $10^{-3} \le d \le 0{,}1$ cm; $10^{-4} < d < 10^{-2}$ cm;
Photoreceptor dielectric constant: $1 \le \varepsilon \le 15$;
Developer dielectric constant: $\varepsilon_d \ge 5$;
Charging potential: $0 \le V_0 \le 1000$ V;
Exposure: $H \ge 0$ J/cm^2;
Exposing light wavelength: $100 \le \lambda \le 1000$ nm;

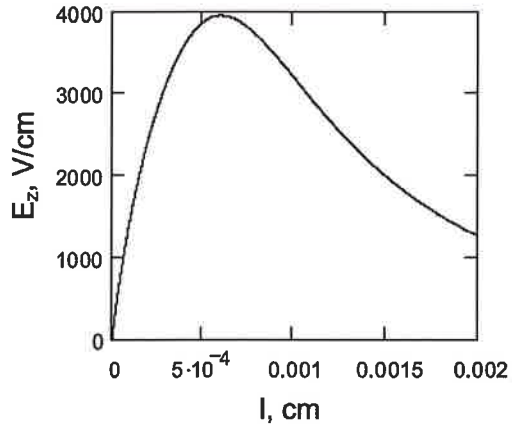


Figure 4: The normal component of development field in dependence on layer thickness

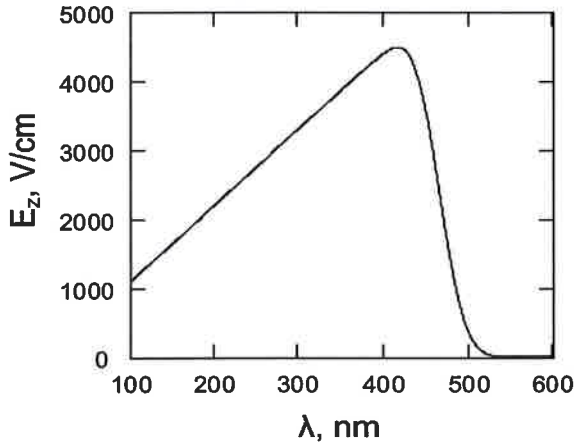


Figure 5: The normal component of development field dependence on wavelength

Line weight of 4×10^{-3} cm was selected because the great bulk of the up-to-date electrophotographic devices have resolution no less than 600 dpi that corresponds to linear dimensions of light spot of 40 μm.

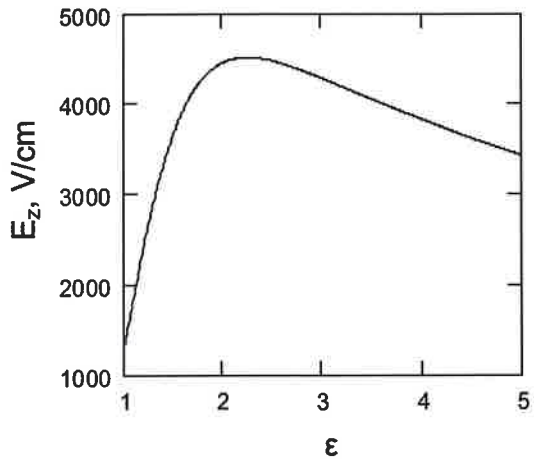


Figure 6: The dielectric constant dependence of normal component on development field

Optimization has given interesting results:

Photoreceptor thickness:	$l = 1{,}366 \times 10^{-4}$ cm;
Development zone thickness:	$d = 10^{-3}$ cm (threshold); $10^{-4} < d < 10^{-2}$ cm;
Photoreceptor dielectric constant:	$\varepsilon = 5{,}835$;
Developer dielectric constant:	$\varepsilon_d = 5$ (threshold);
Charging potential:	$V_0 = 1000$ V (threshold);
Exposure:	$H = 6{,}52 \times 10^{-5}$ J/cm^2;
Exposing light wavelength:	$\lambda = 545$ nm;

Maximal optimized value of development electric field amounts to $E_z = 7{,}43 \times 10^5$ V/cm. By comparison, if to use the given above parameter values typical for the up-to-date electrophotographic devices, then for $H = 6{,}52 \times 10^{-5}$ J/cm^2 from the equation (5) $E_z = 2{,}61 \times 10^5$ V/cm, three times less than the value obtained after optimization. From these data it was concluded that most up-to-date electrophotographic devices are operating in conditions different from optimal ones. Notice also the possibility to optimize other parameters an electrophotographic device, for example, to minimize an exposure or to maximize resolution. To do this, first of all it is necessary to determine the electric field dependence of the free charge carriers generation. The threshold values for some parameters have trivial reasons. For example, irrespective of the other parameters values, V_0 and d take maximal and minimal values, accordingly, as it automatically tends to increase E_z. The minimal value of ε_d determines maximal Coulomb energy of developer and LEI. The operating values of these parameters are determined by the characteristics of the materials used in the photoreceptor, e.g. their electric strength.

In order to test the validity of equation 5, the measurement of photoinduced discharge curve (PIDC) was carried out using the dual layer photoreceptor with given parameters. In Figure 7 is shown the automatic setup for measuring PIDC. The photoreceptor sample was charged by scorotron and then rapidly (during several milliseconds) transferred to the exposure and measurement area. The potential V was measured with a ring electrode. As seen in Figure 8, the results of the experiment is in excellent agreement with those calculated be equation 5. So, equation 5 adequately represents the processes in elctrophotographic photoreceptors and can be used for calculation of electrostatic contrast and optimization of a system photoreceptor-developer in digital devices.

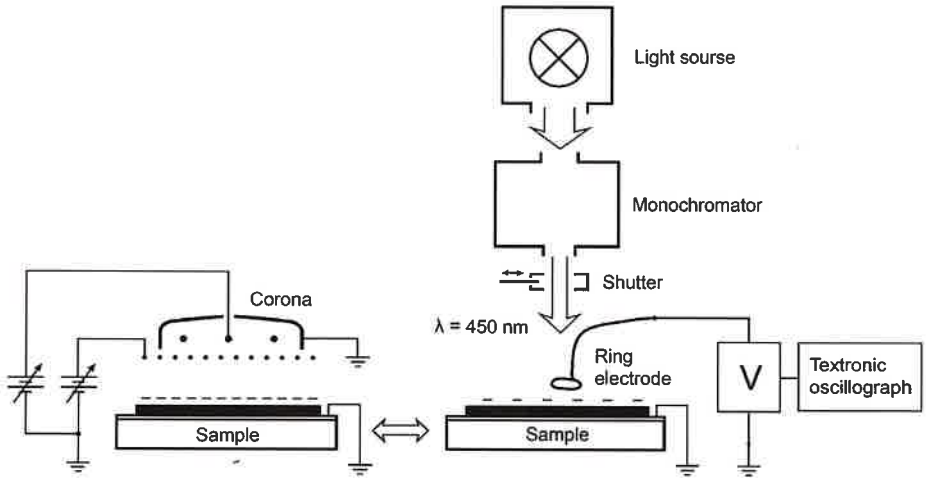


Figure 7: Experimental setup scheme

Thus, experimental photoinduced discharge curve obtained under optimized parameters are in reasonably good agreement with theoretical dependence of the photoreceptor surface potential on exposure. The results discussed above are valid for both analogue and digital electrophotographic devices.

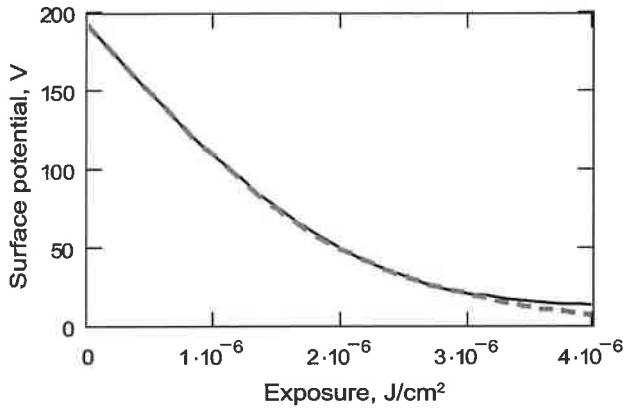


Figure 8: The experimental PICD (solid line) and theoretical dependence (gray dash)

4. Conclusions

So, a process of the free charge carrier generation in the photoreceptor photogeneration layer was analyzed. The process governs operating characteristics of electrophotographic photoreceptor. On the base of performed analysis, the relation between development electric field and other parameters of photoreceptor was determined and optimization of photoreceptor operating characteristics was carried out for the purpose of obtaining the maximal magnitude of development electric field. The presented optimization can be carried out for any electrophotographic photoreceptor if the dependence of distance between electron and hole r_0 in electron-hole pair on wavelength of exposure light λ is known from experience.

References

1. Borsenberger P.M., Weiss D.S., (1998), Organic Photoreceptors for Xerography. N.Y. Marcel Dekker, 768 p
2. Frankevich E., Yusuke N., Akihiko F., Masanori O., and Katsumi Y., (2002), *Phys. Rev., v. B 66, p. 15203*
3. Pai D.M. and Enck R.C., *Phys. Rev.*, (1975), *v. B 12, p. 5168*
4. Scharfe M., (1984), *Electrophotography principles and optimization - Letchworth: Press, 200 p*
5. Vannikov A.V., Grishina A.D., Novikov S.V., (1994), *Russian Chemical Reviews, v. 63, p. 103*



Dynamic interaction between toner and paper in the nip of an electrophotographic printer

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1. Introduction

Fusing is the last step in electrophotographic printing. There are, among others, two main fusing techniques: the hot roll and the Infra Red fusing. In the hot roll technique, the toner covering the paper is heated and pressed between two rollers. The IR fusing consists of radiant lamp at 5 cm far from the print surface. In both technological solutions, a long term fixation is ensured. Most of the optical properties of the printed result depend on the spreading capability of the toners.

The dynamic interactions between the paper and the toner at this stage are of main importance. In order to study the spatial repartition of the toner, information on the temperature field is needed. Indeed, the rheological behaviour of the toner is temperature dependant. Moreover, the pressure (in the case of the hot roll fusing) between the two rollers can not be neglected.

Consequently, the paper topography has also to be considered. The surface profile and surface porosity will affect both the thermal field and the toner spreading.

First, the toner is heated over its glass transition, and then toner particles agglomerate each other. The following stage is the spreading of toner. Finally, the toner layer solidifies and some penetration could occur.

Fusing and binding of the toner onto the paper are schematically represented in Figure 1:

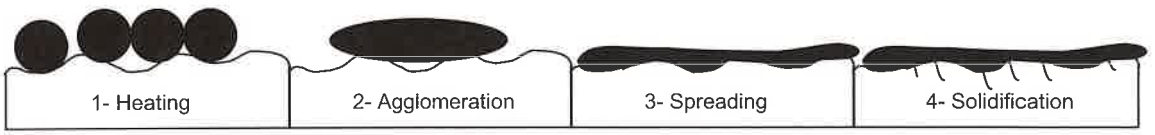


Figure 1: Fusing and fixing of the toner on the paper

The aim of this work is to study the fusing step (especially the hot roll fusing) and the paper/toner interaction occurring at this stage. We have developed an analytical model of the temperature field in the nip which enables to provide information on the paper influence: its heat conductivity and heat capacity. Moreover, the surface porosity is also considered.

We have focused our interest on the dynamic aspect of the paper/toner interaction. Hence, we introduce a new method to collect information on the agglomeration of the toner particles in network. The obtained results are correlated to the spreading tendency of toners. In the last part of the paper, new experimental techniques and especially the X-ray microtomography, are carried out in order to make a 3D characterization of the solid toner layer on the paper surface.

2. Fusing step in electrophotography

The main element of an electrophotographic printer is the central drum, also called image carrier. The five main steps of the system take place around this drum, namely: imaging, charging and exposure, inking or development toner transfer, fixing and finally cleaning.

There are two types of inks intensively used in electrophotographic printing: dry toner and liquid toner. Thanks to an electric potential difference, the toner particles are transferred without contact onto the photoconductor. The small toner particles (around 8 μm in diameter) are electrically charged in order to be fixed onto the photoconducting surface, thus building the image.

Four-color electrophotography can be achieved in two different ways: the multiple pass technique uses a single photoconductor drum: colors are transferred one after each other. Once the 4 print cycles are completed, the sheet is released and conveyed to the fusing station. In the single pass method there is one photoconductor for each color. The fusing step always occurs when the four colors have been transferred.

The type of technology affects the fusing step. It must be dedicated to each kind of toner , and to each kind of paper.

A hot roll unit is schematically represented in Figure 2. The table I gives the typical thickness of constituting elements.

Table I: Thickness of the fusing elements [μm]

Layer	Thickness [μm]
Heat roller core	1500
Coating layer	30
Toner	14
Paper	100
Elastic layer	100

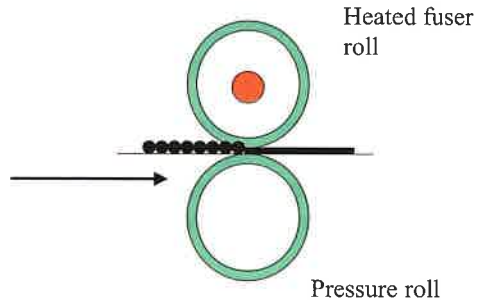


Figure 2: Scheme of the fusing system

In a classical fusing system, the paper covered with the toner is pressed between two rollers (Figure 2). The heater is a hollow aluminum roller coated with a fluoride resin; the pressure roller is coated with an elastomer, commonly silicon rubber. A radiant heater is located in the center of the heater roller. The heater temperature range between 150 and 220°C, depending on the nip length and on the machine speed.

3. Heat transfer through the nip

Rheology and surface tension of the melt toner are strongly related to the temperature in the nip. That is the reason why the knowledge of the temperature field is of main importance.

The heat equation (Eq.1) has to be solved through this system:

$$\rho C \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}(\lambda \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(\lambda \frac{\partial T}{\partial y}) + \frac{\partial}{\partial z}(\lambda \frac{\partial T}{\partial z}) \quad (1)$$

where: T, λ, C and ρ, represent the temperature, the thermal conductivity [W/(m.K)], the heat capacity [MJ/(m^3.K)], and the mass density [kg/m^3], respectively.

Numerical resolution of Eq.1 has been performed under certain hypotheses. Mitsuya (1992) and Leroy (2002) chose more simple conditions. Indeed, they did not consider the two air interfaces, and simplified the Eq.1 in a one-dimension problem, in the thickness direction (z direction). Takenouchi (1998) used an Alternating Direction Implicit method in the case exhibited in Figure 2. To solve this equation, we used a classical methodology (for more detail see [vernhes, 2006]). We developed an approach to simulate the temperature field in the nip based on an analytical resolution of Eq.1. We consider the system as a one-dimension problem. Thus, Eq.1 has to be solved for every layer involved in the studied geometry. For example, the air contained in the toner structure could be taken into account.

A schematic representation of the nip is given by Takenouchi (1998) on Figure 3:

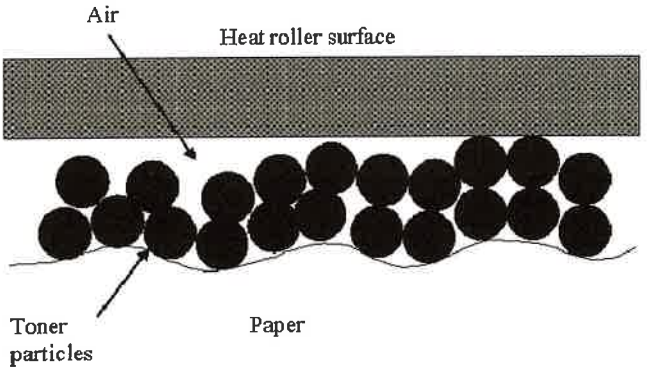


Figure 3: Schematic representation of interfaces in the nip region [from Takenouchi, 1998]

We have plotted in Figure 4 the evolution of temperature of the three interfaces, in a system where we considered the roller, a first air layer, the toner pile, a second air resistance and the paper. Numerical data of the three physical parameters taken into account for the calculation are given in table II. The heater temperature is fixed at 180°C. We have also compared the values given by our analytical model to Takenouchi results (1998) for the paper surface temperature. Our result fits both numerical and experimental data from Takenouchi.

Table II: Thickness and thermal properties of the considered layers [Takenouchi, 1998]

Layer number	Thickness in µm	Heat Conductivity (W/m°C)	Heat capacity (MJ/m^3°C)
1-Air	5	0.03	0.0012
2-Toner	10	0.151	1.51
3-Intermediate air layer	4	0.03	0.0012
4-Paper	100	0.08	1.16

This model offers different possibilities. For example, it is possible to plot the surface temperature interface in function of the paper surface porosity. As a matter of fact the quantity of air present at the paper surface is directly proportional to the paper roughness. We choose 180°C for the hot roll temperature and a dwell time of 40 ms (as illustrated on Figure 4).

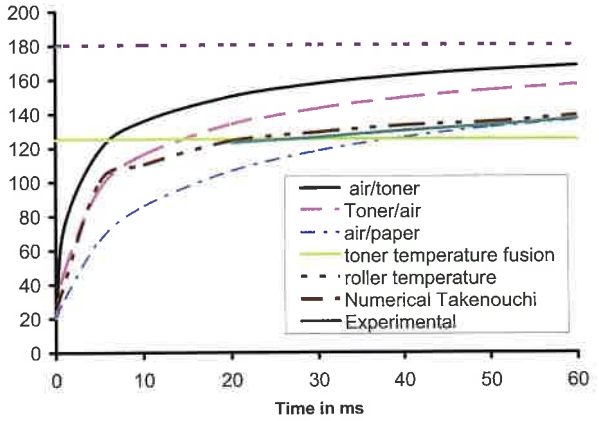


Figure 4: Interface temperature evolution and comparison to the literature results

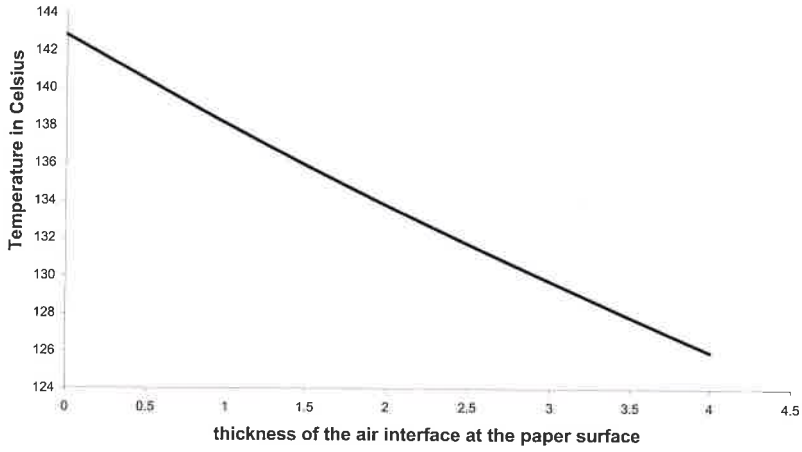


Figure 5: Paper surface temperature vs. the paper surface porosity (expressed as a thickness in μm)

It is also possible to provide paper surface temperature depending on paper thermal conductivity and paper heat capacity (Figure 6).

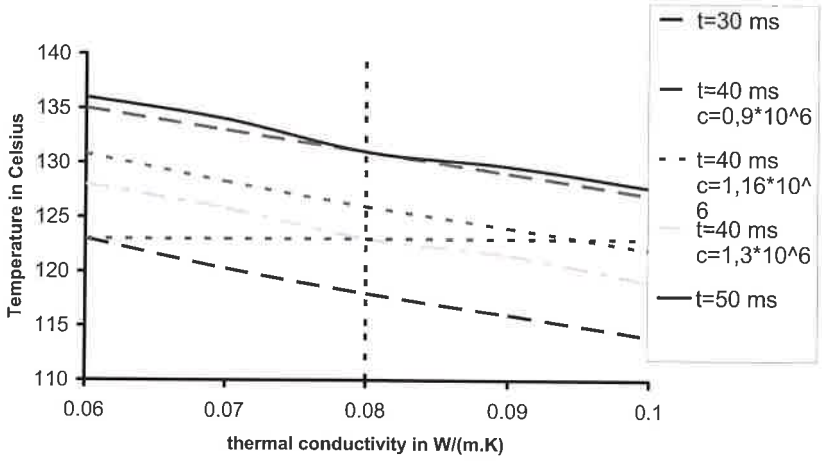


Figure 6: Surface paper temperature Versus paper thermal conductivity, for different heat capacities

An important parameter is the phase change of the toner, which is due to the glass transition. Hence, there are different ways to reach the glass transition temperature of the toner. For example, a paper surface temperature of 123° could be obtained as follow:

- A low thermal conductivity (0.06 W/(mK)) with an intermediate heat capacity (1.16×10^6 MJ/m^3°C) and a short dwell time (30 ms).
- A high thermal conductivity (0.9 W/(mK)) with an intermediate heat capacity (1.16×10^6 MJ/m^3°C) and an intermediate dwell time (40 ms).
- An intermediate heat conductivity (0.08 W/(mK)) with a high thermal capacity (1.3×10^6 MJ/m^3°C) and an intermediate dwell time (40 ms).

It has been thought [Simula, 1998], that requirements for the paper thermal properties are high thermal conductivity and low heat capacity. Under these hypotheses, the paper could reach a high temperature, and cool down rapidly. But as there is no penetration of the toner [Wang, 2000], there is no need to heat up the paper, the main factor consists in the paper/toner interface. The temperature at this interface decreases dramatically when the paper conductivity drops, as shown in Figure 6.

4. Spreading and agglomeration of toner particles: a dynamical approach

Most of the commercial toner particles have a characteristic size of 10 µm. They are composed of binder resins, colorants and additives. The agglomeration and the coalescence of the toner particles in the nip are due to temperature and pressure.

Literatures on toner behaviour at high temperature are quite seldom. There are few references on the kinetics and the thermodynamics of this process [Lee, 1975] [Sipi, 2002].

The study of spreading of individual toner has been recently performed [Pettersson, 2005]. A method has been developed to study in situ the spreading behaviour of individual toner particle during heating. The aim was to simulate the fusing process occurring in electrophotographic printing of paper (for both IR fusing and hot roll fusing).

The theories of interface provide models in case of perfect sphere (like water drop). The toner particles were transformed to perfect spheres by a temperature pre-treatment. Then, they were applied on different substrates in order to measure and calculate the corresponding contact angle.

In fact from the spreading factor A/A_0 (where A is the projected area of the particle and the index $_0$ refer to the initial state) it is possible to determine the contact angle θ. For the spherical cap we have the equations 2 and 3:

- If θ<90°: $$\frac{A}{A_0} = \left(\frac{4\sin^3\theta}{2-3\cos\theta+\cos^3\theta}\right)^{2/3} \quad (2)$$
- If θ>90°: $$\frac{A}{A_0} = \left(\frac{4}{2-3\cos\theta+\cos^3\theta}\right)^{2/3} \quad (3)$$

where θ is the experimental contact angle.

From the final equilibrium state of the toner particle θ_∞ and the surface tension δ_{sl} the thermodynamic work of adhesion can be calculated thanks to the Dupré equation:

$$Wa = (1+\cos\theta_\infty)\gamma_{sl} \quad (4)$$

The Figure 7 summarized the parameters introduced in the Equations 2, 3 and 4.

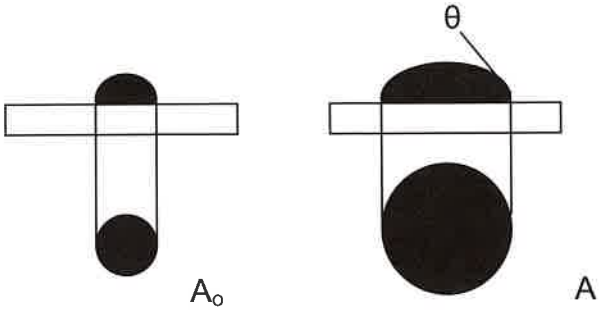


Figure 7: Schematic representation of the considered geometry

Pettersson [2004 and 2005] demonstrated that the spreading factor of 4 different toners at high temperature is related to the surface tension of the substrate. This spreading factor can take values from 1.5 to 8 depending on the toner and on the substrate. Moreover the rate of heating does not play a crucial role in the final state.

Our goal is to study the spreading and the behaviour of the complete network in realistic condition. This includes the spreading factor of the complete structure. Therefore, we will introduce a new way to characterize toner agglomeration, following the evolution of the circularity.

Experimental:

The evolution of toner network was monitored in situ (see Figure 8). The toner samples were dispersed on a clean cover glass. The quantity of toners varies according to the kind of network to be studied. Samples were putt on the heating cell (Linkam THMS 600). For the experiment a rate of 20° per minute was chosen. Nevertheless, the temperature on the glass is only proportional to the frame temperature. Moreover, there exists a delay before reaching equilibrium. A microscope equipped with a 20x lens was used to see the spreading from above. On top of the microscope, we used a CCD (Nikon 2400) colour camera linked to acquisition software (Optimas 6.5). The image analysis itself has been performed with the software imageJ. Images were binarised using an appropriate threshold.

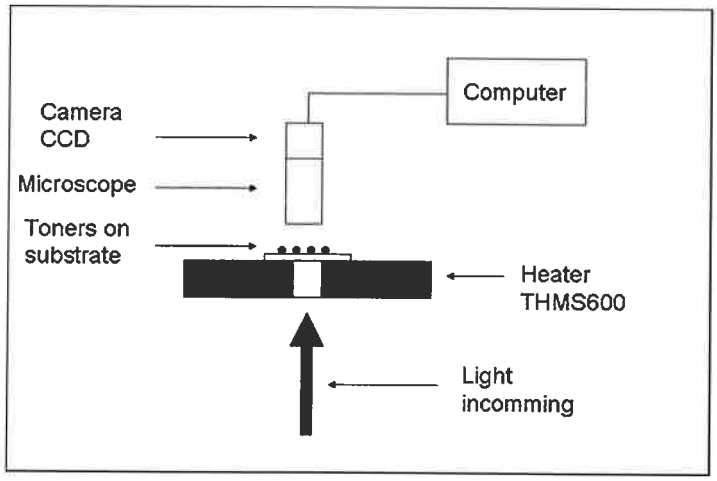


Figure 8: Experimental setup

Four different types of toners have been chosen: Cyan, Magenta, yellow and Black from Xerox printer.

In order to characterize the particles, we have measured the size distribution considering them as discs. (The Figure 9 shows results for the yellow and magenta toner particles):

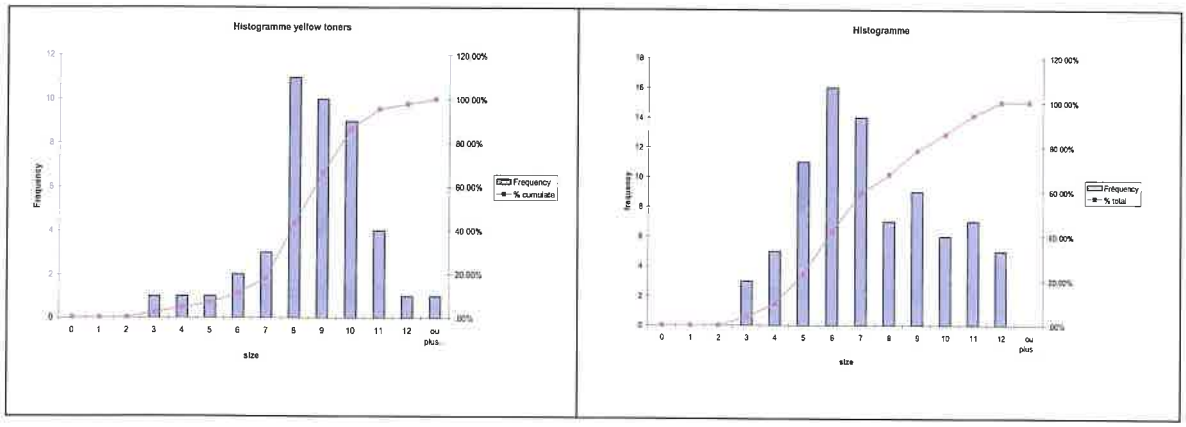


Figure 9: Size distribution of black and yellow toners

The mean diameter is 8.1 µm (the standard deviation is 1.9 µm) for yellow particles and 6.8 µm (the standard deviation is 2.3 µm) respectively for black particles.

Results and discussions:

The spreading of yellow toner particles has been studied according to the experimental method described above. We have chosen a light initial density, around 4% (where the density is defined as: surface of toner particles divided by the total surface). Beside we have focused our attention on various areas. First the whole network has been considered (Figure 10). Then a single particle (Figure 11) and a small network of three particles (Figure 13) were studied. Results are exhibited in Figure 12.

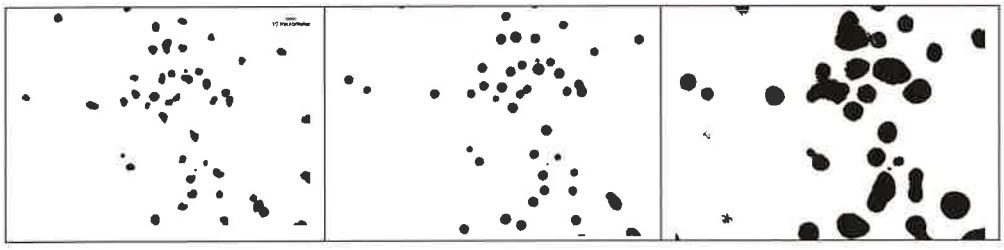


Figure 10: Projected area of light yellow toners network at three temperature (20, 170 and 220° C)

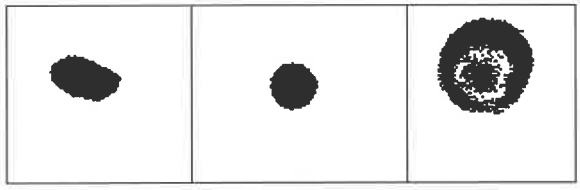


Figure11: Spreading of individual toner yellow particle

Compared to pre treated individual toners, spreading curves are rougher. However the general behaviour is conserved. As a matter of fact there is a sharp increase for each curve between 200 and 250°C.

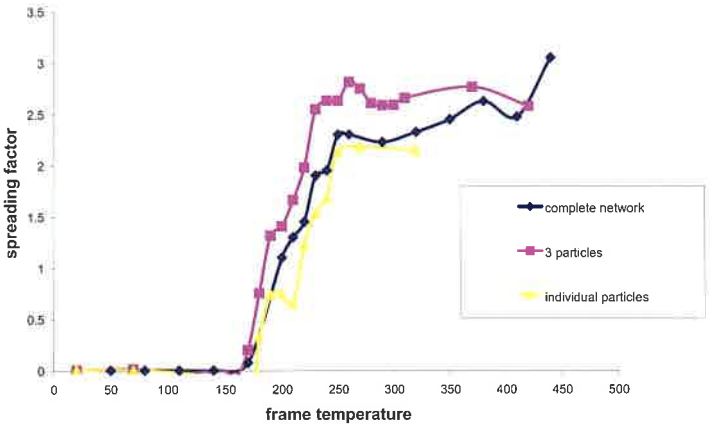


Figure 12: Spreading of various structures Vs the temperature of the metallic frame

The study of the agglomeration of toner particles is tricky. From the Figures 10 and 11, there are obviously different steps occurring during toner melting. First the particles which have random shapes

are getting more and more spherical without spreading. Then, thanks to the temperature increase, they begin to spread. In the case of close network (id: high density of particles), the growing of the independent toner particles can be obstructed by their neighbours. This agglomeration is followed by a rearrangement of the agglomerates. Eventually the system reaches equilibrium. This phenomenon is exhibited in Figure 13, on only three particles:

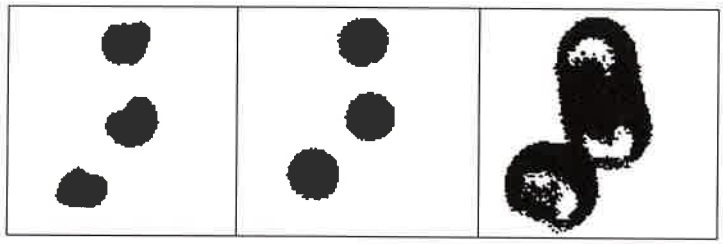


Figure 13: Binarised pictures of toners particles agglomeration (the temperature of the metallic frame are respectively, 20°, 170° and 220° degrees Celsius)

Initially, we have studied the evolution of the area of the projected surface of the toners (either individually or in network). However it does not give any information on the rearrangement of the system. Therefore, we followed the variation of the average circularity of the particles constituting the system. The circularity c, is defined in Eq. 10:

$$c = \frac{4 \times \pi}{a \times p^2} \tag{10}$$

a and p represent the projected area of the object and the projected perimeter of the object, respectively.

Under this definition a perfect circle has a circularity of 1, and a straight line is 0.

We analysed networks with various initial density.

The same network of yellow particles has been treated in order to get the average circularity evolution of the toners (Figure 14). The initial toner's density was 4% and it increases up to 16%.

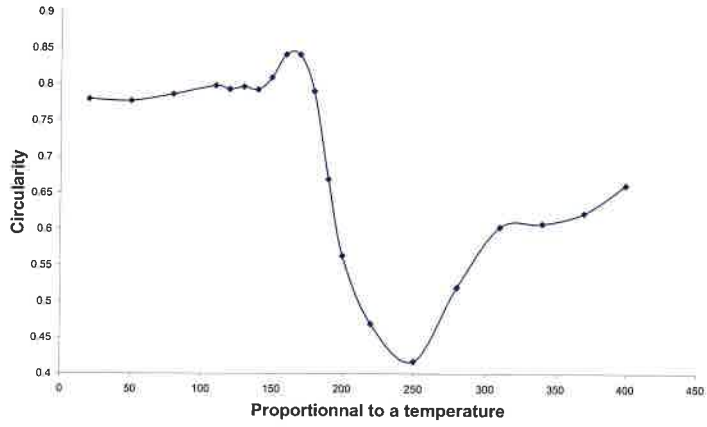


Figure 14: Average particle circularity evolution function of temperature of the metallic frame

From the Figure 14 the three steps (rearrangement of the single toner, agglomeration, and rearrangement of the agglomerate) are clearly observed. Under 150°C, the particles are isolated from the others and see their shape getting more circular. Between 150° and 250°C, there is a dramatic

decrease of the average circularity, due to the agglomeration of the toner particles. Finally the agglomerates spread and are barely transformed into spheres.

An other interesting possibility is to follow on the same scale, the spreading of the structure (that is to say: the increase of the projected area of the particles) and the agglomeration of the toner particles (the circularity evolution):

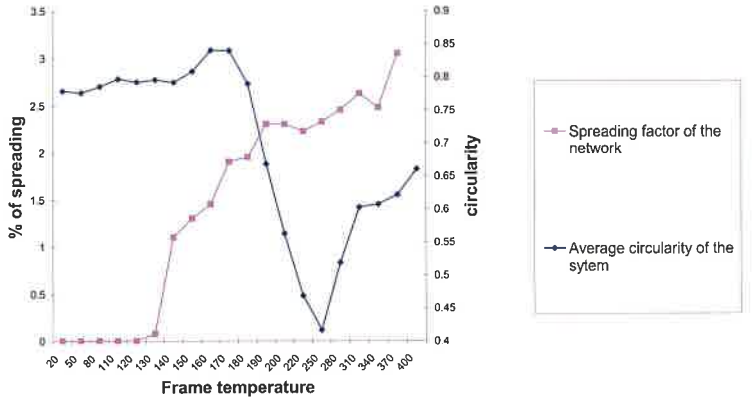


Figure 15: Spreading and mean circularity evolution of low density yellow particle network Vs the temperature

There is a shift between the spreading and the circularity temperature dependency. The huge decrease of the average circularity occurs when the spreading of the structure reaches a plateau (around 180°).

The same test has been performed with a medium initial density (21%) and a high initial density (41%). (Respectively in Figure 16 and 17)

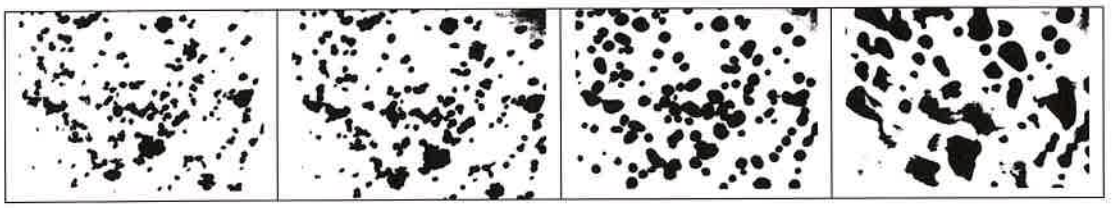


Figure 16: Medium density of magenta toners, spreading at various temperatures (20, 110, 220, 350°C)

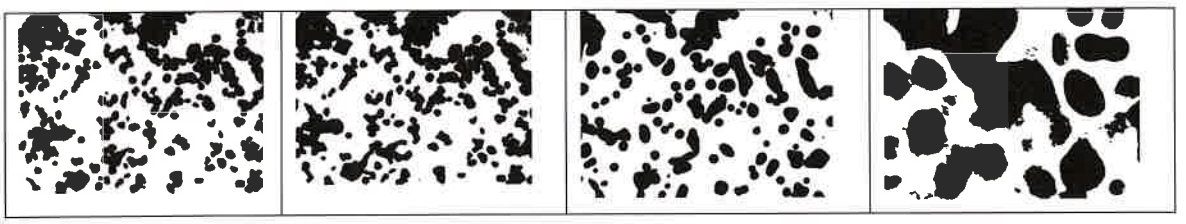


Figure 17: Projected area of packed black toners network at different temperatures (70, 120, 180 and 320°C)

In the case of the medium density there is only two phases. (Figure 18)

From the initial state, there is a small increase of the mean circularity due to the isolated particles. Then, there is a decrease of the average circularity when the percolation is reached.

The same methodology is getting complicated to use for higher density (Figure 17 and Figure 19). The curve is much noisier and the number of independent particles considered is reduced.

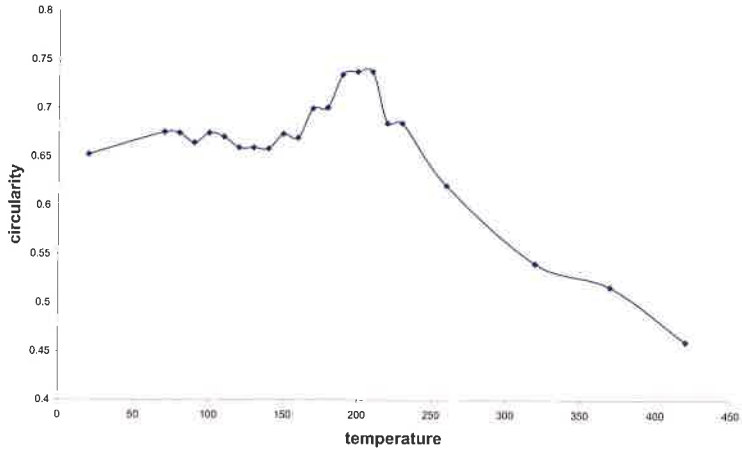


Figure 18: Circularity evolution of a medium toner network Vs the temperature of the metallic frame

It is relevant to compare the spreaded toner particles obtained on the glass to the real printed paper. In the case of half tone printing it is relevant to compare the effective structure of the solid toners structures on the paper to the networks obtained on the glass.

We characterised surface properties of real print with a profilometer (Altisurf apparatus). The system consists of a white light source, lens, spectrophotometer, a signal processing system, together with a motorized stage and appropriate image analysis software (Altimap expert). The resolution is below the micron (see Figure 21). Samples analysed were chosen among those tested in microtomography (see chapter 4).

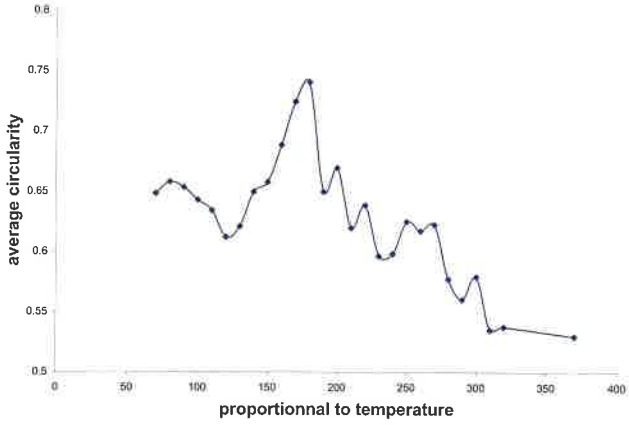


Figure 19: Mean circularity of a packed network of black particles versus the frame temperature

From the raw images it is not possible to extract relevant information. Some data treatments need first to be applied. The following methodology has been applied for the entire sample considered in this study. The surface analysed was fixed at 2 mm x 2 mm. We applied a central rectification. This operation ensures a good flatness of the surface. To maximise the contrast, a threshold is done. To calculate the standard parameters, a refilling of the non measured points is needed. The last operation consists in a 3D Gaussian spatial filtering.

From Figure 21, we can assess that final networks we analysed glasses are close to the real toners distribution on real cellulosic material.

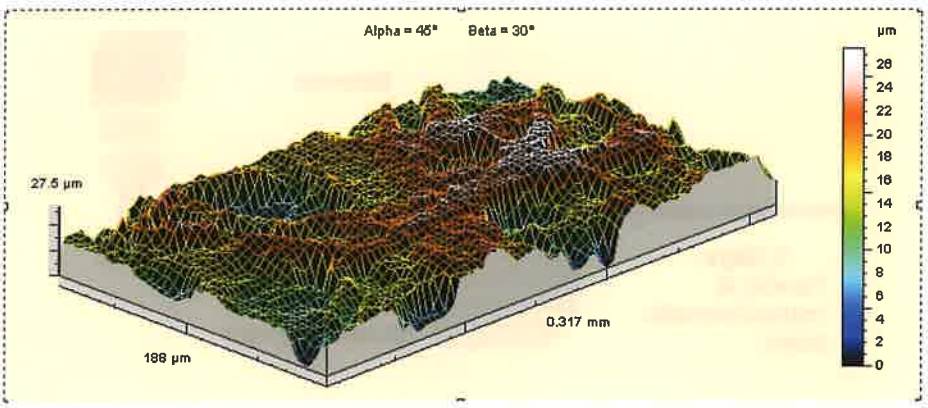


Figure 20: solidified toner network on paper corresponding to a light half toning [Image from Altisurf]

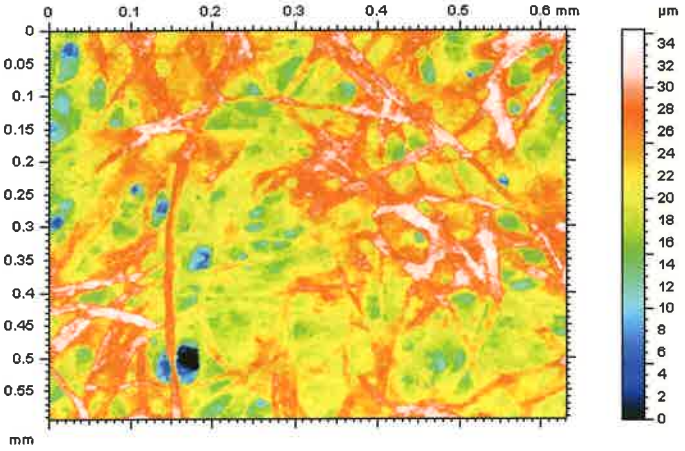


Figure 21: Paper printed sample analysed using altisurf

5. Solidification of the toner

The paper is a complex media. It is composed of cellulose fibers, fillers and air. Besides, it is known that the paper structure and its surface affect the printability. In order to characterize the print surface and the paper structure in a non destructive way, the X-ray microtomography is chosen. Hence, we may relate surface properties and information to the 3D structure. Thus, the shape of the toner dots and their interaction with the paper are shown.

A comparison between two different paper qualities is presented. We chose two different qualities of electrophotographics papers (Q+ and Q-). Those paper are common office papers, Q+ is supposed to have a better quality than Q-).

Microtomography presentation: Imaging technique

From the profilometry measurements, we access to the superficial topography of the toner layers (or solidificated toner dots). However, the paper has a 3D structure inducing complex mechanical interactions at the paper/toner interface. X-Ray Synchrotron Radiation microtomography has been successfully applied to paper samples in phase contrast [Samuelsen, 2001] or in absorption mode [Reverdy, 2001]. Compared to classical analysis tools, this technique allows visualising the paper sample structure in a non destructive and non invasive way [Baruchel, 2000]. All the data presented in this work have been acquired at the ESRF (European Synchrotron Radiation Facility). Figure 22 represents a scheme of the experimental set up installed on ID19.

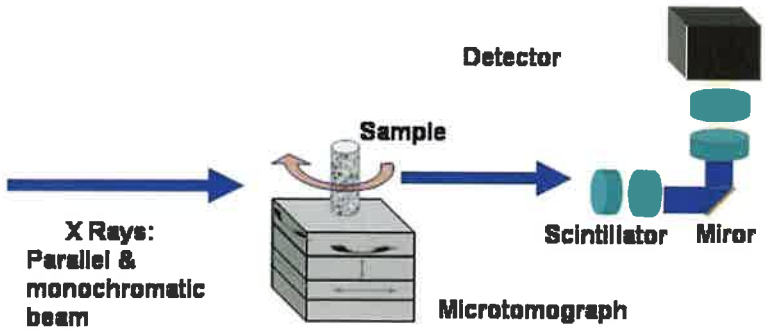


Figure 21: Scheme of the experimental microtomograph set up

A parallel and monochromatic beam (20.5 keV) irradiates a sample, installed on a rotation stage. The transmitted beam is recorded with a CCD camera developed at ESRF. This detector plays a crucial role coupled with the optics; indeed, it defines the pixel size and the field of view. According to paper constituent sizes, a pixel size of 0.7 microns have been chosen. It leads to a field of view of 1.4 mm * 1.4 mm. During data acquisitions, about 1500 radiographs are recorded between 0 and 180 degrees. A filtered back projection algorithm is applied to radiographs in order to rebuild the 3D structure. Figures 25 to 30 illustrate the obtained results on paper samples. Coupled with image analysis tools dedicated to paper samples, this technique allows a quantification of the 3D paper structure [Rolland, 2005].

Compared to the other microscopic techniques, there are two main advantages:

- There is no risk of any kind of contamination of the sample due to the manipulation or to the cut (for example in a case of a cross section);
- The other important issue is to avoid the perspective problem. It is possible to work either in 2D or in 3D.

The sample preparation is a crucial step. The paper sample is placed on a capillary that is fixed to the rotation stage. A post-it comes to avoid glue penetration into the sample. The paper sample is fixed thanks to an adhesive. Hence a light curvature or tilt of the paper cannot be avoided. Concerning the view in plan-section, the analysis of the data is complicated; especially if quantitative analysis is needed (see Figure 22 and Figure 23).

Paper samples

Half-tone areas have been printed on two different papers (Q- and Q-). The coverage area varies from zero to 100%. Then samples of about (1.4 mm x 1.4 mm x paper thickness) were extracted. X-Ray Synchrotron Radiation microtomography was used to visualise these samples. We can observe the four main phases of the samples (figure 23): the inked part, the fibres, the fillers and the pores.



Figure 22: Cross cut of a solid(on Q+)

3D -view of those samples can also be provided (Figure 25).
We first focus on cross-sections obtained from the 3D volumes close to the interface paper/toner.



Figure 23:
View from above of a solid (on Q+)



Figure 24:
virgin paper (Q-)



Figure 25:
3D view of the paper Q+

From all the pictures constituting the Figure 27, it is possible to discriminate the different phases of the paper: the fibers, the fillers (in white) and the air. For example, some fibers have their lumen completely open. The toner film is located on the upper part of the cross section. As explained previously, the developed segmentation permits to discriminate the ink from the paper. On Figure 26_a the toner layer is homogenous, and its thickness is even along the sample. On Figure 28_b, as expected the layer is thinner and part of the paper is toner free. However, the layer still seems to be homogeneous. There is no grey scale variation and the medium is continuous. The typical spherical shape is observable. We can also notice the shape of the edge of toner film, which is smooth. For 17% of haltoning, the ink parts are rare on the paper. However, in this case, the edges are sharp, and the medium is not homogeneous anymore.

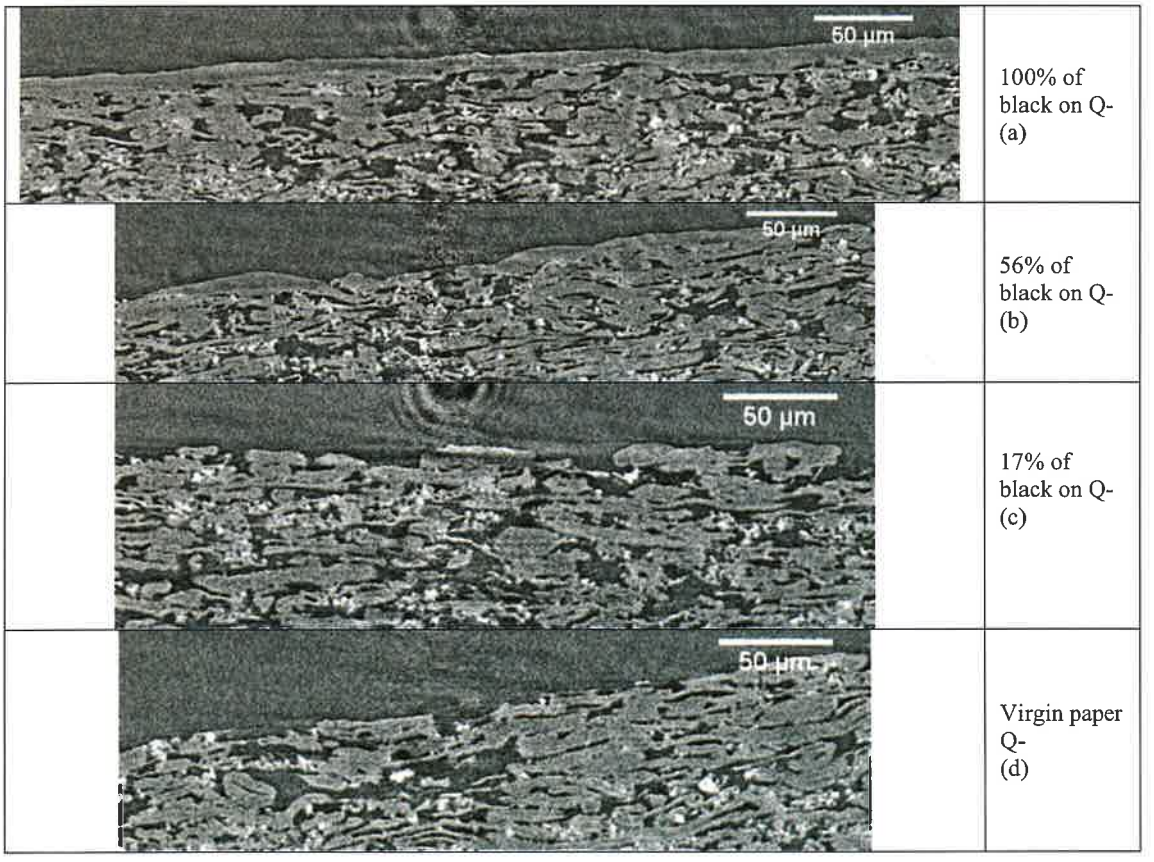


Figure 26: Cross section in the thickness direction of the paper Q-, printed with 4 different halftoning of black toner (0, 17%, 56% and 100%)

The visual exam confirms the results obtained by profilometry. Indeed the toner surface (interface toner-air), is much more rough for a 56% of halftoning than for the sample with 100% of covering (see Figure 28). Besides, as expected, we do not see any penetration of the toner into the fibrous structure.

Relevant information on the levelling and the film formation of the film may be deduced. The ink layers have always been considered as homogeneous and continue. However, even in the toner layer,we can notice pores, as shown in Figure 29. We can remark that the borders of the pores located in the ink layer are well defined: the pores are closed and no blur appears along the edges. We may therefore consider that no swelling occurred during data acquisition which could have modified the paper structure as mentioned in Rolland 2005.

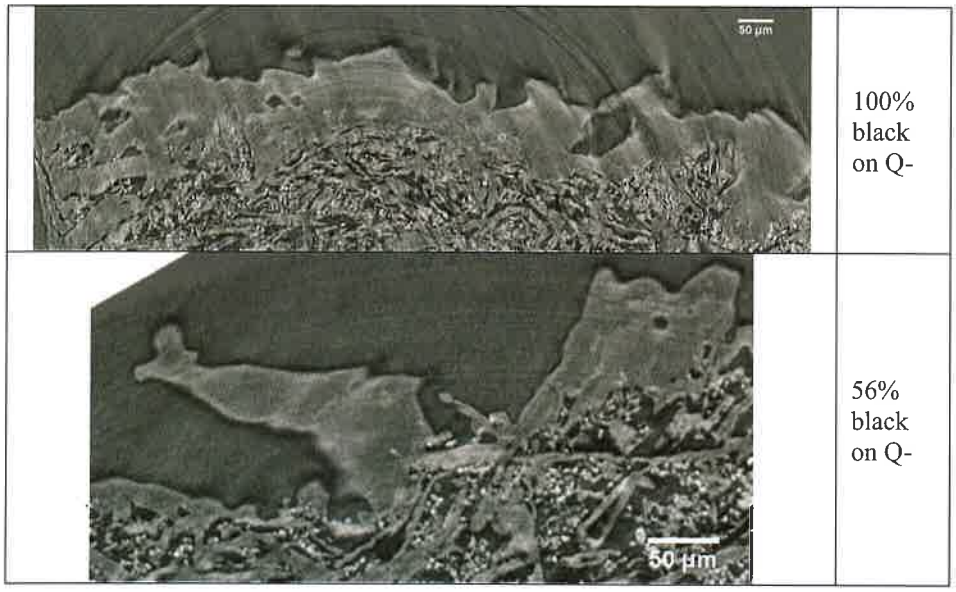


Figure 28: In-plan section of the paper/toner interface (paper Q-, halftoning of respectively 100% and 56%)

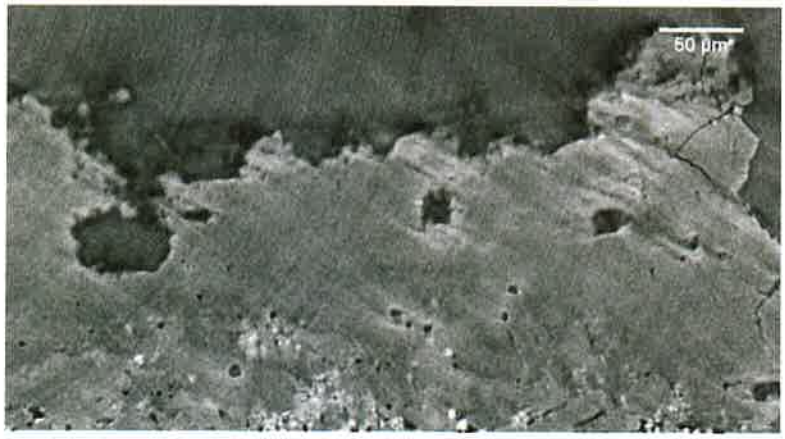


Figure 29: Ink layer on paper Q-

We may also observe that there are two types of porosity: the effective porosity which refers to the fraction of the total volume in which fluid flow may effectively take place and the non connected cavities (also called closed porosity).

The effective porosity is concentrated close to the interfaces, which is connected to the air and to fiber network. On the toner/air interface, different hypotheses may explain this porosity. A delamination of

the upper part of the layer due to the action of the roller in the nip could cause a destructuration. The roughness of the hot roller itself could be responsible for this effective porosity.

There is also a closed porosity inside the layered structure. Those pores are smaller that those close to the interface. During the formation of the toner film, part of the air due to the porosity of the toner pile, is captured in the structure. This phenomenon seems not to depend on the paper quality. Indeed, both Q- and Q+ papers reveal air cavity on their ink layer.

Nevertheless, those two types of porosity are low. We can estimate it around 5%.This internal porosity of the toner layer is worth to be studied for many reasons. First, the toner layer begins to be used as a barrier in packaging applications. A barrier needs to avoid any kind of particles migration into the structure especially in the food or cosmetic industry. Even if those porosities are not connected, the pores, embrittles the structure.

Furthermore, the recent developments of research on the electronic printing have made progress [Blayo, 2005]: it seems realistic to think that in a close future the electronic printing could be used with electrophotography. In this specificity case, the homogeneity of the layer is the key parameter to avoid interferences decreasing the quality of such media.

6. Conclusions

The fusing step is the last step of an electrophotographic print. Most of the optical and adhesive properties are related to this stage. The interaction of the toner on the paper depends on many parameters. The toner fixation process was divided in 4 main steps: heating, spreading, agglomeration and solidification.

Two methods for estimating the thermal field in the nip of an electrophotographic system device were compared. Our new approach based on an analytical method to solve the heat equation provides reasonable results in comparison to the existing numerical solutions and experimental data. But this method introduces interesting modeling possibility. Hence, it was possible to relate the temperature reach in the nip at the different interface considered to the paper properties (heat conductivity and capacity, roughness and thickness).

We correlated this temperature to the coalescence and agglomeration of toners particles in the nip, by following the toner network spreading.

A microtomographic technique was used on print sample. The main result of this experiment was the visualisation of two types of porosities: a close and an effective one. Generally speaking, this new technique is really promising, to get a better understanding of the paper/toner interaction at the scale of the micron. The next step would be to separate the four different phases of the samples analysed that are the pores, the fillers, the fibers and the ink layer to get quantitative measurements.

Acknowledgments

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References

1. Baruchel J, Buffière J-Y, Maire E., Merle P. and Peix G., 2000, X-Ray Tomography in Material Science, Paris: Hermes
2. Blayo A., Pineaux B., 2005, Printing Processes and their Potential for RFID Printing in EUSAI conference Grenoble
3. Duke Charles, Noolandi, Jaan. Thieret, Tracy, 2002, The surface science of xerography, Surface Science, Vol 500. pp 1005-1023
4. Holmstad R., 2004, Methods for paper structure characterisation by means of image analysis, NTNU: Trondheim. p. 178
5. Hwang, S. S., 2000, Toner penetration into paper at fusing, Journal of Imaging Science and Technology, Vol. 44, no. 1, pp. 26-30
6. Leroy Laurence, 2002, Adhesion en electrophotographie, PhD INPG thesis
7. Mitsuya, Teruaki. Kumasaka, Takao, 1992, Heat transfer and toner melting in an electrophographic fuser system, Journal of imaging science and technology, Vol. 46, no. 1, pp. 88-92
8. Petterson Torbjorn, Fodgen Andrew. 2005, Spreading of individual toner particles studied using in situ optical properties, Journal of colloid and interface science, Vol. 287. pp. 249-260
9. Reverdy-Bruas N., et al. Caractérisation de papier avec la microtomogrpahie au rayon X. ATTIP, 2001. 55(4): p. 12-18.
10. Rolland du Roscoat, S, J.-F. Bloch, X. Thibault. 2004, X-ray microtomography applied to paper investigation. in 7th Biennal Conference on High Resolution X-Ray Diffraction and Imaging, Prague
11. Rolland du Roscoat, S, J.-F. Bloch, X. Thibault, 2005, Synchrotron Radiation microtomography applied to paper investigation. Journal of Physics D: Applied Physics
12. Rolland du Roscoat, S, J.-F. Bloch, X. Thibault, 2005, Characterisation of the 3D paper structure with X-Ray Synchrotron Radiation microtomography in 13th Fundamental Research Symposium cambridge: The pulp and paper Fundamental Research society.
13. Samei Mashiro, Takenouchi Kazuki, Kawakita Kazuaki, 1998, Estimation of temperature in toner fusing field, IS&t's NIP 14. pp. 466-469
14. Samuelsen E. J., Gregersen O. W., Houen P. J., Helle T., Raven C. and Snigirev A., 2001, Three dimensional imaging of paper by use of synchrotron x-ray microtomography J. Pulp Paper Sci. 27 50-3
15. Sipi, Katja, 2002, Toner-paper interactions induced by the fixing process in electrophotographic printing, Licentiate thesis, Helsinki University of technology, Finland.
16. Takenouchi Kazuki, Samei Mashiro, Kawakita Kazuaki,1998, Effects of air on fusing temperature field in electrophotographic printers, IS&t's NIP 14. pp. 444-447
17. Vernhes Pierre, Blayo Anne, Bloch Jean-francis, Pineaux Bernard, 2006, Temperature field in the nip of an electrophographic printer and its consequence on the optical properties, TAGA proceedings

Challenges and possible solutions for newspaper production in high-speed ink-jet

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Abstract

If the problems of competition from other channels and production costs can be solved, the benefits of an updated paper-based newspaper in full colour may be a part of our communication society. Since our project mostly focused on the large scale production of a certain amount of different newspapers, which address the target groups of immigrants or businessmen gathered where there are many visitors, i.e. large conference sites, we could see the benefits of a production using high speed inkjet in colour. Any obstacles as regards printing, including runnability and print quality, are considered solvable, if reasonable efforts are made. Full-scale printing trials showed that high-speed ink-jet printing is possible on commercially available newsprint grades; the results, however, can be improved, with slight modifications to the paper properties.

1. Introduction

The objectives of the research presented in this paper are:

- To identify the market for the distributed digital printing of newspapers, in general, and for high speed inkjet printed newspapers in colour, in particular;
- To evaluate the potential of this market by carrying out a pre-study of one of the target groups, viz. immigrants living in Sweden;
- To specify the technical demands on newsprint to be printed in high speed inkjet and full colour.

Background

Is there an evolving market for a distributed digital printing of on-demand newspapers in the world? The market today is small, primarily directed at businessmen who want the latest financial news when travelling and the printing is mainly based on b/w electrophotography. A reduction in the daily transportation of newspapers would, of course, be beneficial, from environmental and energy points of view. Merely in Sweden, every night, 230,000 km are driven in distributing morning papers. One virtual scenario predicted in many foresight reports is a total change with regard to the future of newspapers, where there will only be an Internet publishing of newspapers [Alström et al. 2004].

One way, of partly meeting a scenario of totally paperless newspaper publishing could occur with the use of digital printing technology in newspaper production. It is quite clear that digital printing is unique, in that it can take full advantage of the potentials available for variable data content products as well as on-demand printing. When considering the competition that the Internet poses, this may be one possible prospect for the survival of a paper-based newspaper. Newspapers today, almost without exceptions, have completely digital systems, which is one of the reasons why the fundamental infra-structure for digitally printed newsprint is theoretically in place.

Today, people are travelling more, moving from time to time between different places, while still wanting their domestic newspaper, e.g. businessmen, tourists and, not to forget, immigrants.

One scenario for the research presented in the paper is the printing of remote newspapers, where foreign visitors are gathered and want their domestic (remote) newspapers, but with local news or ads included. Is there a market for these kinds of newsprint-on-demand applications and facilities?

Apart from market demands and the challenges, there are technical matters to take into consideration. Newspapers have traditionally been printed using conventional printing techniques in large-scale printing shops. Printing newspapers with digital print technology and ordinary newsprint quality will consequently place new demands on the substrates to be printed. A substrate must possess the properties to ensure printability and runnability in the printing equipment.

Ink-jet printing technology is based on the application of microscopic ink drops emitted under pressure from a jet onto a substrate [Andreottola 1991]. This printing technique places new demands on the properties of the printing paper. An optimal uncoated paper surface is said to consist of a mat of fibres with an evenly distributed gradient of sizing, additives and fillers. The surface of inkjet papers should be engineered so as to be a highly absorbent interface that, at the same time, exhibits micro-capillarity on a defined scale [Babinsky 1998]. The influence of paper structure on the ink-jet drop impact and spreading must also be considered [Oliver 1984]. In order to achieve a high print sharpness, care should be taken not to have too high a liquid penetration rate in the paper [Bares and Rennels 1990].

Investigations have been made with regard to the visual print factors for inkjet printing on coated paper. McFadden and Donigian (1999) consider print density and colour-to-colour bleed as the most important factors. The most important quality factor for high-quality ink-jet printing is stated to be the colour gamut volume [Gidlund et al. 2005].

The challenge in the current project was to find *the market potential* for digitally printed newspapers. Current business models are based on b/w electrophotographic technology. With high speed inkjet it could meet productivity demands if a viable large scale production of on-demand newspapers is addressed. The added value of colour to the newspaper was also essential to integrate into the concept. The next technical challenge was to identify suitable paper properties in *newsprint* that is to be adapted for *high speed ink-jet printing in full colour.*

2. Background

If digitally printed newspapers are to be a solution to maintain the printed newspaper on a short-term basis, at least partly, special opportunities must be created, where a reader is willing to pay a price that is dictated by the capital investment necessary for the digital pre-press operations, printing and finishing, the size of the digital circulation and the amount of advertising.

Seen from a domestic perspective, an establishing of distributed digital printing of some selected foreign newspapers, with local advertising in four colours available on some strategic sites, would then lead to the potential growth of sales of merchandise, of the promotion of restaurants and culture as well as contributing to the encouragement of tourism. It would provide newspaper publishers with an insight into remote printing and the logistics and technology required for such an operation. Moving globally, the large cities with large conference facilities, where many foreign visitors gather with, one assumes, have a demand for newspapers from various countries.

Opportunities for remote business development have been studied by [Brunner and Erlandson, 2003]. The study was based on original research and interviews with newspaper publishers in 14 northern and western European countries. In all, 53 companies contributed to the research. The study provided an overview of publishers' expectations for digital printing in Europe and their opinions as to how the market for roaming readers might evolve, in the context of current production models for European newspapers. Concerning advertising and making a closer alignment to reader profiles, one of the

conclusions was that there is, as yet, no established working model for how variable information print for customised, individual newspaper editions might work either in production or commercial terms. The use of the Internet is important for content delivery and digital newsprint. It provides access to new markets and has the potential of providing new distribution and production models, thus extending the newspaper industry's established distribution and printing model. Logically, for digital printing, the interrelationship with the Internet, the newspaper content and the remote output is unquestionably intimate. One important factor, through which commercially viable business models for digital newsprint might be developed, is efficient digital workflow management. It is very apparent that digital printing is unique, in that it can take full advantage of the potentials available for variable data content products.

Some potential target groups are immigrants, retired people who have relocated to another country, business travellers, tourists and the rural population in sparsely inhabited areas.
In the following, the market and the technical aims are handled separately, with regard to the methods, results and discussions. The conclusions for the whole concept are, however, collectively dealt with.

3. Market target/Methods

Current business models on the subject of printed newspapers using digital print technology were studied and compared, from marketing, technical and financial aspects.

To investigate customer interest in Newsprint-on-demand, a Focus Group interview was carried out. The target group was immigrants, first and second generations with European and non-European backgrounds and currently living in Sweden. The group consisted of nine people, aged between 25 and 39 years. Seven of these were first generation immigrants and two were second generation. The gender distribution was almost equal, viz. 4 females and 5 males. In addition, 2 in-depth interviews were carried out with elderly immigrants.

One in-depth interview was held with a technical director from a business newspaper and one with the advertising sales director of one of the large newspaper groups in Sweden.

4. Market target/Results

4.1 Current business models

The current systems studied [Mejtoft, 2004] were Satellite Newspaper, NewspaperDirect and Océ Digital Newspaper Network. These 3 systems present business models that are quite different from each other. Satellite Newspaper has print stations that print the newspaper on-demand. NewspaperDirect makes it possible to print newspapers on existing equipment in the office. Océ utilizes a high capacity web-fed xerographic press, printing b/w. Their different approaches make their revenue models different and, with the first 2 systems, there are no costs involved for newspapers that want to join them.

Satellite Newspaper has 2 major products presently available. The first product to be launched was Satellite Newspaper KiOSK, a system based on actual kiosks that are franchised globally. The KiOSK is a print station that produces newspapers on-demand. Each individual owner of a KiOSK decides the sales prices of the newspapers, but Satellite Newspaper recommends a price between $3.50 and $5. Today, there are 125 kiosks in total and each kiosk has a selection of about 190 (June 2006) different newspapers from around the world.

The other service is Satellite Newspaper Client, launched in March, 2004. This is a software that makes it possible to connect to the Satellite Newspaper Control Center in the Netherlands via the

Internet. The client licence makes it possible for the owner to print various newspapers from around the world. These newspapers can then be sold and distributed to a customer. Typically, licensed owners of the Satellite Newspaper Client are hotels and large enterprises that require access to newspapers from different countries.

The following list gives a good overview of the different sources of income for Satellite newspaper and their two major products.

- Satellite Newspaper KiOSK:
  - A fee per sold KiOSK.
  - An annual licence fee for the software that is used in the KiOSK.
  - A fee per sold newspaper.
  - A fee per advertisement video shown on KiOSK.
- Satellite Newspaper CLiENT Software:
  - A fee per sold unit of software.
  - Annual licence fee for the software.
  - A click fee per printed newspaper.

The business model for *Océ DNN* uses the digital printing technique to print international newspapers in b/w on ordinary newsprint. The system is based on a digital web-feed xerographic press, Océ VarioStream 7000, with inline finishing equipment from Hunkeler. The system has a capacity to produce up to 1,000 completed 24 sided newspapers per hour (18.25" x 12.5") on papers between 45 and 52 g/m^2. Océ states that it is possible to print on the same kind of newsprint as for ordinary offset newspaper production. In this way, it is possible to obtain a newspaper with quite the same format and feeling as with an ordinary newspaper.

The system is based on the idea that printing houses with the appropriate digital printing equipment are connected to a section of DNN called International Data Distributor (IDD). This is the centre from which information about the print volumes and the pdf-documents for the newspapers are distributed. All data sent to the printing houses can be printed directly without further work being done. After the printing and finishing is done, the newspaper is distributed through the usual distribution channels. It is then possible to deliver the newspaper concurrently with other local newspapers. The customer receives a newspaper containing the latest news, which may cause greater interest in the newspaper itself, since it is delivered on the same day as it was produced.

The IDD in Océ DNN contributes with the appropriate services that make it possible for newspaper publishers to contract local distributors and other partners that are necessary for an effective workflow. They are also responsible for the secure delivery of the newspapers in a pdf-format to the right printing house and coordinate the current printing volumes.

The big advantage for the newspaper publisher is that they only have to pay for the copies that are actually printed and distributed, thereby minimising the risks involved in distributing the newspaper globally.

NewspaperDirect now has (June 2006) a range of 360 newspapers to deliver in more than 60 countries and 37 languages around the world. The printing and distribution are done through collaborative partners, i.e. NewspaperDirect has made agreements with local independent companies that use their local knowledge to distribute and sell international newspapers. The concept is to reach the consumers in the place where they reside, work and shop, but also when they are travelling. Local partners, e.g. hotels or others that want to join the NewspaperDirect network, pay a licence fee to be able to connect to the network via the client software, NDprintstation. They are thereby able to offer a broad selection of daily newspapers to their customers.

The newspapers are sent from the newspaper publisher via the Internet to ND Network Operation Center, where the digital newspaper files are handled in order for them to be streamlined to fit the

system. The newspapers are then transferred via the Internet to the local partners. This is a system that is to the equivalent of the Satellite Newspaper Client system, meaning that this system does not use any kind of kiosks or other public printing stations.

As for the clients, the technology required is the normal equipment that they most likely already own, viz. a computer, Internet access and an A3 xerographic colour printer. NewspaperDirect has certified approximately 20 different colour laser printers produced by a few different producers that function well with their production systems. Though the system is based on standard equipment, there will not necessarily be any costly investments in new technology for being able to join the NewspaperDirect network.

Since a newspaper is printed using an ordinary xerography copy-printer, the newspapers will not convey the regular feeling of an ordinary newspaper printed on newsprint, such as those that Océ DNN offers.
As regards advertisements, NewspaperDirect can offer the possibility for advertisers to buy extra advertisements in the NewspaperDirect edition of the newspaper. This means that an advertising company can either target a specific group or geographic area with a specific message or advertise in all the newspapers that NewspaperDirect offers. Advertisements can thus be divided into international, national and local advertising.

The extra advertisements are added in such a way that they do not alter the original design of the newspaper, which means that all extra advertisements have been added to extra pages in the newspaper and, in this way, they will not affect the original range of advertisements in the newspapers. The last page of a newspaper is intended for personalisation, i.e. to customize each paper for the individual reader. The local partners are the ones that sell the local advertisements.

NewspaperDirect has chosen to partner up with a number of large international hotel chains and cruising companies, such as Hilton, Radisson and Norwegian Cruise Lines, among others. These can then offer their guests regular newspapers as a service. NewspaperDirect has focused on the more exclusive segment of business travellers and decision-makers around the world. In addition to business travellers, they focus on companies, retailers and home delivery as potential customers. Companies of interest would be those that require newspapers from distant countries so as to obtain a good overview of their market, for example.

The channel of the newspaper as a printed media is not a focal point, since NewspaperDirect makes it possible to offer electronic newspapers that can be read as a pdf on a monitor.

4.2 Focus group and in-depth interviews

The results from the focus group discussions and the in-depth interviews can be summarised as:

- *Fresh news*

The quality and the freshness of news is by far the most important feature of the newspaper. The news channel, itself, is of less importance in that perspective.

- *The choice of a news channel*

If a paper-based classic newspaper was as fast as the other channels in updating the news, the choice would then be a paper-based newspaper. The feeling of receiving a conventional newspaper is very important but, as said, this is not as important as the quality of the news.

- *Form and layout*

Colour in the newspaper gives a feeling of higher quality, which also has an impact on the rest of the content, thus giving the newspaper a superior quality, as a whole. It was pointed out that good survey-ability (overview of the content) as well as the "real newspaper feeling" were important factors as to the reason why a format smaller than a tabloid was not of interest. High design quality was important to everyone. This was also a criterion for an Internet newspaper.

- *Individualisation*

The latest news and ease of accessibility in relation to the format and layout were ranked higher than individualisation. Nevertheless, this feature was of interest as an added value to the product. Such a feature could confer a newspaper with a value that makes it more attractive.

- *Distribution*

For the immigrant group, distribution through organisations, workplaces and public institutions is an interesting alternative to having their own subscription or buying a newspaper.

- *Paying for the newspaper*

Most of the people were rather doubtful about having to pay for news from the Internet. The news that one pays for must include penetrating and serious journalistic articles, guaranteeing good quality and a neutral news coverage. The price for news-on-demand or a domestic newspaper should not, however, be too expensive, when compared to an ordinary newspaper.

- *General news*

The printed newspaper was considered to be highly reliable. The news and other articles were defined as more profoundly analysed in a printed newspaper than on the Internet. The sensation of reading the news from a newspaper on a train, for instance, makes the experience more private.

When it comes to major events or crises in a native country, it is more important to have the latest news. The emotional aspect is a crucial one. To read the news from a native country links one to one's family and friends at home. Another more emotional aspect that was mentioned was the feeling of relaxation in reading a "paper newspaper". This is an opportunity for having time to yourself, even if you are sitting in a crowd, or travelling on a train, both of which were mentioned.

5. Market target/Discussion

A newspaper having the same qualities as today's fastest news channels, e.g. Internet, radio and TV, may be able to take back market shares from these channels. A newspaper therefore offers constantly updated news, together with a sense of quality, reliability and seriousness.

Although the Internet is a major competitor, the focus group stated that it could not be a substitute for a paper based newspaper. A better readability, reliability and surveyability are factors that might be the factors for the success of a printed newspaper. Apart from this, it has sentimental value.

E-paper and its possibility of communicating the news were not considered in the interviews, but this is naturally an aspect not to be omitted. Depending on developments in the technology, this may also be a serious competitor to the printed newspaper.

A newspaper company may consider the option of having a digital printing press added to its normal printing equipment in order to take advantage of the possibility of being able to offer a service of newsprint-on-demand by printing newspapers from different countries. Distribution companies and advertisers are customer groups of interest. Sections of the offset printed newspapers, e.g. pages with stock exchange news, could instead of offset printed be digitally printed.

DNN, the Océ solution, is probably the only one of interest to immigrants. Since larger volumes are printed at a centralised printing house and distributed to customers, using the ordinary distribution channels, this is probably suitable for immigrant groups too. The thing in common with all these systems is that costs for the newspaper production are high. According to the survey carried out by Berghs School of Communication, price is certainly a crucial factor in attaining success. The price sensitivity is moreover different for different target groups. Business men and emigrated persons with a high economy are probably less price sensitive than immigrants, younger people, students etc.. Efforts at finding solutions that make production costs lower have high priority.

With regard to advertising, it must be realised that the advertisers themselves will not ask for news-on-demand or "domestic" newspapers but they need to be convinced that a product, such as an inkjet printed newspaper from another country, may offer the possibility of adding local advertisements. Advertisers must have confidence in and be very convinced that there is good business in advertising in these kinds of newspapers; otherwise they will choose other channels. Therefore, the promotion of a NoD product must be marketed very keenly in order to find the customers.

The same kind of business models that are used for electrophotographic newspapers could probably be used for inkjet printed papers. The only viable model for immigrant group newspapers (at least larger groups) and for large groups of businessmen is thus the use of a high speed inkjet printing press. A tabloid format, printed with colour on newsprint is probably a good option.

6. Technical target/Methods

Paper grades used

Printing trials were carried out with commercially available paper grades. In the study, 5 newsprint grades were chosen. The specifications of the papers appear in *Table I.*

Table I: Newsprint grades used in the printing trials

Paper grade, Manufacturer	Furnish	Grammage	Ash content	Calendering	Brightness	Air permeance ml/min
1 Standard Newsprint, A	50/50% TMP/DIP	49 g/m^2	6-7%	soft	58	188
2 Improved Newsprint, A	100% TMP	49 g/m^2	4%	pile	68	148
3 Improved Newsprint, A	100% TMP	52 g/m^2	10%	soft	75	282
4 Standard Newsprint, B	100% TMP	49 g/m^2	3-4%	hard	63	212
5 Improved Newsprint, B	100% TMP	49 g/m^2	6%	hard	74	162

Printing

The printing trials were performed in the Posten ePP print shop in Stockholm on a Scitex Versamark printing press. The printing trials were executed in two series, viz. test print trial 1, to assess print quality, and test print trial 2, to evaluate runnability.

Test print trial 1, Print Quality

These test print trials were done at printing speeds of 50 m/min, 75 m/min and 100 m/min. The amount of ink applied was governed by a Look-Up table in the software for ink-feed control. In order to ensure runnability, one non-printed page was inserted between each printed page. One hundred copies were printed at each trial point.

Test print trial 2, Runnability

These test print trials were done at a printing speed of 50 m/min. A Look-Up Table of 14 was used, in order to give an ink feed high enough to cause a runnability problem. A print test form with screen areas ranging from 10% to 100%, with an interval of 5%, was used. The size of the printed areas was 200 mm x 170 mm. There were 150 copies printed at each trial point. The trials were run until wrinkles were formed, which lead to the rejection of copies.

Paper testing methods

Air permeance was measured using the Bendtsen method, according to SCAN-P 60:87. Water absorption was measured as $Cobb_{30}$, according to SCAN-P12:64. Wettability was measured as a contact angle using FIBRO 1100 DAT. Dynamic water absorption was measured, using a Water Absorption Tester (WAT) instrument. To suit newsprint, the measurement method was modified using two different measurement modes, viz. with 3 layers of newsprint and with 10 layers of newsprint, in order to obtain measurements with a suitable resolution. Cockled area after water application was measured using the STFI-Packforsk Cockling method.

Print evaluation methods

The colour gamut volume was measured using a GretagMacbeth Spectrophotometer SpectroScan with SpectroChart v.1.0 software. To obtain the colour gamut, colour patches of cyan, magenta, yellow, red, green, blue, key black and paper white were measured with the spectrophotometer. The measurements were done using standard illuminant D50, an observer angle of 2° and a neutral filter. The CIELAB values obtained were used to calculate and visualise the colour gamut, using a Matlab®routine.

Print mottle was analysed according to STFI Mottling BA0041. Print quality was evaluated visually, using pair comparison [Bristow and Johansson, 1983]. The prints were mounted on cardboard and shown to a panel of observers under a standard daylight viewing illumination, D50. Observers were asked to state which print they preferred in terms of overall print quality. Ten observers performed a pair comparison for each evaluation.

7. Technical target/Results

Paper properties

Water absorption properties of papers are important for ink-jet printing with water-based inks and were evaluated for the newsprint grades used in this project. The grades displayed differences in water absorption, statically and dynamically. Figure 1 shows the $Cobb_{30}$ value of the paper grades.

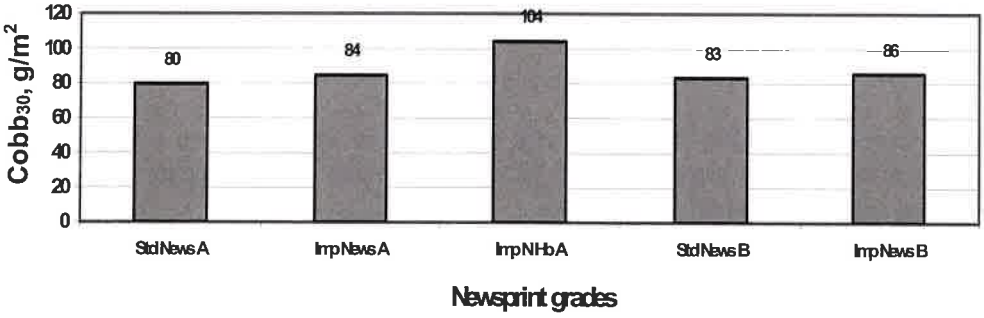


Figure 1: Water absorption expressed as $Cobb_{30}$ for the assessed paper grades

As high-speed ink-jet printing is a rapid process, it was relevant to evaluate the dynamic water absorption. It is possible to get an understanding of the dynamic water absorption by studying the time lapse of the contact angle. Figure 2 shows the contact angle with water for the evaluated newsprint grades after a 0.2 second lapse in time.

Note that the contact angle with water was lower after a specified contact time for the higher quality grade samples, i.e. the papers were more hydrophilic.

Water absorption was also assessed using Water Absorption Time (WAT) measurements. Since the WAT method is primarily intended for the analysis of tissue paper, measurements were made in two different modes, viz. with 3 layers of newsprint and with 10 layers of newsprint. Figure 3 shows the results in the MD, CD and ZD from measurements taken on the 10 layer samples.

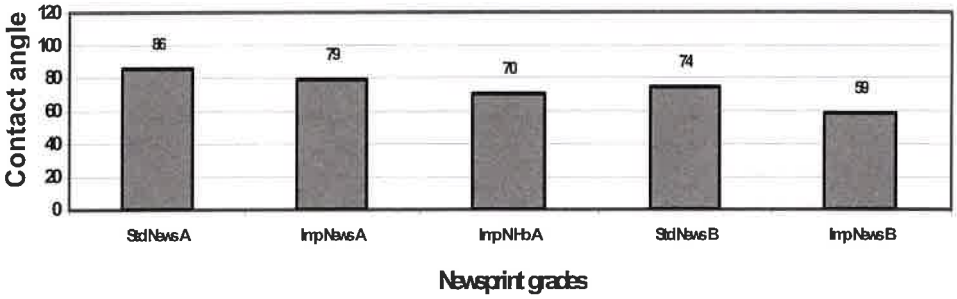


Figure 2: Contact angle with water after 0.2 seconds had elapsed

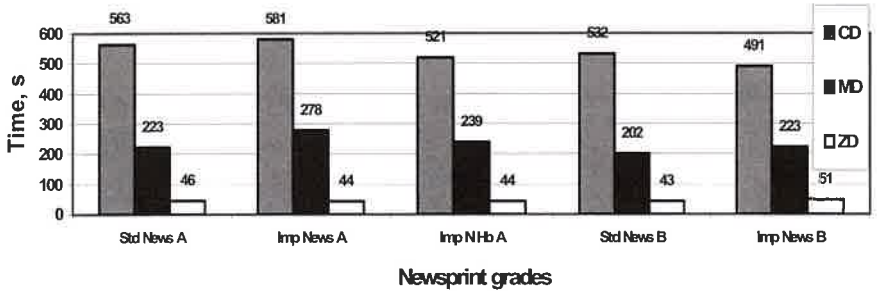


Figure 3: The water absorption times for 10 layers of newsprint

Note that there are significant differences between the cross direction and the machine direction, due to the fibre anisotropy of the assessed paper grades. Water transport is more rapid along the fibres. The water absorption times with 3 layers of newsprint showed similar tendencies. Cockling was measured after water application to the paper grades. Figure 4 shows the results for the assessed grades.

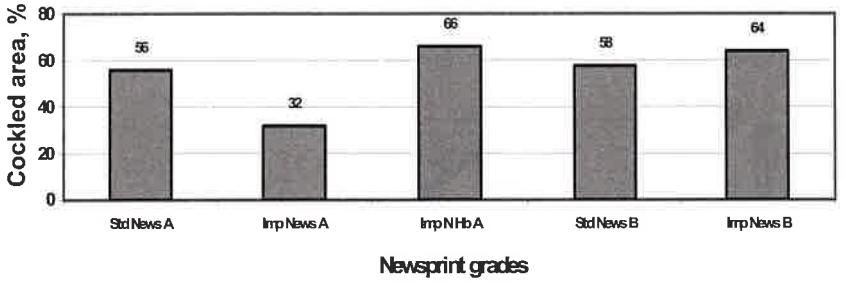


Figure 4: Cockled area after water application

Notice that cockling was significantly lower for paper grade 2, which showed the best result. The other paper grades displayed a noticeably higher degree of cockling. Figure 5 shows the relationship between cockled area and WAT (10 layers) in the CD.

There was a moderate correlation between the cockled area and the water absorption time in the cross direction. A long water absorption time indicates a slow water penetration. This leads to a small cockled area, which is beneficial for good runnability in a printing machine.

The opacity of the evaluated paper grades was measured. There were, however, no great differences among the paper grades.

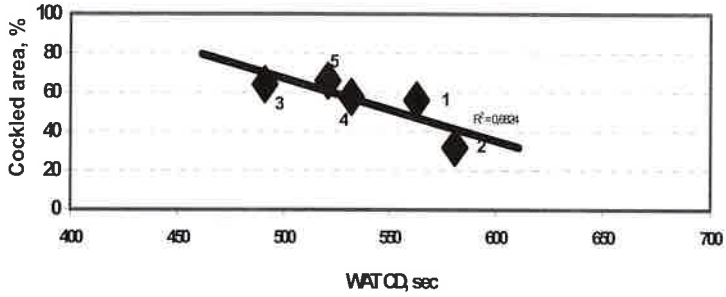


Figure 5: Cockled area as a function of water absorption time in the CD

Technical target/Print quality

The colour gamut was evaluated. Figure 6 shows the colour gamut volume for the evaluated newsprint grades.

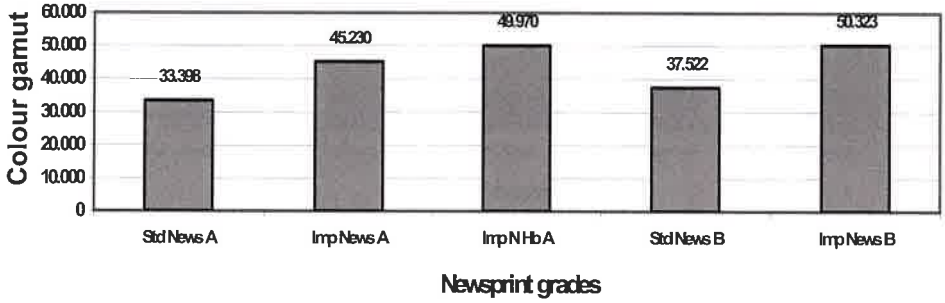


Figure 6: The colour gamut volume of the evaluated newsprint grades

Not unexpectedly, the higher quality grades had a larger colour gamut volume.

The relationship between the colour gamut volume and the contact angle after 0.2 seconds is shown in Figure 7. It can be concluded that the correlation is moderate.

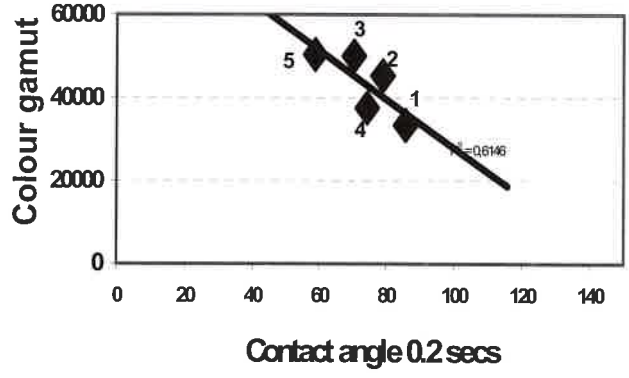


Figure 7: The colour gamut as a function of the contact angle after 0.2 seconds

A low contact angle, which implies a hydrophilic surface, is thus beneficial for the colour gamut volume.

The relationship between the colour gamut volume and the water absorption time in the Z direction is shown in Figure 8. Here, there is a moderate correlation.

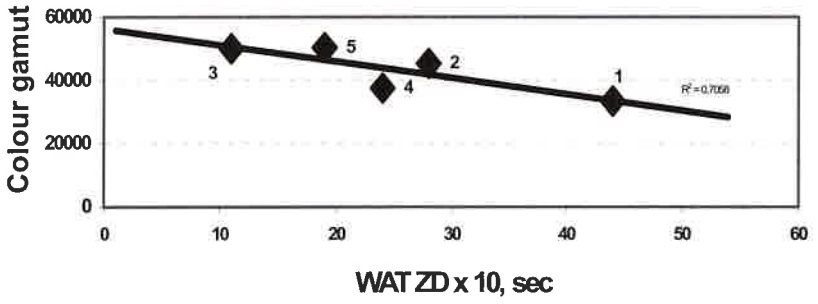


Figure 8: The colour gamut as a function of the water absorption time in the Z direction

Fast absorption of water in the thickness direction is favourable for the colour gamut volume.

Print mottle is an important measurement of print quality. Print mottle in the 1 mm - 8 mm wavelength band on full tone areas, printed with cyan ink, is shown in Figure 9.

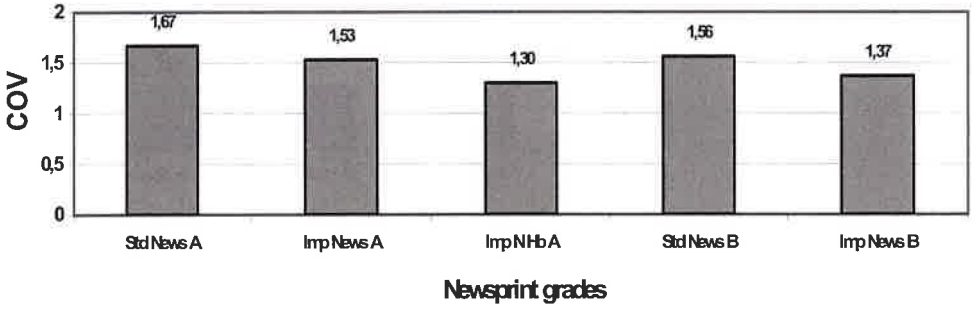


Figure 9: Print mottle in the 1 mm - 8 mm wavelength band.
Print mottle was measured in full-tone areas printed with cyan ink

Print mottle can be affected by the absorption properties of the substrate. Figure 10 shows the relationship between the print mottle and the contact angle, recorded after a lapse of 0.2 seconds.

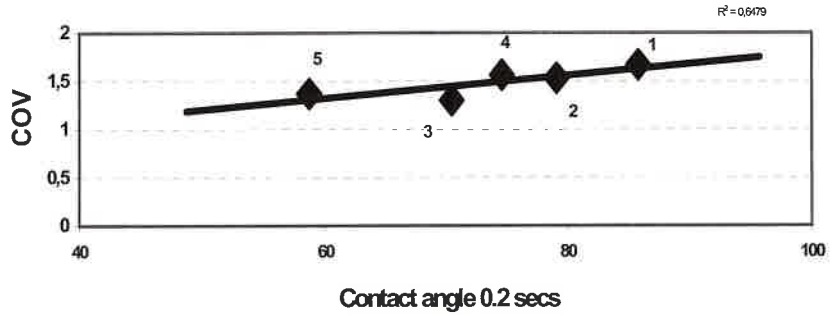


Figure 10: Print mottle as a function of the contact angle after 0.2 seconds

There is a moderate correlation between the print mottle and the contact angle. Figure 11 shows the relationship between the print mottle and the water absorption time in the thickness direction.

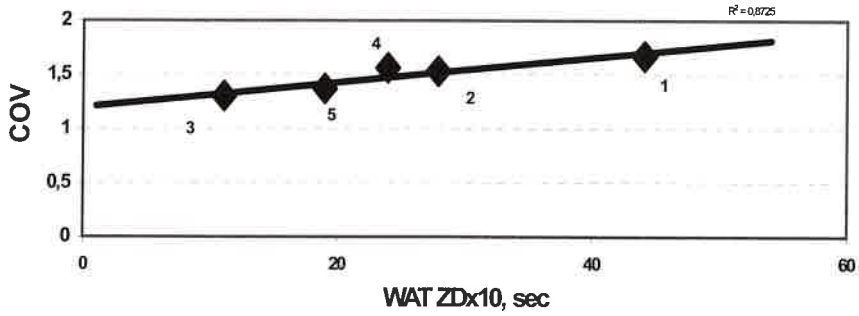


Figure 11: Print mottle as a function of the water absorption time in the thickness direction

There is a strong correlation between print mottle and the absorption time why it is advantageous to have a hydrophilic substrate for diminishing print mottle.

A visual assessment of the print results is one way of obtaining an evaluation of the print quality. Figure 12 shows the results from an evaluation of 3 images in the test print form.

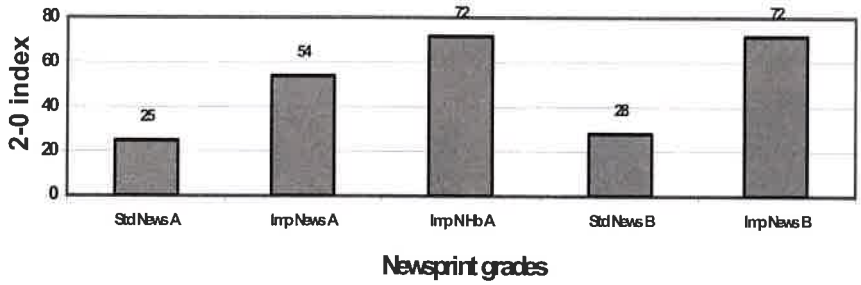


Figure 12: Visual assessment of the overall print quality

There was a clear ranking of print quality among the paper grades. It is interesting to compare the visual assessment results with the measurable print quality properties. Figure 13 shows the relationship between a visual assessment of the print quality and the colour gamut volume. A very strong correlation was found.

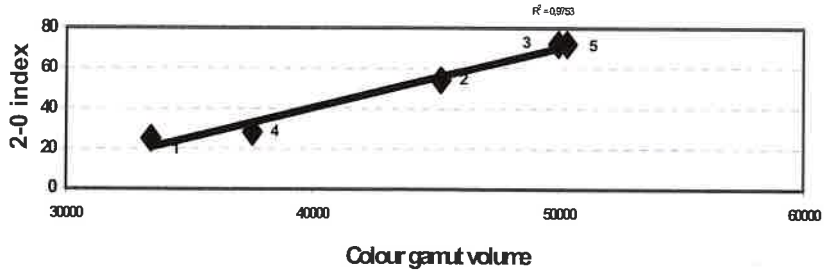


Figure 13: Visual assessment of the print quality as a function of the colour gamut volume

Figure 14 shows the relationship between the visual assessment and the print mottle.

As might be expected, there was also a strong correlation with the print mottle. This elucidates the fact that the colour gamut volume and the print mottle are of vital importance to the perceived print quality.

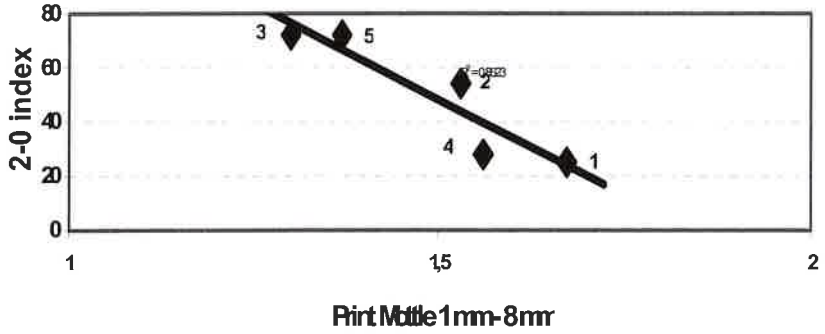


Figure 14: Visual assessment of the print quality as a function of print mottle

Print sharpness was evaluated as regards Raggedness, Blurriness and Line Width. No correlation with the measured paper properties was found, however.

Runnability

Runnability differed among the paper grades. Figure 15 shows the print screen area that caused wrinkles on the printed copies.

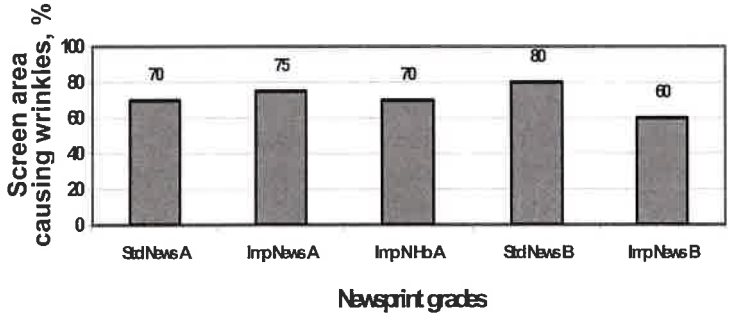


Figure 15: Print screen area that caused wrinkles on the printed copies

Note that the best runnability was achieved with paper grades 2 and 4, which were quite heavily calendered. The screen area that caused wrinkles can be compared with the water absorption time in the three directions, viz. the MD, CD and ZD.

Figure 16 shows the relationship between the screen area causing wrinkles and the water absorption time (10 layers) in the cross direction. A weak correlation was found, i.e. a longer absorption time is related to slightly improved runnability.

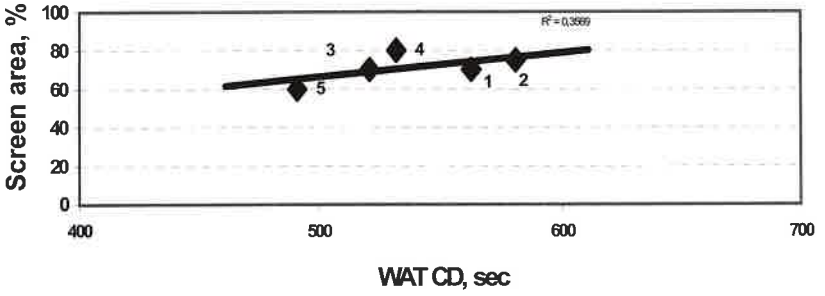


Figure 16: The screen area causing wrinkles as a function of the water absorption time in the cross direction

An explanation of this could be that a substrate with a stronger tendency for in-plane water spreading will have an increased dimensional out-of-plane instability, due to a swelling of the paper surface, while the core of the substrate remains less affected.

Figure 17 shows the relationship between the screen area causing wrinkles and the water absorption time (10 layers) in the thickness direction. A significant influence could be found, with impaired runnability having a relationship to longer absorption times.

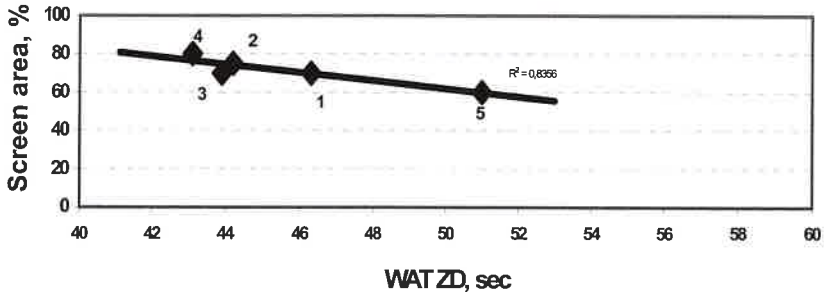


Figure 17: The screen area causing wrinkles as a function of the water absorption time in the thickness direction

This is probably a result of a shorter water absorption time in the thickness direction, causing an increased softening in the core of the substrate. This decreases the out-of-plane dimensional instability, since the softening of the core reduces the bending effects on the substrate, which are induced by the in-plane swelling of the surface. A shorter water absorption time in the thickness direction also indicates a decrease in the in-plane spreading.

8. Technical target/Discussion

The evaluation of printability showed that there is a good correlation among the colour gamut volume and the contact angle as well as the WAT in the Z-direction (3 layers). A low contact angle and fast absorption in the ZD are beneficial. There is also a good correlation among the print mottle and the contact angle as well as the WAT in the Z-direction (3 layers). A low contact angle and a fast absorption in the Z-direction are beneficial. Furthermore, there is a good correlation among the Visual assessment and the Colour gamut volume as well as a low Print mottle. Interesting to note is that for electrophotographic prints there is no evident correlation between visual assessment and colour gamut (Klaman, 2001) due to the fact that the toner behaves more as a coating layer filtering the paper surface properties. There is also a good correlation among the Visual assessment and the contact angle as well as the WAT in the Z-direction (3 layers). A low contact angle and fast absorption in the Z-direction are beneficial.

The evaluation of runnability showed that there is a good correlation between the Screen Area causing wrinkles and the WAT in the Z-direction (10 layers). A fast absorption in the ZD is beneficial. There is also a negative correlation between the Screen Area causing wrinkles and the WAT in the Cross Direction. A low penetration rate in the CD is beneficial.

9. Conclusions

The digital printing of newsprint, preferably in colour, may be an emerging component in the overall printing of newspapers if a number of prerequisites are met. They are:

- The cost of the copies produced must be decreased. Today, the price per copy of digital printing is too high, compared with conventional offset printing. The tolerance, according to cost, is different for the different groups, e.g. businessmen and retirees with good finances, who have moved to a warmer climate, will probably tolerate a higher cost level. However, the price must not exceed 3-5 Euros.
- Advertisers must be convinced that Newsprint-on-demand is an effective and efficient channel for marketing.
- The inserting of local advertisements is of interest, but the way of integrating them must not come into conflict with the integrity of the newspaper.
- Subscriptions are interesting for immigrants or any other groups that want their "own" specific newspaper on a regular basis.
- Proper distribution channels must be found, where the advantages of digital printed newspapers can be utilised.

For immigrants as well as for businessmen who are gathered in places (conferences) where there are many visitors from different countries, the solution of a high-speed colour inkjet printing press will probably be the most effective means of producing the actual newspapers. For other purposes, where the amount of businessmen is not so evident, the solution of using kiosks or a client based output are a better option.

The technical part of the study was carried out to identify the demands placed on newsprint from high speed ink-jet printing, to link them to measurable paper parameters and to propose properties that would be suitable in newsprint qualities, adapted for high speed ink-jet printing. The most significant observations were:

- The print quality achieved with a water-based ink is strongly affected by the water absorption properties of the substrate. A hydrophilic surface (low contact angle) and a fast water absorption rate in the thickness direction (a short Water Absorption Time in the Z-direction) are beneficial for the colour gamut volume and the print mottle.
- A visual assessment of the overall print quality showed, as expected, a strong correlation with the colour gamut volume and the print mottle. A high colour gamut volume and a low print mottle are positive for the perceived print quality. Since these properties are strongly related to the water absorption properties, the perceived print quality showed a good correlation to the water absorption properties as well.
- The runnability in high-speed ink-jet printing with water-based inks is, to a large extent, affected by the dynamic water absorption properties of the substrate.
- A substrate with a stronger tendency for in-plane water spreading will show an inferior runnability, due to an increased dimensional out-of-plane instability, caused by a swelling of the in-plane paper surface, while the core of the paper remains less affected.
- A substrate with a stronger tendency for water spreading in the thickness direction (a short WAT in the Z-direction) will show better runnability, due to a decrease in the out-of-plane dimensional instability, since the softening of the core will reduce the bending effects on the substrate, which are induced by the in-plane swelling of the surface.

A low contact angle with water is therefore of benefit for printability.

Fast water absorption, i.e. a low Water Absorption Time in the Z-direction, is advantageous for printability and runnability.

According to the results achieved, it is recommended that paper adapted for high-speed ink-jet printing with water based inks must have a hydrophilic surface and a core allowing the water based printing ink to penetrate rapidly into the substrate (in the Z-direction).

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The authors wish to express their gratitude to Thomas Mejtoft, a PhD student at STFI-Packforsk, who performed most of the studies regarding the current business models, the student group from Berghs School of Communication that was fully engaged and carried out many of the interviews. Åsa Gidlund, also a PhD student at STFI-Packforsk, is thanked for help with the visual evalutation.of prints. Posten ePP receives our kind gratitude for its support with the full-scale trials. Lastly, we wish to convey our thanks to the Swedish Governmental Agency for Innovation Systems (Vinnova) as well as the Structural Foundation of EU, both of which made the current study possible.

References

1. Alström B., Enlund N. et al., (2004) *En föränderlig medievärld - teknik, ekonomi och journalistik* Vinnova & Teldok, Telematik (2004)
2. Andreottola M. A. (1991) *Ink Jet Ink Technology* Handbook of Imaging Materials, pp 527-544
3. Babinsky V. (1998) *Ink Jet Paper Development* Intertech Conferences: Speciality & Technical Papers 98, San Francisco, California, 12 pp
4. Bares S. J., Rennels K.D. (1990) *Paper compatibility with next generation ink-jet printers* Tappi Journal, (73) Jan 1990, pp 123-125
5. Blohm E. (2005) *High speed ink-jet printing of Newsprint* STFI-Packforsk report 119 (2005)
6. Blohm E., Åslund P. (2004) *Papers designed for high speed ink-jet printing* STFI report CW 248 (2004)
7. Blohm E., Klaman M. (2005) *Newsprint-on-demand* STFI-Packforsk report 112 (2005)
8. Bristow, J. A., Johansson, P-Å. (1983) *Subjective evaluation by pair comparison: Pitfalls to avoid and suggestions for the presentation of results* Proceedings from the 1983 Conference on Advances in Printing Science and Technology, Saltsjöbaden, Sweden, pp. 278-291
9. Brunner L., Erlandson C. (2003) *New opportunities for Remote Business Development* IFRA Special Report 3.36
10. Gidlund Å., Johansson P-Å., Klaman M. (2005) *Quality Space for High Quality Inkjet Prints* Proceedings from 2005 TAGA Conference, Toronto, Canada
11. Klaman, M., (2001) Colour Rendering Aspects in Digital Printing Proceedings from 2001 TAGA Conference, San Diego, USA
12. McFadden M. G., Donigian D.W. (1999) *Effects of Coating Structure and Optics on Inkjet Printability* Proceedings from 1999 TAPPI Coating Conference, Toronto, Canada, pp. 169-177
13. Mejtoft T. (2004) *Current business models for Newsprint-on-demand* STFI report CW 249 (2004)
14. Mittelton J. et al. (2004) *Thesis work, Berghs School of Communication,* 2004
15. Oliver J. F. (1984) Initial stages of ink jet drop impaction, spreading, and wetting on paper Tappi Journal, (67) 10 Oct 1984, pp 90-94
16. Romano F. (2004) *Status report on digital color printing* Presentation at GFF Seminar, Stockholm 2004-05-27

3

Conventional printing

A parametric study of cylinder press screen printing

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Abstract

This paper outlines the development and results of as experimental programme to investigate the effect of the primary screen printing parameters on the print quality and to gain further understanding of the screen printing ink transfer process. The selection of the parameters to be included in the experiments was based on both experience and discussions with industry. Three key areas were identified which were thought to have a substantial effect on the print quality; these were mesh characteristics, squeegee characteristics and ink rheology. Since the investigations found a number of parameters which may have an effect on the quality of the screen process a full factorial experiment was deemed impractical and thus it was decided to use orthogonal array analysis. By engineering design and astute choice of variables, an L18 orthogonal array for the print machine parameters consisting of mesh tension, mesh structure, mesh ruling, a squeegee pressure and edge hardness parameter, squeegee angle and ink characteristics was developed. A test form was designed which facilitated the measuring of image distortion and tonal reproduction Five copies were analysed from each experiment using spectrophotometry. Control conditions were specified which ensured minimum variation between successive experiments by controlling the ink temperature, room temperature and screen emulsion thickness. It was found that 7 of the 8 parameters chosen effect the quality of the printed image. The ink deposit was increased by higher mesh tensions, lower print speeds, lower mesh rulings and squeegee angles closer to the horizontal. The combined squeegee pressure / hardness factor played a minimal role in determining ink transfer while the substrates and inks produced results which could be attributed to their respective properties. Primarily as a result of drying in, mesh ruling had the single largest effect on tone gain. All other parameters followed trends seen with the solid ink deposit. The results provide both corroborating and contradictory evidence for the proposed "push" and "pull" ink transfer mechanisms. Recommendations for further investigations are made.

1. Introduction

The cylinder screen printing process is a transfer process where a viscous medium is pushed through a permeable membrane which imparts an image on the substrate below. The principal behind the process is shown in Figure 1, where the action of the squeegee forces the ink through a fine mesh. The image is dictated by a stencil which is mounted on the underside of the mesh, which is bonded on a rectangular frame. Unlike flat bed screen printing where the frame is stationary and the movement of the squeegee transfers the image, in cylinder presses the squeegee and flowcoat remain stationary while the screen reciprocates.

In comparison with flat bed printing machines, where press speeds are typically a maximum of 900 copies per hour, cylinder presses operate at up to 4500 copies/hour providing a significant increase in production speed. This type of press has made screen printing more productive formed a niche market between the low speed - quick turnaround large format digital printer and the high capital cost of offset lithography printing machines. Their major disadvantage is that the substrate must be flexible as it must conform to the cylinder surface when pulled by the grippers. Cylinder presses are widely used in the reproduction of posters, transfers and ceramic transfers. Many factors influence are known to affect the quality of the screen printing process, [Appleton, Peyskns], and although some studies have evaluated the effect of flat bed screen printing parameters, [Reimer], little has been carried out on cylinder presses.

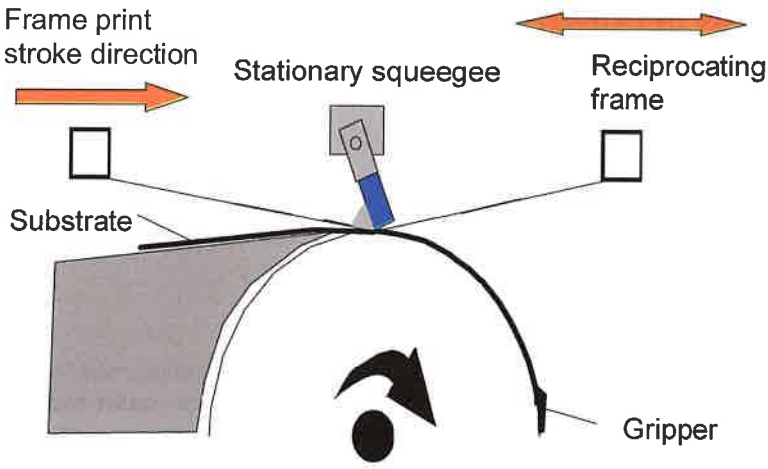


Figure 1: A schematic of a cylinder press

The ink transfer mechanism in screen printing is not well understood. The literature is dominated by two contrasting ink transfer models. The first is based on the transfer of ink as a result of hydrodynamic pressure generated at the squeegee tip/screen interface which pushes the ink through the screen to the substrate [Huner 1989, Huner 1994, Anderson et al, Fox et al]. The other opposing theory is that ink is pulled from the mesh by the adhesion of the ink to the substrate overcoming its internal cohesion [Messerschmitt, Abbott et al]. Although both theories can be well argued, neither has found universal approval.

The aim of the study was to select parameters which were considered to be important, to assess their effect on the printing characteristics and to give a better understanding of the ink transfer mechanism. The tests were carried out on an Sakurai automatic cylinder press. A discussion of the parameters considered important in the screen printing process is presented next together with the experimental design and procedure.

2. Methodology

What ultimately affects the quality of the final print in screen printing is the forcing of the ink though the mesh/stencil and its subsequent adhesion to the substrate below. Four key areas were identified which influence the ink transfer, namely the squeegee, the mesh, press settings and the ink rheology.

A full factorial experiment of the process variables is uneconomical and as such orthogonal array analysis was employed as an experimental method, [Phadke, Bohan et al]. The array is first described prior to an explanation of the reasoning used in the experimental design. An L18 orthogonal array was decided upon since the relationship between the parameters and the measured quality is unknown requiring a three level experiment to be carried out. The L18 array also allows an interaction to be studied in columns 1 and 2, all other interactions are confounded across the other columns, and allows the effect of 8 process variables to be studied. The L18 was designed so as to minimise the number of time consuming changes that must be carried out during the experimental programme, Table I, and deals with process variables over which the printer has control, such as initial frame tension, choice of squeegee, ink, mesh and the press speed.

The mesh is tensioned to draw the mesh away from the substrate after the passage of the squeegee. As result the mesh lies a distance from the substrate, the snap off (or off-contact) gap, [Peyskns]. Theoretically,

in order to limit the distortion of the image caused by the deformation of the mesh the distance between the mesh and the substrate should be minimised, [Claypole et al]. The smaller the off contact gap the greater the mesh tension required to overcome the viscous forces between the ink and the substrate and mesh.

Higher mesh tensions however require stronger mesh and frame materials and mesh structures and may impart a greater drag force on the squeegee. It is not known whether higher mesh tensions may also incur penalties in terms of promoting image stretch and stencil degradation during a print run. Higher squeegee pressures may need to be applied which will apply greater loads on the mesh promoting mesh stretch. For this study, it was decided to evade the mesh tension - off contact gap relationship by keeping the off contact gap constant at 3 mm and concentrating on the mesh tension squeegee down force relationship. In cylinder bed presses the release of the substrate from the screen is aided by grippers on the cylinder which pull the substrate away form the mesh as part of the substrate feed mechanism.

The most time consuming and costly aspect of the varying the parameters chosen, is the stretching of the mesh and the exposure of the image on the stencil. In order to limit this expense to 6 meshes, the mesh tension was inserted in column 1 at two levels of 17 and 21 N cm^{-1} with three levels of mesh ruling of 90 T, 120 T and 150 T threads per cm (where the T represents a thin mesh diameter), with the appropriate stencils of 15, 20 and 25 micron width respectively. This combination of mesh and stencils was chosen as it represents common industrial experience.

The contact angle and pressure between the squeegee, which is made from polyurethane between 60 and 95 Shore A hardness, and the mesh are important parameters which influence the means by which the action of squeegee results in ink transfer through the mesh. The traditional primary squeegee parameters used by printers to control the squeegee action during the print process are squeegee angle, pressure and hardness. However, considerable interaction between these parameters is experienced. All three affect the contact angle and pressure at the squeegee edge/mesh interface where the printing process takes place. The closer the squeegee angle to the vertical the smaller the deflection of the base of the squeegee due to the downward pressure force. Similarly a higher squeegee hardness or lower squeegee downward pressure also limit the deflection of the base of the squeegee. The deflection of the squeegee will directly control the mesh - squeegee interface angle.

Initially it was hoped that the squeegee parameters of angle, downward force and edge hardness could be investigated separately. To ensure that the interactions between the squeegee parameters of angle, downward force and hardness were eliminated an adaption was made to the squeegee. The new squeegee was supplemented by a stiff steel back so that its deflection would be insignificant allowing the mesh - squeegee interface angle to be measured directly as the squeegee angle. Initial trials found that the squeegee down force and squeegee edge hardness interacted so strongly that some combinations could not print at all. Subsequently, a new parameter was designed which maintained the squeegee down force to hardness ratio at a constant value, i.e. If x Newton were applied to a squeegee of y hardness then 2x Newton would be applied to a squeegee of 2y hardness.

Conventionally, the setting of the squeegee load by the printer is done by "feel". This is either set pneumatically or by threaded screws on the squeegee are tightened until a satisfactory print is obtained. This is often adjusted during the initial stages of the print run and as such a variation in quality, and increased product waste, is often encountered. To enable a pressure to be set as a control level in the array, the squeegee arm was mounted on linear bearings beneath load cells, Figure 2. The imbalance voltage of the load cell gives a direct measure of the load applied at the squeegee tip. The 3 load levels were defined as the static, dry load in the centre of the mesh. Since the squeegee has been designed to remove the interactions between the down force - hardness parameter, they may be placed anywhere in the array. The squeegee down force was set using load cells mounted at either end of the squeegee arm which allowed fine control and measurement of the squeegee down force.

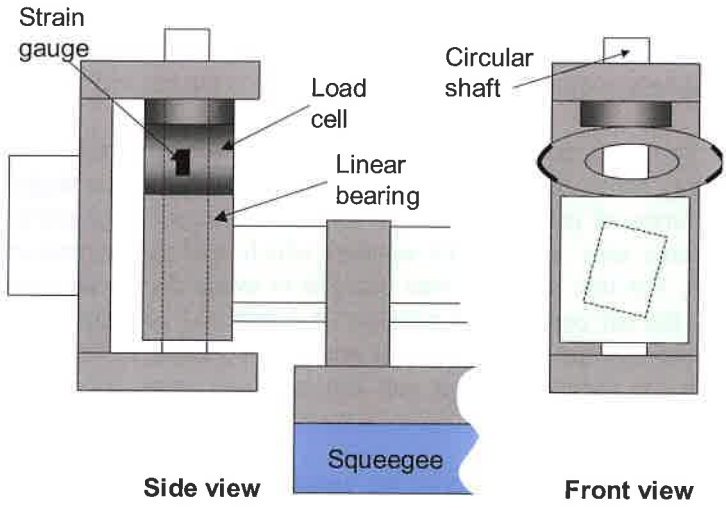


Figure 2: The load measurement system used to set the squeegee load was based on a linear bearing and load cell

The flow of the ink through the mesh is dependent on the mesh structure, ink viscosity and ink shear rate, the ink is normally highly non - Newtonian. For highlight areas the ink viscosity should be low to allow the ink to flow through the narrow openings in the stencil. In the shadow however the ink viscosity should be high to prevent the ink from spreading into the open regions around the dot.

Ink rheological characteristics can have a substantial effect on the image quality, [Jewell et al]. The majority of the ink used is solvent based an increasing number of printers are turning to waster based inks in order to meet environmental and health and safety legislation.

To establish what difference the ink has on the reproduction characteristics, a traditional solvent based, water based air dried and water based UV cured inks were inserted in column 7. Column 8 also contains an ink characteristic, in line (optimised for printing solids) or chromatic (optimised for halftone printing). For the ink colour used, black, the rheological characteristics of the inks are similar since in most printing jobs a single black is used which must fulfil the contrasting needs of minimal dot gain for halftone images and flat solid areas for solid images. Inclusion of this parameter as two levels in column 8 allowed the validity of the experimental design to be assessed as their respective tonal reproduction and density should be comparable.

The most time consuming aspect of the experiment trials was the press set up and analysis, therefore two parameters were included as a full factorial in the experiment but then inserted in the L18 array to be analysed, speed in column 2 and paper type in column 5. The inclusion of these parameters into the trials allowed some full factorial validation trials to be completed but only increased the experiment time by around 10%. A list of the parameters that were set as standard to the experiments are shown in Table II.

To ensure that there was a minimal effect from the initial variation of the mesh tension one hundred copies were run from each mesh prior to testing. Each print run consisted of ten prints giving a print total of 180 prints for the orthogonal array analysis within a total of 1620 prints. During the course of the experiments a number of parameters which were beyond the scope of normal controlled operating conditions, but which may have an effect on the process were controlled. The ink used was from one production batch and its temperature, which has a considerable effect of the ink rheology, was controlled using a thermostatic water bath. The 100 copies printed prior to measurement ensured the squeegee maintained thermal equilibrium with the ink prior to printing.

The test image printed was designed such that it facilitated the measurement of all the quality parameters. Tonal reproduction may be measured using the gradation scales situated unsymmetrically around the image containing 5% steps in coverage for elliptical and square dot shapes at dot rulings of 65, 100 and 150 dots per inch.

3. Results

The results are presented for the solid density before the effect of halftone printing for each of the process parameters in turn. Higher mesh tensions increased the printed film thickness while decreases in speed reduced the transfer of ink, Figure 3. The effect of mesh tension can be attributed to a number of phenomena. Increasing the tension stretches the mesh and thus increases the open area of the mesh allowing a greater ink carrying capacity. Higher mesh tensions also induce higher forces and shearing in the ink, reducing its viscosity and thus aiding ink transfer. Higher mesh tensions may also increase the rate of screen travel away from the substrate which tends to increase ink transfer [Jewell]. This result is at odds with the predictions of the pull model proposed by [Abbott et al].

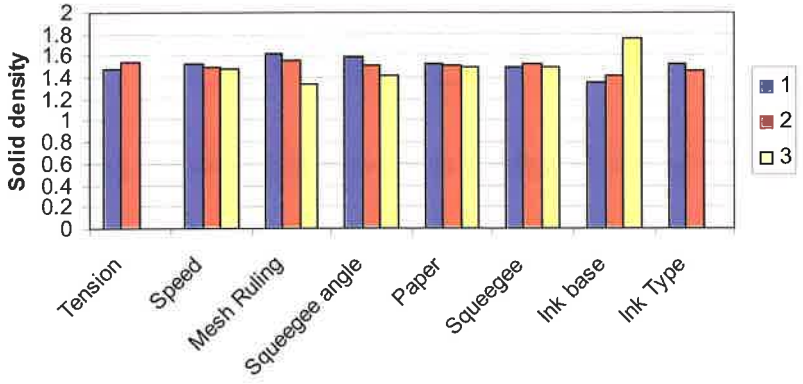


Figure 3: The effect of the cylinder printing parameters on printed solid density (1, 2 and 3 denote the low, medium and high setting of each parameter)

Increasing speed reduces the ink deposit. This is contrary to the push model predictions of [Fox et al] as the ink transfer would increase with increasing pressure in the ink under the squeegee but agrees with the predictions of pull model of [Abbott et al].

The largest single effect on the solid ink density was due to the mesh ruling with increasing mesh ruling reducing the ink deposit. This is in line with that measured with references [Hohl] and can be attributed to the reduction in available volume for ink transfer within the mesh structure.

The ink density showed a stepwise reduction in ink deposit with increasing angle and the effect of the combined squeegee pressure/hardness factor is minimal. This can be explained by the examining the hydrodynamics at the squeegee tip. As the load is applied to the squeegee the squeegee tip forms a contoured shape at the interface with the screen. Increasing the angle reduces the contact width and reduces the hydrodynamic pressure generated in the tip/screen interface [Fox et al]. Distorting the squeegee tip to a similar degree gives a similar amount of ink transfer.

The more matt and absorbent the substrate, the lower the ink deposit. On average, each of the inks produced a different solid density. It is difficult to fully attribute this to differences in wet film thickness (and hence link rheology and ink transfer) as each is likely to contain a different pigment concentration.

The results of the tone gain analysis of the experiment are shown for the square 65 lpi gradation scales in the middle of the print, similar results being obtained for other gradation scales. There was an insignificant difference between the gradation scales around the image highlighting that the screen printing process provides a means depositing an even layer of ink over a surface. The tone gain is characterised by low levels of dot loss in the highlight followed by a sudden tonal jump at around the 50% mark and low levels of dot gain in the shadow. This is typical of screen printing [Danias] although the magnitudes are lower than that specified in the ISO standard 12467-Part 5. The effect of increasing screen ruling is to increase the highlight dot loss and shadow dot gain, Figure 4.

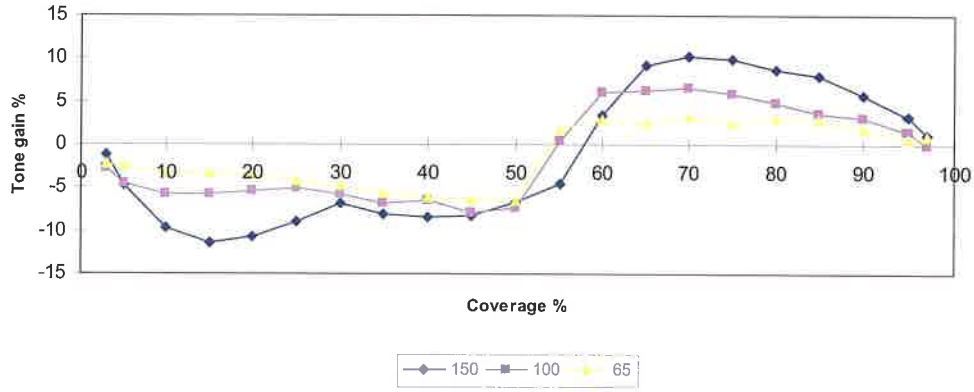


Figure 4: The effect of screen ruling (lpi) on the tone gain

The effect of mesh tension on tone gain is to increase tone gain as the tension increase which is in line with the effect of tension on solid density and represents a greater deposit of ink being printed, Figure 5.

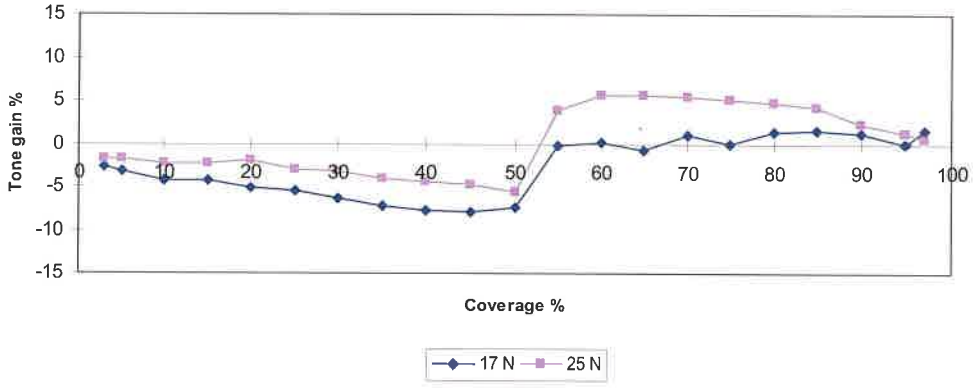


Figure 5: The effect of mesh tension on tone gain

The relationship between the tone gain and press speed was not clear with increasing speed initially resulting in a reduction in tone gain (1000 - 2000 cph) followed by a small increase in tone gain as a result of a further speed increase (2000 - 2500 cph), Figure 6.

The 90 and 120 threads/cm mesh rulings gave similar results while the 150 mesh ruling produced greater dot loss throughout the mid tones, Figure 7. On 3 occasions the 150 mesh produced very poor quality prints which may over emphasise this parameter and have a contributory effect on the high values of highlight and mid tone throughout the analysis. The likely reason for this is that the ink type and best print mesh type combination were not always optimum for each ink according to the data sheets.

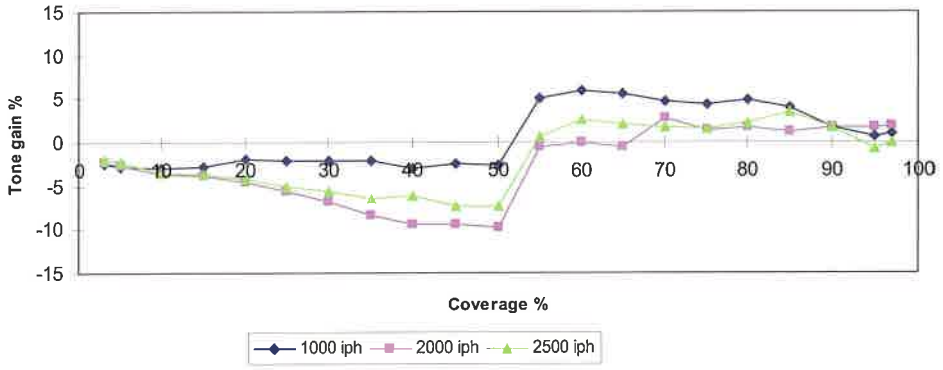


Figure 6: The effect of press speed on tone gain

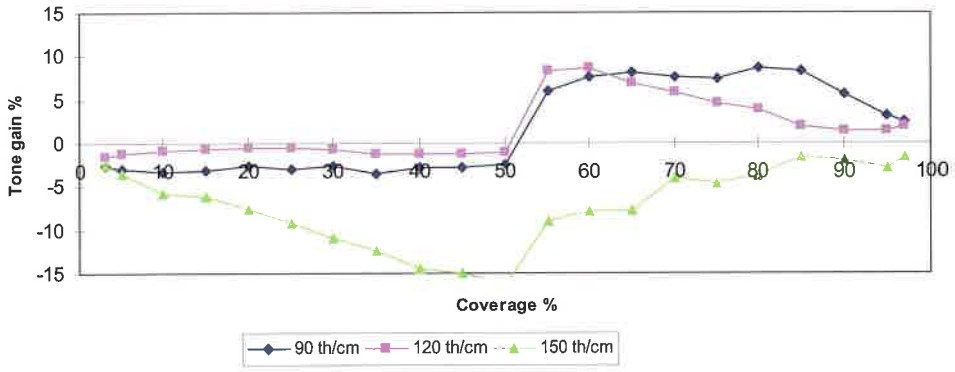


Figure 7: The effect of mesh ruling on the tone gain

Increasing the angle between the squeegee and the vertical reduced the dot loss, i.e. less ink was laid as the squeegee neared the vertical, Figure 8. The increase in ink deposit is in line with the observations of the solid density.

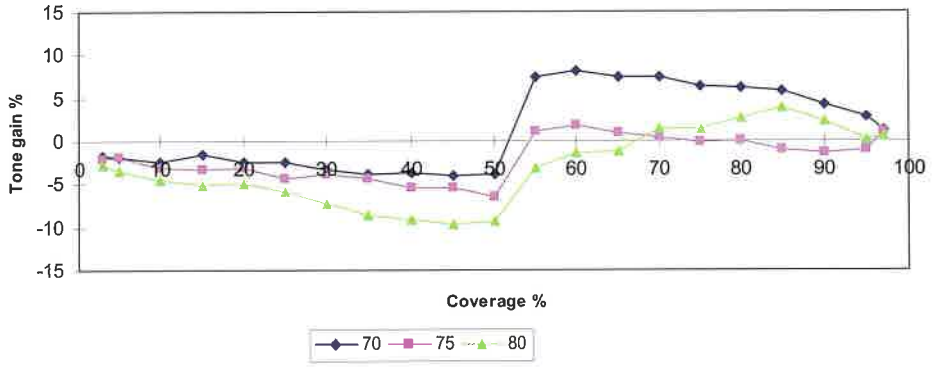


Figure 8: The effect of squeegee angle on the tone gain

The satin and gloss papers produced similar results while higher dot gain in the shadow was experienced on the matt paper, Figure 9. This can be attributed to the increased absorption and spreading of the liquid ink into the matt paper.

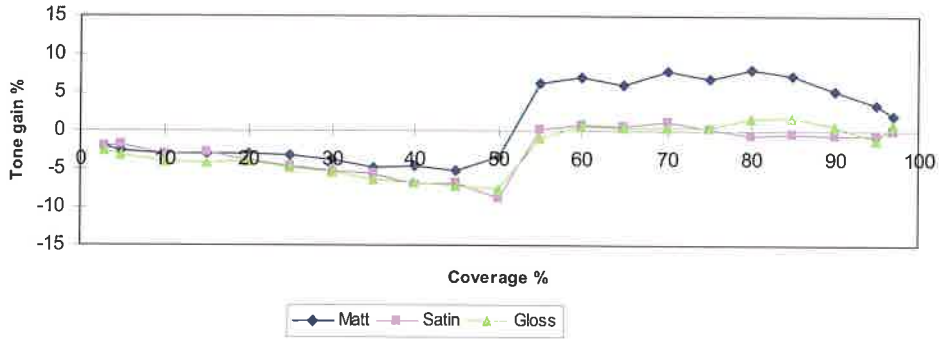


Figure 9: The effect of substrate on the tone gain

The hardness - downward squeegee pressure showed that a higher down force on a harder squeegee produced nearly the same dot gain characteristics with differences of less than 2% between the setups, Figure 10.

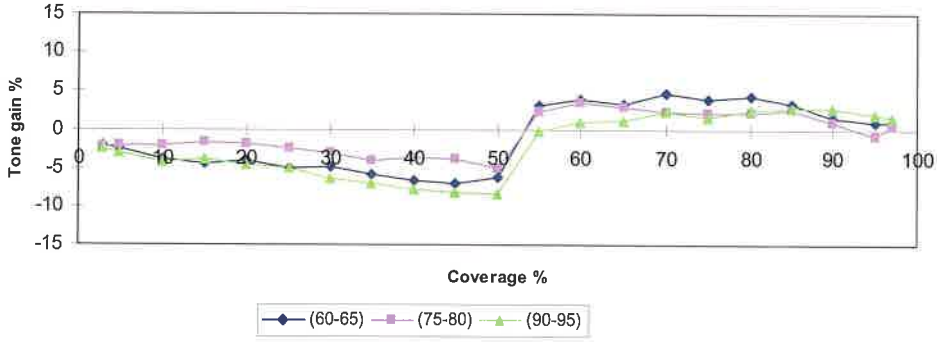


Figure 10: The effect of squeegee hardness and squeegee pressure on the tone gain

The three ink types used showed different characteristics, Figure 11, with the water based UV showing the smallest amount of loss through the highlights and mid tones and the highest gain through the shadow. The low level of gain shown by the solvent based ink is most likely as a result of "drying - in" of the ink in the mesh which reduces the available area for ink passage. This was particularly evident at the higher mesh ruling where the initial available area is smallest.

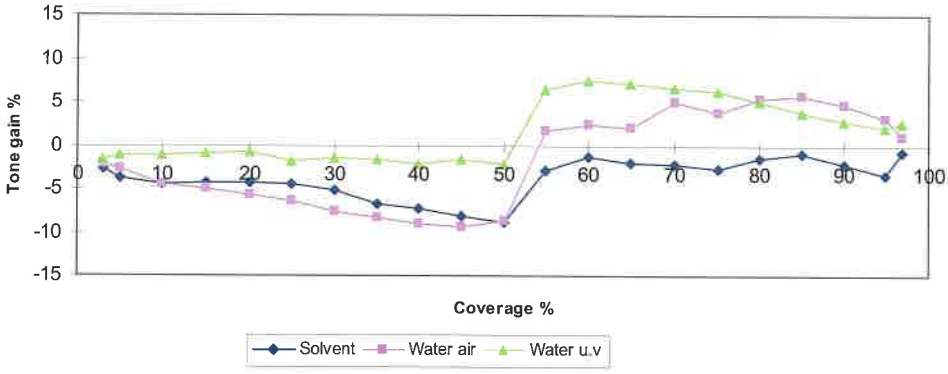


Figure 11: The effect of ink type on the tone gain for the cylinder press experiment

As postulated during the experimental design the tonal reproduction of the line and chromatic inks are almost identical, Figure 12, thus producing some validation of the experimental design.

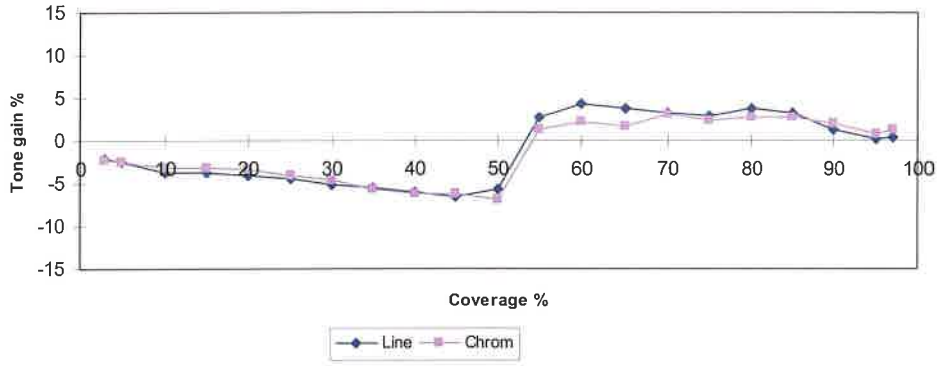


Figure 12: The effect of ink type on the tone gain for the cylinder press experiment

4. Discussion

In terms of understanding the ink transfer mechanism, there is corroborating and contrary evidence for the push and pull ink transfer theories within these results. The effect of squeegee pressure/hardness and angle suggest that the pumping action of the hydrodynamic pressure in the ink/screen nip is a strong contributory factor in ink transfer while the effect of speed is against that predicted. Similarly, the effect of speed is predicted correctly by the pull theory, but this theory ignores any squeegee effects which are clearly present and the effect of tension is incorrectly predicted. Thus, while neither is wholly successful in predicting the effect of process parameters on ink transfer, they can provide an insight into some aspects of the process physics. In order to better predict the ink transfer in screen printing (particularly where ink material costs are high) there is a need to develop a better useable theoretical model for the process. This could significantly reduce material development times, process optimisation and process control.

The almost zero effect of the ink type on the printing characteristics is a vindication of the experimental design and the procedure taken place to minimise any errors since it is the result expected. Any faults in the design or errors would tend to show an effect in column 8, irrespective of whether the parameter itself has an effect. Thus experimental design using orthogonal arrays has been proven to be a valid and practical experimental technique in printing.

The effect of the squeegee parameters should be investigated in a further experimental trials and models. This is particularly important given the regularity with which this is used to control image quality on press.

5. Closure

The primary process parameters which have an effect on the final quality of the print have been investigated in an experimental programme orthogonal array analysis. Overall, the experimental procedure has been successful yielding results which agreed corroborated some aspects and contradicted other aspects of the contemporary ink transfer models. The results also show that close control of a number of parameters is needed to ensure consistent process quality, particularly when halftone printing.

References

1. Abbott S. J, Gaskell P. H, Kapur N; "Screen-Printing: A Mathematical Model for Predicting Liquid Transfer."
2. Anderson J. T., Gethin D. T., Claypole T. C., Jewell E. H., Bohan M. F. J., Korochkina T. V. "Hydrodynamic interactions in the screen printing process", J. Prepress & Printing Technology, pp10-17, March 2000
3. W. Appleton - "High quality screen printing", published by PIRA 1995
4. Bohan M. F. J., Claypole T. C., Gethin D. T. 'The Application of Taguchi Methods to the Study of Ink Transfer in Heat Set Web Offset Printing'; 47th Annual TAGA Tech. Conf., Orlando, Florida, April 1995, pp. 513-530
5. Claypole T. C., Gethin D. T., Jewell E. H., Appleton W. J. 'Distortion of the Image by the Screen Printing Process'; Proc. TAGA, 1996, Dallas, pp. 69-85
6. Danias, J., Claypole T. C., Gethin, D. T. 'Dot Gain and Ink Transfer Behaviour in the Screen Printing Process', JOCCA, 80, 1997, pp. 222-229
7. Fox I. J., Bohan M. F. J., Claypole T. C., Gethin D. T., "Film Thickness Prediction in Half Tone Screen-Printing." Proc. Instn. Mech. Engrs. Vol.217, Part E: J. Process Mechanical Engineering, 2003
8. Huner B. - "A stokes flow analysis of the screen printing process", The international journal of the microcircuits & electronic packaging", Volume 17, Number 17, First quarter 1994
9. Huner B. - "A simplified analysis of blade coating and its application to the theory of screen printing", published by the International Society for hybrid microelectronics, June 1989
10. Jewell E. H, Claypole T. C. and Gethin D. T. - "The impact of ink rheology on the image transfer mechanism in screen printing", Institute of Non Newtonian fluid mechanics, Conference on rheometry, Miskin manor April 2003
11. Messerschmitt E; "Rheological Considerations for Screen-Printing Inks." Screen-Printing. September 1982
12. Phadake Madhav S., "Quality engineering using robust design", published by Prentice Hall International, ISBN 0-13-744723-X
13. Peyskns A.* "The fundamentals of screen printing", published by SAATI

Table I: L_{18} Orthogonal array used for analysis purposes

Exp	Column							
	Mesh tension (N)	Speed copies/ hour	Mesh ruling threads/cm	Squeegee angle degrees	Paper	Squeegee hardness - pressure	Ink[1]	Ink type[2]
1	17	1000	90	70	matt	60-65	S	C
2	17	1000	120	75	satin	75-80	W	C
3	17	1000	150	80	gloss	90-95	WUV	L
4	17	2000	90	70	satin	75-80	WUV	L
5	17	2000	120	75	gloss	90-95	S	C
6	17	2000	150	80	matt	60-65	W	C
7	17	2500	90	75	matt	90-95	W	L
8	17	2500	120	80	satin	60-65	WUV	C
9	17	2500	150	70	gloss	75-80	S	C
10	25	1000	90	80	gloss	75-80	W	C
11	25	1000	120	70	matt	90-95	WUV	C
12	25	1000	150	75	satin	60-65	S	L
13	25	2000	90	75	gloss	60-65	WUV	C
14	25	2000	120	80	matt	75-80	S	L
15	25	2000	150	70	satin	90-95	W	C
16	25	2500	90	80	satin	90-95	S	C
17	25	2500	120	70	gloss	60-65	W	L
18	25	2500	150	75	matt	75-80	WUC	C

Notes:
1. Ink: S = Solvent, W = Water based air dried and WUV = Water based UV
2. Ink Type: C = Chromatic and L = line

Table II: Standard conditions

Parameter	Value
Mesh/stencil types	Coloured polyester 90T XR 15, 120 T XR20, 150T XR15
Press type	Sakurai, Automatic Cylinder
Dot shape	Elliptical, round and square
Snap off gap	3 mm
Mesh angle	90°



Evaluation of neural networks for modelling ink transfer in the gravure printing process

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Abstract

Modelling of the ink transfer in gravure printing presents significant difficulties due to the complexity of the process. This paper outlines the development and evaluation of Artificial Neural Networks for the modelling of the ink transfer. On the basis of experimental data, models were created for the estimation of the optical density of the print as result of engraved cell geometric characteristics (specifically screen ruling, screen angle, volume).

The developed models have been shown to be accurate and reliable, being able to estimate the density within the normal human range of sensitivity to colours and outperforming more traditional modelling techniques such as polynomial regression fitting techniques.

Keywords

Gravure printing, ink transfer, neural Networks

1. Introduction

Ink transfer in the gravure printing process is an extremely complex process influenced by many interacting parameters. Development of a model of the gravure printing process, that correlates the effect of the factors to evaluate and predict the printed results, will be a major benefit. It will improve the evaluation and preparation of the printing process for a specific job, reducing waste and set-up times, allowing the exploration of different solutions.

Traditional modelling techniques rely on a detailed understanding of the physics of the process, which can be translated into relational algorithms. However in multi-interacting variable problems, establishing the detailed physics can be problematic. Neural network methods allow complex relationship to be established between input parameters and output variables [Bishop, 1995].

This paper details the development and evaluation of Neural Networks in the modelling of ink transfer in the gravure process using multivariable data obtained from experimental trials on a commercial press.

Mathematically, the development of a model can be seen as the development of a function that correlate a list of inputs with the output results, Figure 1. In the case of gravure printing, the inputs are the affecting factors, such as the cell geometry, the ink, the substrate, the process set-up and the environmental conditions; these factors are selected and set up by the printer. Outputs of the model are the printed results, such as the shape of the dot on the substrate and the obtained colour density.

The development of a gravure-printing model shows remarkable difficulties. Several studies have shown that the process is characterised by non-linear behaviour with complex interactions among the influencing factors [Bohan et al., 2000]. In addition, since only numerical values can be mathematically analysed and modelled, it is essential to describe the factors in terms of numerical quantities and, due to

their complexity, a list of measurable parameters is usually necessary to be defined for each of them, Figure 2. Furthermore, there is still a lack of knowledge in the underlying physics; for example, knowledge of the wetting process and of the effect of air bubbles in the cells is very limited.

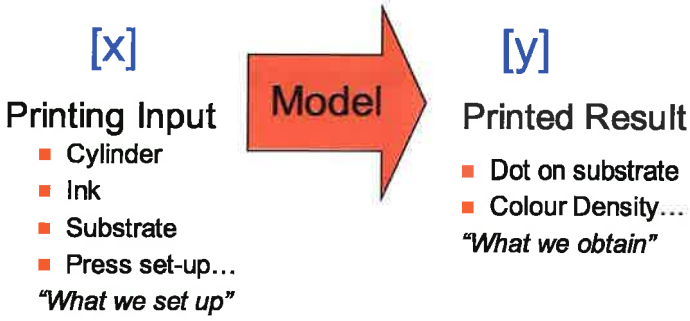


Figure 1: Gravure model

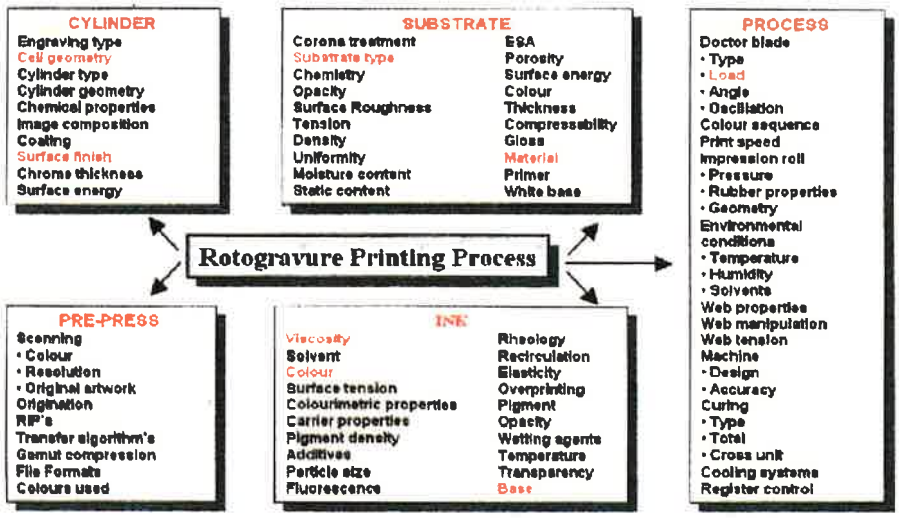


Figure 2: An extensive list of parameters that characterise the gravure process

Finally, gravure printing is subjected to noise in the process, which induces variability in the print.

All the aforementioned factors present significant difficulties in the development of a model when using traditional analytical techniques, such as polynomial fitting, since they are limited by the presence of numerous variables characterised by non-linear behaviour. Direct numerical simulation methods, such as Finite Volume Methods and Finite Elements Models, are limited by the lack of knowledge in the physics [Powell et al., 2002]. It is envisaged that these limitations may be overcome through the use of Artificial Neural Networks (ANNs).

Previous attempts to use Neural networks in the printing have dealt with manufacturing process control [Ding et al., 2004] and not with the predictive physical modelling of the process itself, hence it is proposed to evaluate their ability in modelling ink transfer in the gravure printing process.

The next section provides an overview of artificial neural networks before describing the development of an artificial neural network for the gravure process. The results from the neural network models are then assessed and compared with experiments and polynomial models.

2. Artificial Neural Networks (ANNs)

As an engineering tool, ANNs can be defined as non-linear mapping functions that seek to evaluate any relationship between some input and uncorrelated output data using statistical pattern recognition [Bishop, 1995].

ANNs "learn from experience"; meaning they adapt on the basis of the statistical data provided, improving their mapping accuracy with the increase of data presented.

They have proved to be robust to noisy, incorrect data and able to deal with complex relationship between the inputs and the outputs [Bishop, 1995] [Tarassenko, 1998]. Furthermore, since ANNs work by defining the best statistical link between the input and the output, the theoretical understanding of the problem is necessary only for an appropriate selection of inputs and outputs. On the other hand, ANNs will not provide any explanation of the system behaviour and can provide a reliable estimation only inside the range of provided data.

ANNs are composed by a net of basic units, called neurons. Neurons are connected to each other, forming different layouts. Different ANN layouts can deal with different problems. For modelling purposes, the Multilayer Perceptron feed forward layout is of particular interest, Figure 3, as it can approximate any continuous mapping with arbitrary precision [Bishop, 1995].

In this layout the neurons are organised in two layers between the inputs and the outputs: a hidden layer and an output layer. The neurons of the hidden layer are characterised by a sigmoid transfer functions while the output layer is characterised by linear transfer functions. Neurons of one layer are not connected with each other but are connected with all the neurons of the next layer.

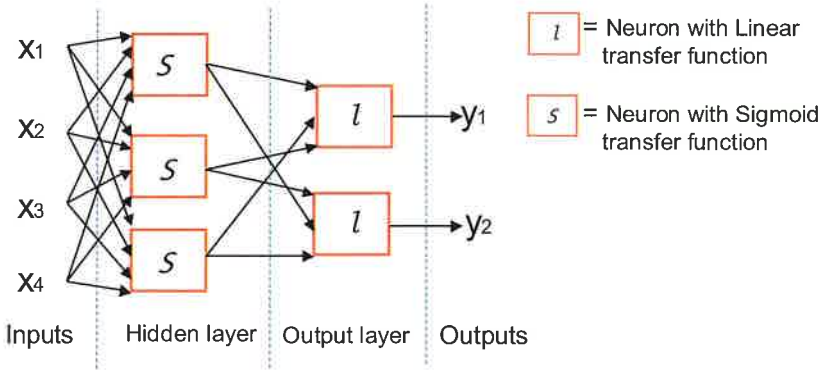


Figure 3: Multi Layer Perceptron layout

A neural network is trained on the basis of experimental data. The aim of training is the minimisation of the mismatch between the desired output and the output obtained from the network for any given input. Training is obtained by modifying iteratively the coefficients (weights and bias) inside the ANN, using a "training algorithm", until the intended minimisation is obtained. Several algorithms have been developed for the purpose, mostly based on backpropagation techniques. Due to the random initialisation of the coefficients, different training runs of the same ANNs with the same data can give different results.

A common risk in the training of the ANN is over-fitting, where the model fits noisy data too well. In order to avoid over-fitting it is a common to keep some data out of the training for a successive validation of the model. Another technique is the use of regularization algorithms, which improve the smoothness of the fit of the model output with the provided data [Demuth, 2000].

3. Development of ANNs of the Gravure process

In order to be able to evaluate the ANNs in the modelling of the ink release in the gravure process, the analysed process has to be simplified; this allows evaluating the capability of the ANNs while keeping the size of necessary experimental data reasonable. Furthermore, in this way it is also possible to easily compare the obtained results with other modelling methods.

As initial step, a print trial was carried out on an industrial press with consistent ink, substrate and printing speed. The gravure cylinder had a range of engraved cell geometries. Parameters chosen to characterise their geometry were the **screen ruling**, the **screen angle** and the **volumes**; these parameters will be the input of the model.

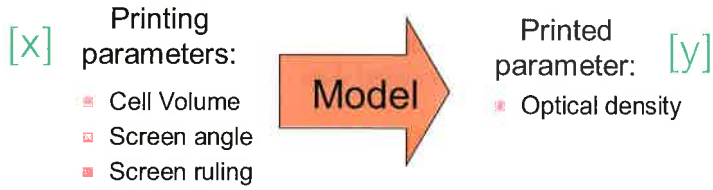


Figure 4: Inputs and output of the ANN model

The cells were mechanical engraved with a 130° stylus tool on a cylinder in consistent patches; each patch had a different combination of the three parameters. The values utilised in the modelling for screen rulings and screen angles were taken from documentation provided with the engraved cylinder; the screen ruling indicates the frequency of the cells over area and is expressed in lines/cm; the screen angle defines the shape of the cell, its aspect ratio, and is expressed in degrees. The cell volumes were measured using White Light Interferometry. Their value is expressed in cm^3/m^2.

To characterise the ink release as output of the model, the optical density was measured from the printed sheets; in fact, for a specific set of ink and substrate the obtained density is related to the quantity of ink deposited; therefore the obtained **colour density** was adopted as output value of the model.

The press trial data were composed by 99 datasets. There were 3 levels of screen ruling (60, 70, 80 l/cm) and 3 of screen angle (37°, 45°, 57°); for each of the 9 combinations, there were 11 patches of engraved cells with different values of volume; the values were chosen to obtain a full printed density range (from 0% to 100%). Each combination of volume, screen ruling and screen angle produced a colour density. These experimental data were the basis for the development of the model.

For the development of the neural network model of the ink release of the gravure process two different network designs were assessed. In both of them the selected structure is the Multilayer Perceptron feed forward layout, having the screen ruling, screen angle and the volume as input parameters and the density as output to be estimated

3.1 Levenberg-Marquardt MLP design

This design is based on a Multilayer Perceptron feed forward layout, adopting in the training the Levenberg-Marquardt back-propagation algorithm and as convergence performance factor the mean square error. This design is well established and extensively used in several fields [Tarassenko, 1998]. In this case, the design was characterised by 3 neurons with a hyperbolic tangent transfer function in the

hidden layer. This low number was chosen to reduce the complexity of the ANNs, reducing the need for large data samples and the risk of over-fitting [Demuth, 2000]. Its schematic is shown in Figure 5.

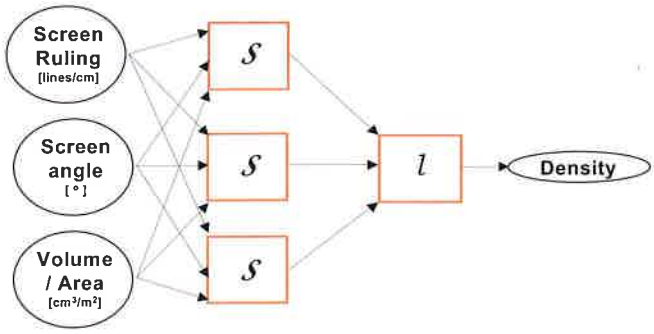


Figure 5: Schematic of the Levenberg-Marquardt MLP design

3.2 Bayesian regularisation MLP design

Again this design is based on a Multilayer Perceptron feed forward layout, but in this case Bayesian regularisation techniques are used in the training algorithm (in conjunction with Levenberg-Marquardt algorithm) and in the convergence performance. It is a more conservative approach than the previous one, in that it tends to enhance the regularisation, the smoothness, of the obtained model, strongly reducing any risk of over-fitting noisy data. For this model, 12 neurons were placed in the hidden layer with a hyperbolic tangent transfer function; large numbers of neurons are usually placed in the hidden layer, since the Bayesian regularisation techniques will statistically decide how many neurons are needed for an effective modelling of the problem [Demuth, 2000].

On the basis of the selected designs and on the experimental data, the training was executed and the ANN models of the described process created. In order to guarantee good training, avoiding over-fitting, the experimental data were divided in two parts: a "training set", used in the training of the ANN, and a "validation set", used to validate the obtained ANN. In the training of Levenberg-Marquardt design, the "validation set" was composed by 16 datasets, in the Bayesian design by only 12 datasets. In the first case, indeed, the validation set was essential since its analysis was necessary to avoid over fitting, while in the second design, regularisation techniques were implemented within.

4. Assessment of the developed ANNs models for gravure

The developed neural networks estimate density on the basis of the input parameters proposed to the network. It is important to verify the obtained models and to measure their quality.

In order to carry out this analysis a performance factor has to be selected; of the different ones available, the Root Mean Square Error ($\sqrt{MSE}$) between the actual measured values of densities and the ones predicted by the ANNs was adopted.

The mean-squared error is one of the most commonly used measures of success for numeric prediction. This value is computed by taking the average of the squared differences between each computed value and the corresponding correct value. The root mean-squared error is the square root of the mean-squared-error. The root mean-squared error gives the error value the same dimensionality as the actual and predicted values; it gives therefore a usable estimate of an average error (at least 50% confidence) of the results.

Verification for the Levenberg-Marquardt ANN and the Bayesian ANN is respectively obtained by comparing the validation sets of experimental data with the values estimated by the ANN models, Figure 6 and 7. In both cases the overlapping of the results is good with a √MSE in the estimation of the density of 0.013 in the L-M design, Figure 6, and of 0.021 in the Bayesian design, Figure 7. In both cases the calculated error was extremely low, within the normal human range of sensibility to colour density (typically 0.025 - 0.05)

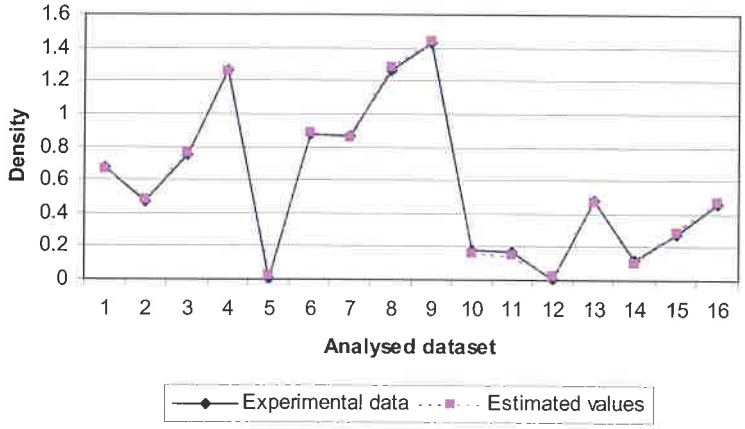


Figure 6: Validation set results in Levenberg-Marquardt design ANN

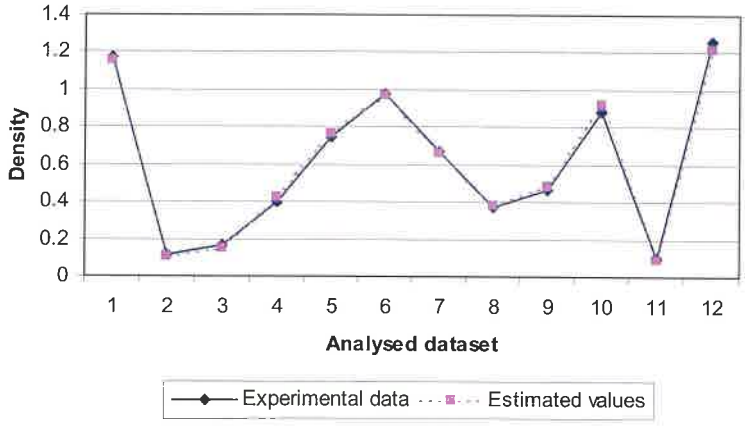


Figure 7: Validation set results in the Bayesian design ANN

In order to evaluate the overall accuracy of the developed models, all the experimental data are compared against the estimated ones by the ANNs. In both the models the results are optimal with a √MSE in the estimation of the density of 0.016 in the L-M design, Figure 8, and of 0.020 in the Bayesian design, Figure 9.

The Levenberg-Marquardt ANN model has a smaller error value; this was expected since the application of Bayesian regularisation techniques in the second model leads to a smoother fitting. The errors are anyway in both cases small. On the charts in Figure 8 and 9, the data points are displayed in ascending lines; each line represents the optical density obtained by a set of screen angle and screen ruling combination with increasing volume.

In the case of the Levenberg-Marquardt design, all the differences betweens the estimated values and the experimental one were within the range of 2*√MSE except one (dataset 49 in Figure 8). A check

of the experimental data explained the reason: the measured value for that specific set of volume was incorrect, due to residual dried ink (Figure 10). The measured value was lower than the real volume; therefore, the density estimated on its basis is correctly lower than the experimental data. This shows the robustness of the ANNs to noisy and incorrect data.

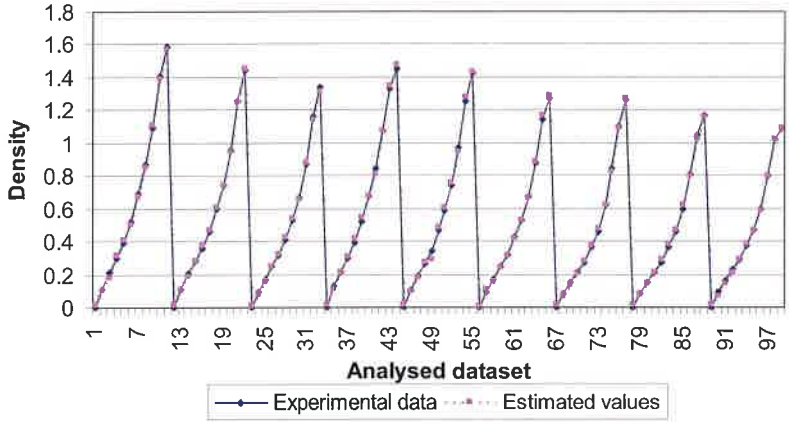


Figure 8: Results for all the data with Levenberg-Marquardt design ANN

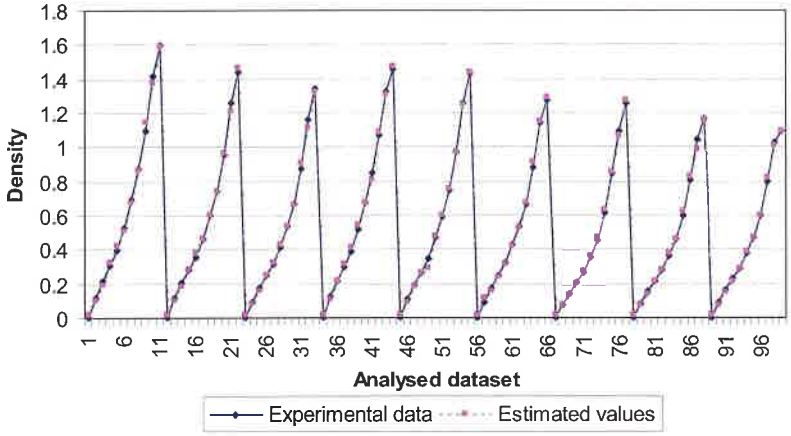


Figure 9: Results for all the data with Bayesian regularisation design ANN

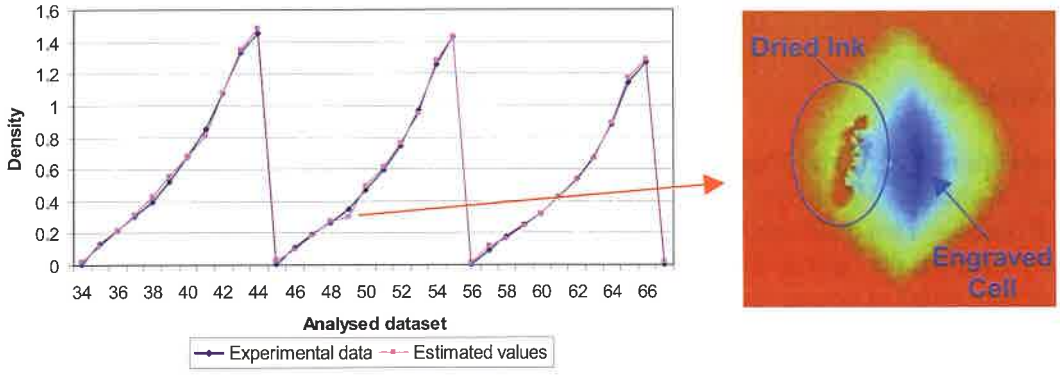


Figure 10: Residual dried ink in the engraved cells induced an incorrect volume measurement

The performances of the ANNs were compared with the classic modelling approach of least-square polynomial fitting. Following this method, a model is created defining the coefficients of a polynomial equation that best fit the provided data in a least-square mean. The basic equation of the polynomial fitting is:

$$y = a_0 + a_1x + a_2x^2 + \cdots + a_hx^h$$

For the definition of the polynomial models all the 99 datasets were used.

In Figure 11, the root mean square error (√MSE) obtained with polynomial models over increasing degrees of complexity is compared with the error calculated with the Neural Networks (using all the 99 datasets).

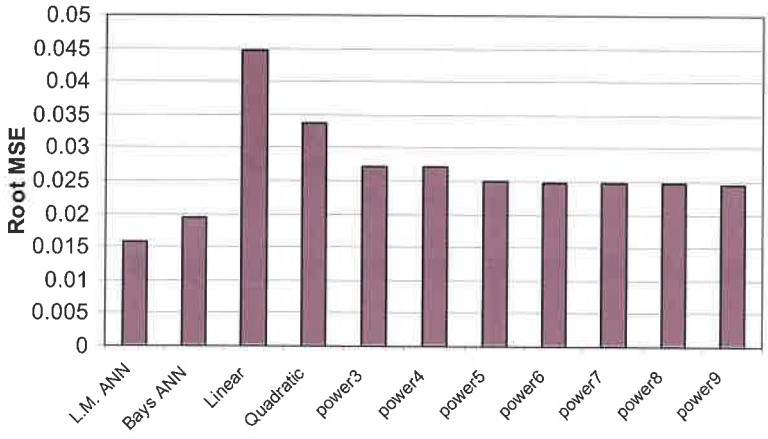


Figure 11: Root Mean square error of ANNs and polynomial models

From the chart in Figure 11, in the polynomial modelling beyond power 5 there was no benefit in increasing complexity, with a root mean square value constantly around 0.025. The results obtained by the Neural Networks are consistently better. Even the Bayesian ANN, with its conservative smooth nature gives a better fitting result with a √MSE of 0.019. The Levenberg-Marquardt ANN achieves an error of only 0.016 Since applying the root square to the MSE reduce the apparent differences between the models, comparing the MSE directly, the ANNs shows an MSE error value three times smaller than the best polynomial.

The developed ANNs fit better the analysed process than the polynomial counterparts; this is probably because they are capable of modelling the complex non-linear relationship existing between the different elements of the process.

5. Conclusions

The capabilities of Artificial Neural Networks in the modelling of ink transfer in the gravure process have been evaluated. The ANNs were shown to be able to create a reliable and accurate model of the proposed process. Two different ANNs models have been tested. In both cases the models were able to accurately estimate the optical density of the print as a result of the cell geometry variation, within the normal human range of sensitivity to colour densities.

A comparison with polynomial regression fitting techniques demonstrates that ANNs are more capable of fitting the experimental data and are able to provide lower estimation errors This provides further evidence of the presence of complex non-linear relationship between the different parameters of the process.

References

1. Bishop, C. M., 1995, Neural Networks for Pattern Recognition, Oxford University Press
2. Bohan, M. F., Claypole, T. C., Gethin, D. T, 2000, The effect of process parameters on product quality of rotogravure printing, Proc Instn Mech Engrs, Vol. 214 Part B
3. Demuth, H., Beale, M., 2000, Neural Network Toolbox User's guide, Mathworks
4. Ding, L., Bamforth, P. E., Jackson, M. R. and Parkin, R., 2004, "Fuzzy Neural Network Control for Gravure Printing'', Proceedings Control 2004, University of Bath, 6-9th September 2004
5. Powell, C. A., Savage, M. D., Guthrie, J. T., 2002, Computational simulation of the printing of newtonian liquid from a trapezoidal cavity, Int. Journ. Of Num. Meth. For heat & Fluid Flow, Vol. 12 Num 4, pp. 338-355
6. Tarassenko, L.,1998, A Guide to Neural Computing Applications, NCAF



A method to determine rotogravure ink transfer

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Abstract

A procedure based on X-Ray Fluorescence Spectrometry (XRF) was developed in order to measure ink transfer to paper during rotogravure printing. Metal components in the ink, or intentionally added tracer elements, are quantified in printed images and used in conjunction with the levels measured in unprinted ink to calculate ink on paper. XRF is accurate, significantly faster and less complicated than Inductively Coupled Mass Spectrometry (ICP-MS) for this purpose. Printing cylinders designed to study print uniformity (mottle) and ink consumption were engraved for Western Michigan University's pilot rotogravure press. Together, the new cylinders and the XRF technique form a powerful, cost-effective tool to investigate and optimize rotogravure printing. Combinations of ink properties and engraving parameters that optimized print uniformity and minimized pigment consumption were found.

1. Introduction

The highly competitive papermaking and printing industries are constantly optimizing quality and costs. It is not difficult to find examples of the latest technologies. They include fast rotogravure presses with cylinder widths exceeding 4 metres, laser engraving, high capacity paper machines with modern calenders, and new papermaking materials, in particular calcium carbonate pigments that provide cost-effective paper optics and smooth printing surfaces. There is a continuing battle between lightweight coated (LWC) and uncoated, highly filled supercalendered (SC) grades; each new development shifting the balance, favouring one or the other in specific applications. SC currently achieves 80 ISO brightness and above while maintaining high opacity, enhancing its ability to compete.

It is difficult to alter one paper property without affecting others. Brightness and opacity, for example, are only two of many paper and print quality parameters that contribute to overall printing performance, and improving them may involve structural changes that can affect ink-paper interactions [Ain, 2003]. While it is desirable to track and evaluate *all* the effects of new materials and processes on printability, costs can be prohibitive given the sheer scale of the papermaking and printing processes. As well, commercial printing situations impose a whole set of parameters (image, inks, etc.) and restrictions that may limit the scope of evaluations that can be made. Ink consumption is particularly difficult, if not impossible, to determine during short-term press trials. A testing capability, in which printing performance could be quickly and inexpensively evaluated, either "off-line" on a pilot press or in a production situation, would be a useful tool for both papermakers and printers.

In order to respond to this need, we designed a set of cylinders specifically to investigate the impacts of ink and engraving parameters on print uniformity and ink pigment consumption, and we developed a quick, relatively inexpensive and accurate method of determining ink transfer based on direct X-Ray

Fluorescence (XRF) measurements of the inked paper surface. Combining the two, we devised an experimental protocol to study rotogravure printability on Western Michigan University's (WMU) pilot scale Cerutti press. Our objectives are not simply the evaluation of paper, but investigating the interactions among paper properties and printing parameters, and optimizing them in order to achieve the best possible result.

XRF has previously been employed to measure rotogravure ink transfer [Elsayad, 1975], [Heintz and Kocman, 1996], and [Chiodi et al, 1978]. Notably, Chiodi investigated ink transfer and compared the ink demand of coated and uncoated papers. All concluded that XRF is a convenient and accurate means of measuring gravure ink on paper.

This paper describes the development and design of the new WMU cylinders and the XRF ink measurement technique. Two printing trials were conducted, providing examples of the interactions among paper, ink and engraving and how they might be optimized for best printing results. The technology is offered as a tool to papermakers and printers as a potential component of their product development programmes.

2. Equipment and procedures

Western Michigan University Pilot Press

Western Michigan University (WMU) operates a 4-colour (one paper side) pilot scale Cerutti rotogravure press, pictured in Figure 1. It is equipped with high velocity 2-zone dryers and electrostatic assist. Cylinder width is 60 cm, and it is capable of operating speeds of 7.6 m/s, although our testing was done at 5.6 m/s. While the press is not equipped with some of the advanced features found on state-of-the-art commercial presses, such as automatic measurement and control of ink properties, the authors are unaware of other facilities offering reasonable-cost press time with operating conditions comparable to those found commercially.



Figure 1: WMU Press

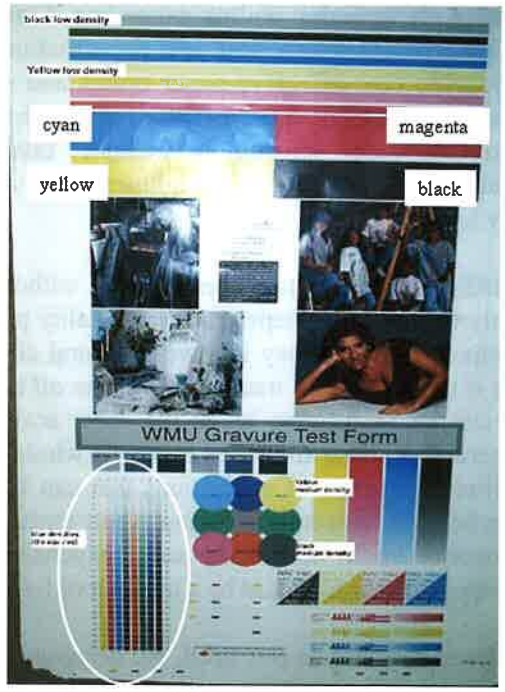


Figure 2: WMU Test Form

The image on the standard WMU test cylinders is suitable for evaluating a wide range of print quality parameters. However, our interest was in print uniformity and ink consumption, and we found that the colour density gradients (circled) were too small for those purposes. The reasons will become more apparent in the discussion of the ink measurement procedures in the following section. To facilitate our studies, we designed and engraved another set of cylinders which produced an image composed solely of 5 x 5 cm squares, Figure 3.

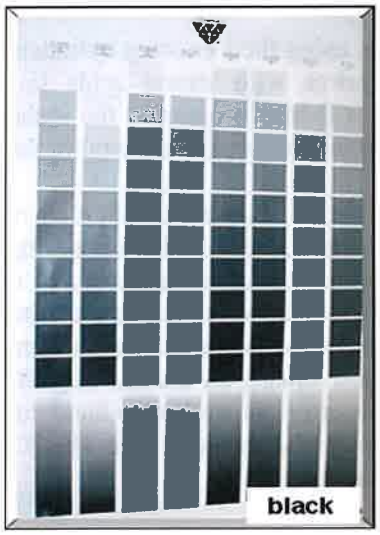


Figure 3: Black Print

We incorporated a variety of engraving parameters that are not typically found together on the same cylinders. On the black cylinder, we included "fine" and "coarse" engraving (more or fewer cells/cm), and diamond stylus engraving angles of 120°, 130° and 140°. Each printed column in Figure 3 corresponds to a specific set of parameters. The fact that all engraving conditions are together on a single print is an enormous advantage, as it completely eliminates the variation in ink properties that invariably occurs during and between press runs.

The black cylinder is printed separately from the other three colours, permitting a greater number of engraved conditions on it and on the colours. The colour (C-M-Y) print is not illustrated as it resembles the black when reproduced in black and white. It was designed using similar principles, but includes ink-on-ink as well as ink-on-paper areas, plus elongated and compressed cells on both the cyan and magenta cylinders.

Print Mottle

The PapEye [Tapio®] image analysis system was used to quantify print non-uniformity. Software detects non-uniformities from 0.17 to 10.2 mm in size in a digital image of the print, then applies a mathematical algorithm that emphasizes flaws between 0.67 and 5.1 mm, features to which the human eye is most sensitive. The result is a single number, theoretically from 0 to 100, but in our case between 5 and 10, higher indicating less uniform (more mottle). Calibration studies with printed SC paper suggest that differences of 0.3 and greater are significant to the human observer.

Ink Determination

Solvent evaporation and the inherent variability of the paper substrate severely limit the application of gravimetric methods to determine the amount of gravure ink on paper, especially if one is interested in the small differences generated by modifying ink properties or by printing different papers. In order to more accurately measure pigment consumption, we turned to spectroscopic techniques to quantify metals found in, or intentionally added to, the inks. Metals such as copper and iron may present. In

their absence, they or others such as cobalt or manganese can be added. Ink on paper is easily calculated when the amount of metal on the printed paper and the concentration of that metal in the unprinted ink are known. The spectroscopic techniques utilized are Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and X-Ray Fluorescence Spectrometry (XRF). Both can be used to determine elemental concentration, but ICP methods typically require samples in liquid form, versus solids for XRF. If the metal of interest is present in the paper, the background concentration is measured and subtracted from the printed paper results.

We began by printing trial papers on WMU's Cerutti press using their existing cylinders. Initially, ink transfer was measured by completely dissolving the prints with strong acids in a pressurized microwave digestion system, followed by analysis using ICP-MS to quantify the metal components. Ink weight on paper was determined by a calculation based on the amount of metal in the original ink.

The ICP-MS technique, while accurate, has several drawbacks. Sample preparation is complex and time consuming. It involves many steps; weighing the sample, adding the acids, digestion at high temperature and pressure, filtration, dilution to known volume, aliquot removal, and the addition of internal standards. Plus, for every analytical run, a set of calibration standards must be prepared and analyzed. Each step must be carefully executed to minimize the potential for contamination and to maximize accuracy. Lastly, the dimensions of each printed square on the existing WMU cylinders were only 8 x 8 mm. This presents another opportunity for error, as we had to hand cut and combine prints from consecutive copies in order to obtain sufficient metal for detection. The ICP-MS method did generate good data but a faster and simpler method was desired.

The new printing cylinders produced a much larger printed area for analysis and a specimen that was much easier to cut to an exact known size. We purchased a precision punch for this purpose. Accuracy with the ICP-MS improved. The larger prints also provided the opportunity to determine if metal content could be measured using X-ray Fluorescence Spectrometry (XRF). Our instrument is a PANalytical (formerly Philips) PW 2400 3 kilowatt Wavelength Dispersive XRF spectrometer fitted with LiF200, LiF220, PET, Ge, PX-1 (57Å) and PX-3 (20Å) analyzer crystals, a rhodium ULET end window X-ray tube, scintillation, flow proportional (P-10) and sealed xenon detectors, a variety of tube filters, a choice of 3 collimators and masks, and a 108 position sample changer. Stainless steel sample holders with aperture sizes of 37 mm and 27 mm are available for specimen presentation. The maximum sample diameter is large, 50 mm, which allowed us to fully utilize the surface area of the larger prints.

To determine if the XRF instrument has sufficient sensitivity to detect the elements of interest, full spectrum wavelength scans were performed on series of WMU prints that had been previously analyzed by the ICP-MS method. The inks were a commercial cyan, containing copper phthalocyanine blue, and black, magenta, and yellow doped with tracer elements (Co, Mn, and Zr respectively). Approximately 45 mm circles were cut from the prints and placed printed side down in a sample holder with a 37 mm aperture. The paper was secured using the plastic centering rings supplied with the sample holders. Comparisons were made to unprinted paper, and 50% and 100% prints. In all cases, it was clear that the XRF instrument is sufficiently sensitive to differentiate the ink coverage by measuring the metal content. Because the specimens are only 50 μm thick, there was concern about interference from backscattered radiation from the holders. This was only evident for Fe and was easily resolved using a liner fabricated from heavy duty aluminum foil.

Since XRF is a comparative technique, calibration standards are required to establish a relationship between the measured X-ray intensity and elemental concentration. We will discuss results with copper in the cyan ink, but found that the technique is equally applicable with the other metals. A group of prints and unprinted paper samples from a prior WMU trial (using the newly designed cylinders) that had already been analyzed by ICP-MS for Cu content was used for this purpose. The units of measure were μg Cu per cm^2 paper which allowed the direct calculation of g/m^2 ink on paper once the Cu concentration of the ink was determined.

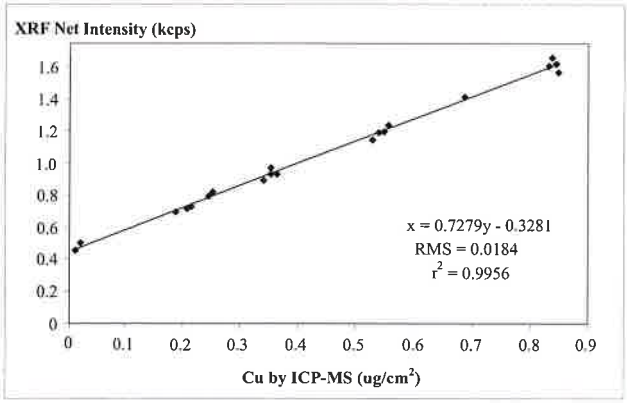


Figure 4: XRF Calibration with ICP-MS

Wavelength Dispersive XRF spectrometers are extremely stable and, once calibrated, the relationship between intensity and concentration can be maintained for years. In addition to the instrument controls already in place, we used a commercial 0.2 μm polypropylene filter known to be Cu free and a glass disc containing about 5000 ppm Cu for analysis quality control. The instrument was set up to use the Cu K-L3 (Kα) line with linear background subtraction at ± 0.5° 2Θ using a LiF 200 crystal , 60 kV 50 mA excitation, 100 second peak count time, 16 second count time on each background point, a 200 μm Al tube filter, a 37 mm aperture mask, 150 μm collimation, and the sample spinner on. The results were excellent, as illustrated by the graph in Figure 4 showing the relationship between X-ray intensity and the amount of copper in the print as determined by ICP-MS. The copper contents calculated using the X-ray intensity and the regression equation are listed in Table I, along with the differences between the calculated and measured values.

Table I: XRF Cu Calibration Data

	Cu (μg/cm^2)		
Sample	Given	Calculated	Difference
16390-00000	0.010	0.005	-0.005
16379-00020	0.208	0.192	-0.016
16379-00021	0.246	0.248	0.002
16379-00022	0.353	0.350	-0.003
16379-00023	0.549	0.540	-0.009
16379-00024	0.686	0.699	0.013
16379-00025	0.844	0.851	0.007
16390-00003	0.020	0.038	0.018
16381-00018	0.252	0.267	0.015
16381-00019	0.353	0.375	0.022
16381-00020	0.555	0.569	0.014
16381-00022	0.837	0.876	0.039
16379-00026	0.187	0.178	-0.009
16379-00028	0.340	0.321	-0.019
16379-00029	0.529	0.507	-0.022
16379-00031	0.848	0.811	-0.037
16381-00023	0.215	0.201	-0.014
16381-00025	0.364	0.348	-0.016
16381-00026	0.539	0.540	0.001
16381-00028	0.831	0.838	0.007

XRF sample preparation was further simplified at this point through the use of a commercially available 5 cm manual fabric punch.

Repeatability and reproducibility of the XRF method was evaluated using two sets of test prints from this trial. Each set consisted of ten levels of ink coverage from 5% - 100%. One set was on SC paper filled with PCC and the other on paper filled with clay. Three replicate prints from each set were measured by XRF. Each set was measured twice, separated by 8 - 16 hours. There were no statistically significant differences detected between the two paper types or between the replicate prints. An example of the results is shown in Table II. The overall uncertainty at 95% confidence was calculated from the calibration and repeatability/reproducibility data, and is 0.03 μg Cu/cm^2 paper.

Table II: Example of XRF Repeatbility Data

	First measured			Re-measured		
Print	Avg. (n=3) Cu μg/cm^2	Standard Deviation	3sigma	Avg. (n=3) Cu μg/cm^2	Standard Deviation	3sigma
5%	0.05	0.002	0.005	0.05	0.003	0.008
15%	0.13	0.001	0.002	0.13	0.003	0.008
25%	0.20	0.002	0.005	0.20	0.001	0.002
35%	0.25	0.003	0.008	0.25	0.002	0.005
50%	0.35	0.004	0.011	0.35	0.005	0.014
65%	0.47	0.003	0.008	0.47	0.006	0.019
75%	0.56	0.001	0.003	0.56	0.002	0.005
85%	0.70	0.001	0.003	0.70	0.006	0.017
95%	0.84	0.005	0.014	0.84	0.001	0.003
100%	0.85	0.006	0.018	0.85	0.001	0.002

To further validate XRF method, an offset ink was formulated to contain the same copper pigment as the WMU cyan ink. This allowed us to compare the ICP-MS and XRF techniques to traditional gravimetric ink transfer obtained from a laboratory Prüfbau press. After weighing the Prüfbau prints to determine ink transfer, each was carefully cut into four uniform 37 mm squares, two for ICP-MS analysis and the other two for XRF. The squares were too small for the XRF sample holders so a second XRF calibration was established using sample holders having a 27 mm aperture. The agreements of the XRF and ICP-MS to the gravimetric results were good, Table III and Figure 5. The ICP-MS and XRF are the average of 2 squares each, and all results include subtraction of blank paper Cu content.

We believe that the slightly higher variability of the gravimetric results compared to the XRF and ICP-MS is a result of non-uniformity of ink application. However, we did not feel it necessary to look into it further as the correlations are still excellent. The quality of the correlations suggests that the spectroscopic techniques could be applied to offset as well as gravure printing.

The results clearly show the suitability of the XRF method. While ICP-MS measurements are still necessary for calibration and validation, XRF spectrometry provided high speed analysis for comparing ink transfer under variable printing conditions using the newly designed cylinders.

The process used to calibrate the XRF for Cu was replicated for a printing trial at WMU (following section) using black ink treated with a Co tracer. A single analytical run on the ICP-MS, including ten samples and the ink was required. Again, excellent results were obtained. For this trial, the XRF method provided results for 530 prints in less than a man-week where only 24 - 36 results could have been provided by ICP-MS, 20 times the productivity.

Table III

	Ink on Paper (g/m^2)		
Sample	Prüfbau	ICP-MS	XRF
M1	3.05	3.01	3.01
M2	2.59	2.73	2.68
M3	2.23	2.35	2.35
M4	1.88	2.08	2.02
M6	3.50	3.48	3.45
M7	3.07	3.06	3.02
M8	2.71	2.79	2.64
M9	2.37	2.41	2.35
D1	3.08	2.86	2.87
D2	2.71	2.60	2.59
D3	2.35	2.26	2.28
D4	2.03	1.97	2.01
D6	3.33	3.26	3.36
D7	2.92	2.91	2.92
D8	2.55	2.59	2.56
D9	2.13	2.19	2.20

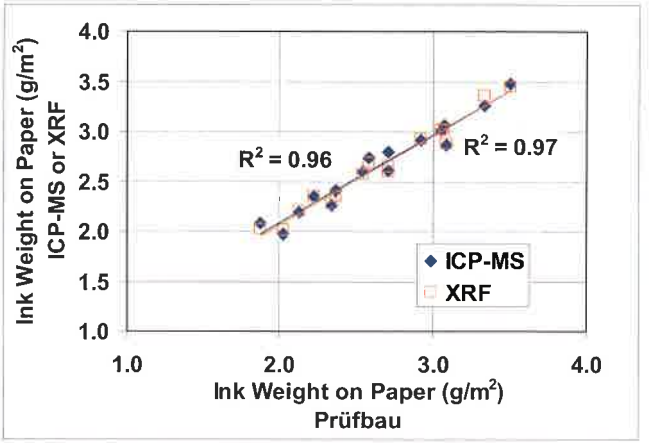


Figure 5: Correlations with Gravimetric Technique

3. WMU Trial Results

A trial was conducted on the Western Michigan University (WMU) pilot gravure press, with a small amount of cobalt tracer added to a standard black "SC" ink made by Flint Ink. Three commercial papers were printed, including uncoated supercalendered "SC" containing either precipitated calcium carbonate (PCC) or clay filler, and a lightweight coated "LWC" sheet. They were selected for this initial experiment because they are typical of these grades. Paper brightness and gloss were similar, with the exception of the SC made with PCC which had about 5 points lower gloss than the others. For this reason we express gloss as "snap", printed minus paper gloss.

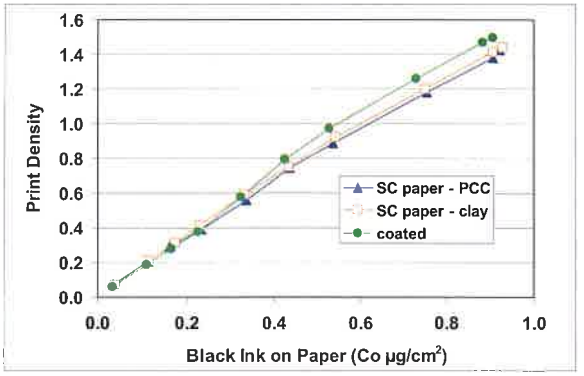


Figure 6: Print Density

We followed the procedures outlined in the previous section in order to determine ink on paper, for comparison to other printability parameters such as print density, gloss, mottle, etc. Here, we will discuss just a small fraction of the results generated by the trial in order to demonstrate the technology and how

it might be implemented. Ink on paper is expressed as µg cobalt per cm^2 paper because the experiment was devised so that cobalt was in constant relative proportion to ink pigment throughout the testing (a further simplification of the test procedure). i.e. the amount of cobalt is directly proportional to the weight of ink pigment on the prints, regardless of the paper. As a point of reference, a 50% dot corresponds to about 0.6 print density.

It is interesting that, at low ink levels, print density and snap for the LWC sheet remain close to the levels achieved by the SC papers, Figures 6 and 7. However, LWC begins to pull away as coverage increases above approximately 50%. This suggests that at least some of the advantages of LWC are realized only at higher ink levels, knowledge that might be used as criteria in deciding which grade to purchase for a particular print job. That is, there may be little advantage in using more costly LWC if a job consisted of mostly text or light halftones. Printed solids on LWC required about 10% less ink, and LWC achieved 0.1 higher peak density with the same amount of ink as SC. Print uniformity, measured by the PapEye, was better with the coated, Figure 8. The number on the x-axis refers to the engraving pattern used for each column, numbered 1 through 8 from left to right, on the black cylinder.

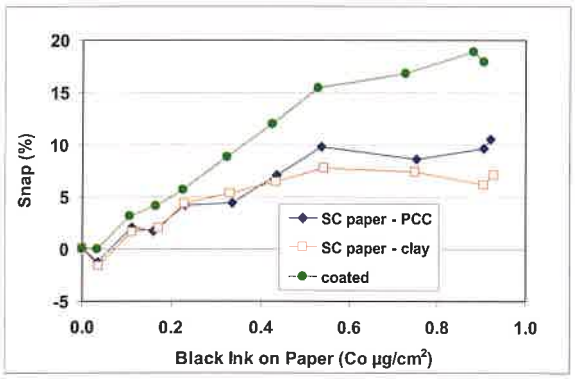


Figure 7: Snap (print - paper gloss)

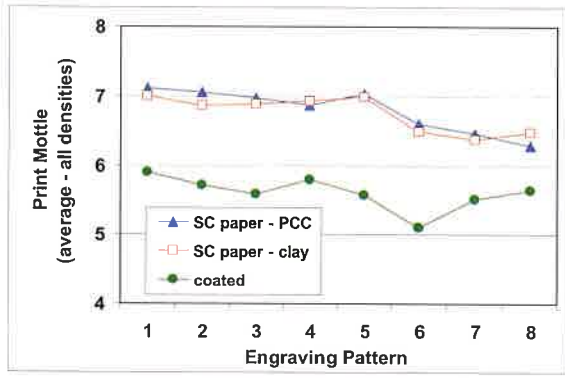


Figure 8: PapEye Mid-tone Print Mottle

We found that it is relatively straightforward to improve mid-tone uniformity by reducing ink viscosity, reducing the ink pigment to extender ratio, or with more engraved cells per cm. These are well known to printers. However, there are competing effects that limit pressroom capability to implement them. For example, while they might improve print uniformity, all tend to make it more difficult to achieve solid density. It is our objective to find combinations of paper, ink properties and engraving parameters that reduce mottle *without* penalties in solid density or ink mileage. Following are two examples from our results illustrating how this might be achieved.

We ran three ink strengths, reflected by the ink concentrate (pigment) to extender ratio, on a single SC web. Figure 9 illustrates the print mottle achieved by the high and medium pigment levels. Engraving patterns 1 and 4 are 89 and 100 cells per cm respectively, with a 130° diamond stylus, fairly typical of the industry. Both the "finer" engraving and lower pigment concentration improved print uniformity, but the question is, "What happened to print density and ink mileage?" These are illustrated in Figure 10. At equivalent pigment consumption, the lower pigment ratio was more effective in achieving print density. So, this combination of "weaker" ink and "coarser" engraving achieved equivalent print uniformity with less pigment.

A further example of how good print uniformity might be achieved while maintaining or even improving ink (pigment) consumption is depicted by Figures 11 and 12. A 120° diamond stylus (engraving pattern 6) produced a more uniform print while maintaining print density, even increasing the maximum that could be achieved. Unfortunately, diamond life would tend to suffer with the narrower diamond. However, if an improvement in print quality could be established, moving in this

direction might be acceptable in some circumstances. If the reader is curious, engraving patterns 7 and 8 involve a 140° diamond. Print uniformity was good (and was even better with the lowest concentration ink), but we were not able to achieve solid print density with the shallow cells produced by the wider diamond, even with the highest pigment concentration.

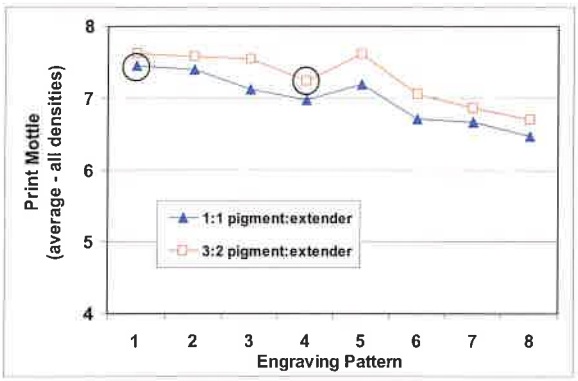


Figure 9: Mid-tone Mottle and Ink Concentration

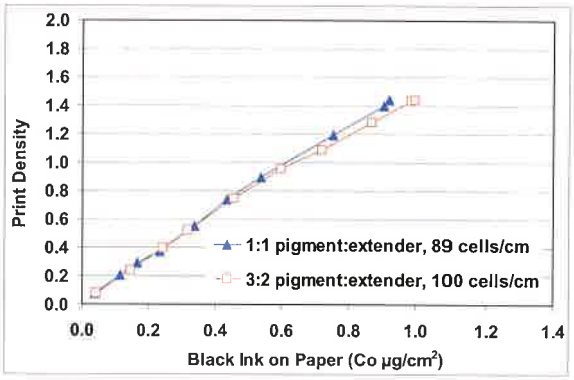


Figure 10: Print Density and Ink Concentration

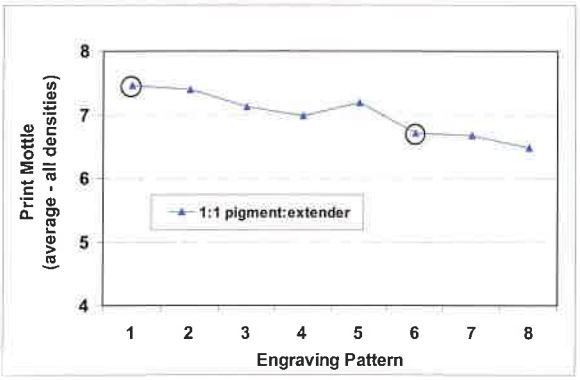


Figure 11: Engraving and Mid-tone Mottle

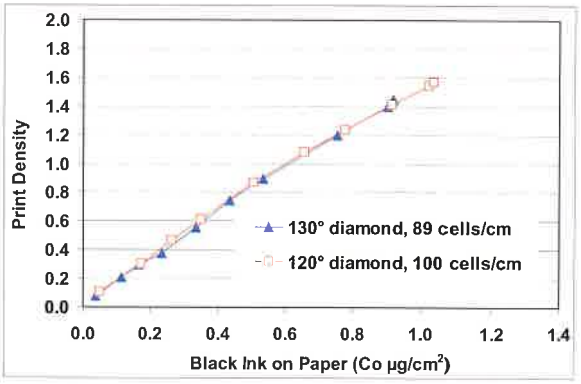


Figure 12: Print Density, 1:1 pigment:extender

4. Conclusions

X-Ray Fluorescence Spectrometry (XRF) provides a fast and accurate means of determining rotogravure, and potentially offset, ink transfer. It is a significant improvement over the ICP-MS method because it produces equivalent results with significantly less sample preparation and is an order of magnitude faster.

The combination of XRF and the newly engraved cylinders for Western Michigan University's Cerutti press, provides a convenient way to investigate and optimize the paper, ink and press parameters involved in rotogravure print quality and ink consumption.

Using these techniques it may be possible to improve print uniformity while maintaining or even reducing ink (pigment) consumption.

Traditionally, the paper grade structure is defined in terms of easily-measured paper properties such as brightness, smoothness and gloss. By better understanding the fundamental parameters that impact and determine the printing outcome, it should be possible to more easily distinguish among different grades and papers, and to evaluate and improve performance and costs.

Acknowledgements

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References

1. Ain, R. and Stevens, S. 2003, Offset Printing with Wood-Containing, Filled, Alkaline Supercalendered Paper, Pulp and Paper Canada 104:12 (2003), 88 - 92, December 2003
2. Elsayad, S. 1975, Gravure Ink-Paper Relationship, American Ink Maker, 55 - 62 and 101 - 103, February 1975
3. Heintz, H. U. and Kocman, V. 1992, The Measurement of Printed Ink Film Thickness by X-ray Fluorescence, Proceedings of the 1992 International Printing and Graphic Arts Conference, 172 - 177
4. Chiodi et al 1978, Heliogravure - Mesure de la consummation d'encre, Revue A.T.I.P. vol. 32 no. 10, 404 - 412, Decembre 1978
5. Tapio® PapEye modular analyzer-software for paper surfaces, www.tapiotechnologies.fi

Effect of viscosity on ink transfer in gravure printing

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Abstract

Ink viscosity is a significant process parameter in gravure printing. An experimental study has been undertaken on the effect of viscosity on ink transfer using a production gravure press. A bespoke test image was printed operated under closely controlled conditions to allow a detailed evaluation of the effect of changes in ink viscosity for several cell geometries on tone gain, colour gamut and over printing of half tones.

As well as graduated half tone scales and over prints, a sub set of the SCID image was used to evaluate ink transfer. The SCID image is designed essential for fingerprinting of printing devices and although it contains many combinations of half tones, it can be difficult to extract information with regard to the fundamental physics of the process. A novel approach based on ordering in terms of hue and lightness was used to obtained information from this part of the image.

These results highlight the importance of viscosity on the application of the ink film during the gravure print process. Both solid and tonal reproduction was found to be sensitive to change in viscosity with the largest effect observed with tonal reproduction. Reduction in viscosity produces an increase in tone gain, which is more significant for the half tones than the solids. This can be attributed to the cell geometry in the direction of printing as the effects are related to the relaxation time of the ink in the cell after doctoring and before printing.

1. Introduction

Ink properties and engraved cell geometry have a significant effect on the ink transfer and subsequent quality of the gravure printed product. Although previous work[1] has highlighted the need for close control of viscosity, there is a dirth of published systematic investigation of the effect of viscosity on ink transfer and its relationship with cell geometry. Laboratory based work performed by Werner Kunz[2] indicated ink viscosity and cell geometry had significant roles on the ink transfer in the gravure process. As the doctor blade wiped the cylinder the ink meniscus was found to be dragged back in a wave on the trailing edge of the cell after which it relaxed back to fill the cell. The speed of relaxation was dependent on the engraving method and the ink viscosity. This results in reduced contact between the ink and substrate in the nip, producing a printed cell with a section missing, the classic "donut print". The ink viscosity was also found to have an operational window out side of which problems occurred and that the viscosity of the ink could be affected by temperature. He also concluded based on a visual comparison between proof prints and a production run that there were differences attributed to speed, however the differences could be "restrictively bridged by optimal viscosity". Debora R Jeske[3] who simulated a gravure printing nip with an impulse press found that the ink transfer increases with reduced ink viscosity. More recent investigations have been performed on production machines under controlled conditions. M. F. J. Bohan et al[4] also found variations in ink viscosity had a significant non linear affect on print quality/colour reproduction.

The published literature points to ink viscosity being a significant parameter in gravure printing, affecting both ink transfer and image quality. This paper reports an experimental investigation on the effect of viscosity on a six-colour Schiavi Concord rotogravure web fed printing press operating with a typical production speed of 3.3 m/s with inter station drying and a web width of up to 1120 mm. This

packaging press was operated under closely controlled conditions to allow a detailed evaluation of changes in ink viscosity for several cell geometries. This study is part of a long term investigation of gravure printing both in the laboratory and on full scale production presses.

2. Experiment

Four colour process cylinders were manufactured for the experimental trial. The cylinder set provided one image per cylinder revolution (Figure 1). The test sheet was subdivided into areas for assessment of different quality characteristics. Density and tone gain information was derived from the graduated scales (area B) in both the print direction and across the width of the web. Maximum gamut and trap were assessed using the calibration squares (area C). The printed patches assessed were the 100% solid single colour for yellow, magenta and cyan and the 100% two colour over prints of magenta on cyan (violet), yellow on magenta (red) and yellow on cyan (green). A subset of the Standard Colour Image Data (SCID)[5] tonal patches (area D) normally used for colorimetric characterisation of printing processes were used to provide colour information for tonal overprints of the four process colours. In addition, area A contained information on two colour separation methods one with and one without under colour removal for subjective visual analysis. Area E was for evaluation of line and text sharpness, i.e. print sharpness. These print attributes have yet to be assessed.

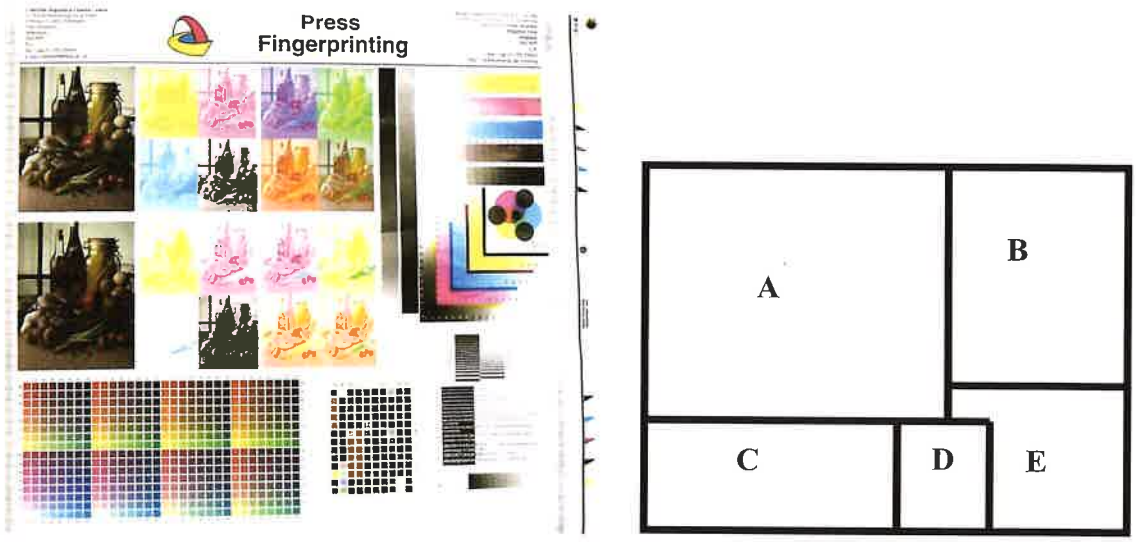


Figure 1: Representation of the test image printed during the trial

The depth of the engraved cell and the number of cells per unit area will govern the amount of ink available for transfer. To avoid screen induced moiré' effects different cell shapes are engraved on the cylinders for each of the process colours (Figure 2). In addition to achieve the full tonal range, the distribution and size of the cells alter as the percentage of the tone decreases. Thus the image contains both different cell sizes as well as geometries for each ink.

The four colour process liquid inks used in the trial were nitro-cellulose resin based with ethanol and ethyl acetate solvents. The typical operating viscosity for this approximately Newtonian ink was approximately 0.0380 Pas. In this trial the viscosity was reduced in stages from its normal level of 0.038 to 0.0255 and 0.006 Pas. An 80 gsm coated one-side paper was used during the trial. All other settings such as doctor blade, pressure angle, pressure roller settings and electrostatic assist were kept constant at normal settings. The temperature of the ink was also measured and found to be consistent at 21 ± 1°C for all inks.

Colour	Cell Orientation	Comments
Yellow		*Normal course cut cell* *45 degree cell*
Magenta		*Elongated cell* *60 degree cell*
Cyan		*Compressed cell* *30 degree cell*
Black		*Normal fine cut cell* *45 degree cut*

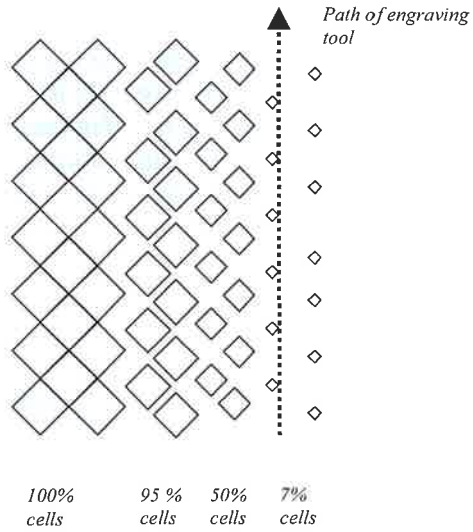


Figure 2: Schematic of the cell orientation for the process colours and engravings for different tone weights

Previous experimental work[4] had shown that a minimum of 30 consecutive samples are required to obtain statistically repeatable measurements and therefore in this case a sample size of 32 data sets was chosen. 34 print repeat images were cut to produce individual test sheets that were measured using a Gretag Spectrolino. The first 32 of the 34 results of each experiment were examined, statistically, to exclude erroneous data points. Initially the mean and standard deviation were calculated and then a first sweep method was used to highlight all data outside 2 standard deviations from the overall mean. Such points were located and examined physically to establish a reason for the variation. Most variations were a result of missing dots or ink splashing, however for some variation there appeared to be no visible cause. All erroneous data and defective points on the print, including those with no visible cause, were replaced by corresponding data from either test sheets 33 or 34. An average result was then calculated from the 32 data sets.

3. Results

The measurement of density for the full tonal range gives a direct comparison of the ink transfer from different engravings. (Figure 3). The effect of changing viscosity by adding solvent is different for the % half tone and each ink. For the yellow print, when the ink viscosity is reduced the density increases for tonal values between 25% to 80 %. Above tonal values of 80% the density is the highest for the ink viscosity of 0.0255 Pas followed by ink viscosity of 0.0380 Pas and then ink viscosity of 0.006 Pas. For the magenta print, when the ink viscosity is reduced density increases for tonal values up to 70%. Above tonal values of 70% the density is the highest for the ink viscosity of 0.0255 Pas followed by ink viscosity of 0.0380 Pas and then ink viscosity of 0.006 Pas. For the black and cyan print, when the ink viscosity is reduced, there is little difference in the density for tone values up to 60%. Above tone values of 60% as the viscosity decreases the density decreases.

The yellow and magenta inks exhibit different printed density characteristics than the black and cyan print. When viscosity is reduced a corresponding decrease in the density would be expected over the whole tonal range, for each of the process colours. However, for black and cyan below 70% tone value there appeared to be little change in density with change in viscosity whilst yellow and magenta showed an increase in density as the viscosity decreased. As solvent is added to liquid ink, a decrease in the pigment ratio occurs so that when the ink is transferred a coating containing less pigment is applied.

The differences in density between each colour at a tonal value of 100% may be a result of the interaction between the different viscosity inks and their respective cell patterns, producing different release characteristics. The density of the yellow and magenta remains relatively constant whilst that of the black and cyan falls as the viscosity is reduced. For the yellow and magenta this could be explained if there was an increase in wet film thickness as viscosity falls, this would maintain the same dry film thickness therefore counteracting the lower pigment loading. This suggests that's there is a better ink release from the yellow and magenta cells than from the black and cyan as the viscosity falls.

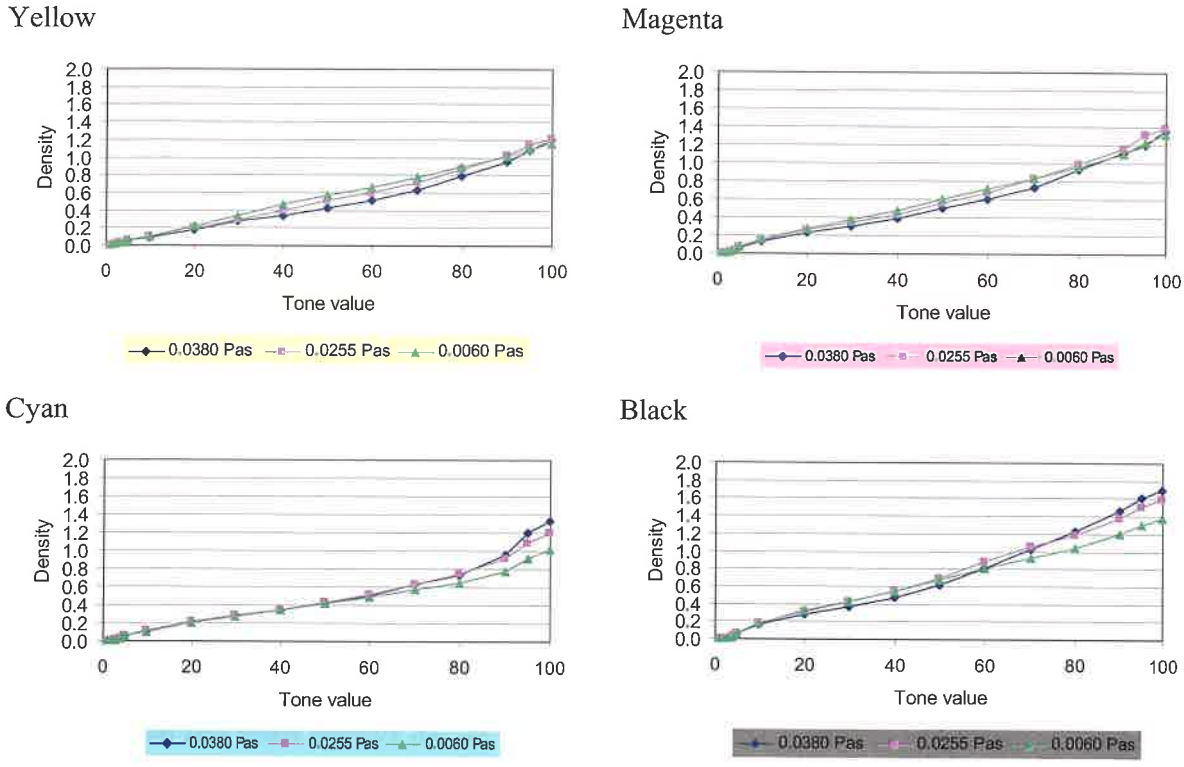


Figure 3: Density readings for the process ink at viscosities of 0.380, 0.0255 & 0.0060 Pas

Despite the reduction in pigment load due to the dilution of the ink by the solvent to reduce its viscosity, the density of the half tones increases. A falling viscosity produces an increase in the dot area (Figure 4). The absorption of light does not increase in proportion to the ink film thickness. Therefore, as the pigment is distributed in a thin layer over a wider area the amount of light reflected is reduced and the density increases. The printed cyan ink dots, at 0.006 Pas are better defined than those of the magenta ink dots. This is in agreement with the data obtained for the density curves that show a larger difference in the magenta when compared to cyan. At the high tonal regions of 90% and above, the printed dots are touching for all viscosities. Changes in density at high coverages are related to changes in pigment loading and volume of ink transfered.

Comparison of the tonal reproduction curves (Figure 5), which are taken with respect to the 100% solid, compensates for the changing pigment load with viscosity and allows the evaluation of the interaction of the viscosity with the cell size and geometry. When the viscosity is reduced the tone gain increases for all tonal values with the largest effect seen in the mid tones between 20% and 80%. The largest change is seen on the yellow print followed by the magenta and then black, for the cyan the change is very small.

The effect of ink viscosity on ink transfer on to a previously printed ink film was investigated by measuring the two-colour trap of yellow on cyan (green), yellow on magenta (red) and magenta on cyan (violet), (Figure 6).



50% tone print of magenta ink at 5.00 m/s a viscosity of 0.0380 Pas



50% tone print of magenta ink at 5.00 m/s a viscosity of 0.006 Pas



50% tone print of cyan ink at 5.00 m/s a viscosity of 0.0380 Pas



50% tone print of cyan ink at 5.00 m/s a viscosity of 0.006

Figure 4: Image processing photographs demonstrating tone gain with reduction in viscosity and their corresponding measured density values

There is little effect on the over print of yellow on cyan and magenta on cyan when the ink viscosity is reduced. The density for yellow and magenta as individual colours do not alter significantly as viscosity falls. However, the trap value for the red increases, indicating as the ink viscosity is reduced that the amount of yellow ink transferred, in proportion to the magenta, increases. Yet the green shows no marked increase and therefore the increase in trap of yellow on magenta is not a function of density but due to an interaction between the yellow and the magenta inks.

The neutral grey gradation bar is produced from printing different percentages of process yellow, magenta and cyan to reproduce a tone of grey - a grey balance. It is printed as a combination of both side by side and overprinted dots of the three process colours. Little difference was found between the density obtained for the reproduction when printed with inks of 0.0380, 0.0255 and 0.006 Pas for tonal values up to 70%. After 70% tonal values the 0.380 and 0.0255 Pas prints show little density difference however the density is reduced when the ink viscosity is reduced to 0.006 Pas. There was also little change in the tone gain as the viscosity of the process inks are reduced, which were similar in shape to those of the cyan for the same parameters.

The affect of viscosity on colour reproduction was evaluated by investigating the maximum achievable colour gamut by printing and over printing the single and two colour combinations of yellow, magenta and cyan. The a* b* values for each measurement were plotted to show the colour gamut, with the change in L* values and the ΔE for the change in viscosity shown as a separate bar charts (Figure 7).

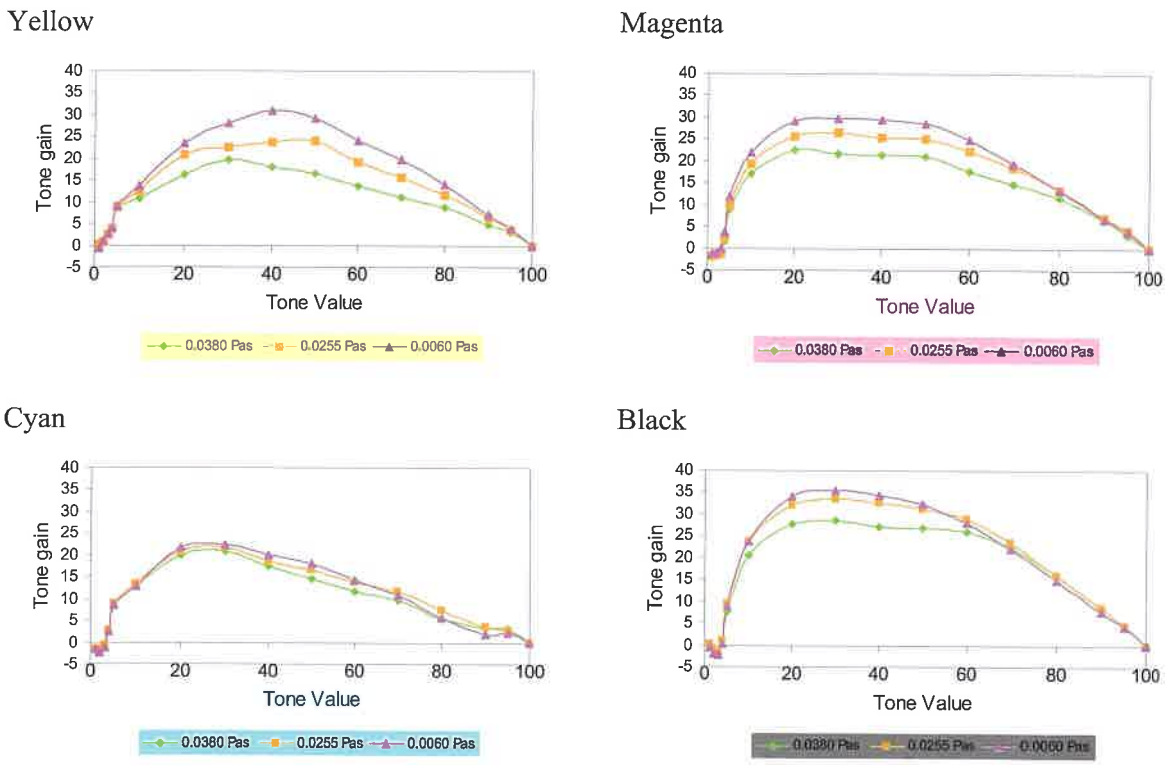


Figure 5: Tone gain curves for ink viscosities of 0.0380, 0.0255 & 0.0060 Pas

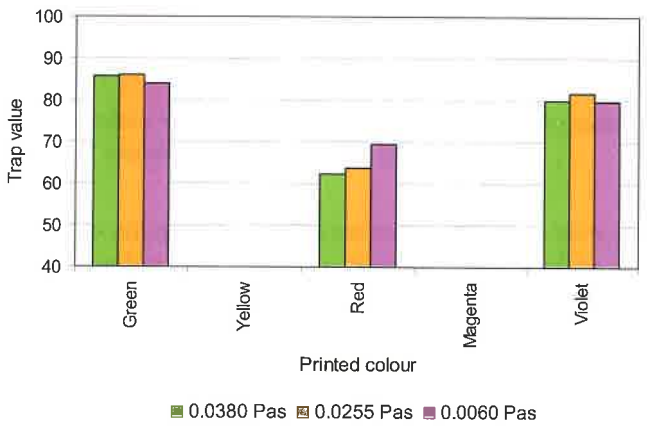


Figure 6: Ink viscosity on trapping of two colour overprints

As the viscosity is reduced the maximum colour gamut achievable alters, the cyan and the green reduce in saturation and change in hue while the violet and magenta increases in saturation and change in hue. The yellow and red showing little or no variation as viscosity is changed. As the viscosity is reduced the lightness of the colour is increased. This is more pronounced in the cyan and the colours containing the cyan namely the green and violet. Addition of solvent to the ink for the reduction of viscosity will also reduce the pigment to solvent ratio. The expected result would be an increase in the lightness L* and a fall in colour saturation of all the inks or a compression of the colour gamut. However the shifts of colour are not identical and the differences in the responses could be attributed to a number of factors. The quantity of solvent required to achieve a viscosity may be different for each of the process colours, resulting in different pigment ratios for each one. The reduction in viscosity will also affect the rheology of the ink altering the interaction between the substrate, the ink and the different cell shape on each cylinder.

All the ΔE variations represent a visually perceptible colour change. The ΔE values obtained are smaller for the first viscosity reduction from 0.0380 to 0.02550 Pas when compared to the viscosity reduction from 0.02550 to 0.0060. The largest change in ΔE is recorded for the viscosity change 0.0380 to 0.0660 Pas. The results are not cumulative as the colours do not move as a vector in colour space inn response to changes in viscosity.

Tonal reproduction was assessed using the SCID squares. The SCID patches were sorted by hue angle.

To reduce the complexity of analysis and the amount of data on any one graph the results were split in to discreet lightness bands of L* 10-20, 20-30, 30-40, 40-50, 50-60, 60-70 and 70-80. No SCID information below a chroma value of 10 was investigated, this excluded a range of neutral greys. The a* b* values for each measurement, within its respective L* value band, were plotted to show the colour gamut with the change in L* values shown as a bar chart and the ΔE plotted on a separate bar chart to show the overall change for the SCID patch. The change in colour gamut with viscosity for tonal reproduction of the process inks at a lightness level in the range 40 to 50 is shown in Figure 8 as being representative of the data obtained.

As the viscosity is reduced the achievable colour gamut shifts. Although it was expected for the colour gamut to compress and the lightness to increase with viscosity reduction, the SCID patches within the lightness band demonstrated different responses with change of viscosity. The cyan, green and yellow change in hue, reduce significantly in saturation and increase in lightness. The changes for the red, magenta and violet are smaller by comparison with the L* value either increasing or reducing depending on the SCID patch. This trend is consistent throughout the lightness range.

Each SCID patch is comprised of differing combinations of side by side and over print of the four colours. The different responses obtained are due to the interaction of the effect of viscosity on both the individual process colour making up the SCID patch and the release characteristics of the ink from the different size and shape cells, and the way in which the viscosity changes the trap of those colours. Examination of the ΔE values indicates a trend is present throughout the range where the largest ΔE values occur for the cyan and green colours, although generally all the ΔE values would be visually perceptible.

4. Discussion

Although there may be slight changes in the pigment concentrations as solvent is added to change the ink viscosity, as these inks were a balanced four colour set, the physical behaviour of the ink should be similar. Reduction in viscosity produces changes in density for different tone values, but these changes are not consistent through the tonal range. The four process colours do not all show the same behaviour with the black and cyan demonstrating similar trends to each other whilst magenta behaves similarly to yellow. This similarity is also highlighted when comparing the 100% solid print, the black and cyan show a constant density fall while the yellow and magenta show a slight rise then a fall for the same viscosity reduction. The densities of the neutral grey were similar to that of the cyan. This was to be expected, as the cyan is the largest component of this composite colour.

The most significant factor for the different responses of the four process colours is the shape of the cells. Kunz[2] described the ink in the cell as it passes under the doctor blade being dragged back by the blade and the ink left in the cell then relaxing back into the cell forming a concave meniscus. The faster the relaxation the more uniform the fill of the cell before it reaches the printing nip and hence a more effective ink transfer. The speed of relaxation is dependant on the viscosity the shape, size and type of cell. The lower viscosity and the smaller and less elongated the cell, the faster the relaxation. The coarse square cells of the yellow and the elongated cells of the magenta have similar lengths in the direction of rotation. Similarly, the fine square cells of the black and the compressed cells of the cyan have similar lengths in the direction of rotation.

The cyan and black show falls in density consistent with a reduction in the pigment ratio. The observed increase in density for the yellow and magenta for the first viscosity reduction may be due to the reduction in pigment ratio being less than the increase in the amount of ink available for transfer from the elongated or coarse cells. For the second viscosity reduction the effect of solvent addition on the relaxation of the ink in the cell is not sufficient to compensate for the reduction in the pigment ratio and hence density values decrease.

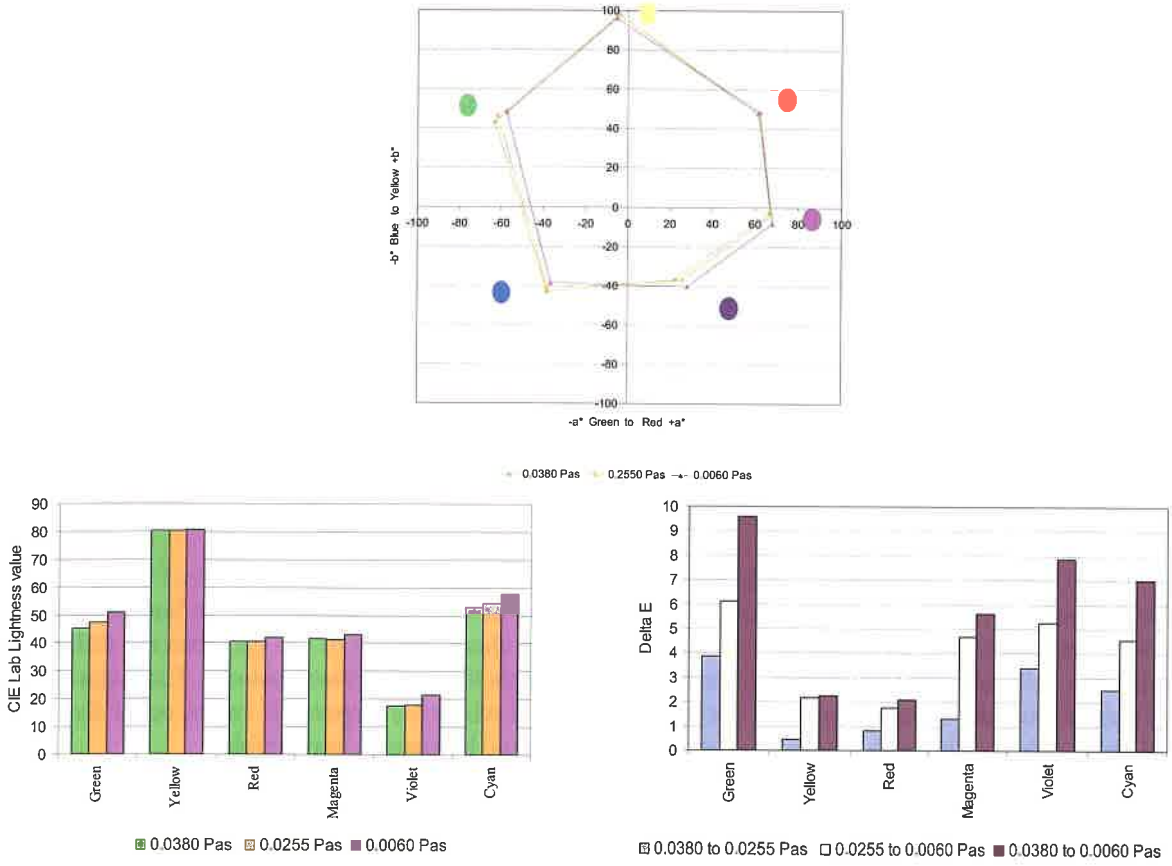


Figure 7: Colour Gamut, lightness and ΔE values for the 100% solid and 100% overprint

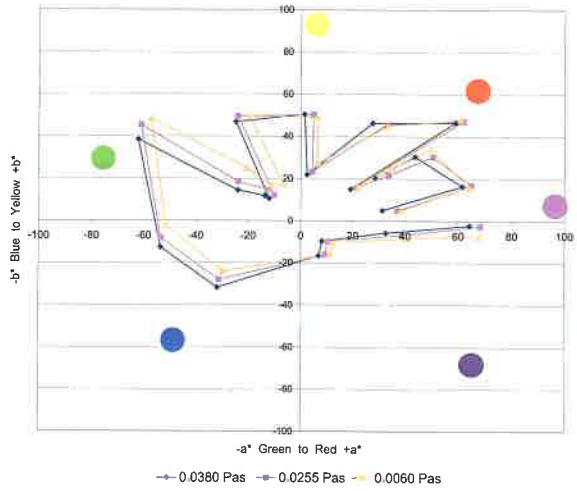


Figure 8a: a b* values for the SCID patches with the initial lightness value in the range 40 - 50*

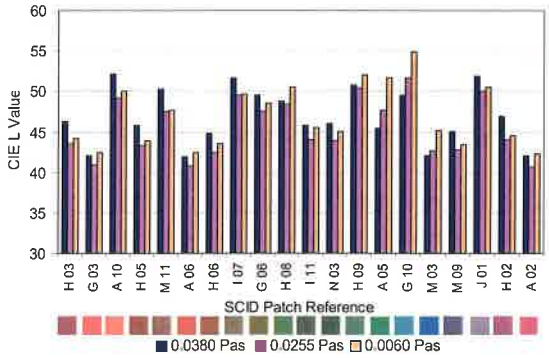


Figure 8b: L values for the SCID patches with the initial lightness value in the range 40 - 50*

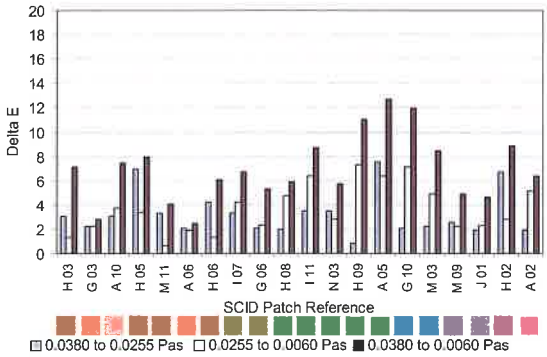


Figure 8c: ΔE values for SCID patches with the initial lightness value in the range 40 - 50

The magnitude of change at the lower tonal values may be a result of the cell size and distribution getting smaller, the effects of the transfer process described would then be reduced resulting in smaller changes.

Comparison of the trap values for the three colour overprints of yellow on cyan (green) or the magenta on cyan (violet) indicate that there was little change in the efficiency of overprinting when viscosity is reduced. However there was a small change for the yellow on magenta (red) suggesting that, due to the differences in interfacial energies on transfer, more yellow could be deposited on the magenta than when on the substrate alone.

Reduction in viscosity results in a shift in the maximum colour gamut with significant variations occurring in the green, violet, cyan and magenta regions. Since the colour is dependent on the way in which the ink is deposited, examination of the solid density verifies that the changes are due to density variations and hence film thickness.

SCID data obtained enabled combinations of over laying the four process colours, both solid and tone, to be examined. With a fall in viscosity the tonal overlays were affected more that the solid prints, and within these tonal regions the blue/green colours showed the largest ΔE values. The lightness values varied for all the colours with viscosity change, however, there was no apparent pattern to its rise and fall.

5. Conclusions

The effect of viscosity on ink transfer on a production gravure packing press has been investigated. These results highlight the importance of viscosity on the application of the ink film during the

gravure print process. Both solid and tonal reproduction was found to be sensitive to change in viscosity with the largest effect observed with tonal reproduction. Variation in ink viscosity resulted in significant changes to most colours although the effect on the cyan, green and yellow is more prevalent. Although in both instances the lightness values are affected the change is less predictable for change in viscosity. The results highlight the importance of viscosity on colour reproduction

Reduction in viscosity produces an increase in tone gain, which is more significant for the half tones than the solids. The process inks appear to behave as pairs, yellow with magenta and cyan with black. This can be attributed to the cell geometry in the direction of printing and not the change in pigment loading due to the dilution by solvent when the viscosity is reduced.

The study has highlighted the complex relationship between the cell geometry and the ink release. As this is not a direct relationship across the full tonal range and overprinting range, this would suggest the need for gravure presses to be fingerprinted at the operating viscosity.

Acknowledgements

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References

1. Davies G. R., Hawthorne G., and Claypole T. C. "Automatic Viscosity Control in gravure printing" Proc. TAGA 57 Annual Technical Conference 2005
2. Kunz, W. "Ink Transfer in Gravure Process", Proc TAGA Annual Technical Conference 1975
3. Jeske, D. R., "Impulse Press Simulation Of A Gravure Printing Nip", International printing and graphic Arts Conference 1990, pages 97-104
4. Bohan M. F. J, Claypole T. C., and Gethin D. T. "An Investigation into Ink Transfer in Rotogravure Printing", Proc TAGA Annual technical Conference 1998 pg. 484-494
5. ISO 12642

The influence of backpressure on ink drying and dot gain in sheet fed offset printing

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Abstract

Preliminary test printing indicated that increasing the impression of the paper against the blanket cylinder in sheet-fed offset printing might lead to a faster ink drying. Therefore in order to verify the results a new test run was carried out based on print trials using a Solna 424 sheet-fed press where the impression was adjusted from low to high values. Three paper grades, gloss coated, silk coated and uncoated grades were printed with two blankets with different hardness.

Ink drying was measured as rub-off at time intervals so that drying curves could be plotted.

The ink transfer was measured by using XRF, x-ray fluorescent technology.

Print density and dot gain was measured in 100%, 80% and 40% dot area.

The results from the drying evaluation disagree with the results from the preliminary test printing, no correlation between drying rate and level of impression was found.

The results from the dot gain measurements show that the dot gain is not increased with increased level of impression, it remains on a constant value.

1. Background

Sheet-fed offset printers in Sweden noticed a shorter drying time with increased impression pressure. The research council at IMT, the Institute for Media Technology, now merged with STFI, Stockholm, therefore decided to start a new project in order to follow this up.

2. Objective

The objective of this study is to test the hypothesis that the ink drying time can be decreased by increasing the backing pressure in sheet-fed offset.

3. Introduction

In sheet-fed offset printing the ink the ink is transferred from the printing plate onto the blanket and then onto the paper held on the impression-cylinder. A process specific contact pressure of 0.8-2 MP is needed to transfer the ink to the paper [Kipphan 2001]. The ink transfer from the blanket to the paper is highly dependent upon the force applied from the impression cylinder. The pressure applied is adjusted by altering the indentation of the paper by the blanket, which in turn is done by altering the position of the impression cylinder. The indentation must be adjusted according to paper grade in order to avoid print mottle due to uneven ink transfer. For a gloss-coated paper normal setting is 0.10 mm, for matte-

coated 0.15 mm and 0.2 mm for uncoated 0.25 mm. A too low impression will lead to print mottle. New presses are normally preset to 0.10 mm for gloss coated paper grades. Paper manufacturers often give recommendations for impression for their paper-grades.

In order to describe the ink transfer from the printing plate or blanket onto the paper Walker -Fetsko have presented a general equation describing the total amount of ink transferred. [Walker 1955] However this equation does not take into account the ink distribution into the paper which can affect the ink drying or the ink spread on the paper surface will affect the mechanical dot gain.

Megat Ahmed et al. (1997) have presented a model for the ink impression into a porous substrate describing how the radial ink flow depends on paper structure and applied pressure. If the pressure is increased from a normal value by a factor of ten the amount ink is increased noticeably mainly as a radial flow rather than as penetration. Thus the model predicts an increased dot gain with increased pressure in the printing nip.

According to Oittinen and Lindqvist (1981) the ink spread in the printing nip is inversely proportional to the radius of the ink layer, the half tone dot size. This will lead to a higher dot gain in areas with lower tonal values compared to areas with higher tonal values.

Takahasi et al. (1986-7) have measured the ink film thickness on the and found that the thickness increases with dot size from low tonal values up till 55% tonal areas where it reaches a constant value. This will lead to increased dot gain with increased dot size.

4. Methods

In order to find possible correlation between ink drying and increased backpressure in the printing press the following evaluation methods were used.

Full-scale print trials in sheet fed offset were conducted at different levels of backpressure by adjusting the impression cylinder from low to high values. The drying rate was therefore calculated by making a number of rub-off measurements during the drying until stable condition is obtained.

To see if the ink-transfer was affected by the impression level, the ink transferred was measured by x-ray fluorescent technology. Densitometer based measurement of ink transfer is not a reliable method since the print density can change with time. Further it cannot be assumed that print density is unaffected by the nip pressure.

Drying

Drying was measured with a GFL K&N rub-off tester at different times after printing. The rub-off tester is described in a GFL report, Arnamo (1983) and in a FOGRA report, Rieger (1987) under the brand name Weap-Wischentestgerät. A special rub-off paper was rubbed against the printed area and the rub-off on the paper was measured with El Repho 2000. The logarithmic value of the reflectance was then calculated. Each measurement was made on two samples. The results were then plotted in graphs over rub-off as a function of time. There is no established rub-off level for when a print is considered to be dry.

Transferred ink with X-ray fluorescent

The amount of ink transferred was measured with x-ray fluorescent technology. The method is based on detecting copper-atoms in cyan pigments by exposing the printed samples to x-ray radiation and then detecting the transmitted signal from the Copper-atoms. The amount of ink in g/m^2 was calculated after

printing the papers with a Prüfbau laboratory printing press where the transferred ink was measured gravimetrically. In this way it was possible to make a calibration diagram between g/m^2 and x-ray response from the full scale printed samples.

Print density and dot gain

Print density and dot gain in 40% - and 80% dot area was measured in a UGRA-control wedge with a Gretag D186 densitometer with polarization filter. Each reported value was based on 3-5 measurements.

5. Results

Trial 1

The preliminary study was based on printing one gloss coated paper grade in a Solna 425 sheet-fed offset press at three different levels of impression, ranging from 0.10 mm to 0.30 mm. The ink transferred onto the paper was measured with densitometer and by x-ray fluorescent technology based on registering the copper atoms in the cyan pigment in the ink.

The drying rate was measured as rub-off as a function of time.

Dot gain was measured in the 40% and 80% dot areas.

The results from the test trial indicated an increased drying rate with increased impression, see figure 1. The ink feed had to be reduced in order to remain a constant print density for the two highest indentation levels. The amount of transferred ink was accordingly lower for these two levels of indentation.

Printing conditions and materials

Printing press:	Solna 425, only cyan unit printing
Offset plate:	Conventional negative offset plate
Blankets:	Compressible, surface profile: 0.4 - 0.7 µm
Dampening solution:	pH 5.5 and 12% IPA
Ink:	mineral oil containing ink, cyan
Printing speed, imp./h:	5500
Paper:	Silk coated, 240 g/m^2

Print series

Sample no	Indentation	Density, D 100% area
4	0.1	1.50
5	0.2	1.50
6	0.3	1.50
8	0.1	1.50
9	0.2	1.57 adjusted to 1.50
10	0.3	1.57 adjusted to 1.50

Drying speed, rub-off

X-ray fluorescence - calibration of printed samples

In order to be able to calculate the ink film thickness i g/m^2 from the samples taken from the full scale test run a separate printing with Prüfbau laboratory printing press was carried out made with the same

ink paper as in full scale printings. With the Prüfbau press it is possible to measure the transferred ink in g/m^2 for each printed sample. The samples were then measured with respect to copper with x-ray fluorescence, see table II.

Table I: Rub-off values for three levels of indentation and two series

Time, h	Sample/Indentation, mm					
	4/0.1	5/0.2	6/0.3	8/0.1	9/0.2	10/0.3
1	0.087	0.084	0.086	0.088	0.088	0.076
2	0.079	0.078	0.081	0.08	0.079	0.075
3	0.084	0.084	0.079	0.081	0.082	0.076
4	0.077	0.079	0.081	0.082	0.082	0.079
21	0.061	0.059	0.06	0.064	0.061	0.057
25	0.064	0.062	0.06	0.064	0.064	0.056
120	0.060	0.06	0.062	0.064	0.061	0.055
192	0.060	0.064	0.062	0.061	0.061	0.056

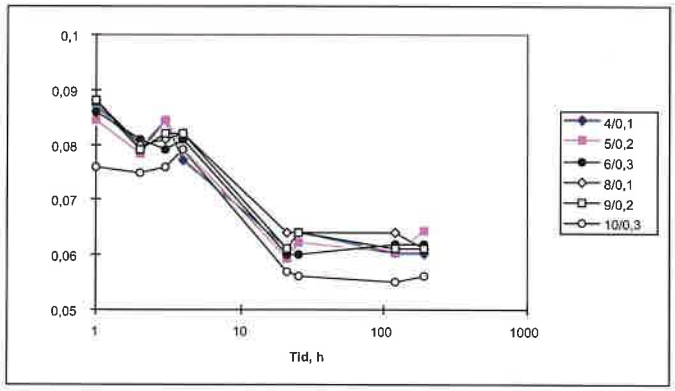


Figure 1: Rub-off as a function of time for three levels of impression, 0.10 mm, 0.20 mm and 0.30 mm

Table II: Result from measurement of copper in the samples printed with Prüfbau laboratory press

Prüfbau sample no	g/m^2, calculated	Conc. Cu
1	1.009	1.892
2	1.944	3.643
6	1.250	2.342
7	1.742	3.265

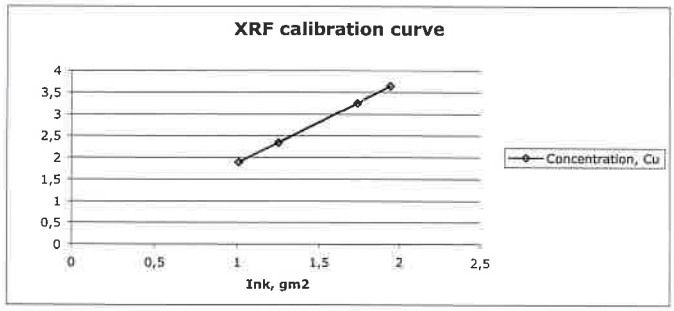


Figure 2: Calibration curve. Diagram showing results from copper concentration x-ray measurements of the samples printed in the Prüfbau laboratory printing press

Print samples

For six samples corresponding to the six different full-scale print trials the concentration of copper was measured and the corresponding amount of ink in g/m^2 was then calculated based on the calibration curve above, the result see table III.

Table III: Calculated ink transfer for the full-scale print trials

Sample no	Conc. Cu	Calculated ink coverage, g/m^2
4	2.3294	1.243
5	2.3530	1.255
6	2.2833	1.218
8	2.3475	1.252
9	2.2817	1.217
10	2.3101	1.232

Ink drying and coverage

Rub-off values according to table I measured 192 h after printing which were considered as final drying, and the corresponding calculated ink coverage in g/m^2 can be seen in table IV.

Table IV: Final drying as rub-off for the printed samples and corresponding ink coverage

Serie/Impression	Rub-off	Ink coverage, g/m^2
1/0.10	0.060	1.243
1/0.20	0.064	1.255
1/0.30	0.062	1.218
2/0.10	0.061	1.252
2/0.20	0.061	1.217
2/0.30	0.056	1.232

Print density and dot gain in 40% and 80% screen areas

For the print samples print density and dot gain in the 40% and 80% areas were measured. The results can be seen in table V and figure 3.

Table V: Result from measurement of print density and dot gain for three levels of indentation

	Sample/indentation					
	4/0.1	5/0.2	6/0.3	8/0.1	9/0.2	10/0.3
Print density	1.50	1.52	1.53	1.49	1.50	1.52
Dot gain, 40% area	29	30	30	29	30	29
Dot gain, 80% area	14	14	14	14	14	13

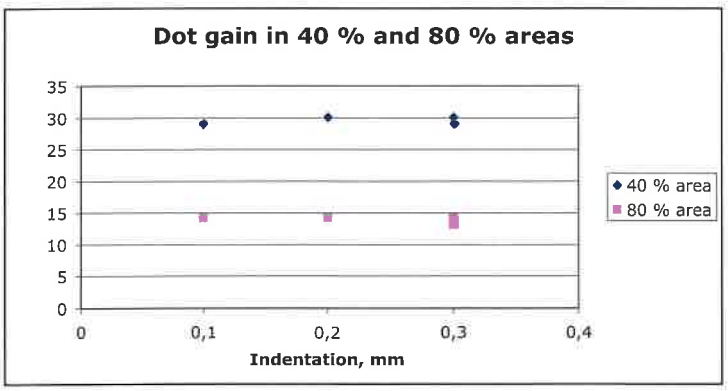


Figure 3:
Dot gain in 40% and 80% areas for three levels of impression

Total dot gain consists of two parts, one mechanical and one optical. The mechanical dot gain is plate and press related. The press related part is connected to ink transfer from plate to blanket and from blanket to plate. Finally the optical part of the dot gain is caused by light scattering in the paper surface and depends on porous structure of paper and/or coating. Dot gain correlates with ink feed within a normal adjustment interval. An increased ink fed leads to increased dot gain. The mechanical dot gain depends mainly on the tension between plate and blanket. This tension is set by the under packaging of the plate and the blanket.

The results from this test trial show that the dot gain in the 40% and 80% tone areas remains on a constant level at all indentations levels, se figure 3.

Since the results were based on just one print trial, it was decided to make a new extended print trial, now with three paper grades and two different blankets.

Trial 2

Full-scale printing was carried out with three paper-grades and with two different blankets and at print-density 1.50. Before printing the press was running 30 minutes in order to reach stable conditions. The impression was adjusted from 0.10 - 0.30 mm in four steps and finally back to 0.10 mm again. For each print run 100 signatures were taken for evaluation.

The print samples were stored under stable conditions, temperature 22°C and relative humidity 50%. Samples were taken randomly and measured with respect to ink transfer, print density, dot gain and rub-off.

Print trials in a commercial sheet-fed press, at normal production speed and with three different paper grades; coated gloss, coated satin and uncoated. Printing with four levels of backpressure; 0.10, 0.15, 0.20 and 0.30 mm indentation of paper against the blanket. The print trials were carried out with two different blankets.

Printing conditions and materials

Printing press:	Solna 425, only cyan unit printing
Offset plate:	Conventional negative offset plate
Blankets:	Blanket 1, hardness: 78 shore A, surface profile 0.4 - 0.7 µm
	Blanket 2, hardness: 80 shore A. surface profile 0.8 - 1.2 µm

Dampening solution:	pH 5.5 and 12% IPA
Ink:	mineral oil containing ink, cyan, for coated and uncoated paper
Printing speed, imp./h:	5500
Paper:	Gloss coated, 170 g/m^2
	Silk coated, 150 g/m^2
	Uncoated, 140 g/m^2

Rub-off

The results from the rub-off measurements can be seen in table 6 and the corresponding curves in diagram 4. The rub-off was measured once every hour for seven hours then after 24 h and 168 h. The correlation between drying as rub-off and level of indentation was calculated by calculating the difference in rub-off for the different indentation levels. The difference between 0,10 mm and 0.15, 0.20 and 0.25 mm was calculated for every time interval. For all six diagrams in figure 4 the total difference between the reference curve, 0.10 mm, and the other three curves was calculated. A positive value means that higher indentation gives lower rub-off. The coefficient of correlation was calculated for all combination of paper types and blankets, 18 combinations, to $r_{corr} = 0.09$. This means that no general correlation was found between level of indentation and drying as rub-off.

Table VI: Result from measurement of rub-off for three paper grades, gloss coated, silk coated and uncoated for two blankets, no 1 and no. 2

Gloss coated	Blanket 1				Blanket 2		
	Indentation, mm						
Time, h	0,1	0,15	0,2	0,25	0,1	0,15	0,2
1	0,06	0,054	0,055	0,047	0,071	0,072	0,068
2	0,047	0,057	0,048	0,052	0,069	0,073	0,071
3	0,048	0,048	0,057	0,054	0,063	0,064	0,071
4	0,047	0,05	0,051	0,053	0,067	0,063	0,064
5	0,052	0,049	0,053	0,055	0,066	0,067	0,062
6	0,058	0,052	0,055	0,055	0,071	0,069	0,064
7	0,046	0,049	0,051	0,052	0,068	0,068	0,067
24	0,052	0,054	0,048	0,049	0,061	0,067	0,058
168	0,047	0,048	0,047	0,047	0,057	0,06	0,055
Silk coated	Blanket 1				Blanket 2		
	Indentation, mm						
Time, h	0,1	0,15	0,2	0,25	0,1	0,15	0,2
1	0,084	0,087	0,081	0,076	0,073	0,085	0,077
2	0,084	0,082	0,075	0,086	0,079	0,082	0,082
3	0,083	0,086	0,079	0,075	0,08	0,084	0,081
4	0,087	0,082	0,08	0,083	0,082	0,075	0,082
5	0,082	0,08	0,082	0,082	0,09	0,082	0,077
6	0,077	0,083	0,085	0,085	0,077	0,081	0,079
7	0,08	0,079	0,085	0,082	0,078	0,078	0,084
24	0,074	0,076	0,082	0,075	0,072	0,078	0,078
168	0,07	0,072	0,071	0,076	0,067	0,066	0,06
Uncoated	Blanket 1				Blanket 2		
	Indentation, mm						
Time, h	0,1	0,15	0,2	0,25	0,1	0,15	0,2
1	0,062	0,058	0,067	0,065	0,053	0,05	0,048
2	0,058	0,055	0,056	0,062	0,048	0,044	0,048
3	0,065	0,062	0,055	0,051	0,048	0,047	0,049
4	0,057	0,065	0,052	0,054	0,056	0,052	0,045
5	0,056	0,06	0,05	0,052	0,047	0,045	0,055
6	0,051	0,051	0,062	0,059	0,053	0,043	0,043
7	0,059	0,058	0,05	0,05	0,045	0,043	0,052
24	0,049	0,051	0,05	0,048	0,048	9,049	0,037
168	0,034	0,036	0,026	0,026	0,032	0,029	0,035

Print density and ink transfer

The print density was stable after altering the indentations also the ink transfer according to x-ray fluorescent measurements remained constant, see table VII.

Table VII: Result from measurement of ink transfer, g/m²

Indentation, mm	0.10	0.15	0.20	0.25
Blanket 1 Uncoated	0,49	0,49	0,49	0,49
Blanket 2 Uncoated	0,39	0,36	0,43	0,37
Blanket 1 Silk 0,18		0,15	0,19	0,15
Blanket 2 Silk 0,26		0,26	0,28	0,26
Blanket 1 Gloss	0,29	0,30	0,27	0,30
Blanket 2 Gloss	0,25	0,28	0,28	0,28

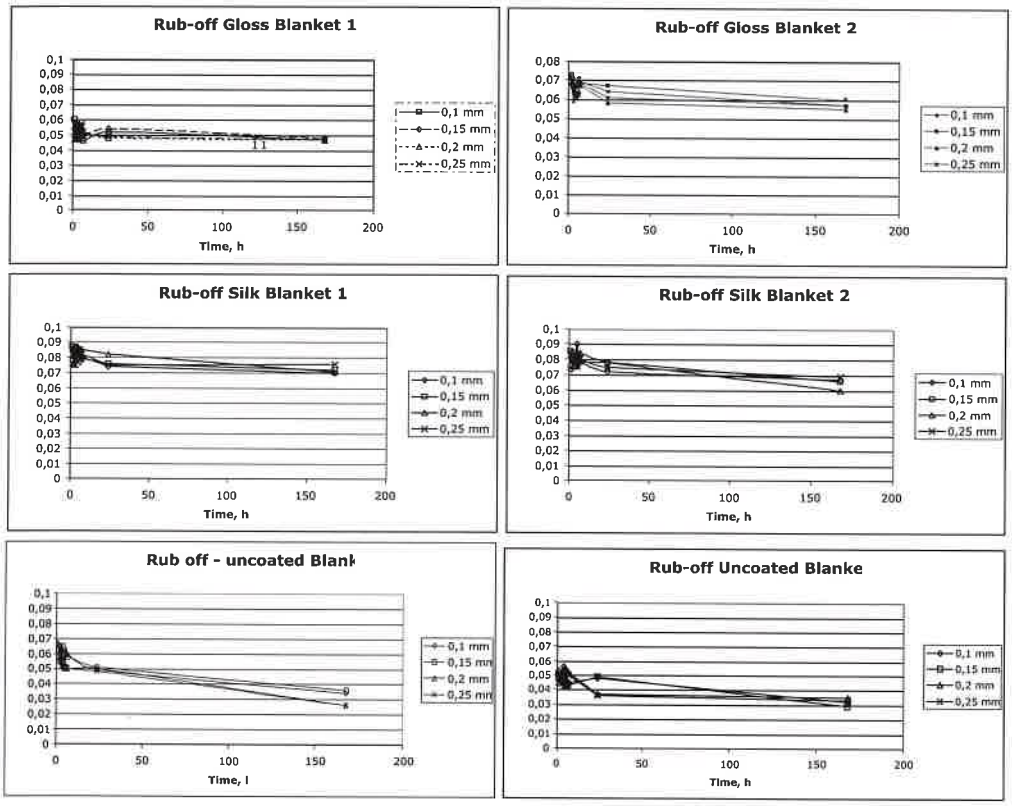


Figure 4: Rub-off curves for two blankets and three paper-grades. In each diagam there are four curves corresponding to the indentation levels, 0.10, 0.15, 0.20 and 0.25 mm

Dot gain

Dot gain in 40% and 80% areas was measured. The difference between 0.25 mm and 0.10 mm indentation was calculated, see figure 5.

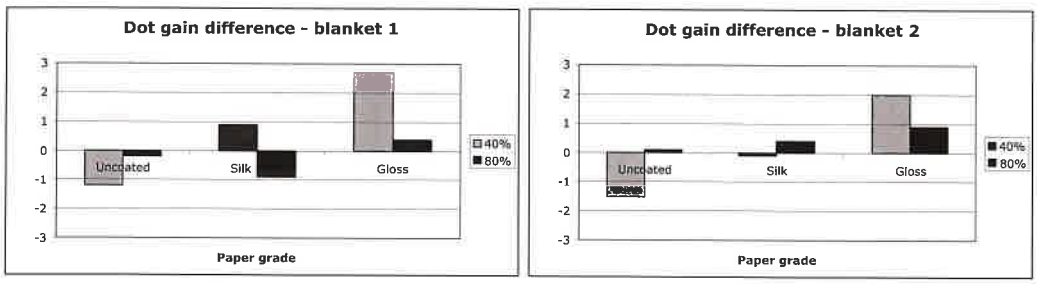


Figure 5: Dot gain difference between 0.25 mm and 0.10 mm indentation in 40% and 80% tonal area

The results show that for the uncoated grade there is a negative dot gain of 1% unit, silk coated a dot gain of 1% unit and gloss coated shows an increase in dot gain of 2% units.

6. Discussion

The preliminary result from the earlier study indicating that the drying process is increased with increased backpressure could not be verified. Instead the results from the second investigation show clearly that the drying is not affected by the level of impression within normal setting values. The hypothesis that an increased back pressure leads to a lower ink demand caused by a calendaring effect of the paper in the ink transfer zone which in turn would lead to faster drying of the ink could not be verified.

The measurements of ink transfer show that ink transfer and print density remain constant and are not depending upon the indentation level.

The results from this study show that the dot gain is not closely related to the impression. One explanation could be that the porous structure of the paper surface interacts with the vehicles in the ink and functions as a binder to the surface causing the ink to penetrate deeper into to paper rather than spreading with increasing pressure.

7. Conclusions

The results from this investigation showed that:

- no correlation was found between ink drying rate and level of indentation,
- transferred ink to paper was not affected by the degree of indentation,
- dot gain is affected to some extent by the degree of indentation,

The uncoated grade showed a slight decreased dot gain, -1%.
The silk coated grade showed a slight increased dot gain, 1%.
The gloss coated grade showed an increased dot gain, 2%.

References

1. Arnamo A., (1983), *Provningsmetoder utvecklade av GFL Del 1, GFL Projektrapport nr 49, 18-20*
2. Kipphan, H., (2001), *Handbook of print media, Springer, 2001*
3. Megat Ahmed M. M. H., Gethin D. T., Claypole T. C. and Roylance B. J.), (1977), *Numerical and experimental investigation itot porous sqeeze films, Tribology Int. submitted*
4. Oittinen P. and Lindqvist U., (1981), *The behaviour of printing ink in an offset printing nip, Paperi Ja Puu No 6-7, pp 432-7*
5. Rieger G., (1987), *Der Einfluß mattgestrichener Papiere auf die mechanishe Wiederstandfestigkeit von Offsetdruckfarben, Tel 2, 6-7*
6. Takahashi Y., Fujita H. and Sakata T., (1986-7), *Ink transfer and dot gain mechanisms in the offset printing process, graphic arts Japan, 28, 22-32*
7. Walker W. C., Fetsko J. M., (1955), *A concept of ink transfer in printing, Amerikan Inkmaker, 33, 1955, pp 38-44, 69-71*



The effect of process characteristics on image reproduction in flexographic printing

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Abstract

Ink transfer in the flexographic printing process relies on the flow from the anilox roll onto the image regions of the plate and then from the plate onto the substrate. Parameters such as the viscosity of the ink will have effect on how the ink transfers out of the anilox cells onto the plate, whilst other parameters, such as impression pressure can affect the ink transfer to a porous substrate.

An investigation has been performed to quantify how process characteristics affect the printed image in flexographic printing. Using a banded anilox roll, with varying screen ruling and cell volume, a test image was printed to quantify the effect of ink viscosity, impression pressure and anilox volume on solid density and tonal reproduction.

Results showed anilox cell volume had the largest effect on solid density and tonal reproduction. Results where ink viscosity was lowered without altering pigment concentration showed very little change in solid density. For inks where the viscosity was reduced conventionally, which resulted in a reduction in pigment concentration, a linear relationship was observed between viscosity and density. Impression pressure was shown to have negligible effect on solid density.

As a result of the investigation, it was concluded that anilox cell volume has the largest effect of all the parameters investigated on both solid density and tone gain. Pigment concentration was also found to have a strong influence on the appearance of the final printed image.

1. Introduction

There are many parameters that influence the quality of the final printed image in flexographic printing. These range from ink characteristics to surface energy effects on the substrate. Controlling density in flexographic printing is achieved by varying the volume of the anilox roll. However, changes in density will also occur due to any additions of reducer to the ink, to adjust its viscosity. This is often necessary to ensure the ink flows properly through the press. Furthermore, it may also be necessary to perform an initial cut-back of the ink to reduce its pigment concentration if the ink is saturated with pigment when it is manufactured. It is therefore important to fully understand the effects that changing ink viscosity can have on the printed image, to enable the flexographic printing process to be fully optimised.

Previous research [Bould, 2001, 2004] into the flexographic printing process has shown that the characteristics of the printing plate have a large effect on the final image with deformation of the individual halftone dots contributing to the overall tone gain. This was shown to be most significant in the highlight region, where the effect of plate to substrate engagement had the largest effect. Overall however, the contribution of the printing plate through the midtone and shadow regions was shown to be in the order of a quarter to a third of the total tone gain observed. A subsequent investigation [Bould, 2005], using finite element techniques, showed that of all the parameters associated with the flexographic printing plate, engagement between the plate and the substrate had the largest effect on

tonal reproduction. Line ruling was also shown to contribute to the overall plate gain. This paper continues the investigation by comparing the contribution of ink viscosity to engagement, line ruling and anilox cell volume.

The trial was undertaken on a narrow web flexographic printing press having a maximum speed capability of 260 m/min, although for this investigation, a printing speed of 130 m/min was used for all experiments. A single colour test image was used for the press trial, which consisted of six tonal strips at varying line rulings, a large solid region and lines of varying thickness. For the purposes of this paper, only the data relevant to the tonal strips will be considered. The line rulings used in the test image were 33.4, 39.4, 47.2, 52.4, 59.0 and 68.9 lines per cm (lpcm). Ink was supplied to the anilox roll via a chambered doctoring system. A banded anilox roll, consisting of six bands of differing cell volume was used. Therefore the test image was repeated six times across the printed width. The final test image used for the experimental trial is shown in Figure 1.

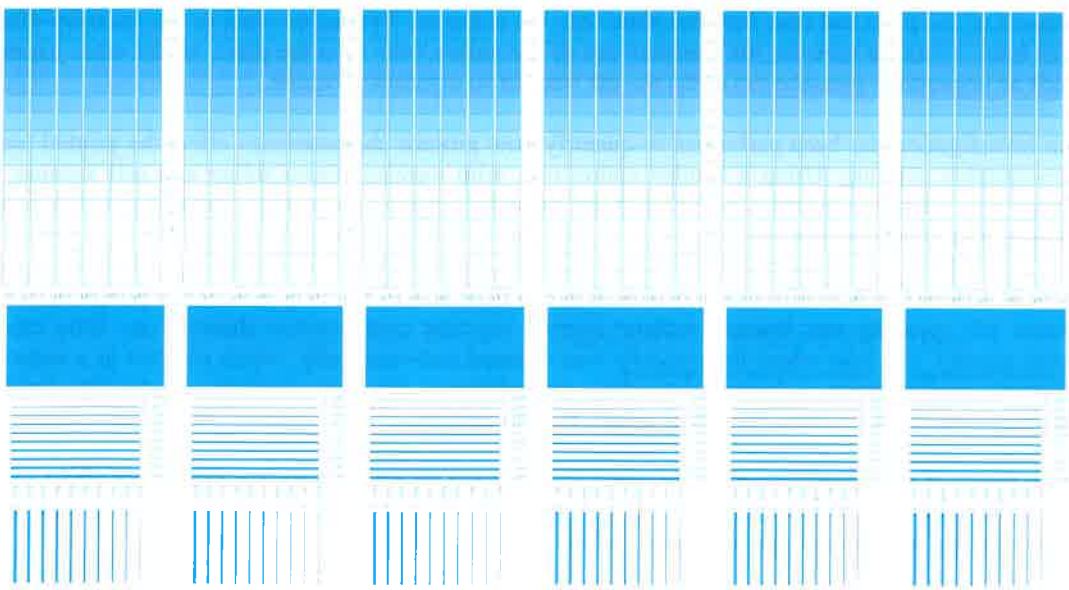


Figure 1: Test image

Three inks were used during the investigation; a cyan ink whose viscosity was altered by adding a reducer, a cyan ink whose viscosity was altered by varying the ratio of the reducer to the tinter and a magenta ink whose viscosity was altered by adding a reducer. The purpose of the different methods of viscosity reduction for the cyan inks was to quantify the changes in density due to reductions in pigment concentration, which was achieved using the first cyan ink, and to quantify how the density is affected as the viscosity is altered whilst maintaining a constant pigment concentration. This latter objective was achieved using the second cyan ink, where the pigment concentration was kept constant as the reducer to tinter ratio was varied. The third ink was included to allow comparison with the first cyan ink, to quantify any effects due to the pigment itself.

2. Methodology

The cell volumes of the bands on the anilox roll were quantified using White Light Interferometry [WYKO, 1999, 2000]. White Light Interferometry is a non-contact method of quantifying surface topography, by using interference patterns of light waves to determine the surface profile. Each band of the roll was measured at multiple locations around its circumference and the data analysed to give the screen ruling and average cell volume of each band, Table I.

Table I: Anilox roll properties quantified using White Light Interferometry

Band	1	2	3	4	5	6
Cell Count (lpi)	252.2	303.9	501.5	610.0	752.3	1003.1
Cell Volume (cm^3/m^2)	10.28	8.56	4.92	4.31	4.15	2.68

A coated paper was used during the investigation, which enabled ink transfer by both absorption into the paper and film splitting at the nip exit [De Grâce and Mangin, 1983, 1987]. A summary of the experimental conditions used during the investigation is shown in Table II. Also shown in Table II are the proportions of the neat ink, reducer and tinter used for each viscosity reduction. For each ink type, the viscosity reductions were performed next to the press, using a Zahn 2 reflux cup. In order to try to achieve similar viscosities for each of the three inks, it was necessary to adjust each ink by different amounts. However, due to the viscosity of the neat magenta ink being significantly lower than either of the two cyan inks, it was impossible to achieve the same initial viscosity.

Table II: Summary of experimental conditions

	Ink type	Viscosity (s) {Zahn 2}	Ink proportion Ink:Reducer:Tinter	Engagement (μm)
1	Cyan - conventional reduction	54	100:0:0	100, 125, 150
		32	75:25:0	100, 125, 150
		21	66:33:0	100, 125, 150
2	Cyan - constant pigment reduction	47	50:50:0	100, 125, 150
		31	50:35:15	100, 125, 150
		23	50:20:30	100, 125, 150
3	Magenta - conventional reduction	30	100:0:0	100, 125, 150
		24	85:15:0	100, 125, 150
		21	80:20:0	100, 125, 150

Once the press trial had been performed, the printed samples were analysed spectrophotometrically, to determine the solid density and tone gain. Although the investigation was performed as a full factorial trial, it was decided to analyse the results using orthogonal array techniques. A description of orthogonal arrays and their use in experimental design and optimisation is presented by Phadke (1989). Orthogonal arrays are a subset of a full factorial experiment, which were developed to reduce the time required to study the effect of parameters by reducing the number of individual experiments required to complete the analysis without sacrificing accuracy. As well as reducing the number of experiments, it is possible to investigate any interactions, where the combined effect of any two parameters is different to the sum of the two parameters considered individually. For the purposes of this investigation, an L_{27} array was used for each of the ink sets to analyse the parameters. Viscosity, engagement and anilox volume were each considered at three levels. As only three levels were considered for viscosity and engagement during the press trial, all three levels were considered in the array analysis. For the anilox cell volume, bands 1, 3 and 5 were selected (low, medium and high volumes). Band 6 was not used as it was observed that the highest volume band of the anilox roll did not produce an acceptable print under all printing conditions. This was attributed to the use of water-based inks, which do not perform well at high ink volumes. The settings for the orthogonal arrays are summarised in Table III.

Table III: Summary of orthogonal array settings

	Level 1	Level 2	Level 3
Viscosity	High	Medium	Low
Engagement	100 µm	125 µm	150 µm
Anilox	Band 1 (low volume)	Band 3 (medium volume)	Band 5 (high volume)

3. Results

The effect of viscosity, engagement and anilox volume on solid density for the conventionally reduced cyan ink is shown in Figure 2. The graph shows the difference in density, plotted relative to the settings at level 1. The engagement had negligible effect, which produced no difference in density between level 1 and level 3. This shows the same trends as those found by De Grâce and Mangin (1983, 1987), where it was found that the film splitting ratio at the nip exit was not affected by changes in impression pressure. Although the current investigation also includes absorption into the substrate as a method of ink transfer, which can be affected by changes to nip engagement, the results suggest that absorption into the substrate is small in comparison with ink splitting. The results show that as the viscosity decreases, the density decreases, due to the reduced pigment concentration at the lower viscosities. The largest difference was observed between levels 1 and 2, with a smaller decrease between levels 2 and 3. However, as the variations in viscosity were irregular (Table II) and comparing variation in density with viscosity (Figure 3) showed a linear relationship. The variation of density with anilox volume was in agreement with expected trends, with density increasing linearly with cell volume. No interactions between the parameters were observed.

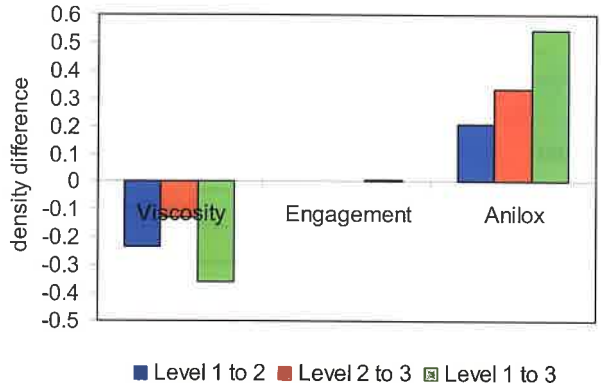


Figure 2: Orthogonal array results for ink 1

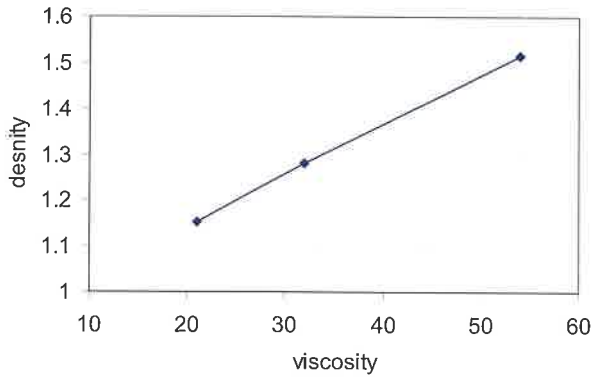


Figure 3: Relationship between density and viscosity, ink 1

For the constant pigment strength reductions of the cyan ink, the overall densities were lower than the densities for the conventional reduction of the cyan ink. This was attributed to the method used to reduce the ink, without reducing the pigment concentration, which was to take 50% cyan ink and each time divide the remaining 50% between the tinter and the reducer, in different concentrations, to alter the viscosity. Therefore although the pigment concentration remained constant, it was initially lower than that for the conventionally reduced cyan ink. The differences in density, relative to level 1 are shown in Figure 4. The trends for the engagement and anilox are the same as for ink 1, with no change in density with engagement and increasing changes in density with anilox volume. The changes in viscosity were much smaller than those for ink 1. This shows that while the majority of the density changes for the conventionally reduced cyan ink could be attributed to a reduction in pigment concentration as viscosity increased, the viscosity of the ink itself is also having an effect on the density. It was anticipated that viscosity reductions for ink 2 would result in an increase in density, due to improved ink release from the cells. However, as this did not occur, further investigation is required to determine the exact relationship between viscosity and the cells in the anilox roll.

For the magenta ink, although the highest viscosity was lower than for either of the two cyan inks, the densities were found to be the highest observed during the investigation. This highlights the variation that can occur during the ink manufacturing process and the need to adjust colour strength and viscosity, prior to the ink reaching the press, to ensure consistency between all the colours used. The results for the density differences are shown in Figure 5. Again, the trends for the engagement and anilox are the same as for inks 1 and 2. For the viscosity, the reductions in density as viscosity decreased were less than for ink 1, but greater than ink 2. This was attributed to the fact that the viscosity range for ink 3 was smaller than for inks 1 and 2 (Table II).

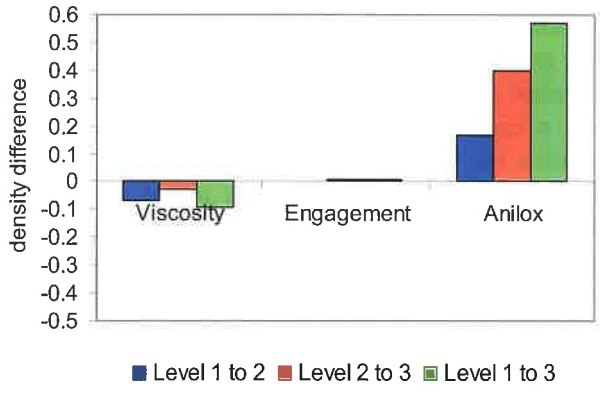


Figure 4: Orthogonal array results for ink 2

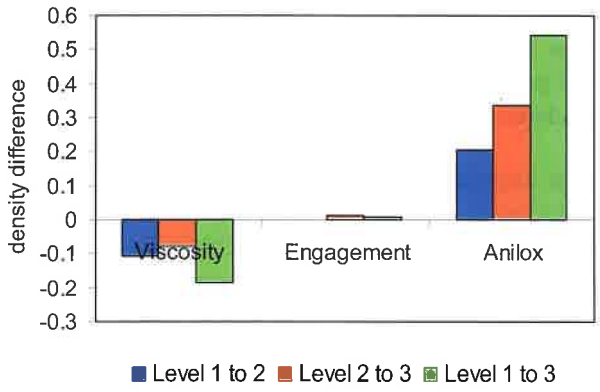


Figure 5: Orthogonal array results for ink 3

Results for the tonal variation for each of the inks showed little difference between the three ink types. Representative results from ink 1, which show the difference in tone gain between levels 1 and 3 are shown in Figure 6. Viscosity and engagement show little change in gain throughout the tonal range. Anilox cell volume however, had a large effect, with a maximum increase of 22.2% at the 50% coverage, as the cell volume increased from low to high.

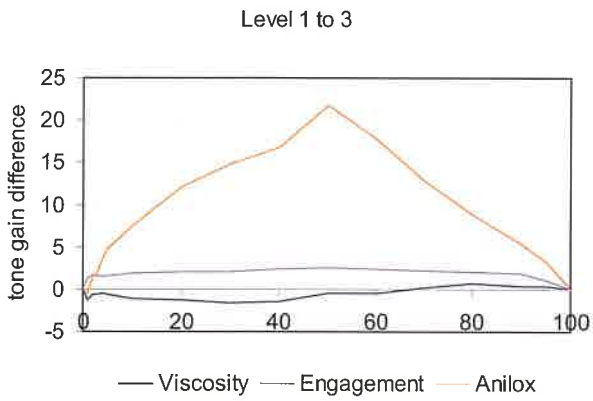


Figure 6: Tone gain difference for ink 1

4. Discussion

In order to achieve consistency in the flexographic printing process, it is necessary to understand the effects of the main process parameters and how any changes to those parameters will affect the quality of the printed image. Whilst the anilox roll is the primary method of controlling the ink film thickness on the press, it is important to control the pigment concentration of the ink and to ensure that the viscosity is maintained at a suitable level, to ensure optimum transfer of the ink from the anilox roll to the substrate. The purpose of this investigation has been to quantify how changes to viscosity and ink concentration affect printed solid density and tonal reproduction. The initial differences in density and viscosity, between the conventionally reduced cyan ink and the conventionally reduced magenta ink have highlighted the potential variation that can exist between inks. These variations need to be understood, in order that normalisation can occur between the inks on the different stations of the flexographic printing press, to reduce difficulties that would otherwise arise such as achieving colour balance.

The results of the investigation have shown that reducing the ink viscosity reduces solid density. This was observed for all inks, although for the cyan ink where the viscosity was reduced without altering the pigment concentration, the change in solid density was much lower than the density differences observed as the pigment concentration was reduced due to viscosity reduction. Prior to the investigation, it was hypothesised that reducing the ink viscosity without compromising pigment concentration would result in improved flow through the press and give a higher density. Further investigation is required to fully understand the fundamental science of the ink release from the anilox to the plate.

The investigation showed that impression pressure had no effect on solid density. Due to the use of a porous substrate, a small variation in density had been expected, prior to the start of the investigation. That no variation occurred may be attributed to two possible reasons. Firstly, the levels of engagement between the plate and the substrate were higher than are normally used in flexographic printing. These values were selected as the effect of engagement up to levels of 100 μm had previously been investigated on an OPP film [Bould, 2001, 2004, 2005] and it was therefore decided to extend the range of engagements to higher levels to observe the effects on print quality. At these higher levels of engagement it is possible that the pores in the substrate were already saturated with ink and increasing the engagement had no further effect on the absorption into the paper. The second possible explanation

as to why no density variation was observed could be due to the use of a coated substrate, which could have resulted in the pores in the paper already being filled by the coating layer, preventing any further absorption. Further investigation of the ink transfer for lower engagements should therefore be performed to quantify the exact effects of absorption of ink into porous substrates.

The results for the tonal variation for the three ink systems considered showed little difference between the different ink types. However, as the solid densities varied by different amounts for each of the inks, the physical change dot sizes due to viscosity variations will be different for each ink. This will have a large effect on the final printed image and is therefore important to understand how effects of the different viscosity reductions not only on the optical dot size (affected by variations in pigment concentration), but also the physical size of the dot, due to variations in the viscosity.

5. Conclusions

As a result of this investigation, the following conclusions have been drawn.

- Pigment strength has the largest effect on solid density. The rheology of the ink has also been shown to be a contributing factor to density variations, although its effects are much smaller than those due to pigment concentration.
- Plate to substrate engagement was shown to have negligible effect on solid density under all conditions, even though penetration into the substrate was a possible mechanism of ink transfer, during the investigation. Any penetration that did occur was therefore small, compared to the transfer due to filament splitting at the nip exit.
- Variations in anilox cell volume showed the largest variations for all ink types. This was observed for both solid density and tone gain. This emphasises the need to select the correct anilox when printing and to ensure that compensation for dot growth is correct for the anilox used.

Acknowledgements

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References

1. Bould D. C., 2001, 'Quality improvements in flexographic printing' PhD Thesis, University of Wales Swansea
2. Bould D. C., Claypole T. C. and Bohan M. F. J., 2004, 'An investigation into plate deformation in flexographic printing' Proc. Instn. Mech. Eng. Part B, Journal of Engineering Manufacture
3. Bould D. C., Claypole T. C. and Bohan M. F. J., 2005, 'An Experimental investigation into flexographic printing plates' TAGA Journal, Vol 1
4. De Grâce J. H. and Mangin P. J., 1983, 'A mechanistic approach to ink transfer. Part I: Effect of substrate properties and press conditions' IARGAI Vol. 17 pp312-332
5. De Grâce J. H and Mangin P. J., 1987, 'A mechanistic approach to ink transfer. Part II: The splitting behaviour of inks in printing nips' IARGAI Vol. 19 pp146-161
6. Phadke M. S., 1989, 'Quality Engineering using robust design'
7. WYKO, 1999, Surface Profilers Technical Reference Manual. Veeco Metrology Group
8. WYKO, 2000, NT2000 Setup Guide



Key factors affecting print quality on corrugated cardboard using flexography printing

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1. Introduction

Corrugated packaging is the most popular and cost-effective packaging material for providing tremendous protection to the objects inside today, and it plays a vital role to illustrate actual product characteristics which is for graphic communications [Flexographic Technical Association, 1999]. Among the four printing processes, flexography has always been the major printing process used by corrugated cardboard printers due to the relative ease and economy with which flexo could put simple graphics and linework onto corrugated without crushing flutes [Roger, 2000; Perkowski, 2006].

High-quality graphics is a necessity today. The quality of flexographic printing on corrugated continues to improve as technological advancements push the process from all sides of the corrugated flexo market [DeRosa, 1998]. Successful printing requires that the ink be deposited onto the substrate in a controlled and uniform way. The use of photopolymer printing plate is challenged by the demand to provide finer halftone print result, high resolution, brilliant dot formation, and an excellent ink transfer. Different photopolymer printing plates in combination with different type of cushion backings and liner material lead to a great variety of combinations. To standardize print quality, corrugated printers have been using increasingly thinner photopolymer plates [Jansen & Stebani, 2002]. The interaction between plate and printing setting such as printing pressure and print speed can also be directly associated with print quality. An inappropriate combination of plate type, printing pressure, and print speed may cause a high tone value increase and low print contrast. Consistency of conditions must be monitored when setting the pressure between plate and impression cylinder. It is necessary to manipulate key variables and establish optimum combinations of those variables for the printing process to achieve good printability and runnability of liners and corrugated board from sheet to sheet during the print run.

This research was an experimental study in nature. Its main purposes were twofold: (1) to identify important factors that influence the print quality of corrugated cardboard printing using the flexographic press, and (2) to establish optimum process operating parameters so that the minimum yield of tone value increase and the maximum yield of print contrast could be obtained. This experimental study utilized a randomized 23 factorial design in which every factor was run at two specified levels (1 = high level, -1 = low level, fixed effects). The factorial levels were determined based upon the practical operating conditions of the flexographic press at a major printing plant in Taiwan.

2. Methods

This study is considered truly experimental in nature. It utilized a randomized 23 factorial design in which every factor was run at two specified levels (fixed effects) determined based upon the practical operating conditions using a NIWA two-color flexo press at a major printing plant in Taiwan. The primary considerations of choosing a factorial design for this experiment include: (1) it was more

efficient than one-factor-at-a-time experiments; (2) it was necessary because the factor interactions may be present; and (3) it allowed the effects of a factor to be estimated at two levels of the other factors, yielding conclusions that would be valid over a broad range of experimental conditions [Montgomery, 1996]. The three factors were thickness of plate (X1), printing pressure (X2), and press speed (X3). This resulted in a total of eight different treatment combinations (press runs).

2.1 Experimental Design

Table I depicts the 2^3 factorial design which includes eight treatment combinations. The run order for the eight treatment combinations was randomly determined by computer (randomized design) to reduce possible biases introduced by unplanned changes in the experiment.

Table I: 2^3 factorial design

	Low Pressure		High Pressure	
	Low Speed	High Speed	Low Speed	High Speed
Thin Plate				
Thick Plate				
Factors	Factor Level			
	-		+	
Thickness of Plate (X_1) Printing Pressure (X_2) Press Speed (X_3)	3.94mm knot 5.0 60 sheets/min		7.01mm knot 5.3 120 sheets/min	

Table II: Experimental and Controlled Variables

Variables	Materials and Equipments	Type
Dot shape	Round	Controlled
Line screen	50 lines per inch (lpi)	Controlled
Imagesetter	ECRM Script Setter VR 36	Controlled
Thickness of plate	1. 7.01 mm (+), Cyrel HDC276 (hardness: 40 ± 2A, thickness: 7.01 ± 0.026 mm) 2. 3.94 mm (-), Cyrel HDC155 (hardness: 42 ± 2A, thickness: 3.94±0.026mm), with R/bak material 3.05 mm	Experimental
Plate exposure	Dupont CYREL 1001E	Controlled
Plate developer	Dupont CYREL processor 2001P	Controlled
Exposure control	for Cyrel HDC276 plate: back exposure: UV light 250 ± 50 sec. face exposure: UV light 600 ± 50 sec. for Cyrel HD C155 plate: back exposure: UV light 60 ± 10 sec. face exposure: UV light 450 ± 50 sec.	Controlled
Press	NIWA two-color press	Controlled
Corrugated cardboard	White color, B-Flute, bursting test: 9.6 kg/cm^2, inter liner strength: 220p; outer liner strength: 220p; medium strength: 180p	Controlled
Ink	Yi Pin Shin Ink, Best new series, Black water-based ink, pH value = 8.5	Controlled
Ink viscosity	13 seconds (measure by ZAHN Cup #4)	Controlled
Anilox	250 lpi (screen count: 250 lpi)	Controlled
Press speed	120 (+), 60 (–) sheets/min	Experimental
Printing pressure	Plate-to-substrate pressure, knot 5.3 (+), knot 5.0 (–)	Experimental
Press operator	One experienced operator	Controlled

2.2 Variables of the Study

There is a great variety of variables affecting tone value increase during corrugated cardboard printing process, and most of them are interdependent. It is not possible to study all the variables at the same time. One delimitation of this study was that only those variables suspected of significantly affecting tone value increase on flexo presses were investigated (experimental variables), and those variables controlled in everyday practice or other than press factors were held constant. Table II summarizes the experimental variables and variables that were controlled and how they were controlled.

2.3 Experimental Process and Data Collection

Test Form

A combination chart of different screen number and halftone step was employed in this study (as shown in Figure 1, from left to right are 50 lpi, 60 lpi, and 66 lpi). Screen count 50 lpi had been selected for study because it is the most common printing condition used in corrugated printing in Taiwan. The halftone step includes 3%, 4%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% tints. In addition to halftone step, the test form includes slur patches (two hexagons on the left-hand side of the test form) and vignette target (two squares on the right-hand side of the test form).

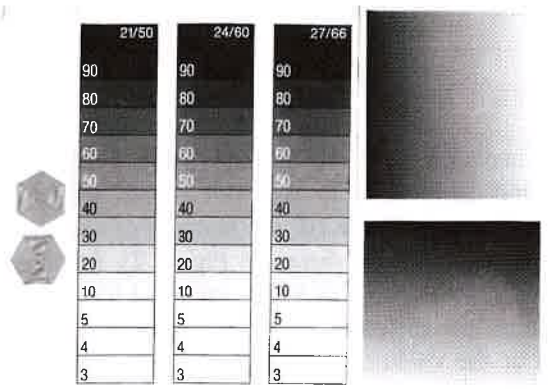


Figure 1: The test form for the experiment

Platemaking

The imagesetter used to output the computer-generated film for this experiment was calibrated and linearized before the experiment. The imagesetter was ECRM Script Setter VR 36. The thickness of plate is one the of experimental factor in this study. The two levels for plate thickness were 3.94 mm (low level) and 7.01 mm (high level).

The 2^3 factorial design resulted in eight monochrome press runs (printed in black color), which required 8 printing plates for the experiment. Four plates were exposed using thicker plate and the other four plates were exposed using thinner plate. A total of 8 plates were made. The exposure setting had been controlled. For the thicker plates (7.01 mm), the back exposure time was 250 ± 50 sec with face exposure 600 ± 50 sec. For the thinner plates (3.94 mm), the back exposure time was 60 ± 10 sec with face exposure 450 ± 50 sec.

Printing

Black water-based ink was used in this experiment. ZAHN cup #4 was employed to determine ink viscosity until the viscosity of black ink achieved a value of 13 seconds. Screen count for anilox roller

was 250 lpi. After each press run, the press was shut down and cleaned, the run counter was set to zero, and the desired materials and conditions were made ready for the next run. During each press run, the ink density was balanced out across the corrugated board to 1.70 for the black.

Measuring and data collection

One hundred corrugated cardboards were printed for each press run after the desired solid ink density being achieved; therefore, a total of 800 (8*100) corrugated cardboards were printed. Thirty-five cardboards were then systematically randomly sampled for each of the eight treatment combinations for a total sample size of 280 (8*35). Solid ink density, print contrast, and tone value increase at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% tints for each sampled cardboard were read with an X-Rite® 530 spectrodensitometer using Status T measurement. Each measured patch on the sampled cardboard was read five times to reduce the measuring error. The final data entered onto computer for the factorial analysis was a mean of five readings from the X-Rite® 530.

3. Results and Discussion

This section reports the results and findings gained through analyses of the experimental data. The software packages employed to analyze the data were SPSS 12.0 and Minitab 14.0.

3.1 Descriptive Statistics

Table III displays the descriptive statistics of the measurements on solid ink density (SID), tone value increase percentage (TVI), and print contrast (PC). The grand mean value in each cell is obtained from 1400 data (8 treatments * 5 readings * 35 cardboards). As shown in Table III, the average of solid ink density is 1.79. The greatest tone value increase occurred at 30% tints (as shown in Figure 2), followed by the 50% (28.14%), 20% (27.38%), 60% (24.2%), 10% (22.43%), 70% (19.91%), 80% (14.93%), and 90% (8.83%). This tone value increase phenomenon is somehow different from that on typical offset presses, which the greatest tone value increase is found at the midtone areas. The average of print contrast is 34.12%.

Table III: Descriptive Statistics

Variable	N	Min.	Max.	Mean	Std. Dev.
Solid Ink Density	1400	1.54	2.08	1.79	0.10
10% Tone Value Increase	1400	9	36	22.43	3.50
20% Tone Value Increase	1400	16	44	27.38	3.71
30% Tone Value Increase	1400	14	46	32.31	3.04
40% Tone Value Increase	1400	20	43	30.33	3.13
50% Tone Value Increase	1400	22	39	28.14	2.28
60% Tone Value Increase	1400	17	34	24.20	1.91
70% Tone Value Increase	1400	15	26	19.91	1.58
80% Tone Value Increase	1400	11	19	14.93	1.22
90% Tone Value Increase	1400	6	10	8.83	0.66
Print Contrast	1400	18	45	34.12	4.01

3.2 Examining the important effects for desired print attributes

This section discusses the results of the ANOVA and Stepwise Regression analyses for the main effects of the independent variables and their interaction effects on the dependent variables. It is

important to note that the significant level was set at .05 for all the analyses, i.e., $\alpha = 0.05$. The full model derived from 2^3 the factorial design is:

$$\hat{Y} = \alpha+\beta_1X_1 +\beta_2X_2 +\beta_3X_3 +\beta_4X_1X_2 +\beta_5X_1X_3 +\beta_6X_2X_3 +\beta_7X_1X_2X_3 + \varepsilon, \quad (1)$$

Where X_1 = thickness of plate; X_2 = printing pressure; X_3 = press speed.

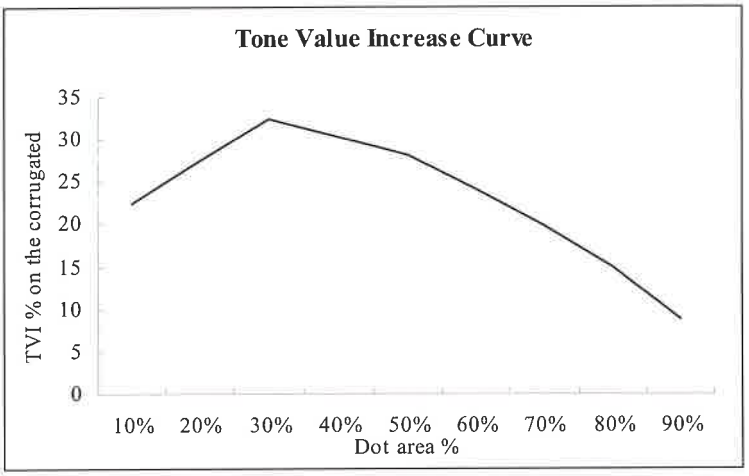


Figure 2: The Tone Value Increase (TVI) curve

The significant effects were selected from the full model by the Factorial analysis procedure using Minitab 14.0 for each observed attribute. Then those significant effects were included in the reduced model for the regression analysis, factorial analysis, and analysis of variance. Due to the length limitation, the paper would present only the summarized results of the following attributes:

1. the significant effects selected to be included in the reduced model and the size and direction (positive or negative) of their effects,
2. the best treatment combinations, including their levels, to achieve the most desired print attributes (solid ink density, tone value increase, and print contrast),
3. the estimation of the observed print attributes derived from the best treatment combinations and the prediction equations,
4. the R-square analyses to valid the prediction equation. The R^2 values indicate that the significant effects collectively explained approximately R^2 % of the total variability in the dependent variable.

Discussion in solid ink density

The summary of the ANOVA and Stepwise Regression analyses for the main and interaction effects on the solid ink density is exhibited in Table IV. The Pareto chart of the standardized effects is displayed in Figure 3 and cube plot of the eight treatment combinations is exhibited in Figure 4.

As shown in Table IV and Figure 3, the positive effect (0.15071) of press speed (X_3) had the greatest impact on solid ink density among the three factors. Other dominant effects on solid ink density include the interaction effect of "thickness of plate" and "printing pressure" (X_1*X_2), the interaction effect of "printing pressure" and "press speed" (X_2*X_3), and the three-way interaction effect of "plate thickness", "printing pressure", and "press speed" (X_1*X_2*X_3). In Figure 4, the numbers on the eight corners of the cube represent the response means of solid ink density printed by the eight treatment combinations. The cube plot, therefore, displays the relationships among three factors for two-level factorial at a glance. As shown in Figure 4, the best treatment combination for solid ink density is (X_1,

X_2, X_3) = (1, 1, 1) in terms of the maximum solid value; i.e., when the plate thickness was 7.01 mm, the printing pressure was set at knot 5.3, and the press speed was set at 120 sheets/min, the estimated maximum solid ink density value is 1.89. In other words, when (X_1, X_2, X_3) = (1, 1, 1) treatment combination was used to print corrugated cardboards, the value of solid ink density could be raised from 1.79 (observed grand mean) to 1.89. The regression equation used to predict the mean of the solid ink density is shown as Equation 2. The R^2 value (96.89%) in Table IV implies that the reduced model explains approximately 96.89% of the total variability in solid ink density (X_3, X_1*X_2, X_2*X_3, and X_1*X_2*X_3 collectively).

$$\hat{Y}_{_SID} = 1.80 + 0.0754\ X_3 + 0.0126\ X_1X_2 + 0.0089\ X_2X_3 - 0.0069\ X_1X_2X_3 \quad (2)$$

Table IV: ANOVA and stepwise regression summary for solid ink density

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Max. Value	R^2
$\alpha = 0.05$	$X_3 = 0.15071$; $X_1X_2 = 0.02524$; $X_2X_3 = 0.01782$; $X_1X_2X_3 = -0.01378$	X_1 = thick plate X_2 = high pressure X_3 = high speed (1, 1, 1)	1.89	96.89%

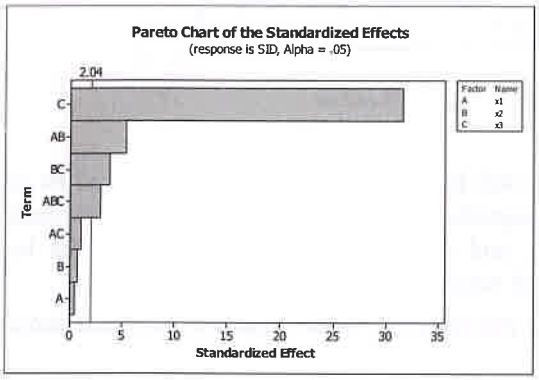


Figure 3: Pareto chart for SID

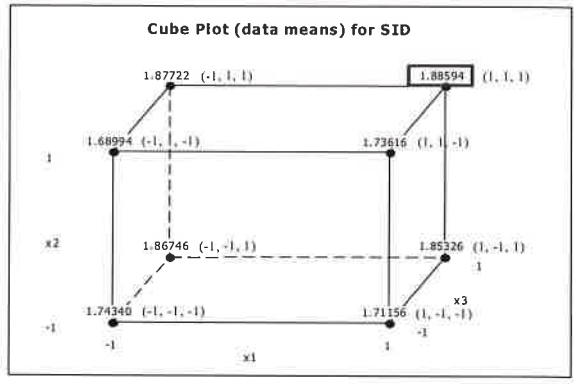


Figure 4: Cube plot for SID

Discussion in 10% tone value increase (TVI)

Table V displays the summary result of the ANOVA and Stepwise Regression analyses for the main and interaction effects on the 10% tone value increase (TVI). The Pareto chart of its standardized effects is displayed in Figure 5 and the cube plot of eight treatment combinations is exhibited in Figure 6. Table V and Figure 5 indicate that the dominant effects on the 10% TVI are the three main effects and the interaction effect of "plate thickness" and "press speed" (X_1*X_3). As shown in the cube plot in Figure 6, the best treatment combination for 10% TVI is (X_1, X_2, X_3) = (-1, -1, -1) in terms of the minimum TVI value; i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the mean value of 10% TVI could be decreased from 22.43% to 18.83% (the minimum TVI was achieved). The regression equation used to predict the 10% TVI is shown as Equation 3. In Table V, the R^2 value of the prediction equation is 54.5%; it means that the reduced model (X_2, X_3, X_1*X_3, and X_1 collectively) explains approximately 54.5% of the total variability in the 10% TVI. It implies that the prediction equation for the 10% TVI needs to be corrected and improved.

$$\hat{Y}_{_10\%TVI} = 22.4 + 1.04\ X_2 + 0.863\ X_3 - 0.668\ X_1X_3 + 0.582\ X_1 \quad (3)$$

Table V: ANOVA and stepwise regression summary for 10% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_2 = 2.0705$; $X_3 = 1.7265$; $X_1X_3 = -1.3365$; $X_1 = 1.1635$	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	18.83%	54.5%

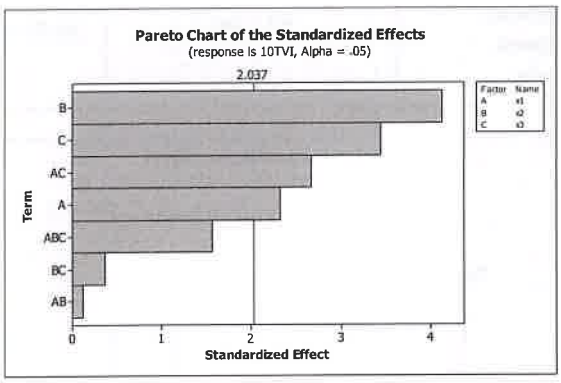


Figure 5: Pareto chart for 10% TVI

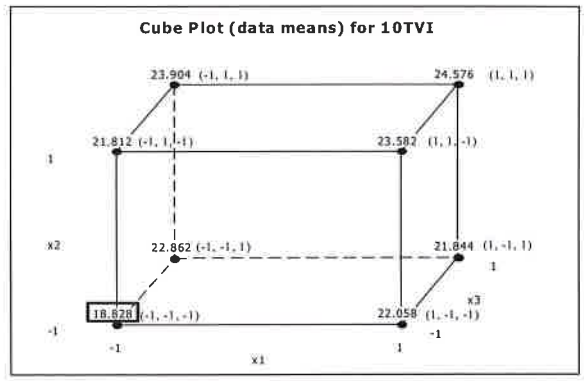


Figure 6: Cube plot for 10% TVI

Discussion in 20% tone value increase (TVI)

The summary of ANOVA and Stepwise Regression analyses for the main and interaction effects on the 20% tone value increase (TVI) is exhibited in Table VI. The Pareto chart of its standardized effects is displayed in Figure 7 and the cube plot of eight treatment combinations is exhibited in Figure 8. Table VI and Figure 7 indicate that the positive effect (3.027) of plate thickness (X_1) had the greatest impact on the 20% TVI among the three factors. Figure 8 (cube plot) shows that the best treatment combination for 20% TVI is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the mean value of 20% TVI could be decreased from 27.38% to 24.18%. The R^2 value of the prediction equation (shown in Table VI) is 80.7%; in other words, 80.7% of total variability in 20% TVI could be explained by the reduced model (X_1, X_1*X_2, X_1*X_2*X_3, X_2*X_3, and X_3 collectively).

$$\hat{Y}_{_20\%TVI} = 27.4 + 1.51\,X_1 + 0.851\,X_1X_2 + 0.810\,X_1X_2X_3 - 0.714\,X_2X_3 + 0.616\,X_3 \qquad (4)$$

Discussion in 30% tone value increase (TVI)

Table VII displays the summary of the ANOVA and Stepwise Regression analyses for the main and interaction effects on the 30% TVI. Figure 9 and Figure 10 display the Pareto chart of factor effects and Cube plot of the eight treatment combinations respectively. As shown in Table VII and Figure 9, the main effect of press speed (X_3) was positive (2.395) and it had the greatest impact on the 30% TVI among the three factors. The estimated main effects of the printing pressure (X_2) and the thickness of plate (X_1) were also positive. Figure 10 shows that the best treatment combination for the 30% TVI is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the estimated minimum 30% TVI value is 29.38%. In other words, when (X_1, X_2, X_3) = (-1, -1, -1) treatment combination was employed to print corrugated cardboards, the mean value of 30% TVI could be decreased from 32.31% to 29.38%. The prediction equation used to predict the mean of the 30% TVI is shown as Equation 5. The R^2 value (73.7%) in Table VII indicates that the reduced model (X_3, X_2, and X_1 collectively) explains approximately 73.7% of the total variability in the 30% TVI.

$$\hat{Y}_{_30\%TVI} = 32.3 + 1.20\,X_3 + 0.863\,X_2 + 0.649\,X_1 \quad (5)$$

Table VI: ANOVA and stepwise regression summary for 20% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_1 = 3.027$; $X_1X_2 = 1.701$; $X_1X_2X_3 = 1.62$; $X_2X_3 = -1.429$ $X_3 = 1.233$	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	24.18%	80.7%

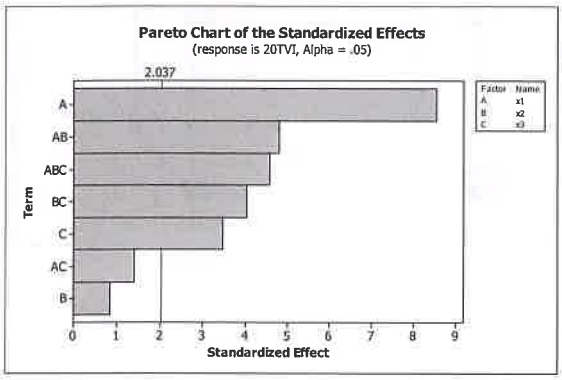


Figure 7: Pareto chart for 20% TVI

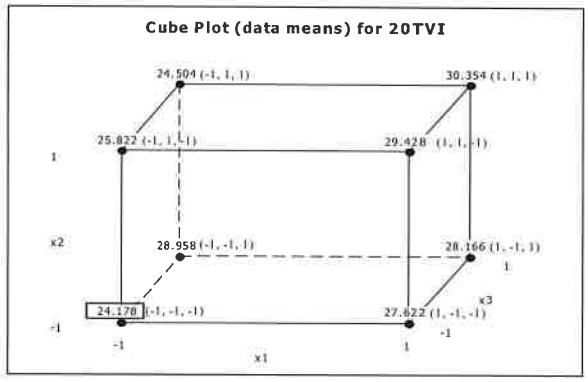


Figure 8: Cube plot for 20% TVI

Table VII: ANOVA and stepwise regression summary for 30% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_3 = 2.395$; $X_2 = 1.726$; $X_1 = 1.298$;	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	29.38%	73.7%

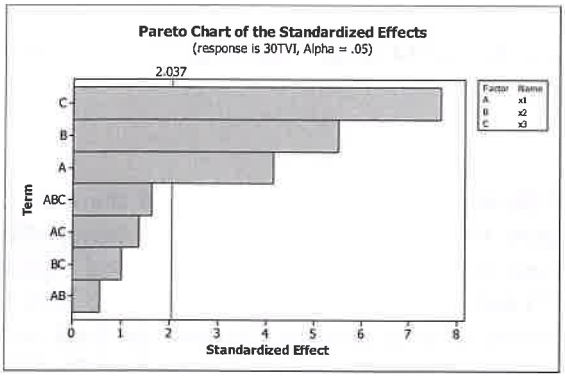


Figure 9: Pareto chart for 30% TVI

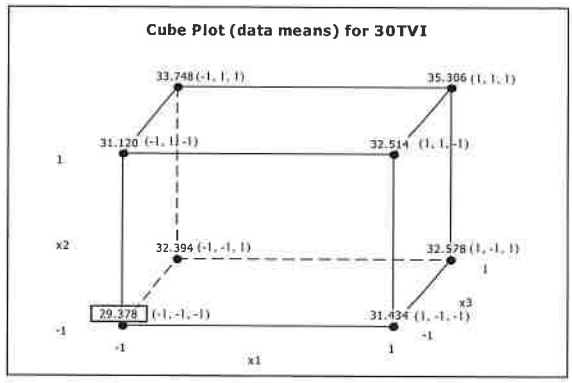


Figure 10: Cube plot for 30% TVI

Discussion in 40% tone value increase (TVI)

The ANOVA and Stepwise Regression analyses for the main and interaction effects on the 40% TVI are displayed in Table VIII. The Pareto chart of the factor effects is displayed in Figure 11 and the

cube plot of eight treatment combinations is exhibited in Figure 12. Table VIII and Figure 11 show that the main effect of press speed (X_3) was positive (2.598) and it had the greatest impact on the 40% TVI among the three factors. The estimated main effects of the printing pressure (X_2) and the plate thickness (X_1) were also positive. The X_1*X_3 interaction was one of the significant effects and its effect was negative (-0.741). As shown in Figure 12, the best treatment combination for the 40% TVI is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the mean value of the 40% TVI could be decreased from 30.33% to 27.44%. The R^2 value of the prediction equation in Table VIII is 81.6%; in other words, 81.6% of the total variability in the 40% TVI could be explained by the reduced model (X_3, X_2, X_1, and X_1*X_3 collectively).

$$\hat{Y}_{_40\%TVI} = 30.3 + 1.30\,X_3 + 0.722\,X_2 + 0.429\,X_1 - 0.370\,X_1X_3 \quad (6)$$

Table VIII: ANOVA and stepwise regression summary for 40% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_3 = 2.598$; $X_2 = 1.445$; $X_1 = 0.895$; $X_1X_3 = -0.741$;	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	27.44%	81.6%

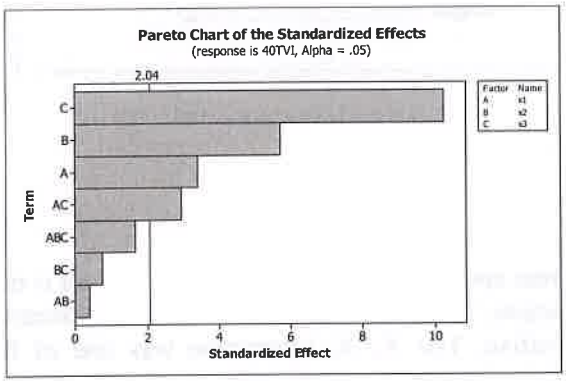


Figure 11: Pareto chart for 40% TVI

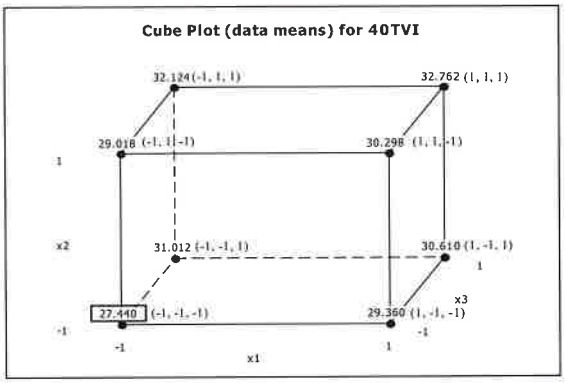


Figure 12: Cube plot for 40% TVI

Discussion in 50% tone value increase (TVI)

Table IX displays the summary of the ANOVA and Stepwise Regression analyses for the main and interaction effects on the 50% TVI. The Pareto chart of the factor effects is displayed in Figure 13 and the cube plot of the eight treatment combinations is exhibited in Figure 14. Table IX and Figure 13 indicate that the main effect of press speed (X_3) was positive (2.454) and it had the greatest impact on the 50% TVI among the three factors. Other dominant effects on the 50% TVI include the main effect of printing pressure (X_2), the main effect of the thickness of plate (X_1), the interaction effect of "plate thickness" and "press speed" (X_1*X_3), and the interaction effect of "plate thickness", "printing pressure", and "press speed" ($X_1*X_2*X_3$). Figure 14 shows that the best treatment combination for the 50% TVI is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the estimated minimum 50% TVI value is 25.25%; in other words, when (X_1, X_2, X_3) = (-1, -1, -1) treatment combination was employed to print corrugated cardboards, the mean value of the 50% TVI could be decreased from 28.14% to 25.25%. The prediction equation used to predict the 50% TVI is shown as Equation 7. The R^2 value (86.7%) in Table IX indicates that the reduced model (X_3, X_2, X_1, X_1*X_3, and $X_1*X_2*X_3$ collectively) explains approximately 86.7% of the total variability in the 50% TVI.

$$\hat{Y}_{_50\%TVI} = 28.1 + 1.23\ X_3 + 0.690\ X_2 + 0.473\ X_1 - 0.307\ X_1X_3 + 0.285\ X_1X_2X_3 \quad (7)$$

Table IX: ANOVA and stepwise regression summary for 50% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_3 = 2.454$; $X_2 = 1.38$; $X_1 = 0.946$; $X_1X_3 = -0.615$ $X_1X_2X_3 = 0.57$	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	25.25%	86.7%

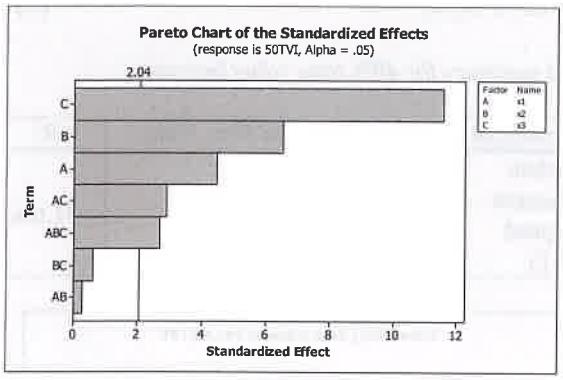


Figure 13: Pareto chart for 50% TVI

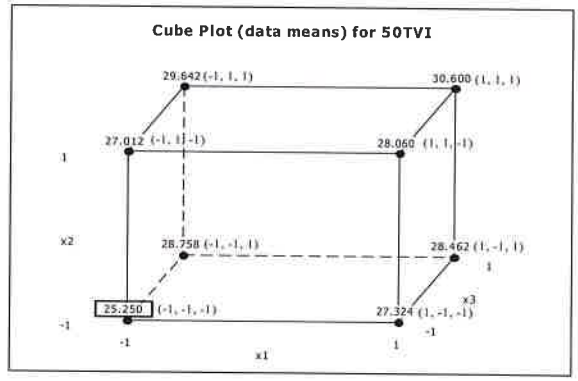


Figure 14: Cube plot for 50% TVI

Discussion in 60% tone value increase (TVI)

Table X and Figure 15 show that the main effect of press speed (X_3) was positive (1.9765) and it had the greatest impact on the 60% TVI among the three factors. The estimated main effects of the printing pressure (X_2) and plate thickness (X_1) were also positive. The X_1*X_2 interaction was one of the significant effects and its effect was positive (0.4475). Figure 16 shows that the best treatment combination for 60% TVI is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the mean value of the 60% TVI could be decreased from 24.20% to 22.30%. The prediction equation used to estimate the mean of the 60% TVI is shown as Equation 8. The R^2 value of the prediction equation in Table X is 81.6% and it means that 81.6% of total variability in the 60% TVI could be explained by the reduced model (X_3, X_2, X_1, and X_1*X_2 collectively).

$$\hat{Y}_{_60\%TVI} = 24.2 + 0.988\ X_3 + 0.526\ X_2 + 0.503\ X_1 + 0.224\ X_1X_2 \quad (8)$$

Discussion in 70% tone value increase (TVI)

Table XI and Figure 17 show that the main effect of press speed (X_3) was positive (1.741) and it had the greatest impact on the 70% TVI among the three factors. The estimated main effects of the printing pressure (X_2) and the plate thickness (X_1) were also positive. Figure 12 shows that the best treatment combination for the 70% TVI is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the mean value of the 70% TVI could be decreased from 19.91% to 18.56%. The equation used to predict the 70% TVI is shown as Equation 9. The R^2 value (86%) in Table XI indicates that the reduced model (X_3, X_2, and X_1 collectively) could explain approximately 86% of the total variability in the 70% tone value increase.

$$\hat{Y}_{_70\%TVI} = 19.9 + 0.870\,X_3 + 0.285\,X_2 + 0.188\,X_1 \quad (9)$$

Table X: ANOVA and stepwise regression summary for 60% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_3 = 1.9765$; $X_2 = 1.0525$; $X_1 = 1.0065$; $X_1X_2 = 0.4475$	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	22.30%	85.5%

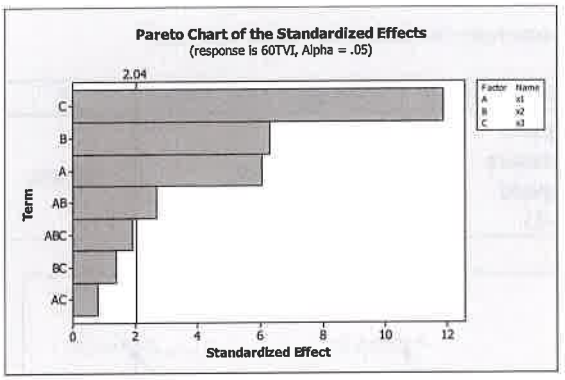


Figure 15: Pareto chart for 60% TVI

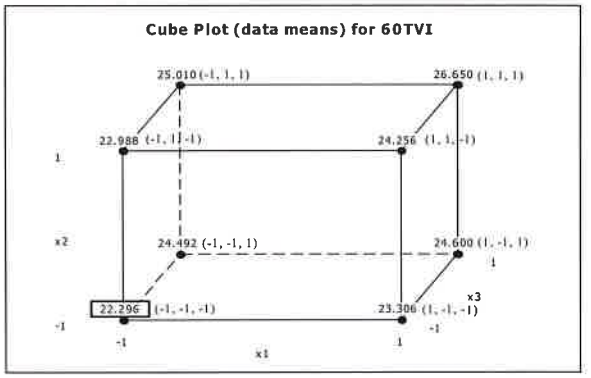


Figure 16: Cube plot for 60% TVI

Table XI: ANOVA and stepwise regression summary for 70% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_3 = 1.741$; $X_2 = 0.57$; $X_1 = 0.376$	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	18.56%	86.0%

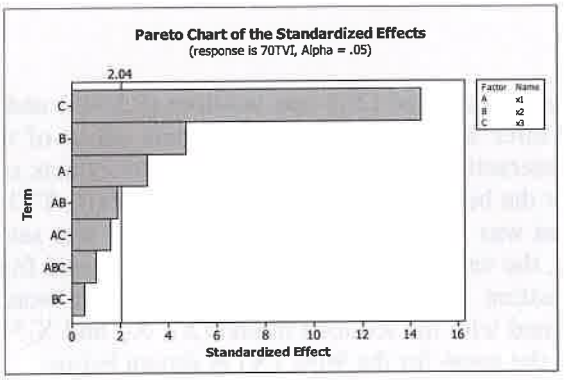


Figure 17: Pareto chart for 70% TVI

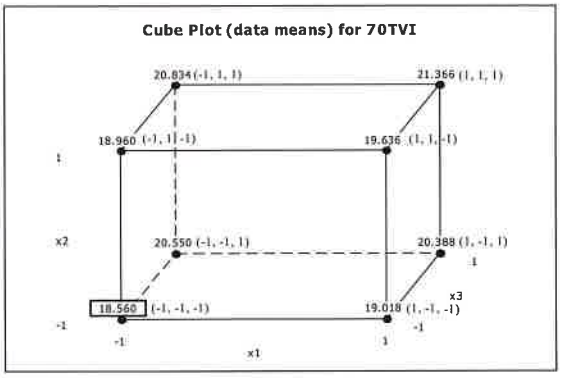


Figure 18: Cube plot for 70% TVI

Discussion in 80% tone value increase (TVI)

Table XII and Figure 19 indicate that the main effect of press speed (X_3) was positive (1.385) and it had the greatest impact on the 80% TVI among the three factors. Other dominant effects on the 80% TVI include the main effect of printing pressure (X_2), the interaction effect of "plate thickness" and "press speed" (X_1*X_3), and the three-way interaction effect of "plate thickness", "printing pressure",

and "press speed" (X_1*X_2*X_3). Figure 20 shows that the best treatment combination for the 80% TVI is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the estimated minimum 80% TVI value is 13.7%. In other words, when (X_1, X_2, X_3) = (-1, -1, -1) treatment combination was used to print corrugated cardboards, the mean value of the 80% TVI could be decreased from 14.93% to 13.71%. The prediction equation used to estimate the mean of the 80% TVI is shown as Equation 10. The R^2 value (93.4%) in Table XII indicates that the reduced model (X_3, X_2, X_1*X_3, and X_1*X_2*X_3 collectively) explains approximately 93.7% of the total variability in the 80% TVI.

$$\hat{Y}_{_80\%TVI} = 14.9 + 0.692\ X_3 + 0.236\ X_2 - 0.205\ X_1X_3 + 0.0890\ X_1X_2X_3 \quad (10)$$

Table XII: ANOVA and stepwise regression summary for 80% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_3 = 1.385$; $X_2 = 0.473$; $X_1X_3 = -0.409$ $X_1X_2X_3 = 0.178$	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	13.71%	93.4%

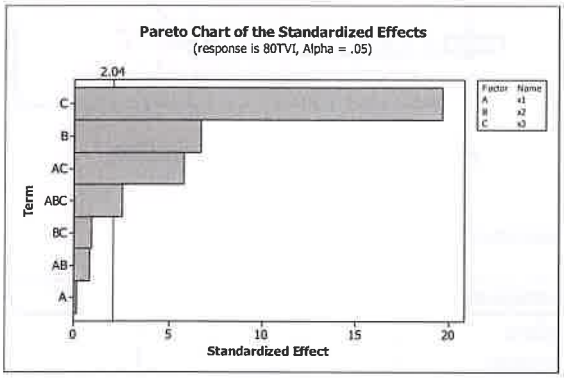


Figure 19: Pareto chart for 80% TVI

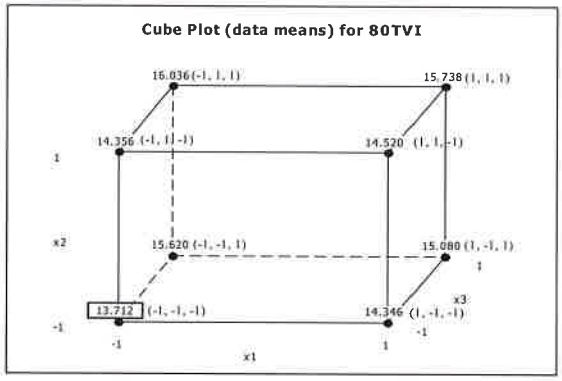


Figure 20: Cube plot for 80% TVI

Discussion in 90% tone value increase (TVI)

Table XIII and Figure 21 show that the main effect of press speed (X_3) was positive (0.5945) and it had the greatest impact on the 90% TVI among the three factors. The estimated main effect of the printing pressure (X_2) was also positive. The X_1*X_3 interaction was one of the significant effects and its effect was negative (-0.1555). Figure 22 shows that the best treatment combination for 90% TVI is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the value of 90% TVI could be decreased from 8.83% to 8.39%. The R^2 value of the prediction equation in Table XIII is 84.6%; in other words, 84.6% of total variability in 90% TVI could be explained with the reduced model (X_3, X_2, and X_1*X_3 collectively). The prediction equation used to estimate the mean for the 90% TVI is shown below:

$$\hat{Y}_{_90\%TVI} = 8.83 + 0.297\ X_3 + 0.0872\ X_2 - 0.0778\ X_1X_3 \quad (11)$$

Table XIII: ANOVA and stepwise regression summary for 90% tone value increase

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Min. Value	R^2
$\alpha = 0.05$	$X_3 = 0.5945$; $X_2 = 0.1745$; $X_1X_3 = -0.1555$	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	8.39%	84.6%

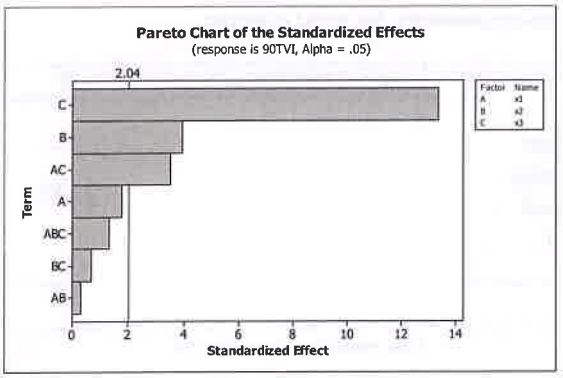


Figure 21: Pareto chart for 90% TVI

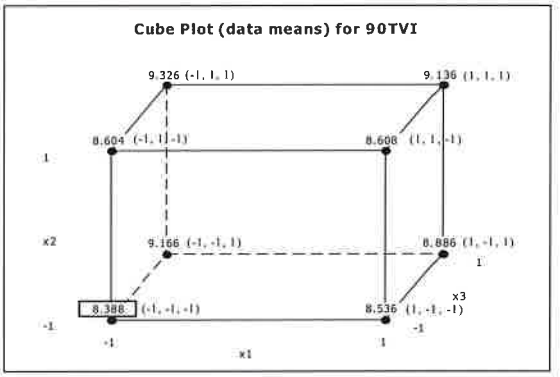


Figure 22: Cube plot for 90% TVI

Discussion in print contrast (PC)

The summary of the ANOVA and Stepwise Regression analyses for the main and interaction effects on the print contrast (PC) is exhibited in Table XIV. The Pareto chart of the standardized factor effects is displayed in Figure 23 and the cube plot of the eight treatment combinations is exhibited in Figure 24.

As shown in Table XIV and Figure 23, the dominant effects on the PC included all the main effects and the interaction effects except for the interaction effect of printing pressure (X_2) and press speed (X_3). The cube plot displays that the best treatment combination for PC is (X_1, X_2, X_3) = (-1, -1, -1); i.e., when the plate thickness was 3.94 mm, the printing pressure was set at knot 5.0, and the press speed was set at 60 sheets/min, the estimated maximum print contrast value is 37.13%. In other words, when (X_1, X_2, X_3) = (-1, -1, -1) treatment combination was used to print corrugated cardboards, the mean value of the PC could be increased from 34.12% to 37.13%. The regression equation used to estimate the print contrast is shown as Equation 12. The R^2 value (81.8%) in Table XIV indicates that the reduced model (X_1*X_3, X_2, X_1*X_2, X_3, X_1*X_2*X_3, and X_1 collectively) could explain approximately 81.8% of the total variability in the print contrast.

$$\hat{Y}_{PC} = 34.1 + 0.863\, X_1X_3 - 0.854\, X_2 + 0.703\, X_1X_2 - 0.658\, X_3 - 0.376\, X_1X_2X_3 + 0.362\, X_1 \qquad (12)$$

3.3 Examination of the residuals of the prediction equations for the print attributes

A residual is the difference between the observed value of the dependent variable and the value predicted by the regression line. It is important to examine the residual plots to check whether the required assumptions of linearity, normality, constant variance, and independence of observations are met because residuals are conceived as a measure of the error component in a regression analysis. The DOE (Design of Experiments) procedure by Minitab provides four residuals plots at a time.

The four residuals plots for the print attributes based on the discussed Equations are exhibited from Figure 25 to Figure 35. As shown in these Figures, the points on the normal probability plot of the residuals lie reasonably close to a straight line. The histogram of residuals is approximately normally distributed and symmetrically about zero. The dots on the "residuals versus the order" plot tend to fluctuate randomly about zero with no particular trend as the observation number changes, with the exception of 10% tone value increase. There is a recognizable pattern in the residuals versus the fitted values plot where residuals increase as fits increase for 10% tone value increase. To sum up, the residual diagnostics for solid ink density, tone value increase at the 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% tints, and print contrast are acceptable. Conversely, the residual diagnostics for 10% TVI is unacceptable and needs to be corrected. The R^2 value of the prediction equations for all the print attributes are greater than 70% except for the 10% tone value increase.

Table XIV: ANOVA and stepwise regression summary for print contrast

Sig. Level	Significant Effects	Best Treatment Combinations	Estimated Max. Value	R^2
α= 0.05	X_1X_3 = 1.7265 X_2 = -1.7085 X_1X_2 = 1.4055 X_3 = -1.3155 $X_1X_2X_3$ = -0.7515 X_1 = 0.7235	X_1 = thin plate X_2 = low pressure X_3 = low speed (-1, -1, -1)	37.13%	81.8%

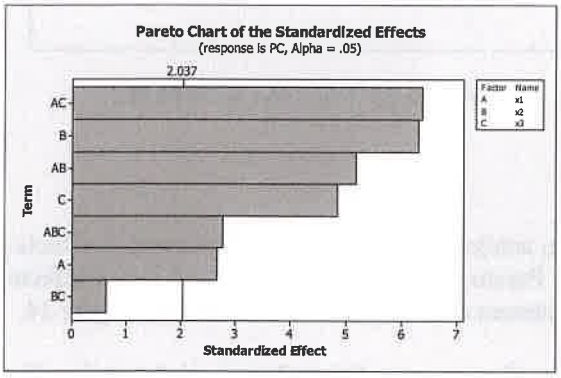


Figure 23: Pareto chart for PC

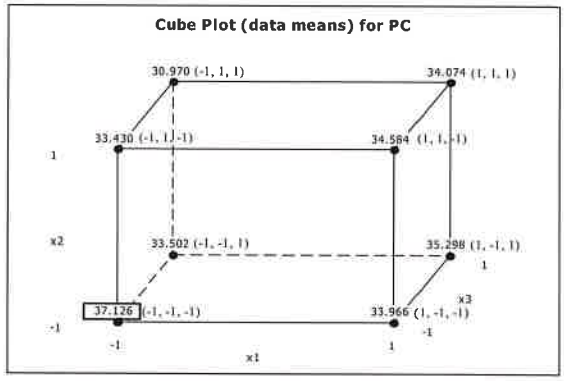


Figure 24: Cube plot for PC

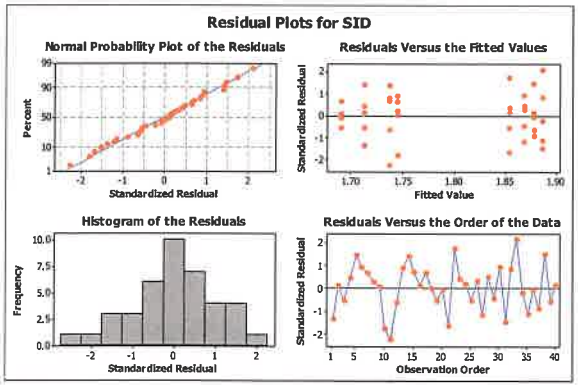


Figure 25: Residual plots for SID

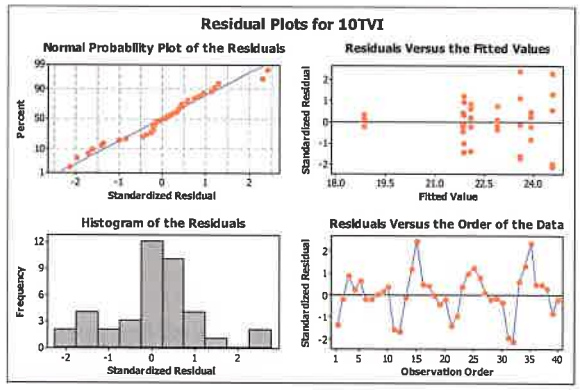


Figure 26: Residual plots for 10% TVI

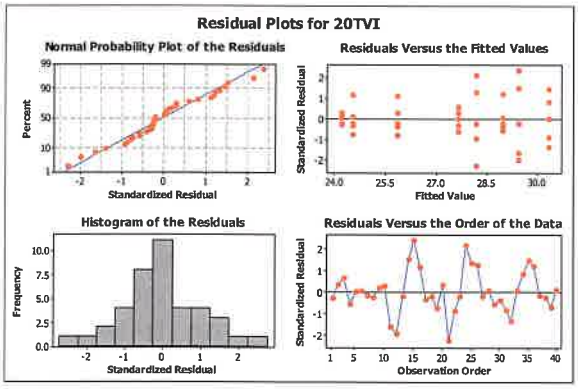


Figure 27: Residual plots for 20% TVI

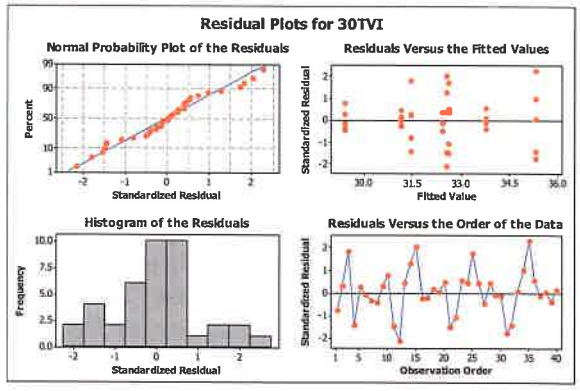


Figure 28: Residual plots for 30% TVI

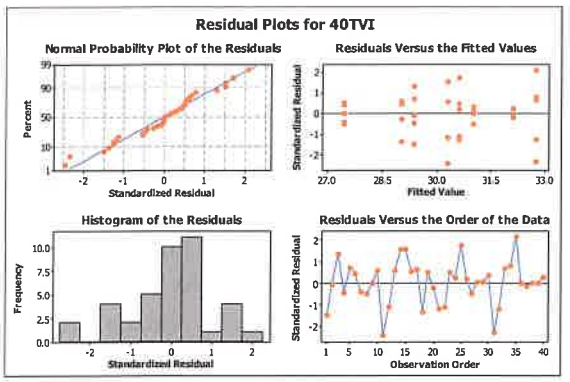


Figure 29: Residual plots for 40% TVI

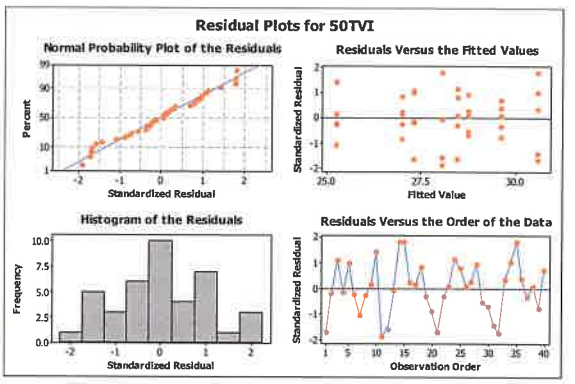


Figure 30: Residual plots for 50% TVI

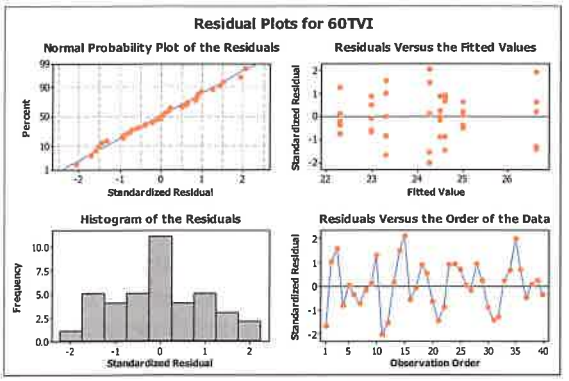


Figure 31: Residual plots for 60% TVI

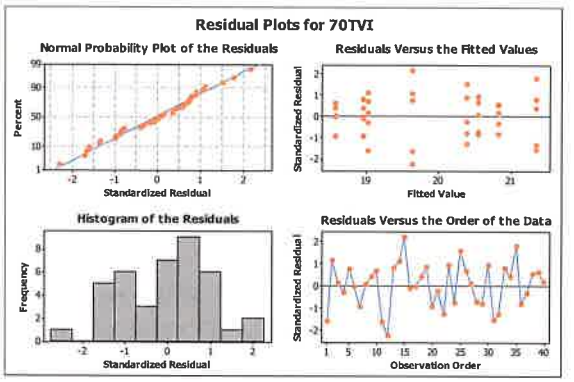


Figure 32: Residual plots for 70% TVI

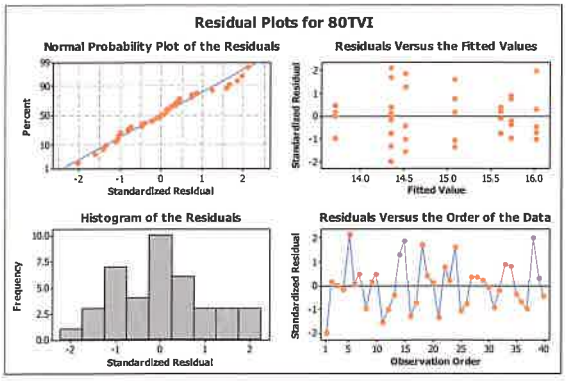


Figure 33: Residual plots for 80% TVI

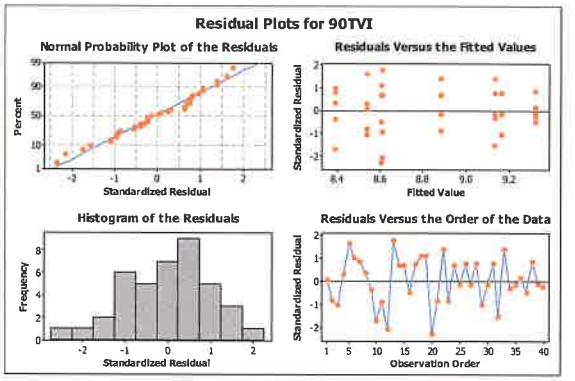


Figure 34: Residual plots for 90% TVI

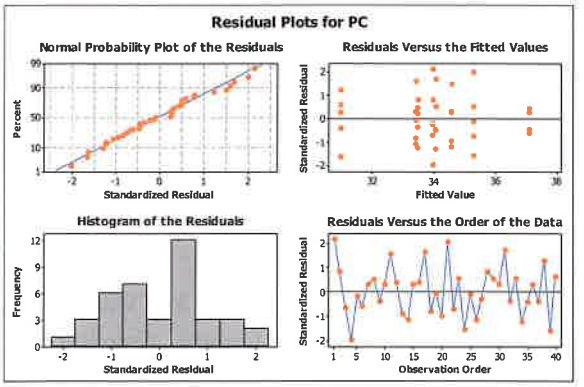


Figure 35: Residual plots for PC

4. Conclusions

The study provides the flexographic printing industry a practical reference when choosing various combinations of printing pressure, printing speed, and thickness of plates to print corrugated cardboards. The overall results suggested that the press speed (X_3) was the most dominant variable affecting on-press solid ink density. For tone value increase, the two most significant effects were the main effect of "press speed" (X_3) and "printing pressure" (X_2), with the exception of 10% and 20% tints. The dominant effects on the print contrast included all the main effects and the interaction effects except for the interaction effect of printing pressure (X_2) and press speed (X_3). The main results of the study are as follows:

1. Faster printing speed and higher printing pressure using thicker plate print greater solid ink density. The results show that the influence of printing speed on solid ink density was significantly greater than that of printing pressure and thickness of plate.
2. For dot reproduction, the smallest tone value increase could be obtained when the plate thickness (X_1) was at the low level (3.94 mm), printing pressure (X_2) at the low level (knot = 5.0), and press speed (X_3) at the low level (60 sheets/min); in other words, when (X_1, X_2, X_3) = (-1, -1, -1) treatment combination was used to print corrugated cardboards, the values of tone value increase could be decreased by 3% at 10% - 60% tints and 1% at 70% - 90% tints.
3. For print contrast, the greatest print contrast could be achieved when (X_1, X_2, X_3) = (-1, -1, -1) treatment combination was used to print corrugated cardboards; the value of print contrast could be increased from 34.12% to 37.2%.
4. The residuals of the prediction equations were uesd to examine the prediction models for the discussed print attributes. R^2 value is based on the average size of residuals, which is useful in determining whether the fit of the regression equation is good or bad, and whether the explained variation is adequate. The R^2 value of the prediction equation for each print attribute investigated in this study is greater than 0.70 except for 10% tint.
5. The vignette target on the right-hand side of the test form is used to test whether there are bandings. Eight experts were invited to observe the banding phenomenon and grade them according to the severe degree. The results show that the thinner the plate, the less the banding. The least banding could be obtained when (X_1, X_2, X_3) = (-1, -1, -1) treatment combination was used.

The graphic corrugated segment of the overall corrugated packaging industry represented about 23% of the total corrugated produced in 2004 [Perkowski, 2006]. It is becoming a high-quality, color-enhanced, complex-graphics sector. The bulk of the corrugated industry has functional packaging printed on one-, two- and three-color folder/gluers. Due to time constraint and cost considering, this study focused only on black color printing. Further researches are necessary to establish practical references of print attributes for color corrugated printing.

Acknowledgement

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References

1. DeRosa, Michael. (1998). *Product Trend Report: Corrugated Substrates.* Flexo, 23 (4). pp. 20-25
2. Flexographic Technical Association. (1999). *Flexography: Principles & Practices (5th ed).* Ronconkoma, NY: Foundation of Flexographic Technical Association, Inc
3. Hsieh, Yung-Cheng & Wu, Yu-Ju. (2001). *An experimental study to identify key factors affecting dot reproduction on CD-ROM decoration using UV offset printing.* TAGA Proceedings 2001, pp. 223-257
4. Jansen, Dipl-Ing. Volker & Stebani, Uwe. (2002). *Inside Corrugated.* Flexo, 27 (11). pp. 32-34
5. Montgomery, Douglas C. (1996). *Introduction to Statistical Quality Control (3rd ed).* John Wiley & Sons, Inc
6. Perkowski, Frank. (2006). *The Graphic Corrugated Market Growth Opportunities for Flexographic Printing.* Flexo, 31 (1). pp. 22-24

Topographical micro changes of corrugated board liners induced by heat treatment and their effect on flexographic print quality

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Abstract

The effect of washboarding occurs very often in the corrugated board production process. This is a problem since it creates stripy print images in the flexographic post-print, which are more disturbing than colour deviations or smaller print defects. Much effort has been devoted to locating the problem and trying to minimize it. However, no studies have been made of whether changes in the liner surface could cause such stripy images. The worst conditions that a surface, which is supposed to be printed can be exposed to, are friction, heat, pressure and moisture at one and the same time. Exactly these conditions prevail in the double baker of the corrugated board machine. Therefore, this study was set-up trying to simulate the conditions in the double baker in order to gather knowledge of which factor(s) influence and what to what magnitude. The topography of the sample surfaces was measured and compared with the original, untreated surface. Furthermore, the treated and untreated samples were printed in the IGT-F1 laboratory flexo-printer to gather knowledge about how the above factors influence the print quality. The print was finally evaluated with print density measurements.

1. Introduction

Stripes in a print image on corrugated board are an unwelcome phenomenon in flexographic post-print. Periodical print defects, such as stripes, on a corrugated board package is a serious problem as it is more easily perceived than random print defects [Netz, 1996]. A wavy corrugated board surface (washboarding) leads to a macro scale print defect, while minor variances of the liner surface pose a micro scale print defect. Such stripy appearance is, commonly a result of washboarding of the outer liner. However, it can also be induced by the printing force above the liner positions that are in contact to the fluting (induced washboarding). This occurs more commonly for liners with surface weights higher than 150 g/m^2, because they have a higher stiffness and the internal stresses in the glue, between fluting and liner, consequently have a lesser effect [Cusdin, 2000]. Deviations of surface properties can also influence the whole printing process and so the final printed image.

Tribology (from greek *tribo,* meaning *I rub*) explains the interaction between solid surfaces in relative motion [Persson, 2000]. Back *et al* (1991) stated that a low coefficient of friction of paper against metal is desirable in the corrugator, i.e. that highly polished metal surfaces are important. Furthermore, Back *et al* found that the friction coefficient decreased with increasing temperature of the corrugator. Zang *et al* stated that surface roughness, porosity and water absorbency are the most important factors affecting the flexographic print quality. Paper-Metal friction has an effect on at least two of these three factors.

The only unit in the corrugator, that can affect the print stripiness as a function of the friction, is the double baker, which combines the single wall (fluting plus inner liner) with the outer liner. The double baker has a length of approximately 10 m, depending on the corrugator, where the combined corrugated board is pulled over a hot plate (about 190°C, dry saturated steam @ 13 bar) at an average speed of 200 m/min. Consequently, the printing side is exposed to this high temperature and pressure impact for about 3 s, depending on the speed [Pinnington 2003, Mensing 2003].

The pressure distribution in the double baker over the corrugated board is commonly sinusoidal due to the supporting underlying fluting. This explains the stripy image but leaves the question: *"Is the tip of the outer liner's surface affected and if so to which magnitude?"*. Performing a laboratory test to simulate the corrugation process is practically impossible without specially designed and expensive test equipment. Nevertheless, to answer the question, one needs appropriate test equipment, and with some different treatments it is possible to gain information about:

- *Is the surface roughness affected?*
- *Does the surface roughness between tip and valley vary?*
- *Is the time, speed and/or temperature influencing the result?*
- *And most interesting: does the flexo post-print show print defects, like stripes?*

All these questions can be answered in the laboratory, but only as trends, not with results directly comparable to the real corrugator scale.

2. Materials

Four different uncoated outer liners from two different manufacturers were used. Two low grammage liners: 100 g/m² (113 g/m²) and 110 g/m² (109 g/m²), and two higher grammage liners 170 g/m² (169 g/m²) and 175 g/m² (176 g/m²) were selected. The values within brackets are the grammage values measured according to the EN ISO 536 standard. The samples are coded: 1u110, 1u170, 2u100 and 2u175, where the first digit represents the manufacturer, the "u" = uncoated and the last three digits are the grammage of the papers.

Special equipment (Figure 1) was used to distribute the starch on the liner, simulating the pressure at the tip and to achieve conditions similar to those in the double baker. That equipment was made of Teflon® instead of metal in order to maintain shape accuracy and to give as low heat transfer as possible. Too high heat transfer from the gluing zone would decrease the drying rate of the starch glue.

The printing cliché used for testing was DuPont™ Cyrel® DPC, supplied by Miller Graphics, Sunne, Sweden, with a thickness of 1.7 mm and hardness of 40 Sh A. Cyrel® DPC is a digital plate, mostly used for flexo-print on corrugated board. The print cliché had a width of 50 mm and in the evaluation area it contains one half full tone and the other one a 70% halftone stripe. Water based cyan ink, Scanbrite Raster from Sun Chemical AB, Kista, Sweden, was used. The ink viscosity, measured with a Brookfield viscometer RVDV-I, was 23 s (DIN Cup #4). The surface tension of the ink was 32.1 mN/m measured using the DuNouy ring method.

3. Methods

Sample preparation

Simulating the process of the corrugator in laboratory scale is difficult, mainly due to the high speed (100-400 m/min). To get reasonable results also under laboratory conditions, the only way to compensate for that problem, without changing too many other parameters, is to decrease the temperature. The temperature was therefore set to 150°C, instead of the commonly used temperature of 190°C. An overview of the test procedure is illustrated in Figure 1.

Step (1) in *Figure 1* illustrates the pre-heating of the gluing side of the liner for the curing process of the starch. The heating plate (App. 257, Lorentzen & Wettre, Kista, Sweden) was set to a maximum temperature of 147°C with a cycling temperature of 8°C and cycling time of 10 min. The pre-heating operation could not be simulated to completely mirror the conditions in the real corrugator, because in

the real corrugator one needs a certain web tension to have a uniform alignment at the pre-heater to get a uniform heat distribution. This web tension is induced through the brakes of the reel stand, where the paper roll is mounted. To bypass this problem, a square metal plate weighing 2130 g was used to apply a pressure of 537 N/m² on the liner. To prevent heat transfer to the metal plate from the liner during pre-heating, a corrugated board sheet was glued on the contact side of the metal plate. Then the pre-heating step (1) was performed by putting the liner with the gluing side faced downward on the heating plate and the metal plate on top for 0.5 s.

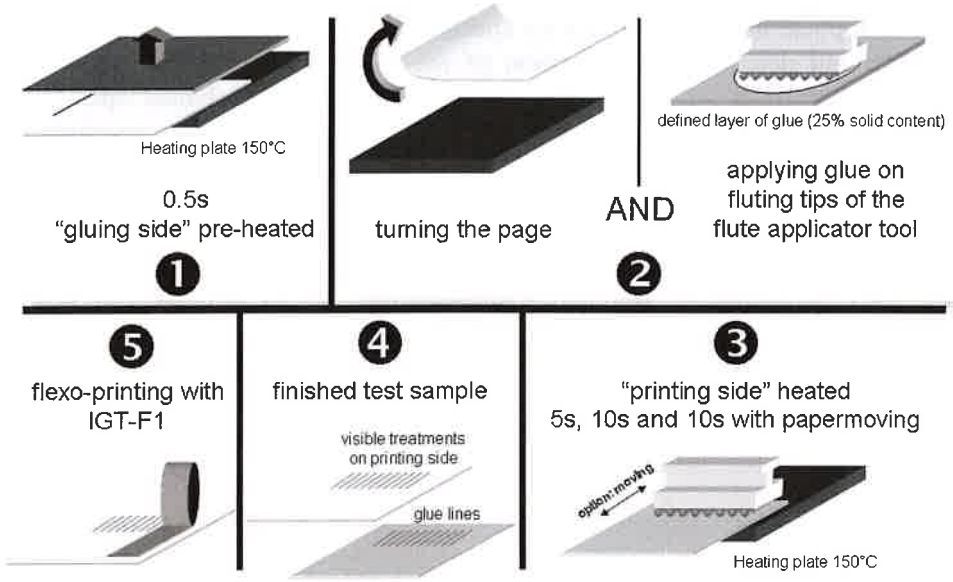


Figure 1: Test procedure for producing differently treated samples. Step (1) is to pre-heat the liner for curing the applied glue. At (2) the liner sheet is turned and glue is applied on the applicator made of Teflon®. Step (3) simulates the Double Baker process, where the fluting and liner are glued together. In this case, only glue stripes are applied. The finished samples (4) now have cured glue lines at the inner side and quite visible surface changes on the printing side, depending on the treatment (step 3). The last step (5) was printing on the samples with the IGT F1 Flexo laboratory printing machine

For the gluing process (2), the liner had to be turned and the flute applicator tool, constructed to apply the glue on the backside of the liner, was immersed into a defined layer of glue. This step needs to be done very quickly to avoid loss of heat in the liner, which is needed for the curing process. The finished glue (Definol FK 237, Crespel & Deiters) had a solid content of 25 wt% and was easier to handle and to prepare than commercial glue. The reason for not using a commercial starch was that only the influence of moisture from the glue was of interest and not its curing and stiffness properties. The tool was designed according to EN ISO 7263 (Corrugating medium - Determination of the flat crush resistance after laboratory fluting), shaped as an A-flute with a pitch of 8.5 mm and a head radius of 1.5 mm. The weight of the tool is 1250 g, which creates a linear, distributed pressure of 13.4 mN/mm. This value is in the same range as the value in a real double baker.

The next step (3) was to put the liner on the heating plate and the applicator tool on the liner. The printing side of the liner faced the heating plate as in a double baker. This step included different treatment forms: 5 s, 10 s or 10 s with movement (10 sM) of the paper on the heating plate. The paper was moved back and forth on the heating plate. The samples were coded according to these treatments, for example 2u175_10 sM, which means manufacturer no. 2, uncoated liner, 175 g/m² and 10 s with movement. The treatment code is either "5 s", "10 s" or "10 sM". The finished samples had glue stripes on the back and slightly visible surface changes on the printing side. This test procedure was performed in a standard climate of 23°C and 50% RH.

Topography Measurements

The optical topography was measured with MicroProf® from FRT - Fries Research & Technology GmbH. It is a non-contact measuring instrument and works as profilometer (2D) and as well as 3D imaging device. In both modes, the roughness and waviness of surfaces can be determined according to DIN EN ISO standards. The sensor works with focused white light which illuminates the sample and internal, passive optics, which using chromatic aberration, splits the white light into different colours (corresponding to different wavelengths). The light beam is reflected by the sample and again passes through the optical unit to the miniature spectrometer. This spectrometer detects the colour of the reflected light and determines the position of the focus point, and by means of an internal calibration table, the vertical position on the sample surface. The technical specifications of the chromatic sensor CWL are: measuring range in z-direction 300 µm, maximum resolution z-dir. 3 nm, resolution in x-y-dir. 1-2 µm and measuring angle 90° ± 30° (FRT).

The Confocal Laser Scanning Microscope (CLSM) Radiance 2000 (Bio-Rad Laboratories, USA), equipped with Kr/Ar laser, was used to explore the surface micro roughness of the liner tips and valleys with a 200 x magnification. Roughness measurements can be conducted by indirect or direct methods such as surface profilometry. CLSM offers a non-contact method for surface profilometry like the FRT MicroProf®. The technique is especially suitable for evaluation of microscopic roughness [Moss et al., 1993]. The reason for using CLSM was to obtain images of what the surface looks like in higher magnification and to verify the MicroProf® results.

Printing

Printing was performed with an IGT F1 flexographic laboratory printing machine (IGT Testing Systems, Amsterdam, Netherlands). The IGT F1 consists of an inking unit with anilox roll and doctor blade and a printing unit with a printing form on a cylinder. The printing width is 50 mm and the perimeter of the cylinder with printing form is 534 mm with a diameter of 170 mm [Chalmers, 1997]. For the testing, three similar samples of each quality were chosen (1u110, 1u170, 2u100 and 2u175), in all 12 samples (3x4).

The following settings gave the best print quality in pre-tests on the original, untreated liners: printing force 50 N, anilox force 35 N, printing speed 0.6 m/s and two revolutions. Two times revolution means that the photopolymer is inked twice by the anilox to improve the result. The anilox roll had a cell volume of 4.5 ml/m², an angle of 45° and a resolution of 140 l/cm (IGT-Ref. no.: 402.208). The printing cliché was mounted with DuploFLEX 5.3 (Lohmann Klebebandsysteme, Neuwied, Germany) with a thickness of 0.55 mm and compressible properties.

Print Analysis

The printed samples were measured with 938 - Spectrodensitometer (X-Rite®, Grandville, MI., USA). The range of the measured reflectance spectrum is 400-700 nm, at an interval of 20 nm. The illumination angle of the test area is 0° and the viewing angle 45°.

As measurement points of the samples were chosen reference, tip and valley and all three in full- and halftone. As each point was measured three times, and there were 6 measurement points per sample, a total of 18 values for each sample were obtained. With 3 printed samples per quality, one gets 9 values per measurement point, which should improve the reliability of the results.

4. Results and Discussion

Before using any measurement tool, the visible inspection immediately showed some interesting facts. When the sheets were held into reflecting light from a lamp, a clear difference could be distinguished between the liners, which were moved on the heating plate and the ones, which were not. The moved liners had shiny stripes at the tip caused by the pressure load during the curing procedure (step 3, Figure 1). This stripy pattern also appears after corrugated board production where the printing side of the outer liner is pulled over the hot steel plates - but not to the same extent.

Topographical Evaluation with FRT MicroProf®

The next step was to measure the surface roughness. MicroProf® makes it possible to measure exactly on the tips and in the valleys between. The measurement range was set to 1 x 5 mm and a resolution of 10 x 1000 pixels, which means an x-resolution of 5 µm. Figure 2 illustrates the results obtained with MicroProf®.

The values of 1u110 (Figure 2a) are abnormally high compared to the reference, and this cannot be fully explained. Therefore, the focus will be more on the other samples. From Figure 2b, c and d many conclusions could be drawn. The differences between the samples are of little interest, but the differences between different treatments and the differences between tips and valleys are greatly interesting.

Beginning with the treatment form, the tips of papers treated without movement (5 s, 10 s) in all cases show a slightly higher surface roughness than the reference. On the other hand, in papers treated with movement (10 sM) the reduction in surface roughness is larger than the increase in surface roughness of non-moved liners. The factor "movement" thus has a huge influence on surface roughness. In the papers treated with movement, which are similar to real treated liners in the double baker, the valleys always have a higher surface roughness than the tip and also than the reference. This is surprising and will be discussed in the CLSM results.

The high standard deviation should be discussed, too, because in most cases it was too high to allow any conclusion. The problem was that the samples always had small particles on the surface which created a peak of almost 100 µm, where the average of the surface was around 20 - 30 µm. Cleaning the surface with air did not change the result. Therefore it was chosen to use the results and to discuss only the trend and not the values in detail.

CSLM-Image Evaluation

The same measurement positions were chosen for the CLSM analysis as for the MicroProf®. The 2u175 sample was chosen for the test. The images in Figure 3 show examples of the CLSM surface topography measurement. All images have a uniform scale (0 - 40 µm).

The untreated surface Figure 3a) differs clearly from the others, with its more open, porous and deeper surface structure. The image of the non-movement treated sample Figure 3b), measured on the tip, illustrates that the surface is compressed due to the weight of the application tool. A similar appearance is reflected in Figure 3d), but this image is taken in the valley of the liner surface of the moved paper. Therefore, the magnitude of the weight load, when the paper is not moved, has a lesser effect, but this will be further discussed in connection with the surface roughness, Rq, results in the following chapter. The image of the tip of the movement treated liner Figure 3c) shows a highly compressed surface topography. Most of the fibres are between 0 - 10 µm. According to these images, the second question in the introduction can be answered with "Yes" - there is a difference between tip and valley and furthermore a huge influence factor: "the movement".

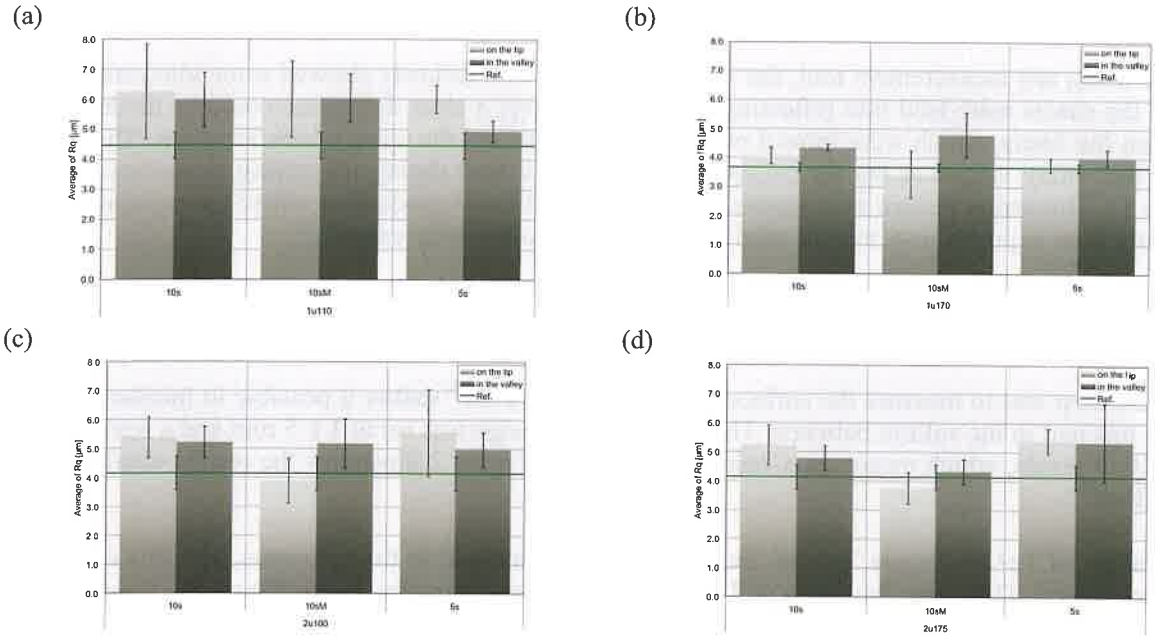


Figure 2: Results of the topographical measurements and surface roughness Rq calculations of all samples. Each chart illustrates one liner quality and every paired bars show the result of tip and valley for the treatments 5 s, 10 s and 10 sM, respectively

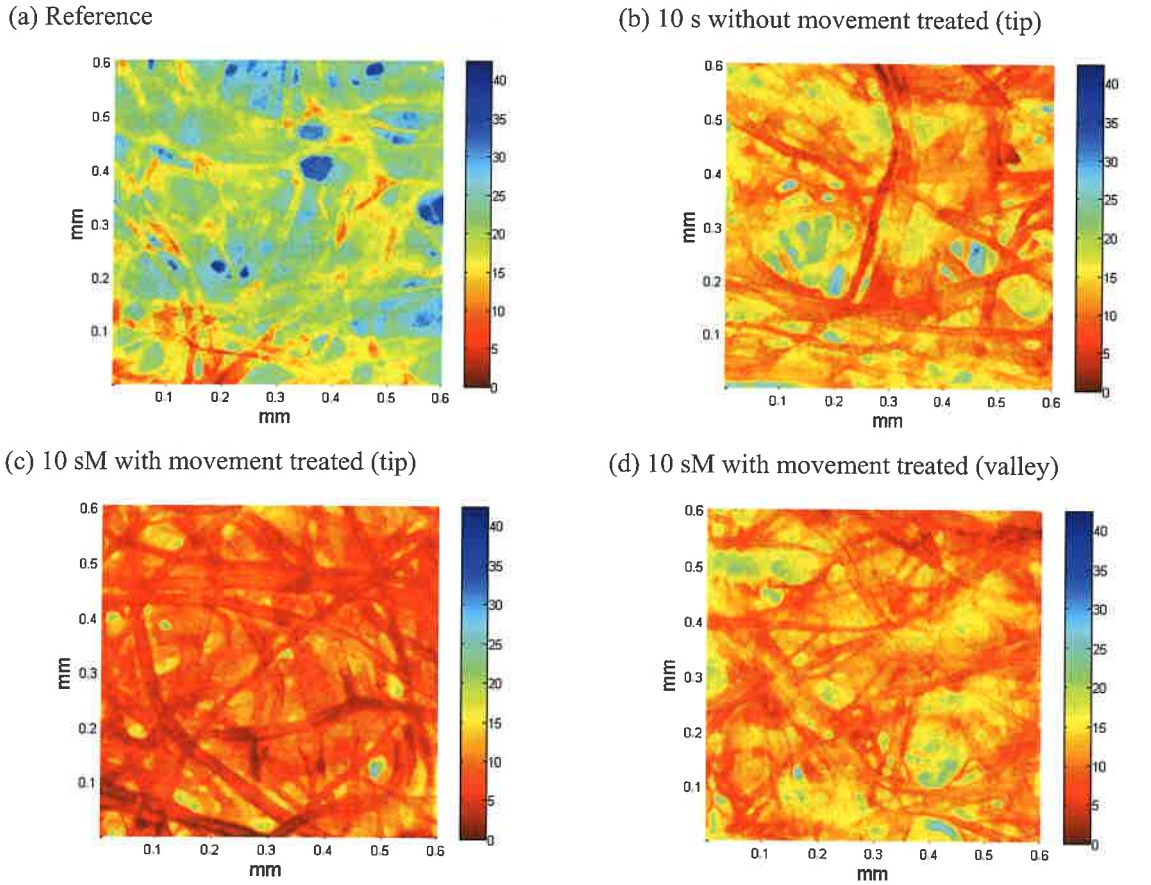


Figure 3: Confocal laser scanning micrographs of liners that are untreated (a) and with (c and d) and without movement (b). (c) is an image of the tip and (d) of the valley

The chart in Figure 4 supports the image interpretation. As expected, there is a great difference between the tips of the samples 10 s (without movement) and 10 sM (with movement). The surface roughness of the 10 sM sample is much lower than that of 10 s. The value of the 10 s tip is also slightly lower than the reference. But the real corrugated board, as well as the laboratory prepared samples, has the washboarding effect which means that during the curing process (double baker) the pressure on the tip is much higher than in between. Therefore, the valley must have a different change in surface roughness from that of the tip. Figure 4 illustrates that without movement treatment, the surface roughness in the valley of the samples is slightly higher than in the reference. On the other hand, with movement treated surfaces present a lower surface roughness in the valley. The only explanation for this can be that with movement, the liner valley is without pressure load but still in contact with the heating plate. But only in the first seconds, because then the curing effect induces the washboarding effect and the valley lifts off the heating plate.

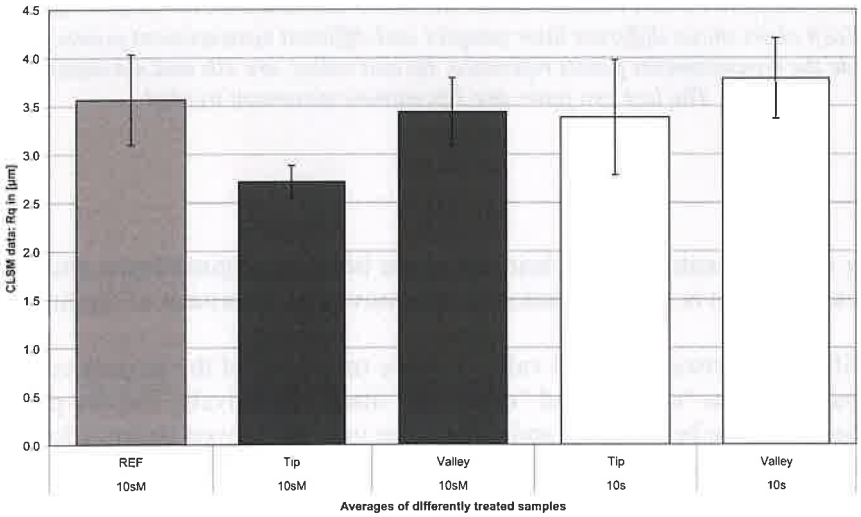


Figure 4: Roughness average Rq derived from CLSM measurements with 200x magnification of the 175 g/m² paper (2u175). The left bar is the untreated reference; the next two bars show the tip and valley results from with movement treated sample. The roughness on the tip is clearly lower than that in the valley. The two bars to the right represent the without movement treated sample. The roughness on the tip in this case is slightly increased

Print Analysis

As long as the liner is unprinted, surface roughness does not enter the equation. But what happens when it comes to the print? 63.5% of the production of corrugated board is printed (VDW 2005) and as mentioned in the introduction, stripiness is the highest problem most readily perceived by observer.

Figure 5 illustrates the results from the print analysis with the Spectrodensitometer and at a first glance; some huge differences between the samples and the respective measurement point are evident. Figure 5b shows high variances, especially as to the measurements on the tip. The explanation is that during the sample preparation, the applied glue induced thickness differences at the tip position. Therefore, the pressure during the printing process was higher at this point and Dot Gain increased the print density values. For the valley it is the other way around; the printing pressure is lower than normal.

Figure 5a shows the result of the fulltone area (100%), but the variances are not as high as in Figure 5b. However, in average the tip has a lower print density. Therefore, the washboarding effect cannot influence the result since the Figure 5b indicates the opposite. One explanation must be that the surface changes affect these variances and as mentioned in the introduction, too, the surface change is no dominating effect.

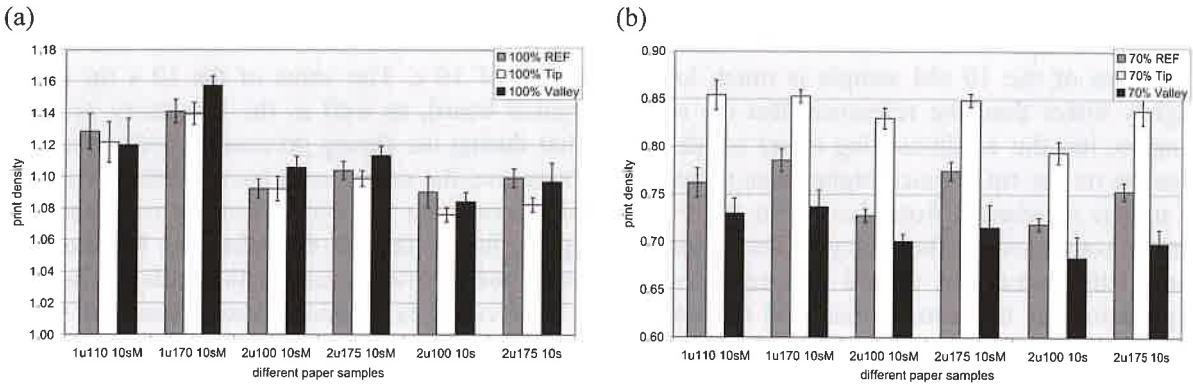


Figure 5: Results from print density measurements. (a) shows the data from the fulltone area and (b) from the halftone area. Each chart shows different liner samples and different measurement points. The first four pairs, which include the measurements points reference, tip and valley, are 10s and movement treated sheets. The last two pairs are 10s without movement treated

5. Conclusions

The topography measurements show a clear difference between original liners and treated liners. The surface roughness of the tip is most dependent on the movement treatment of the liner.

However, the difference between tip and valley surface roughness of the respective samples is smaller than the difference between "moved" and "unmoved" liner, respectively. But the print quality is more dependent on the difference between tip and valley. But only the moved papers allow a clear statement due to the standard deviation, that the surface roughness on the tip is lower than the surface roughness in the valley.

Finally the topography measurements confirm the statements made in the introduction. In the real corrugator, there is metal-paper friction at a high temperature and under pressure. This laboratory test does not imitate real corrugator conditions, but gives information about in which direction and at what magnitude the influences appear. A visual inspection shows that both under real conditions produced corrugated board and the laboratory samples present shiny stripes at the tips when the sheets are held into reflecting light from a lamp.

The print density measurements do not clearly corroborate the statement that surface changes affect the print quality. Here again, the standard deviation was too high to allow any conclusions, but in both cases, moved and non-moved papers, the print density values on the tips were always slightly lower than those in the valley. But here too, the visual inspection shows clear differences when the printed sample is held into reflecting light. Further studies should include visual perception tests.

In order to consider all affecting factors, glue was applied on the liner backside. In future tests, however, the glue application should be excluded or replaced by water to minimize or even avoid the washboarding effect during the flexo-print with IGT F1.

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References

1. G. B. Cusdin (2000), Why does 'Washboard' show up in my print, Flexo, Germany, pp 28-36
2. E. Netz (1996), Washboarding and Print Quality of Corrugated board, Licentiatav-handling, Stockholm, KTH
3. B. N. J. Persson (2000), Sliding Friction - Physical Principles and Applications, 2 ed., Springer Heidelberg
4. E. L. Back (1991), Paper-To-Paper and Paper-To-Metal Friction, International Paper Physics Conference, Proceedings, pp 49-65
5. T. Pinnington (2003), The corrugated industry - In pursuit of excellence, chapter 9, Andover, UK: Brunton Technical Publications, pp 87-93
6. H. J. Mensing (2003), Die neue Maschinengeneration in der Wellpappenindustrie und deren Anforderungen an die Rohpapiere, Wochenblatt für Papierfabrikation, no. 9, pp 523-529
7. Y. H. Zang, J. S. Aspler (1995), Factors affecting the flexographic printability of linerboards, Tappi Journal - October, pp 240-24-33
8. VDW- Verband der Wellpappen e.v., information by phone (2006)
9. I. R. Chalmers (1997), Flexographic printability of packaging grade papers; Appita, pp 335-341
10. G. G. Barros, C.-M. Fahlcrantz, P.-Å. Johansson (2005), Topographic Distribution of UnCovered Areas (UCA) in Fulltone Flexographic Prints, Taga Journal 2(1), pp 43-57
11. E. A Moss (1993), E. Relulainer, H. Paulapuro, P. Aaltonen, Taking a new look at pulp and paper: Applications of confocal laser scanning microscopy (CLSM) to pulp and paper research, Paperi ja puu - Paper and Timer, Vol. 75, No. 1-2, pp 74-79





4

Print quality and measuring methods

Measuring and evaluating the surface quality of gravure papers

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1. Introduction

The quality of a print product is determined largely by the interaction of printing paper, printing ink and other printing parameters (the printing press). There are many specific aspects arising from the printing process itself, however, that must be taken into consideration as well. Paper engineers are therefore very much interested in knowing what impact the paper will have on the print results even before the printing process begins. As far as printers and papermakers are concerned, paper-induced impairment of printing process productivity and print quality usually go hand in hand with high costs. Attempts to minimise such costs have given rise to demands for comprehensive paper characterisation to thus be able to predict the runnability and printability of the papers prior to the actual printing process. Fig. 1 proceeds from the papermaking process and illustrates a typical way of characterising the quality of printing papers and print products.

Predicting the outcome of printing based on test prints is at one and the same time a practicable, time- and labour-consuming method, although it is not an entirely reliable one. This engenders a demand for measuring techniques that are both simple and fast, but still provide reliability and precision.

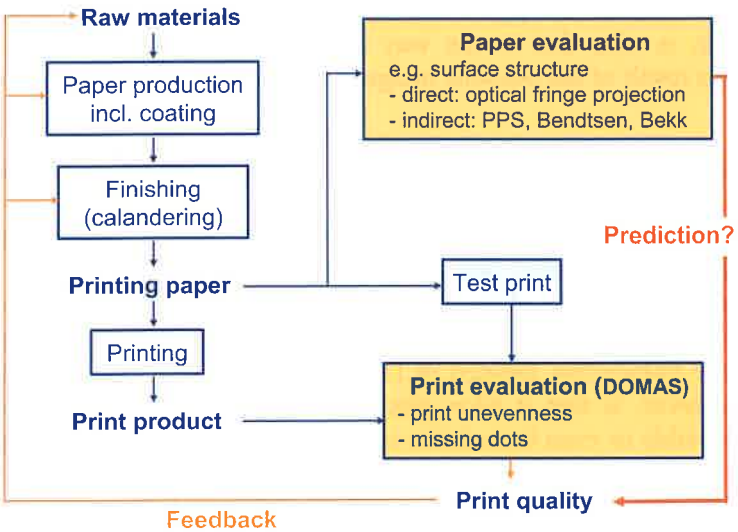


Fig. 1: Objectives

Although a number of paper properties are determined nowadays in the metrology laboratory, this technology has not yet been able to successfully and reliably predict the two printing parameters of runnability and printability. The reasons for this are the complexity of the printing process on the one hand and on the other hand the fact that the properties currently being measured do not provide sufficient detail to describe the papers themselves nor how they will behave during printing. For

example, in order to evaluate surface topography, a factor that greatly impacts the print results especially in gravure printing, instruments are preferentially used that yield an indirect measure of smoothness, although this variable is in turn influenced to a greater or lesser degree by other paper properties. These indirect methods, air stream measuring techniques in most cases, will continue to retain their importance even in the near future, especially in the quality control sector. This is confirmed by the fact that in the meantime, paper engineers have developed the appropriate standards and that a comprehensive database is available for a wide variety of different papers and paperboards.

Tab. I contains a compilation of a few surface characterisation methods, a distinction being made here between direct and indirect procedures. Both main groups are then again broken down according to the pressure that prevails during measurement. Except for the contact area measuring instruments (that simulate the pressure conditions in the printing nip), the pressure that prevails is low and depends on the measuring procedure being used. A common feature of all methods is that smoothness is determined in a static state, thus taking no account for any of the dynamic paper deformation processes that occur during printing.

Tab. I: Overview of roughness measuring techniques acc. to Volk [1]

Indirect Methods	Direct Methods
without measuring pressure	
• Gloss meter • Capacitive instruments	• Laser profilometry • Digital fringe projection
with measuring pressure	
• Air leak instruments (Parker Print Surf, BEKK, Bendtsen) • Friction tester	• Mech. sensing profilers • Contact area measurement

Direct surface measurement devices are finding increased dissemination owing to the rising demands for detailed information needed to optimise existing and to develop new paper qualities. Greater dissemination, however, is also due to the way prices have developed in measuring instrument manufacture as well as a result of the possible integration of intelligent evaluation software.

2. Digital fringe projection - non-pressurised direct topography measurement

A modern, non-sector-specific optical measuring technique for surface characterisation is digital strip projection coupled with the acquisition and evaluation of a sequence of images based on the phase shift method or a combination of the phase shift method and coded light techniques. This measuring technology allows 3D height images to be generated which can then be used to determine quickly and reproducibly the surface parameters defined in DIN EN ISO 4287-1998 [2]. One drawback of this evaluation process, however, is that it takes place under non-pressurized conditions, i.e. the paper deformation that is inevitable or even intended in industrial converting, is not taken into account.

Fig. 2 illustrates the sequence of operations involved in acquiring topographic parameters by digital strip projection. As indicated in the camera image, a pattern of successive strips is projected on to the surface of the paper to be evaluated and then scanned by a CCD camera. Software is used to calculate the topographic strip deformation and create a height image that is subsequently aligned so as to compensate for deviations in the parallelism of the paper and image planes. The aligned height image contains all information regarding the primary surface profile.

Additional filtering (e.g. a wave filter as prescribed in DIN EN ISO 4287-1998 [2]) breaks the primary information down into detailed information such as waviness and roughness (Fig. 3). The parameters R_a and R_q, variables known from metalworking, are pertinent to the roughness parameter.

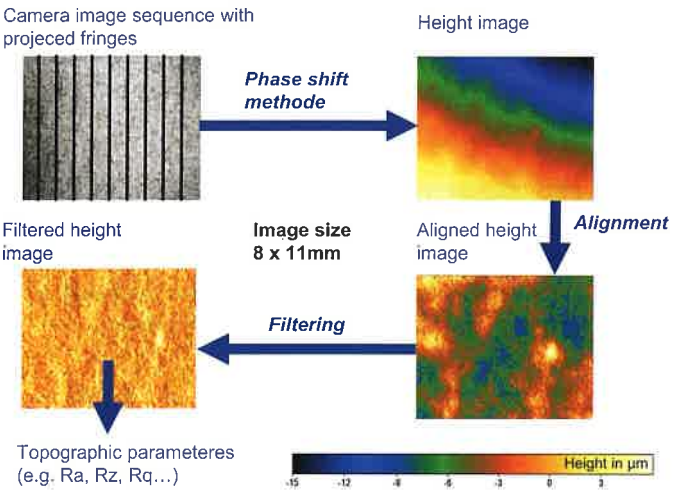


Fig. 2: Optical 3D surface measurement technology (fringe projection, phase shift method)

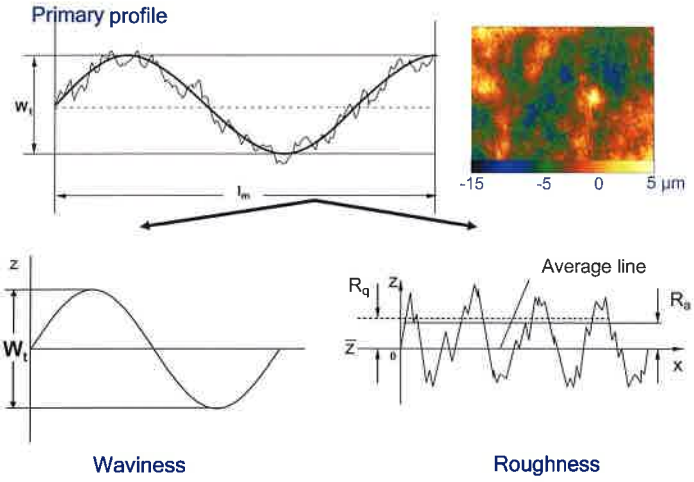


Fig. 3: Vertical parameters

The arithmetic mean of the profile ordinates R_a is defined as the average of all deviations of the ordinate values z(x) from the mean profile. The arithmetic mean thus corresponds to the distance that the roughness profile fluctuates equidistantly from the reference line. Integration of the individual areas virtually eliminates exaggerations of the profile. This means that the deviation of this value is small, even in the case of inhomogeneous areas, thus enhancing reproducibility.

$$R_a = \frac{1}{L} \cdot \int_0^L \left| z(x) - \bar{z} \right| \cdot dx, \qquad R_q = \sqrt{\frac{1}{L} \cdot \int_0^L \left(z(x) - \bar{z} \right)^2 \cdot dx}$$

$$\bar{z} := \frac{1}{L} \cdot \int_0^L z(x) \cdot dx$$

where:

- R_a - Arithmetic mean of the profile ordinates in µm
- R_q - Root mean square of the profile ordinates in µm
- L - Total measuring section in µm
- z - Ordinate value in µm
- $\bar{z}$ - Reference line height in µm

This parameter allows neither peaks nor valleys nor different profile shapes to be differentiated. The root mean square of the profile ordinates R_q is identical to the standard deviation of the roughness profile. It reacts to peaks and valleys with greater sensitivity than R_a.

The integral vertical parameters (amplitude parameters), such as the averages of the profile ordinates (R_a, R_q) as well as the greatest height of the profile R_z, are only conditionally suitable for making credible statements about the paper surface. This means that the complexity of the surface structure is characterised only inadequately.

The Abbott curve, which provides characteristic parameters for the peak, core and valley zones, on the other hand, does permit greater differentiation. Fig. 4 outlines how the curve is derived. It is clear that two profiles that are actually very different, have the same R_a value, but may differ significantly in their parameters for the peak, core and valley zones. The profile depicted at the bottom of Fig. 4, for example, might be the result of strong calendering of the paper surface.

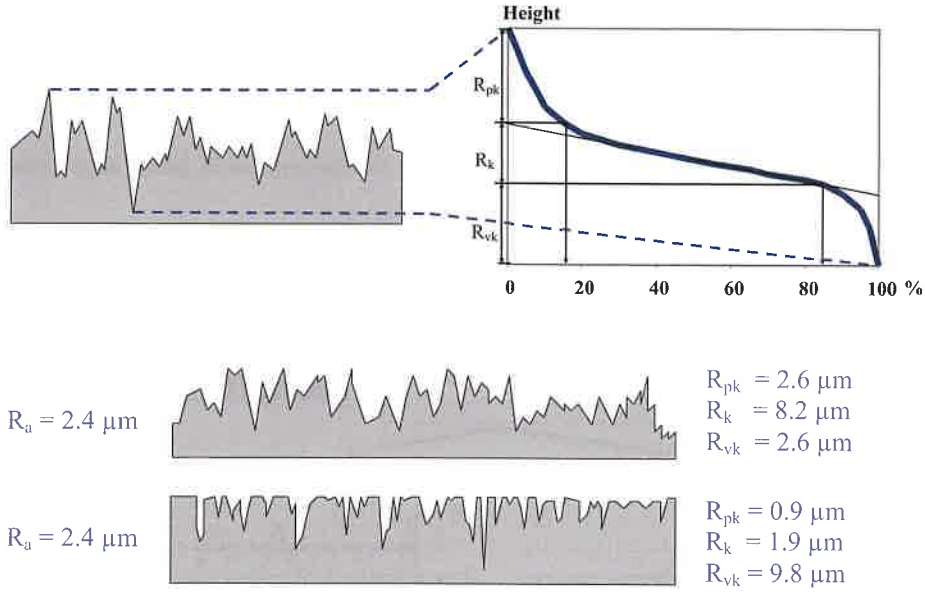


Fig. 4: Parameters of the Abbott curve

3. Modified FOGRA optical contact tester - direct pressurised surface structure measurement

Accurate measurement of paper properties under practice-oriented conditions in the laboratory is normally not readily possible owing to the dynamics of paper converting operations and other contributory factors. The development of new measuring technologies, however, is focussing on this aspect to an ever greater extent. With the realisation that the paper surface structure changes as pressure is applied, attempts were made as early as the 1960s to evaluate the pressure-induced structural change based on the principle of total reflection and disturbances. The instruments that were developed and used in this context include the Chapman tester, the FOGRA optical contact tester and the Pira printing smoothness tester. One major drawback of these devices is that they provide integral values only.

This deficit has now been eliminated by coupling an existing FOGRA optical contact tester to a digital image analysis system (one contact area image every 100 ms), digitalising the contact pressure and contact area, and incorporating high-precision distance measurement equipment which is accurate to $\geq$ 20 nm (Fig. 5). The result of the measuring operation is now a data image matrix that describes in detail the surface structure in the form of the contact area as a function of paper deformation under pressure. All data and contact area images are created at the same time. In addition, this measuring procedure allows the total compressibility of the paper to be determined as a reduction in thickness compared to the original thickness of the paper.

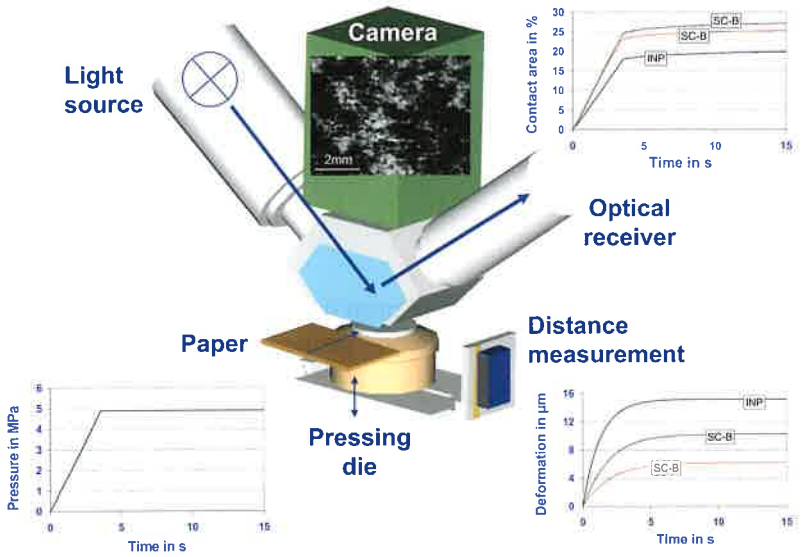


Fig. 5:
Modified FOGRA optical contact tester

The resulting vectors of the data matrix can be plotted against one another in such a way that new findings and interpretations about paper behaviour under pressure are possible.

Fig. 6 presents by way of example the relationships associated with total paper deformation over time for three gravure papers. Pressure begins to build up at t = 0 s, attains 5 MPa after 3.6 s and then remains constant. The rapid paper deformation at the beginning of pressure application is clearly evident. However, the paper continues to undergo deformation even after the final pressure has been reached. This phenomenon is known as paper flow. The deformation curves shown in Fig. 6 differ considerably regarding the maximum final deformation that is achieved. As might be expected, material flow not only causes further total deformation of the sample, but also acts to change the surface topography as shown in the two contact area images.

4. Designing and conducting trials

Both measuring technologies, the non-pressurised optical method and the contact area deformation measurement, were used to characterise the surfaces of eight natural gravure papers (2 SC-A papers, 2 SC-B papers, 4 super improved newsprint papers). For comparison purposes, the papers were also measured using the conventional smoothness measuring methods according to Parker Print Surf, Bendtsen and Bekk.

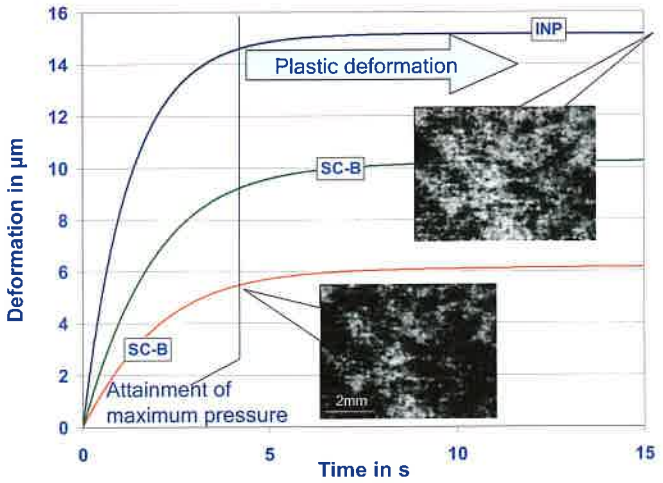


Fig. 6:
Paper deformation as a function of contact pressure and time

In addition, the papers were printed both in a large printing trials and with a laboratory-scale printing press (EINLEHNER gravure test press). The print results were assessed visually by comparing pairs of test prints on the one hand and by image analysis using the PTS DOMAS system on the other hand. Image-analytical evaluation included both printed areas with a low degree of coverage (missing dots, part missing areas, dot patterns) as well as solid areas (print unevenness).

5. Results

Tab. II contains a compilation of results selected from the paper and print evaluations. Samples P1 and P2 were printed in a first print trial and samples A-F were subsequently printed in a second print trial. The two print trials are not comparable.

The results of the print quality parameters must be interpreted as follows. The paired comparison index of a test print is higher, the better the print result was found to be.

For the values determined using the DOMAS image analysis software, MD indicates the number of missing dots/cm² in areas of low coverage. The DU parameter is derived from a power spectrum analysis of selected solid areas and is lower, the more uniform the image of the surface is.

The results of both direct surface measurement methods are compared below and their validity established for the print result. It should be mentioned at the outset that none of the conventional air stream measuring methods for surface characterisation correlated well with the existing test print or practical print results.

Fig. 7 shows the development of the number of missing dots with increasing core roughness. An exponential dependency becomes evident. The values also show, on the other hand, that not all papers can be classified by this parameter with respect to print quality at low print densities. This is the case with paper C. Reference is made to the fact that the surface measurement method studied functions without pressure and thus does not truly mirror the operations that actually take place during paper converting.

Tab. II: Paper grades, paper properties and print results

No.	Grade	m_A	ρ	FS	FI	Print quality				
						Visual - paired comparison index			DOMAS	
		g/m²	g/cm³	%	(PSA)	Overall	MD	PU	MD	PU
A	INP	51.5	1.01	35.0	415	60	20	44	5.06	31.6
B	INP	51.8	1.08	35.1	367	116	120	184	2.31	16.6
C	SC-B	51.8	1.04	32.1	358	80	168	88	1.69	27.4
D	INP	52.0	1.06	34.9	400	60	16	8	6.44	35.8
E	INP	52.1	1.11	35.9	360	72	140	80	1.38	29.6
F	SC-B	52.2	1.13	37.8	221	156	120	180	1.25	20.9
P1	SC-A	55.9	1.19	38.6	229					
P2	SC-A	55.3	1.18	37.3	268					

FS	Filler content	Overall	Overall print evaluation
FI	Formation index	MD	Missing dots in areas of low coverage
INP	Improved newsprint	PU	Print unevenness

In addition to the known vertical parameters, horizontal parameters can also be extracted from the height images obtained by digital strip projection by evaluating the slopes of the profile in both lateral directions

(by derivation). Such a parameter is the root mean square of the profile slope (Δq) and this correlates well with the number of missing dots except for paper C. Better agreement was obtained for this parameter when making an overall subjective evaluation of the print result (paired comparison index).

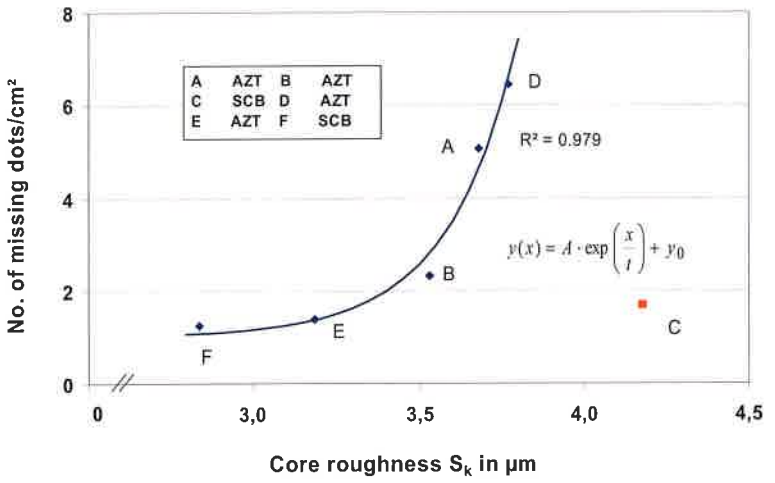


Fig. 7: Number of missing dots as a function of core roughness S_k

The results show that the evaluation of the paper surface under non-pressurised conditions is not adequate to be able to make reliable predictions about the print results in full-scale printing.

The existing FOGRA optical contact tester was therefore modified as described above. It was now possible to obtain information on changes in surface topography and on overall paper deformation under a semi-static load (pressure build-up in 3.6 s). In order to estimate the conditions that prevail during full-scale printing (dwell time in the printing nip is approx. 3 ms), it became necessary to derive the initial reaction of the paper surface under pressure application from the existing data material. To do this, the relationship between contact area (CA) and contact pressure (p) was described by an approximation of the data pairs using a mathematical model. The first derivation of the target function was created at p = 0. The result is defined as the parameter $Grad(CA)_p$ and represents the sought description of the initial reaction of the paper surface under pressure (Fig. 8). This value correlates exceptionally well with the number of missing dots (Fig. 9).

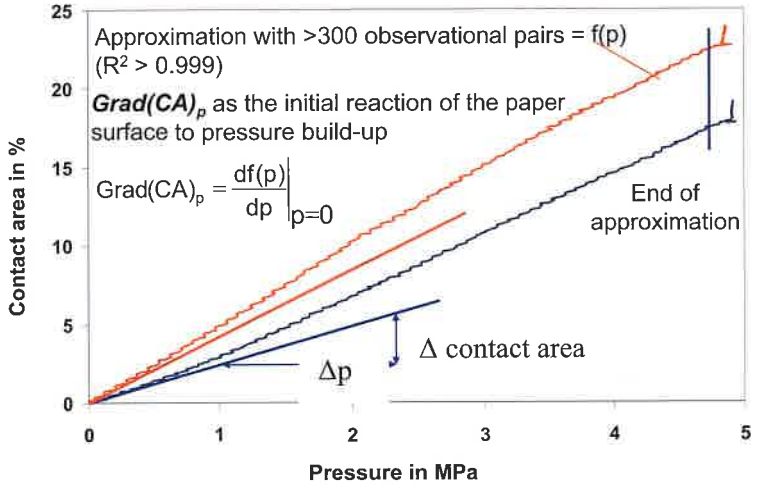


Fig. 8: Definition of parameter $Grad(CA)_p$

The value of parameter Grad(CA)$_p$ is higher, the more the paper surface reacts during pressurisation by enlarging its contact area. Paper C has high core roughness and exhibits a high deformation potential of its surface during this procedure. This apparently results in a smaller number of missing dots.

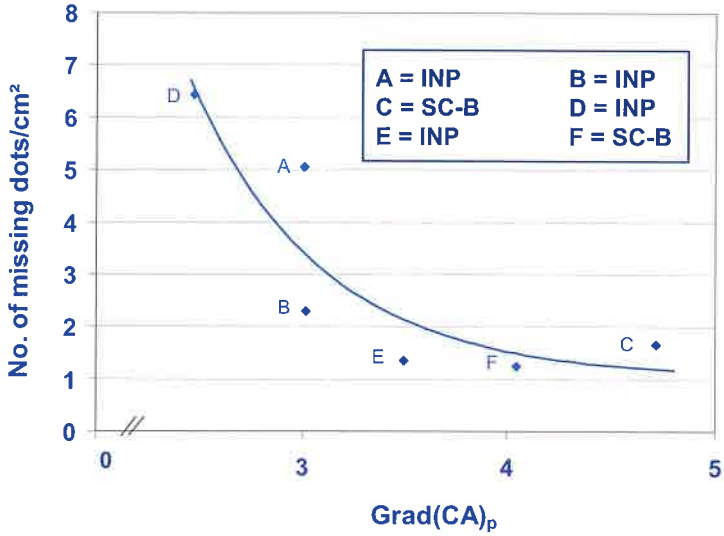


Fig. 9: Number of missing dots as a function of parameter Grad(CA)$_p$

The following findings regarding the reaction of the paper sample to pressure can be formulated using the modified FOGRA optical contact tester. On the one hand, information can be derived pertaining to the overall deformability of the sample under semi-static pressure conditions or by gradient formation at the time of pressure build-up. On the other hand, evaluation of the contact area images yields findings regarding the manner and speed of surface deformability during pressurisation in conjunction with distance and time co-ordinates. A metrological study of the papers during pressurisation makes it possible to correlate all measured papers - something that cannot be done in the case of non-pressurised measurement.

The results show that the old familiar demand for a "soft and smooth" paper for gravure printing remains valid, although it rather refers to the flexibility of the surface. It has also been found that papers with high overall deformability can indeed exhibit a large number of missing dots in the printed image (Fig. 10).

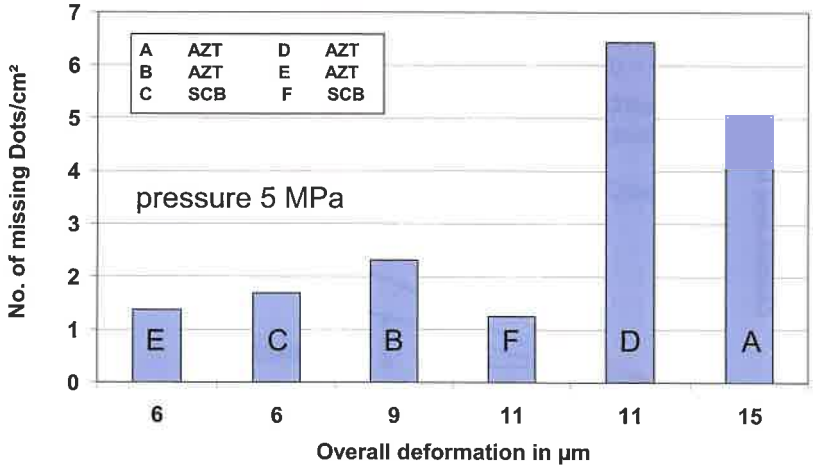


Fig. 10: Number of missing dots compared to overall deformability

Furthermore, additional gradient formation revealed that the prerequisite for a good printed image (few missing dots) is a high ratio of surface structure change to overall compressibility. In addition, overall compressibility at a given contact pressure should be low, i.e. surface deformability is far more important for good print results than compressibility (Fig. 11).

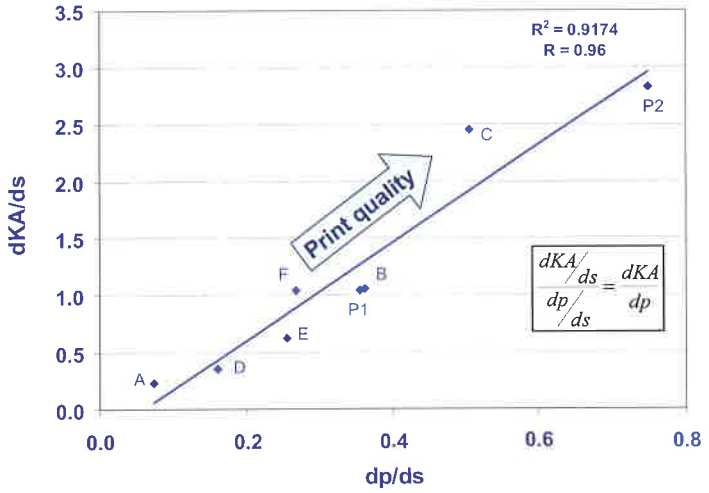


Fig. 11: Initial paper reaction during pressure build-up

6. Summary and future prospects

Proceeding from the realisation that conventional air stream measuring methods for surface characterisation could not establish a clear correlation between smoothness as a paper property and the printability results, two direct surface measurement methods for topographic evaluation of papers were chosen and compared with respect to their validity regarding the expected missing dots in full-scale printing.

Non-pressurised measurement according to the principle of digital strip projection produces quickly reproducible results that characterise the printability behaviour of most papers.

This method, however, came up against limiting factors considering that it is possible to characterise paper comprehensively only under real converting conditions. This lack of practical orientation was greatly diminished by modifying the FOGRA optical contact tester, thus making it possible to correlate the printability results (missing dots) of all papers tested.

All in all, the following findings regarding the printability results (missing dots) can be derived from the trials that were conducted:

- the surface must have good deformability properties (high value for $Grad(CA)_p$),
- the overall deformability of the sample should be low, i.e. the pressure energy should be used to deform the surface and not to deform the entire structure.

Continuing paper studies that will focus on interactions with liquids (absorbency, penetration behaviour, porosity, surface tension) and on electrostatic behaviour are scheduled and are intended to supplement the results already achieved.

Such studies are necessary because it was not possible to explain the difference in print results with a low degree of coverage between full-scale prints and test prints.

Furthermore, these properties are also of interest for the second important parameter of print quality, i.e. print unevenness in solid areas. As might be expected, it was not possible to establish a clear

correlation between surface structure and paper compressibility for the latter parameter. In view of the fact that there is sufficient ink available when solid areas are being printed, the impact of surface structure on the print result is not as dominant as when printing at low print densities.

References

1. Volk, W. Überblick über die Glättemessverfahren Wochenblatt für Papierfabrikation 98 (1970) 2, S. 45-51
2. DIN EN ISO 4287; 1998, Geometrical Product Specifications (GPS) Surface texture: profile method Terms, definitions and surface texture parameters

Determination of parameters that might alter ink strength measurements

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Abstract

A study was carried out on a Datacolor spectrophotometer to determine parameters that could potentially influence strength measurements. Through conventional lab testing, critical parameters limiting the strength comparison of two ink samples had already been identified, such as: the type of white medium, the absence of metamerism (color appearing different under two different lights), the strength of the tested sample having to be within +/- 10% compared to the reference sample and the color difference between the two compared inks having to be minimal.

The strength calculations and physical elements influencing measurements were investigated. Even if the strength calculation is based on the Kubelka-Munk equation, the way data is entered into the Datacolor software plays a crucial role on the accuracy of the strength calculation.

Being the first physical element to be explored, the depth of the cell significantly affects the strength measurement. Depending on the color measured, the depth of the current cell is not always the best way of ensuring accurate measurement.

1. Introduction

As ink is the second most expensive printing material after paper, printers put a lot of effort into specifying and monitoring ink consistency through the consideration of specific ink lab characteristics, one of these being ink strength. In order to help printers, a major research project was conducted by QIGC to improve the lab strength testing methodology commonly carried out on a Datacolor spectrophotometer.

Ink strength is the ability of ink to impart its color to a white medium. A mixture of predetermined quantities of ink and standard white medium is evaluated and measured with a spectrophotometer with diffuse geometry. As a default value of 100 value is allocated to the reference ink sample, a 100% strength value indicates that the two compared inks (tested batch and reference) color the white medium similarly. A lower value indicates that the tested ink tints the white medium less and thus has lower pigment efficiency than the reference ink. Theoretically, the higher the strength, the better the ink performance on press. An increase in pigment concentration and finer particle dispersion tend to increase strength and allow better mileage. However, too high a strength results in a deterioration in ink transfer and may affect other ink properties, such as ink mileage for instance.

As strength measurement is widely used in the industry, this testing protocol must be investigated in greater depth. It is therefore crucial to understand in detail the way a Datacolor spectrophotometer functions, i.e. the type of data used to calculate strength and the physical parameters influencing the measurement.

Through internal conventional lab testing measurements, some limits have already been identified. The strength of two inks can only be accurately compared if:

- they have a minimal color difference,
- their strength difference is within +/- 10%,
- there is no metamerism; the term metamerism denotes the fact that color changes depending on the illuminant/lights,
- the same white medium is used to prepare the mixture of both the reference and the tested ink.

2. Objectives

This study aims to understand the technology behind the Datacolor spectrophotometer, which is a piece of equipment widely used in the ink industry. Knowledge and understanding of the measuring principles used in this machine are essential to explore the strength calculation and its limitations.

One specific highlighted problem directly relates to one Datacolor feature that allows for the manual recording of reflectance values in order to generate a "virtual" strength measurement. However, the strength values obtained through the use of this feature are unrealistic.

On the other hand, several physical parameters such as the ink/white ratio, the temperature of the mixture, and the cell depth and orientation during the measurement were identified as having an impact on strength measurements. The first tests were carried out on the ink/white ratio, cell depth and cell orientation.

3. Methodology

The project was conducted in the following stages:

a. Technical review

A review was carried out to find all of the available information about both instrument and strength properties. The objective was to produce an exhaustive list of the parameters that might influence strength.

b. Understanding the mechanisms of strength calculation with the Datacolor Instrument

The basic principles of a Datacolor spectrophotometer and strength calculation were detailed. Briefly, the Datacolor is an integrated spherical spectrophotometer that measures the luminous response (spectrum) of a sample lit by a specific illuminant. Comparative results are obtained and the ratio of absorbed light and diffused light obtained on a batch of ink is compared to the same ratio obtained on another ink sample of the same type.

If a given ink imparts a stronger color to the white medium than another ink, its strength is said to be higher. Once printers approve an ink, it becomes the standard with a default strength value of 100. Odd strength results were analyzed to determine the type of data taken into consideration in the strength calculation and to understand how the strength value is obtained.

c. Tests on parameters that might influence ink strength results

As a result of the technical review of strength properties, some chemical and physical parameters were identified as having in influence on strength measurement. Transparency was identified as one of the physical parameters. Ink transparency directly affects strength measurement, as, with the Kubelka-Munk equations used in the strength calculation, layer of material of infinite thickness has to be measured.

An over-transparent ink will allow incident light to be reflected at the bottom of the cell, which means that the measurement will be biased.

In order to quantify its importance, cell depth and cell rotation were the first two parameters investigated. The results are detailed later on in this study.

In addition, different ink/white quantities (but keeping the same ink/white ratio) were identified as giving more accurate results. This parameter was thus tested internally.

d. Selection of an ink set

An ink set was selected to evaluate the influence of cell depth and cell orientation on the ink strength.

Each printing process (offset, flexography or gravure) requires a specific ink type adapted to the process and to the printed substrate. Ink types are thus numerous. The first tests were carried out on internally available "heatset coated inks". An ink set is made up of four colors (cyan, magenta, yellow and black) used to reproduce all colors. A comparison of inks done visually with a drawdown - cf. definition below - allows for the most transparent inks to be selected as a starting point.

Drawdown - Definition
This test allows for the color and transparency of an ink to be assessed visually. The inks to be compared are drawn down with a spatula on a white paper sample presenting a black printed strip. The color and transparency differences between the two inks are then put into relief. If the black strip appears visually to be less covered by one of the two inks, this ink is said to be more transparent than the other one.

4. Mechanisms of strength calculation used by the Datacolor instrument

Before investigating the physical parameters that could influence strength measurements, how the spectrophotometer operates was explored, together with the calculations used.

e. Definition

Definition: strength is the ability of a given ink weight to impart its color to a white medium.
The following figure (Figure 1) illustrates the basic principles with magenta ink.

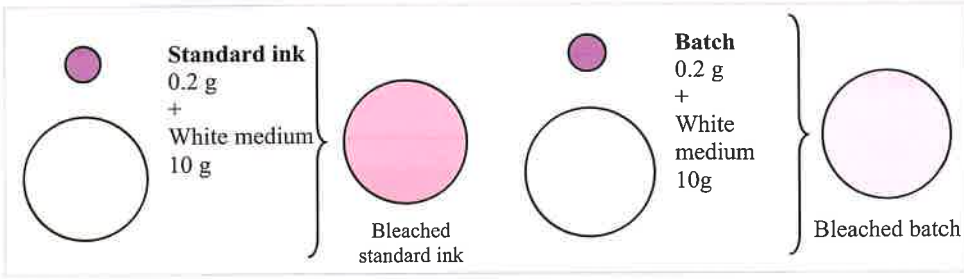


Figure 1: Principles of strength measurement - Magenta

In the example (Figure 1), the batch is weaker: more ink would be needed to reach the same color as the one obtained with the bleached standard. The strength of the batch versus the standard is lower than 100%.

Note: the ink/white ratio, 0.2 g of ink to 10 g of white, is as recommended in standard ASTM D 2066-97 (the standard used internally to measure ink strength).

f. The Datacolor spectrophotometer

The spectrophotometer is made up of a light source, a prism or a diffraction grating to separate wavelengths from incident light, and a signal processor (Figure 2).

Spectrophotometers have several measurement geometries. In this study, an integrated spherical spectrophotometer was used. The integrated sphere's ability to measure diffuse light rather than reflected

light ensures accurate measurements. In fact, the sphere amplifies the light signal and allows for the variability of the light to be put into relief. Spherical geometry is also sample texture independent, as changes in light angles have much less influence on the measurement.

The spectrophotometer is equipped with a diffraction grating to separate wavelengths from incident light (Figure 3). Although all spectrophotometers measure the reflected light of an object, they differ in their measuring accuracy: the higher the value of the reflectance measurement, the more accurate the measurement.

The diffraction grating is a critical component of a spectrophotometer. It separates incident light into wavelengths and allows for the measurement of the reflected light of the sample. Datacolor allows for the measurement of incident light from the sample and incident light from the sphere every 3 nm; however, the "Colortools" software v1.3 (which is provided with the spectrophotometer to calculate strength) only supplies reflectance values every 10 nm.

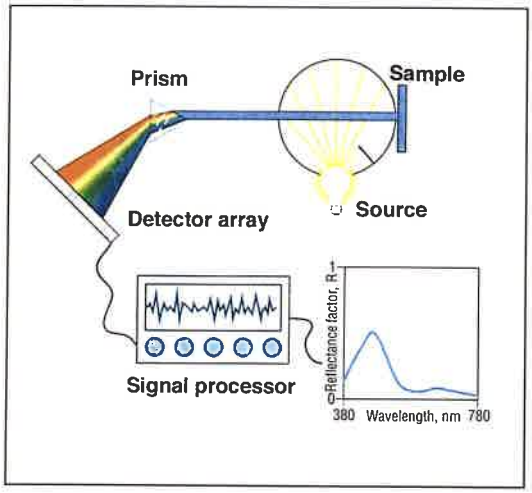


Figure 2: Principle of a spectrophotometer

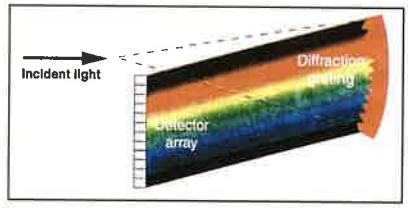


Figure 3: Diffraction grating

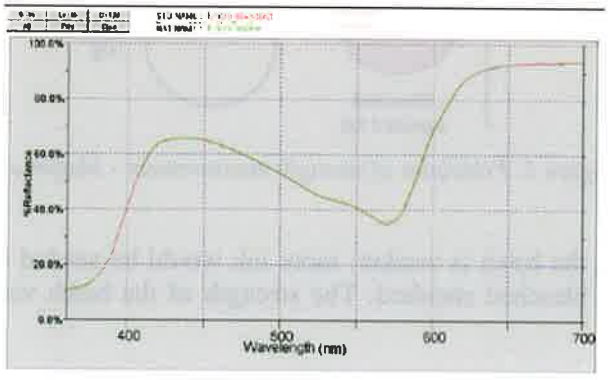


Figure 4: Example of a magenta spectral curve

For each sample, a spectral curve is obtained (Figure 4): % Reflectance as a function of wavelength.

g. Principles of measurement

A standardized cell containing the mixture (ink and white medium) is used to measure the reflected light of a sample (Figure 5).

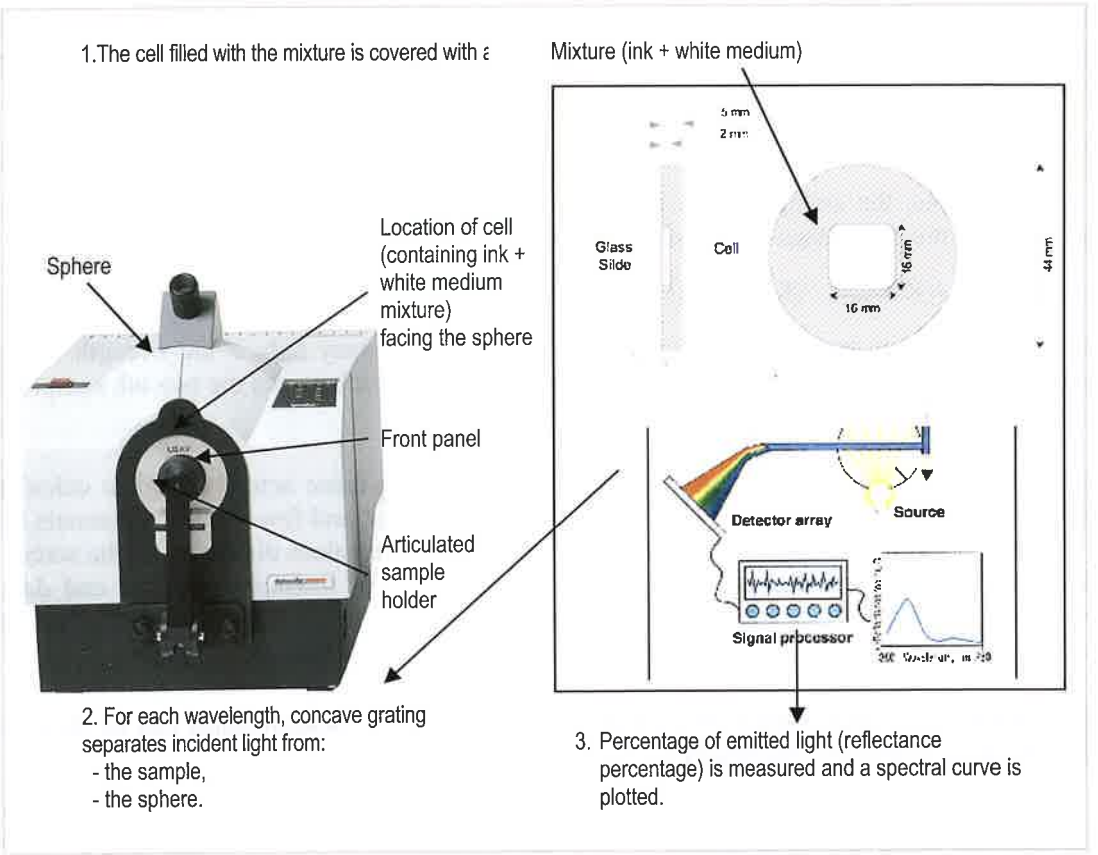


Figure 5: Principles of measurement

h. Strength calculation

Equations using the percentage of the sample's reflectance are used to calculate the strength. This value varies depending on both the testing methodology and the equations used. Methods based on Lambert-Beer's law are used for transmission samples and methods using the Kubelka-Munk equations are used for reflective samples. The latter equations were used in the rest of this study.

Once the reflectance data has been recorded in the software, the software can use one or more of these values to calculate the strength. The method used in this study is the maximum peak of absorption corresponding to the minimal reflectance value used in the strength calculation. This method was chosen because a previous study conducted jointly with EFPG *(École Française de Papeterie et Industries Graphiques de Grenoble)* demonstrated that it was the most accurate.

Light is sent to the sample, which reflects part of it. The percentage of reflected light is measured from 360 nm to 700 nm. Only the lowest reflectance value (R_{min}) is used:

$$R_{measured} = \% R_{min} / 100 \quad (1)$$

Saunderson's correction is applied to the $R_{measured}$ value to take into account refraction of the light caused by the change in the air/ink environment. The corrected value is $R_{corrected}$:

$$R_{corrected} = (R_{measured} - r_0) / [(1-r_0)*(1-r_i) + r_i*(R_{measured}-r_0)] \text{ where } r_0 = 0.04, \; r_i = 0.6 \quad (2)$$

r_0 and r_i being the Fresnel reflectance coefficients. It is recommended that they be 4% and 60% respectively for inks and paints [Fred W. Billmeyer, Jr. & David H. Alman, 1973].

Kubelka-Munk equations are then used to measure the K/S value; K and S are respectively the absorption and diffusion coefficients i.e. the proportion of light absorbed and diffused in a very tiny part by the sample:

$$K/S = (1 - R_{corrected})^2 / 2 \times R_{corrected} \quad (3)$$

For a given sample, the strength value is always assessed in comparison with another sample. The strength value is the percentage of a batch versus the standard:

$$\text{Strength } (\%) = [(K/S)_{batch} / (K/S)_{standard}] \times 100 \quad (4)$$

The spectrophotometer manufacturer guarantees measuring accuracy only if the strength value falls between 90% and 110%. Outside this range, the strength difference between the two ink samples is too large and affects the accuracy of the strength value.

Searching in the files generated by the software and retrieving those actually used to calculate the strength was a difficult process. There is very little documentation and few reference manuals relating to the operation of the Datacolor and the strength calculation. The values displayed on the screen were thus insufficient to explain the strength results calculated by the instrument. In the end data files retrieved using the Colortools software allowed us to establish that the instrument uses 35 reflectance values measured to six decimal places, every 10 nm from 360 to 700 nm.

However, when reflectance values are entered manually, only 31 measurements can be stored (from 400 to 700 nm) to 2 or 3 decimal places.

Data used in the strength calculation:

- *When the same method of acquisition is used for the two inks being compared, i.e. the two samples are either measured or reflectance values are entered manually for both samples:*

The strength calculation is based on reflectance values at the maximum peak of absorption determined for the **standard** ink.

E.g. Standard: maximum peak of absorption at 680 nm
Batch: maximum peak of absorption at 670 nm
The strength calculations will be based on reflectance values of 680 nm for both the standard **and** the batch.

Note: although the maximum peaks of absorption for the standard and the batch are generally at the same wavelength, the maximum peak of absorption of some tested inks may differ between the tested ink and the standard. In the strength calculation and for both inks, the reflectance value is always considered at the standard ink's wavelength.

- *When the data is acquired differently for the two inks to be compared i.e. one sample is measured, whereas the reflectance values for the other one are entered manually:*

The Datacolor instrument has 35 measured values in one case (from 360 to 700 nm), whereas 31 values are entered manually in the other case (from 400 to 700 nm). The resulting strength value will differ depending on the sample chosen as being the standard.

Note: The strength calculation always incorporates reflectance values at the maximum peak of absorption determined for the standard.

▪ *Standard entered manually / Batch measured*

If the standard is entered manually while the batch is measured (for example: maximum peaks of absorption at 440 and 450 nm respectively for the standard and the batch), then the strength will be

calculated from the standard's reflectance values at 440 nm and also from the batch's values at **400 nm**. The software acts as if the reflectance values for both the standard and the batch correspond to the same wavelength. The shift of 4 missing values with the manual method leads to a move of 40 nm for the batch's wavelength used in the calculation (Figure 6).

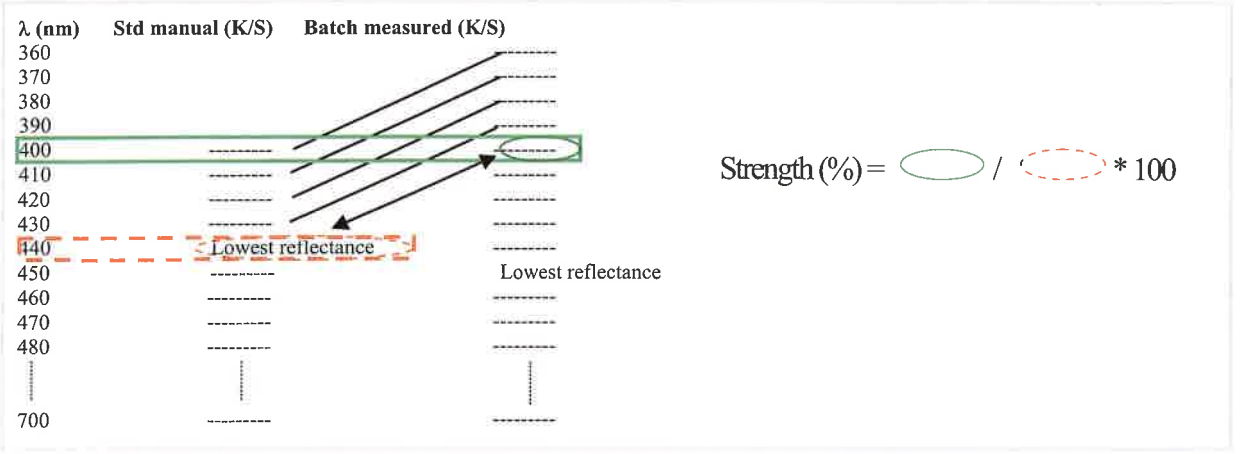


Figure 6: Standard entered manually / batch measured - Example

- *Standard measured / Batch entered manually*

If the standard is measured while the batch is entered manually (for example: maximum peaks of absorption at 440 and 450 nm respectively for the standard and the batch), then strength will be calculated from the standard's reflectance values at 440 nm and from the batch's values at **480 nm**. Once again in this case, the shift of 4 missing values with the manual method leads to a move of 40 nm for the batch's wavelength used in the calculation, because the software considers the reflectance values of both samples to be at the same wavelength (Figure 7).

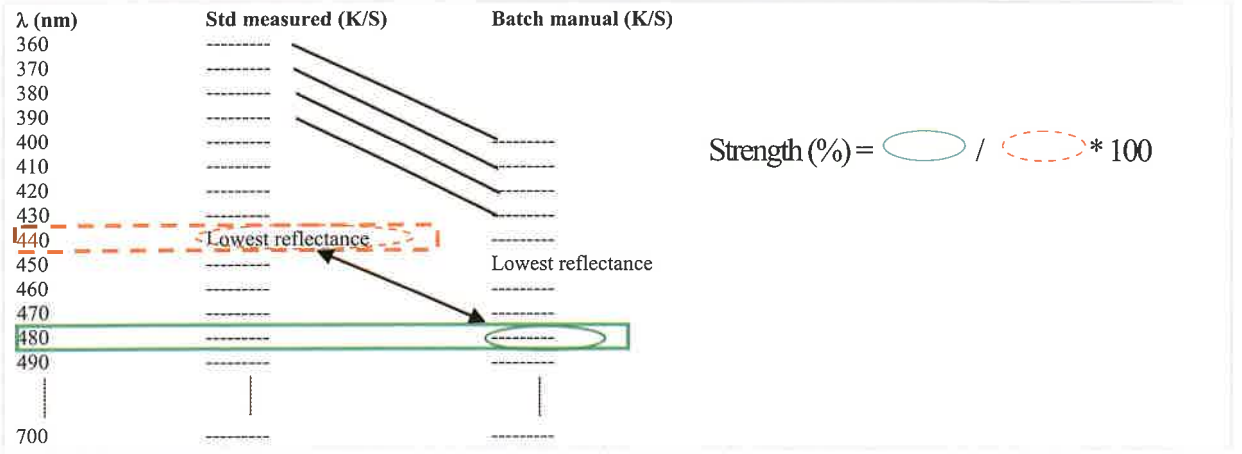


Figure 7: Standard measured / batch entered manually - Example

Conclusions on strength calculation

A thorough, in-depth analysis of both the methodology and data used for strength calculation highlights the importance of acquiring the reflectance values for both the standard and the batch by the same method (manual entry or measurement). The software runs the calculation as if both samples had the same available quantity of information. In any other configuration, the strength values are distorted. This

information is crucial. In some cases, the inaccuracy of the strength comparison is easily detectable, while in some situations, the calculated strength appears to be plausible but is not valid.

5. Physical parameters that could affect strength value

In the strength calculation, the K/S ratio, which is related to the reflectance percentage of the sample at the maximum peak of absorption, is a critical element. The higher the batch's K/S value compared with the standard's K/S value, the higher the strength. The K/S ratio is high when the reflectance value at the maximum peak of absorption is low; it corresponds to a more absorbent ink.

The technical review highlighted chemical (ink components) and physical ways in which the strength value could be affected. Of the physical parameters, the ink/white ratio, temperature of the mixture (related to the time of mixing), cell depth and cell orientation were retained. The first parameters tested were the ink/white ratio and cell depth and orientation.

A set of 4 process heatset coated inks (cyan, magenta, yellow and black) was chosen. Drawdowns allow for a comparison of the color and transparency of several inks of similar strength, the goal being to select the most transparent ones.

Except for the measurement's duration (the time elapsed between measurement and end of mixing - usually less than 45 seconds - was longer for deeper cells), the parameters are those used usually (Table I):

Table I: Parameters used internally

Illuminant / Observer	D65 / 10 degrees
Aperture	SAV/SCI (Small Aperture View/Specular Component Included)
Bleaching white	Hostmann white characterized and controlled from batch to batch to avoid any measurement discrepancy
Speed and time of mixing	5 min at 3,000 rpm
Methodology used to calculate strength	Maximum peak of absorption
Instrument calibration	Every hour
Time between measurement and end of mixing	Less than 1.10 min

i. Ink/White ratio

The ink/white ratio usually used to perform strength tests is 0.2 g of ink to 10 g of white. However, a modified mixture made up of 0.4 g of ink and 20 g of white allows for the same ratio to be kept while reducing weighing error.

Experiment conditions

- Trials were performed at least 3 days apart.
- With 0.2 g of ink to 10 g of white, the strength for each test was expressed relative to the first strength measurement performed on the same ink in the same proportions.
- With 0.4 g of ink to 20 g of white, the same reference was used (this one chosen for the 0.2 g/10 g test).

Results

Notes:

- *DE (or Delta E) is the colorimetric difference measured between bleached samples (ink + white medium). It is a dimensionless value. In both cases as the same ink is compared to itself, almost no colorimetric difference was noticed. The DE is very low except for the second test with 0.4 g of ink.*
- *Coefficient of variation (%) = (Standard Deviation / Average) x 100.*
- *According to Datacolor, repeatability should be around 2%.*

Table II: Results of measurement repeatability with two different ink/white ratios

	0.2 g / 10 g	DE	0.4 g / 20 g	DE
Test 1	100.37	0.06	100.66	0.07
Test 2	99.16	0.1	98.44	0.18
Test 3	100.55	0.05	99.7	0.1
Average	**100.03**	**0.07**	**99.6**	**0.12**
Standard deviation	**0.76**	**0.03**	**1.11**	**0.06**
Coefficient of variation (%)	**0.76**	**37.80**	**1.12**	**48.74**

Comments

Contrary to previous studies, which favored the 0.4/20 ratio, internal repeatability was better with the 0.2/10 ratio. The standard deviations and DE are lower with this dilution ratio. Two factors may explain these results:

- Operators used to working with the 0.2/10 ratio,
- The non-uniformity of the 0.4/20 mixture; the white was not properly mixed with the ink.

Container used was probably too small or mixing time was not appropriate.
The 0.2/10 was therefore used in the rest of the study.

j. Cell rotation and thickness

Note: The results of this study are only valid for these tested inks as they are transparency dependent.

Result summary

Usual cell thickness is about 2 mm. Trials were performed with various cell depths: 6, 9 and 12 mm. Three tests were repeated per color; for each test, the cell was rotated as follows: 0°, 90°, 180° and 270° (Table III).

As the measurements at 270° were always done last, the strength increase might be caused by the time needed to rotate the cell. Tests are underway to validate this hypothesis.

Table III: Description of tests run on cyan color

Color	Cell thickness	Rotation	Number of tests
Cyan	Standard	0°	3
		90°	
		180°	
		270°	
	6 mm	0°	3
		90°	
		180°	
		270°	
	9 mm	0°	3
		90°	
		180°	
		270°	
	12 mm	0°	3
		90°	
		180°	
		270°	

Cell selection

For each color, the most suitable cell would be the thinnest one, above which the strength measurements would be constant even if the cell thickness is increased. The Kubelka-Munk equations are only fully appropriate if an infinite layer of material is measured (the level above which reflectance measurements remain the same even if layer thickness is increased).

A thinner cell also for easier filling in and for the strength to be measured within one minute.

Test results

The following graphs show the strength variations per color, as a function of the rotation angle.
The four curves represent the four different cell sizes:

- each point represents the average of three tests,
- the standard deviation is drawn only for the standard cell.

Black ink

For black, all of the cells have quite similar curves, except at 0°. For the latter, the difference between the strength values is greater.

Whatever the cell thickness, the strength difference between the first and last angle is less than 2% and standard deviations vary minimally for all cells, except the 9 mm cell, for which the standard deviation is close to 1%.

The color difference remains consistent at 0.15 to 0.25.

The standard cell is suitable for black strength measurements.

Table IV: Summary of black results

		Average	Standard deviation	DE average
Std	0°	100,00	0,48	0,11
	90°	101,27	0,23	0,18
	180°	101,81	0,45	0,23
	270°	101,93	0,50	0,26
6 mm	0°	100,57	0,37	0,15
	90°	101,19	0,12	0,18
	180°	101,72	0,54	0,24
	270°	102,04	0,48	0,27
9 mm	0°	100,97	0,44	0,19
	90°	101,23	0,84	0,19
	180°	101,42	0,90	0,2
	270°	101,59	0,88	0,24
12 mm	0°	101,36	0,41	0,24
	90°	101,57	0,24	0,21
	180°	101,83	0,27	0,26
	270°	102,32	0,16	0,34

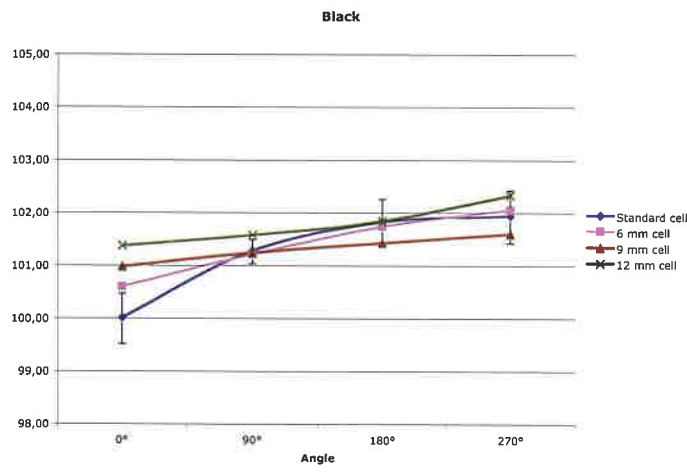


Figure 8: Graph of black strength results

Cyan ink

For cyan, the strength results with the 6 mm cell are different from those carried out on the 9 and 12 mm cells. With the standard cell, the strength difference between the first and last measurements is slightly greater than 2%. The strength values obtained with the 9 and 12 mm cells are similar.

Standard deviations are less than 1%, except for the 12 mm cell, and the average dE is consistent for all cells at between 0.25 and 0.40.

The 9 mm cell is suitable for cyan strength measurements.

Table V: Summary of cyan results

		Average	Standard deviation	DE average
Std	0°	98,21	0,45	0,42
	90°	99,86	0,70	0,26
	180°	100,34	0,32	0,22
	270°	100,57	0,88	0,21
6 mm	0°	98,08	0,22	0,48
	90°	98,87	0,30	0,39
	180°	98,99	0,31	0,34
	270°	99,46	0,37	0,3
9 mm	0°	98,78	0,56	0,43
	90°	99,28	0,74	0,39
	180°	99,74	0,13	0,32
	270°	100,27	0,10	0,29
12 mm	0°	99,16	1,25	0,4
	90°	99,26	0,96	0,38
	180°	99,71	1,33	0,33
	270°	99,91	1,04	0,28

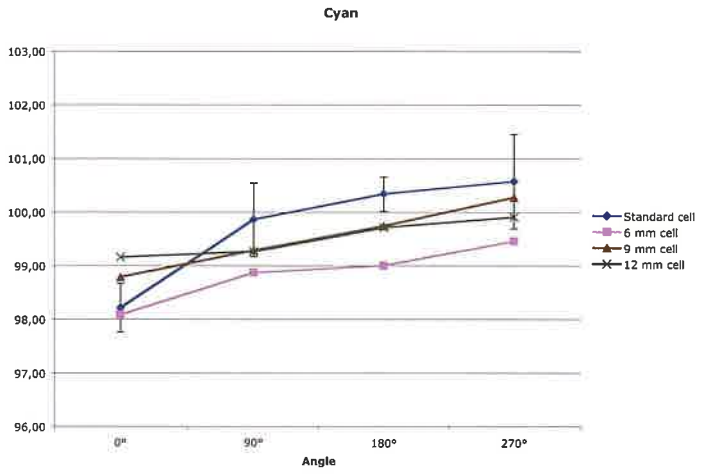


Figure 9: Graph of cyan strength results

Magenta ink

For magenta, whatever the angle of rotation of the cell, the 6, 9 and 12 mm cells show similar strength results.

The standard cell stands out from the others in that the strength variation between the first and last measurements is very close to 2.5% and about 2% for the others.

Furthermore, the standard deviations for the 6, 9 and 12 mm cells are smaller than those for the standard cell.

For all cells, the colorimetric differences are less than 0.5.

The 6 mm cell is suitable for magenta measurements.

Yellow ink

For yellow with the standard cell, the strength difference between the first and last measurements is close to 4%. For other cells, the difference is about 2%; closer curves are obtained with the 9 and 12 mm cells.

For all cell sizes except the 6 mm cell, the standard deviations are less than 1% and the color differences are less than 0.20.

The 9 mm cell is suitable for yellow measurements.

Table VI: Summary of magenta results

		Average	Standard deviation	DE average
Std	0°	100,64	1,63	0,15
	90°	102,85	1,43	0,41
	180°	103,32	1,44	0,51
	270°	103,16	1,15	0,52
6 mm	0°	99,94	0,85	0,25
	90°	100,78	0,90	0,14
	180°	101,49	0,77	0,16
	270°	102,41	0,85	0,28
9 mm	0°	100,10	0,82	0,25
	90°	101,13	0,36	0,16
	180°	101,66	0,62	0,17
	270°	102,08	0,93	0,23
12 mm	0°	100,17	0,98	0,19
	90°	100,83	1,04	0,12
	180°	101,40	0,66	0,14
	270°	102,23	0,65	0,24

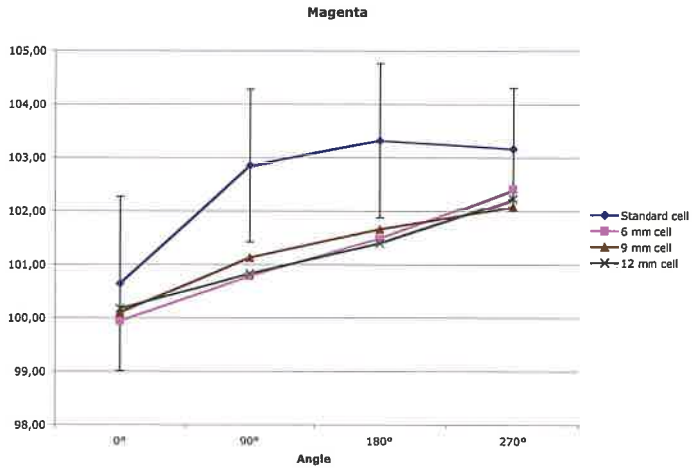


Figure 10: Graph of magenta strength results

Table VII: Summary of yellow results

		Average	Standard deviation	DE average
Std	0°	98,92	0,36	0,21
	90°	100,69	0,39	0,09
	180°	101,17	0,46	0,17
	270°	102,82	1,08	0,42
6 mm	0°	99,23	1,47	0,17
	90°	99,28	1,44	0,17
	180°	99,89	1,65	0,16
	270°	100,05	0,97	0,14
9 mm	0°	99,02	0,20	0,09
	90°	99,64	0,90	0,05
	180°	100,28	0,90	0,07
	270°	100,71	0,61	0,08
12 mm	0°	99,19	0,13	0,08
	90°	99,60	0,20	0,06
	180°	100,56	0,52	0,07
	270°	101,16	0,75	0,12

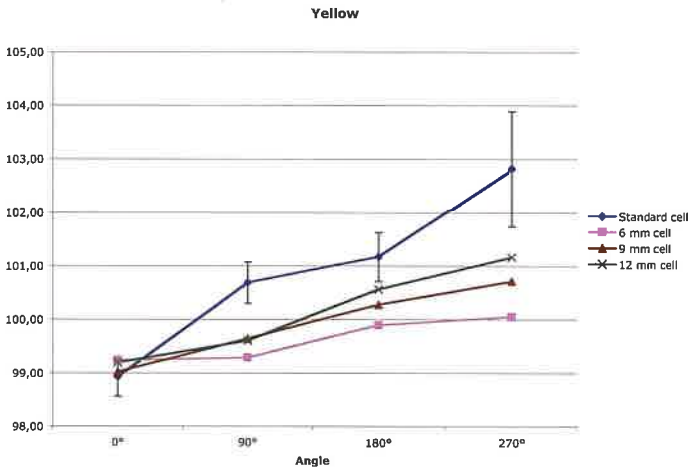


Figure 11: Graph of yellow strength results

Results summary

Table VIII: Results summary

	Average strength variation between first and last measurements	Standard deviations on strength values	Average DE	**Retained cell size**
Black	All cells: < 2%	Std cell, 6 and 12: < 0.5% 9 mm cell: close to 0.85%	All cells: < 0.45	**Standard**
Cyan	Std cell: > 2% Other cells: < 1,5%	Std cell, 6 and 9 mm: < 1% 12 mm cell: close to 1.25%	All cells: < 0.4	**9 mm**
Magenta	Std cell: close to 2.5% Other cells: close to 2%	Std cell: close to 1.5% Other cells: < 1%	Std cell: < 0.5 Other cells: < 0.2	**6 mm**
Yellow	Std cell: close to 4% Other cells: < 2%	Std cell, 9 and 12: < 1% 6 mm cell: close to 1.5%	Std cell and 6: < 0.2 9 and 12 mm: < 0.1	**9 mm**

The standard cell would not be the best suited for cyan, magenta and yellow. The minimum suitable size for this ink set would be 9 mm (Table VIII).

This test highlighted the impact of the depth on the strength value. The effect differs from one color to another. Other tests on other ink types will have to be performed to determine if the influence of cell depth is comparable for all ink series.

6. Conclusion

This study gives a better understanding of the principles of the Datacolor spectrophotometer and the calculations used when ink strength is measured.

With regard to strength calculation, a correct value will be obtained only if both inks' reflectance values are acquired in the same way, either manually or by measurement. As the number of values collected is different, the strength calculations can be affected if a combination of methods is used to collect the data for the standard and batch samples.

With regard to measurement accuracy and relevance, different ink/white quantities in the same ratio and cell depth and cell orientation were tested. The results showed that the ink/white quantities usually used where the most suitable as operator habits and/or unsuitable equipment gave less accurate results in the strength measurement. With regard to cell depth and orientation, the rotation/time needed to take the measurement has a greater impact than the cell depth. For rotation, the strength difference was sometimes higher than the permitted repeatability and more specifically for the standard cell. On the other hand, cell depth has a greater impact on the strength value depending on color. Black, magenta and yellow strength measurements are consistent with the three deepest cells whereas for cyan, a more significant difference between cell depths was noticed.

Strength measurement is quite a complex measurement as the procedure to measure the percentage of reflectance can affect the strength value: ink/white ratio, cell depth and cell orientation were studied first, but other parameters such as the temperature of the ink/white mixture (time of mixing) and pigments in the white medium also have an influence on the relevance and accuracy of the measurement.

Chemical parameters related to ink composition and ink manufacturing were also taken into consideration.

Of the parameters that could improve strength measurement, some have been qualified but not quantified:

- better dispersion of pigments and particles: the light ray is then trapped among the particles and a very small amount of light is sent back. This will also improve all other areas of ink performance on press. This process is however costly and difficult for ink suppliers to reproduce,
- increase in pigment concentration: the pigment is however the most expensive ink component and beyond a specific threshold, too high a pigment concentration will prejudice other ink properties such as ink printability,
- addition of absorbent particles such as toner to increase ink opacity,
- addition of specific as yet unidentified particles allowing for light to be trapped more efficiently or visible radiation to be absorbed and then re-emitted in another part of the spectrum, this part being "invisible" to the Datacolor instrument.

All of these parameters are issues that could be studied in order to improve the strength measurement procedure.

References

1. ASTM (sixth edition) D2066 - 97, *Standard Test Methods for Relative Tinting Strength of Paste-Type Printing Ink Dispersion, p. 112-117*
2. Fred W. Billmeyer, Jr. & David H. Alman, (1973), *Exact Calculation of Fresnel Reflection Coefficients for Diffuse Light, Journal of Color & Appearance; 2; No. 1; p. 36 - 38*

Measurement of the dynamic elongation of paper after printing with water-based inks

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Abstract

The main goal of this paper is to measure the dynamic elongation of the paper substrate (Decor- paper) after printing with water-based inks (casein ink). The aim of these measurements is to examine the possibility of drying the ink by means of microwave heating before the relevant dimension changes occur. This is important to avoid registration and other problems which generate loss of quality in multi-colour printing process with water based inks.

To accomplish that, a device was designed and built to measure this dynamic elongation of the paper after printing with water based inks, by such device it can be use different amounts of ink on the paper and ink viscosities. Relevant: the printing direction is perpendicular to the elongation of the paper to avoid interference between printing and measurement.

The measurements of the dynamic elongation of the paper after printing with water based ink showed a surprising behaviour, as the elongation depended on both, amount of ink on the paper and viscosity of the ink. The measured elongation times after printing with water based inks are much larger than those assumed earlier. The elongation times assumed earlier were based on the elongation of paper after bringing a water film on it. After wetting with water the paper changes its dimensions one order of magnitude faster than after printing with water based ink or more.

Keywords

Ink viscosity, microwave dryer, printing paper characteristics, water based inks, web extension

1. Introduction and aims of the development

There is an increase towards the use of water based inks instead of solvent based inks to avoid the environmental problems. For these reasons our research group is working since a longer time on the application of water based inks with the aim of reducing the environmental impact of the printing inks.

The water content of these inks leads to dimension changes of cellulosic printing substrates, especially paper. Still worst, these dimension changes are only partially reversible, as the paper do not planishes back after drying (after the whole evaporation of the water of the ink and after the paper reaches the moisture corresponding to the relative humidity of the air, usually 50% at 22°C) a definitive lost of quality may be feared. [Fogra, 1984].

The solution for these problems is to find out a drying mechanism which:

a) Produces a heat up and therefore drying only the wet ink, as long as water is present in the ink, but not in the unprinted paper areas.
b) Is a drying method able to reduce the amount of water in the ink film in a very short time. This means the drying of the water molecules in the ink film in a shorter time than migrate time of those water molecules to the cellulose fibres, therefore avoiding dimension changes of paper substrate.

Such a drying mechanism was found and successfully tested: a combined microwave-air convection drying method, keeping the substrate at room temperature. [IARIGAI, 2004]

With a first pilot plant it was possible to reach encouraging results, but it was evident that it was needed more exact information about the dynamic of the dimension changes of paper after printig it with water based inks. It was not possible to find publications about this item.

There were some literatures avielable about the dynamic of interaction of paper with water or moisture [EMCO, 2004], but not with water based inks.

From reports of industrial printers using water based inks and from our printing run measurements it was evident that, the dynamic of the dimension changes of the same paper after printing with water based inks and pure water are quite different. In principle may be assumed that, the dynamic elongation may depend as well from the viscosity of the ink as from the amount of ink film.

2. Measurement of the dynamic elongation of paper after printing with water based ink

The experiences from production presses for decor-papers show that the transversal dimension changes would be in order of 2 to 3.7% [Richard E.Mark, 1983] and need a time in the order of magnitude of several seconds. No more information in detail was available about the dimension changes for water based ink on the paper. Therefore we have built up a special measuring device as shown in figure (1) to study the dimension change of paper as function of the time. In this measuring device, the paper samples were printed in a very short time with different viscosities of water based ink and also with pure water in order to investigate the change of dimension after printing. The details of research methods are as the following:

a. *The printing unit*: It is done with a printing cylinder rolled on the strip of paper (260 mm × 85 mm ± 0.5 mm) from a flat-bed inking system. To avoid a coupling between the printing process and the measurement the printing cylinder rolls transversally over the paper strip. The paper strip was placed on a rubber blanket. The ink film was brought on to the paper in less than 0.14 s. It was possible to produce solid prints with different amounts of ink on the paper, up to ink films of 18 g/m².

To avoid evaporation of water from the ink, the inking unit was cooled at a temperature under the dew point.

b. *The measurement of the dimensions changes:* For this aim a metallic bar was used which flections changed with the elongation of the strip; obtaining an electrical signal to the elongation by means of a strain gauges bridge on the bar and a bridge amplifier. The final elongation was read from a mechanical displacement gauge.
c. *The record of the dimensions changes as function of the time:* A two channel digital oscilloscope with a hard copy printer was used. The measurements were trigged by the signal of a ceramic piezoelectric sensor placed under the blanket of the printing unit.
d. *The measurement of the amount of water in unprinted or printed paper:* The amount of water was determined through weighing the paper and the print before and after drying in an oven at 105 °C for a period of 30 min. [DIN EN 20287]

2.1 Measurements

After a successful test of the new device (figure 1) confirming its ability to measure the dynamic elongation of paper immediately after printing it was possible to begin with the measurements. The

aim of the measurements is to find out how the dynamic elongation changes as a function of both the viscosity of the ink and the ink film thickness. Therefore the measurement plan included:

- Elongation measurements for water based ink with viscosities corresponding to 10.5 s to 24 s (e-flux-cup Frikmar, 4 mm nozzle diameter, room-temperature).
- For comparison the elongation measurements was also made with water instead of ink.

At each condition a larger amount of measurements to get statistical relevant results were conducted. The measurements were done in a acclimatised room with ϕ = 45% to 60% and t = 21°C to 23°C. [DIN 50014]

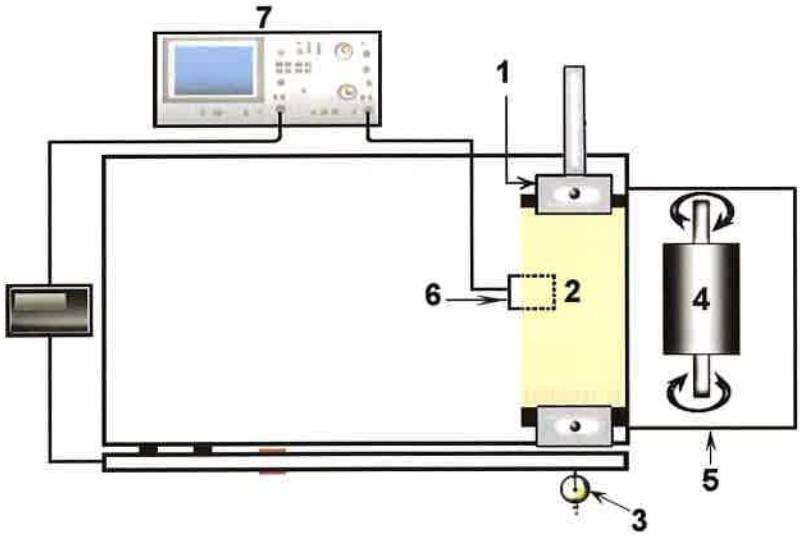


Figure 1: Structure of the Device to measure the paper elongation after printing with water based inks
1: Screw to set up the paper strip tension; 2: Paper strip (260 × 85 mm) ± .5 mm
3: Mechanical displacement reader; 4: Inking roller
5: Inking plate; 6: Piezoelectric sensor; 7: Digital storage oscilloscope

3. Materials and methods

The first steps of our developments were devoted to study the decor-paper printing. Therefore the measurements were done with papers and inks used for decor-printing.

Such decor-papers are used mainly for furniture i.e. laminated on wood fibre plates which are printed on gravure presses. The amount of ink on the substrate may be relatively high, up to 18 g/m².

3.1 Papers

The decor-paper used here is of 70 g/m² having 3 - 4% moisture content in the paper. These papers are light weight uncoated papers consisting mainly of natural fibres. Therefore they have an evident tendency to web-breaks.

3.2 Inks

As well known, in decor-printing the water based inks are used with casein as binder. Contrary to other water based inks they do not dry irreversible. Therefore they do not contain ammonium or amines.

These inks were used with a production kinematics viscosity corresponding to 24 s (e-flux-cup Frikma, 4 mm nozzle diameter, room-temperature). The amount of water in the ink is about 60% of the total ink constitutes.

4. Results

From our measurements it can be seen that the final elongation is - as expected - in a first approximation proportional to the total amount of water from the ink on the paper. This elongation is as expected much larger in transversal as in longitudinal direction [Fogra, 1984]. As such a behaviour which is well known. hence it needs no more explanations.

About the elongation as a function of the time: The paper elongation **x** after being printed went asymptotically to a final value **x0,** without dead time after the printing; either there is no dead time or the dead time is below the resolution of our device. It was assumed for the change of dimensions in the time **t** an exponential behaiviour as follows:

$$X = X_0 \left(1 - e^{\frac{-t}{\tau}} \right) \tag{1}$$

Where: τ is a relaxation time.

Figure 2 shows one example of a measurement of the enlargement after printing as a function of the time. From such measurements it is possible to obtain the value of the relaxation time.

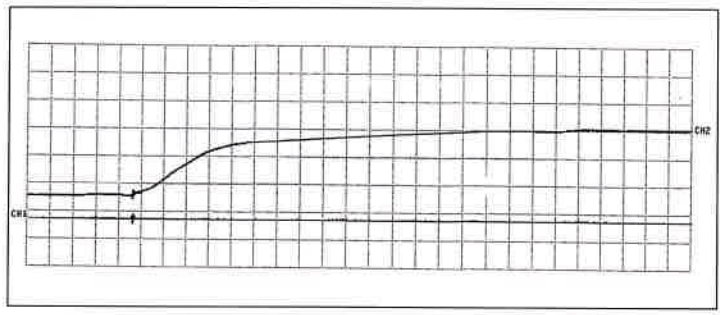


Figure 2: the elongation of paper after printing as a function of the time, where:
- CH1 is signal of a ceramic piezoelectric sensor to record the time
- CH 2 is electrical signal to record the elongation by means of a strain gauges bridge on the bar and a bridge amplifier

Figure 3 shows the relaxation time as function of the amount of water which is applied on to the paper with ink in six viscosities (corresponding to 10.5 s up to 24 s, e-flux-cup Frikmar, 4 mm nozzle diameter, room-temperature) and also for water. It is evident that:

- there is no or a very short dead time
- the dynamic of dimension changes after printing, characterised over the value of the relaxation time τ as in equation (1) shows quite different behaviours depending on the viscosity.

Surprising result: the relaxation time τ changes with the total amount of water, but the gradient depends on the viscosity.

As seen, the relaxation time τ is much larger than the remaining time of the printed web in the microwave dryer. Therefore the microwave dryer for water based ink is quite relevant to the initial speed of dimensions change of the paper.

Figure 4 shows this speed as a function of the amount of water content of the ink and of the viscosity.

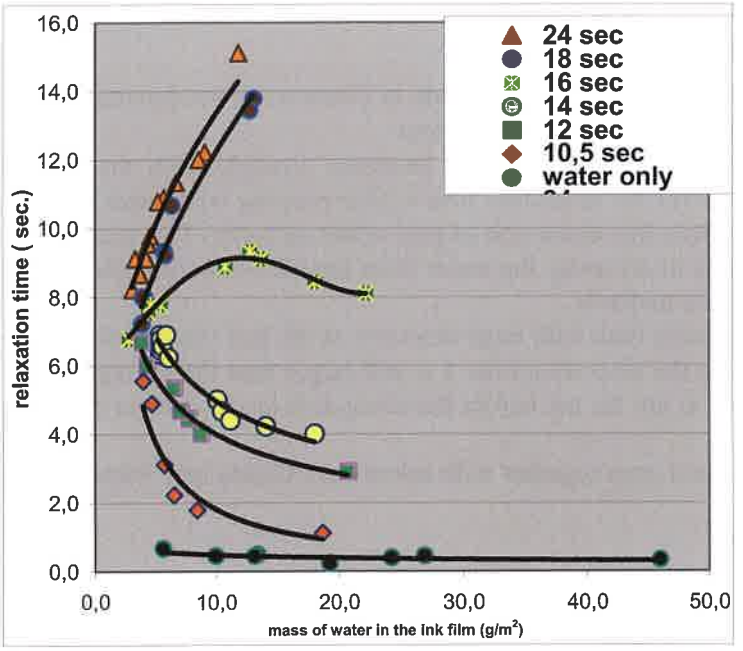


Figure 3: The relation between the mass of water in the ink versus the relaxation time

5. Conclusion and resume of the results

The use of water based inks on cellulose substrates as paper is relevant as a way to replace organic solvents and reducing of the environmental impact from printing industry. Immediately after printing, as water from the ink film interacts with paper it changes its dimension and also degrades its mechanical properties.

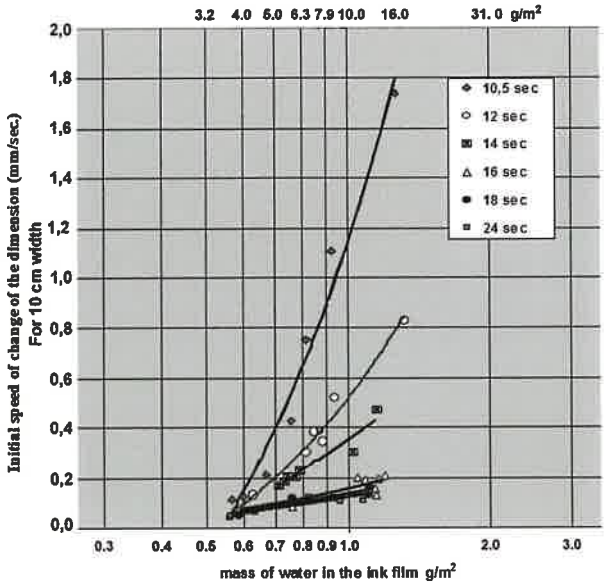


Figure 4: The initial speed of the dimension changes as a function of the amount of water in the ink and of the viscosity

Therefore it is quite important to know that the characteristic times for this interaction between water as component of the ink and the paper. Up to this moment only data for pure water were available.

The findings of our research:

1. Identified a relaxation time τ as magnitude to characterise the dynamic of the interaction between water as component of the ink and the paper.
2. Found out that the relaxation time $\dot{\tau}$ increases strongly with the viscosity of the ink. The elongation process (or the relaxation time τ after printing with water based inks need much more time as assumed from the interaction of pure water on paper. This means that by using microwave dryer, it is possible to dry away the water from the ink before it leads to unwished changes in the paper with adequate methods.
3. Found out that exactly both with large amounts of ink and viscosities corresponding up to 24 s as used in production the relaxation time τ is still larger than the drying time. This means that there is even more time to dry the ink before the elongation leads to losses of quality.

These results are new and open together with microwave drying new ways for the application of water based inks.

Reference

1. FOGRA, Beziehungen zwischen ausgewählten Eigenschaften von Druckpapieren und ihrem Umgebungsklima, H. L. Bumgarten und K. Wurster, 1984
2. IARIGAI, Rodriguez, J., Saad A., drying of water based inks with microwaves, Copenhagen, 2004
3. Druckmark 23, EMCO, Das Entdecken versteckter Papiereigenschaften, 2004
4. Richard E.Mark, Handbook of physical and mechanical testing of paper and paperboard, New York, 1983
5. Deutsches Institute für Normung, DIN 50014 -1985-07
6. Deutsches Institute für Normung e.V., DIN EN 20287-Die übersetzung der international Norm ISO 287, papier und pape Bestimmung des feuchtegehaltes wärmeschranksverfahren, sep. 1994

New method of measuring and evaluating streaks

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1. Introduction

Due to the conditional nature of the process streaks across printing direction are inherent in several printing methods, in particular, in offset printing. In other words, the theoretically assumed density profile over the length of a sheet printed with a screen tint or a solid shows, beside gradual fading, peak-shaped irregularities, which are perceived as streaks.

The main reasons for such streaks are: Transversal vibrations of the printing cylinders, common above all in sheet-fed and web-fed printing machines due to gap bounce effects, torsional vibrations resulting from unevenness of the drive or ghosting effects due to an unfavourable design of the inking unit. The appearance of such streaks can be intensified by inconvenient printing conditions like, for instance, excessive impression pressure or more damping than necessary.

With the printing methods applied at present such streaks cannot completely be avoided, but the effect can be minimised to such an extent that the human eye will hardly or even not at all perceive it. How far a printing press is able to print streak-free or nearly streak-free to the greatest possible extent is today acknowledged as a quality feature of the press, and is also a criterion for the technical inspection and approval of printing presses by the bvdm (German Print & Media Association).

The problem so far has been that this quality feature could not be measured in a perfect and reproducible way. In the first half of the nineties the first published method was developed with colorimetrics, which by that time had just become affordable. This measuring method was developed on behalf of the bvdm and is mainly applied in machine inspections.

2. Methods

2.1 Description of the measuring method applied up till now

To start with sheets are printed with the following parameters:

Printing forme

- Screen area coverage: 70%
- Screen width: 60 cm
- Screen angle: 0°
- Screen type: round dot

Print conditions

- Printing ink: cyan
- Paper: glossy art print, 135…150 gms
- Mean optical density of the screen area: 0.7
- Minimum damping

The printing machine to be tested runs at 85% of its maximum speed. One of the printed sheets is taken and a colorimeter is used to determine the colour coordinates in form of Lab values in printing direction at a distance of 2.5 mm. The colorimetric distance ΔE between two neighboring measuring points can than be determined.

The values of this ΔE series are then adapted to each other by finding a floating mean value of 4 Lab values. Is one of these ΔE values above 0.6 [1] and [2] postulate that a streak has appeared at this defined part of the printed image. If this value is above 0.9 the streak will clearly be visible and severely disturb the printed image. If values above 0.9 are found with this method, the checked machine does not fulfill the streaking criterion.

Since with this test the color coordinates are only determined on a line running across the streaks, one cannot exclude that also color changes are measured, which have not been caused by streaking. Such measuring errors may occur at paper creases, dirt particles or other inhomogeneities. As a result the ΔE streak diagrams have little or no resemblance to the optical impression of the printed image and are difficult to reproduce. Due to the measurement's low resolution of 2.5 mm the influence of the starting point of the measurement is another source of errors.

Since a color measurement is carried out only every 2.5 mm while the Lab values are always measured between two neighboring points the shifting of the starting point by only 1 mm may result in considerably different ΔE diagrams. The following figure (figure 1) compares two measurements carried out on the same line, but with the starting points shifted by 1.25 mm against each other. The differences of the two diagrams are considerable.

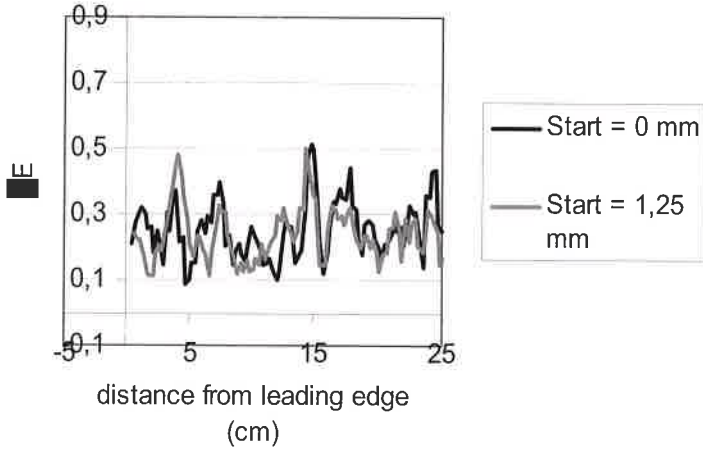


Figure 1: Streak measurement according to bvdm with 2 different starting points

2.2 The new method

The new method is also based on printing sheets from a streak test forme. Like with the previous method cyan was printed with an average density of 0.7 under the same conditions as described under 2.1. With a scanner a digital image file was generated of the whole printed sheet or of an interesting section of the sheet. Color or grey values are then averaged along the streak formation over the whole extension of the image file. This way one receives color value diagrams over the image width. These diagrams with their individual values, which are the average values over a defined image length, represent the optical impression of the image in terms of streaks better than diagrams produced over a single line only. Likewise the result of the measurement is less influenced by possible printing faults like hickies, smudges or other non-streak-shaped inhomogeneities.

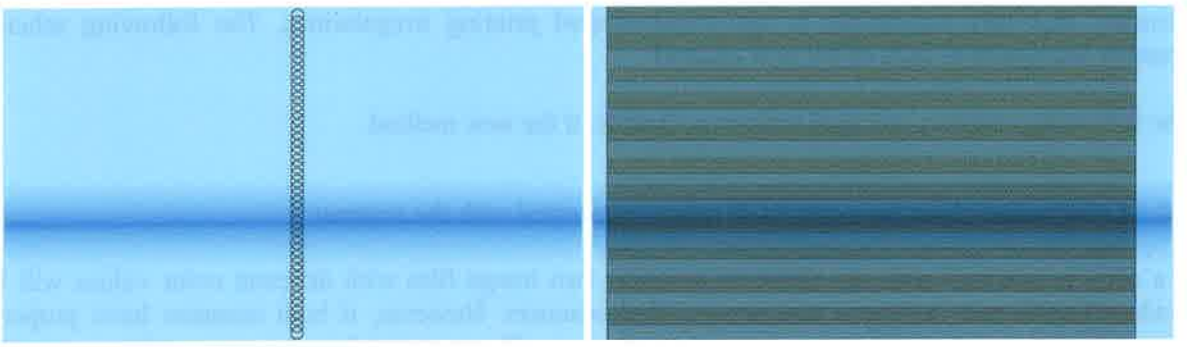


Figure 2: Measuring range of the previous and the new method

The color or grey values are converted into CieL* values. Similar to the previous method ΔCieL* diagrams are calculated from these values, with the CieL* values being calculated between defined pixel rows in the image.

The two essential sources of errors of the old method (scanning of a single line, resolution only 2.5 mm) have been explained under 2.1. Both sources of errors are avoided with the new method: Line scanning is replaced by the averaging of color values over the whole scanning width and the low scanning rate by a much higher resolution. Figure 2 compares the basic idea of the new method to the previous one.

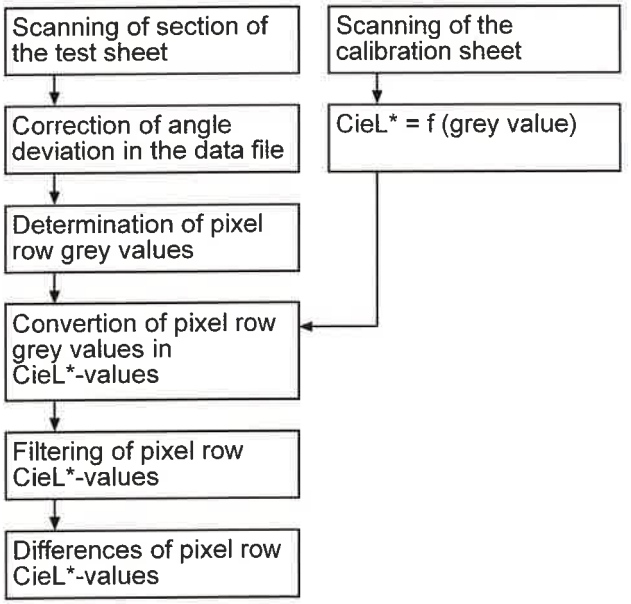


Figure 3:
Diagram of the streak analysis

The left row of circles illustrates the alignment of the measuring points with the measurement according to bvdm. The diameter of 4.5 mm of the measuring points is given by the used colorimeter, however, not demanded by bvdm guidelines.

The lines running across in the rectangle to the right illustrate the new measuring method. While the sector measured according to bvdm contains only 47 measuring points with a diameter of 4.5 mm in only one line the section measured with the new method contains app. 240 lines to be evaluated (corresponds to a scan resolution of 50 dpi). Most important is the fact that the new method evaluates a much greater width than only a line of 4.5 mm. In the figure this width is 19 cm. This is the width if a DIN A4 scanner is used. This makes the measuring method considerably safer in terms of measuring

accuracy and less susceptible to non-streak-shaped printing irregularities. The following scheme presents the essential facts of the new method.

The following chapters will deal with some details of the new method.

2.2.1 Calibration of the grey and RGB values generated with the scanner

If a copy is scanned with two different scanners two image files with different color values will be produced with non-calibrated and non-profiled scanners. However, if both scanners have properly been calibrated and profiled and the generated image files are stored in the same color gamut two image files with practically identical color values should be received.

However, during the work on the project it turned out that this degree of accuracy was not sufficient for the measuring task. Because in contrast to a multi-color image the color does practically not vary on a single-color uniform screen tint, as used here, fine color shades must be converted into reference values in the narrow color range of the screen tint.

For this reason a calibration sheet was produced for the evaluation of the cyan screen tints, which consists of measuring targets of 40 to 90% cyan area coverage.

The calibration sheet is scanned and the color values of the individual measuring targets in the file are determined. The mathematical correlation between color values and CieL* values of the used scanner is established together with the CieL* reference values by means of a regression calculation. This correlation is used to convert the color values of the scanned screen tint (same scanner and same scan settings) in CieL* values.

Values generated with different scanners can thus be compared or ageing effects of scanners be compensated, provided, of course, that calibration sheet and sample sheet are scanned with the same scanner and the same scanner settings. Automatic setting functions like brightness, contrast, shadows, highlights must by all means be deactivated.

2.2.2 Formation of pixel row mean values

After the image file has properly been aligned it is possible to determine the mean grey values of each pixel row or of a defined color channel. In order not to distort the pixel row mean value by faults caused by impurities in the paper and others a confidence control can be introduced in the formation of the pixel row mean values. Figure 5 shows the grey values of a pixel row section. All black values become part of the mean value formation. The grey values lie outside the 2.5 - fold standard deviation of this example and have not been included in the mean value formation.

2.2.3 Convertion into CieL values*

After the last calculation step the mean values of each individual pixel row still remain to be grey or colour values, which depend on the absolute and spectral sensitivities of the RGB sensors of the scanner used, and, again, these sensitivities depend on the type and age of the scanner. Settings of the operation software during the scanning operation also influence the pixel row mean values. If later results are to be comparable with results of other streak analyses these unstandardised pixel row mean values must be converted into standardised ones. This is done by means of the scanner-specific correlation between grey or color value and CieL* values described already under 2.2.1. After their convertion the pixel mean values are calibrated CieL* values.

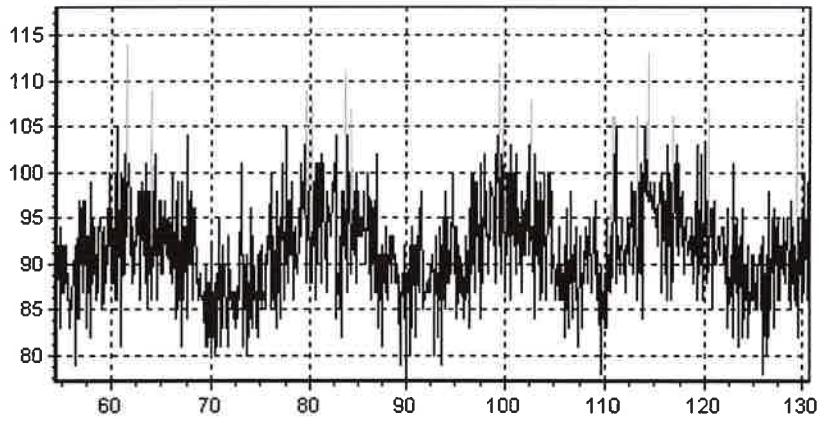


Figure 4: Grey values of a pixel row with confidence interval

If these pixel row mean values are assigned to the distance of the respective line from the lead edge one receives the pixel row mean value curve which can be presented in a diagram. The following figure 6 shows an example.

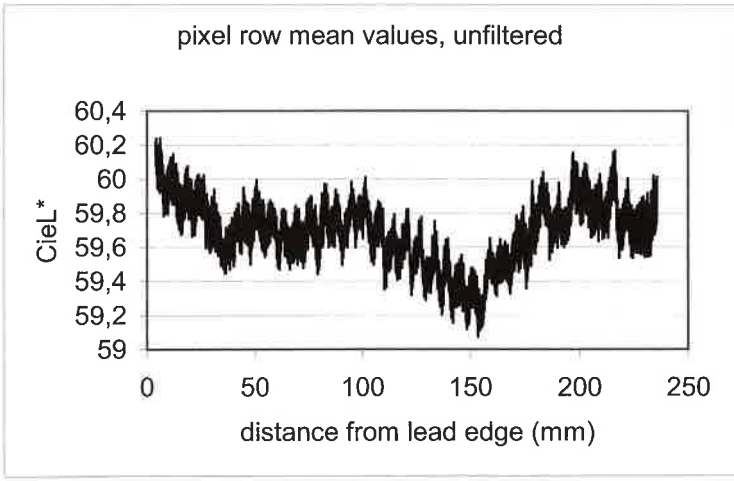


Figure 5: pixel row mean values

2.2.4 Frequency filtering

One can see clearly that the grey value curve in figure 6 heavily fluctuates already over small sectors caused on the one hand by bright-dark fluctuations in form of screen dot (lines) on the printed sheet and on the other hand by inaccuracies of the scanner. If the difference formation of the pixel row mean values would be carried out on the basis of this disturbed signal the result would be more or less accidental due to the more or less accidental nature of these fluctuations.

When viewing streaks at a distance of one meter or more the human eye is no longer able to recognize weak bright-dark differences between a width of one millimetre. The streaks to be studied (torsion vibrations, bending vibrations, ghostings) are always wider. Therefore, fluctuations below this limit are filtered out with a low-pass filter.

The difference formation of the pixel row mean values aimed at with the next step would in most of the cases deliver a diagram corresponding with the visual impression after the high-frequency parts have

been filtered out from the signal. However, it may happen that due to a color fading that superimposes the streak wrong differences occur which are not proportional to the visual impression. Beats resulting from the superimposition of scan resolution and screen width may also produce seeming grey value drops in the data. As a consequence also low frequency parts are filtered out from the pixel row mean value curve. Figure 7 show how filtering is done in practice. The high and low frequency parts of the fluctuations are filtered out from the pixel row mean value curves (filter curves 1 and 2).

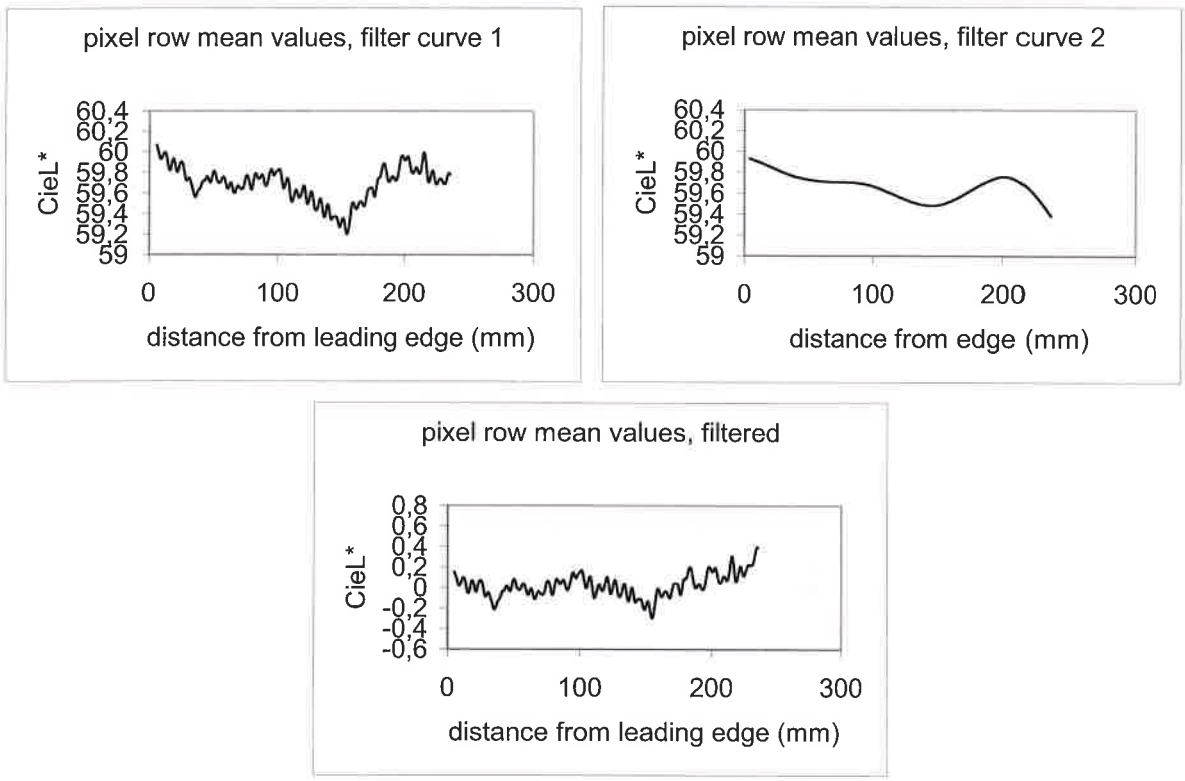


Figure 6: Filtered pixel row mean values

Through substraction of the filter curve 2 from filter curve 1one gets a pixel row mean value curve which contains only the relevant fluctuation shares. A band pass filter has practically come into being with the subtractive linking of both low-pass filters, which filters out that frequency band that is of interest for the streak analysis. It goes without saying that for analyzing other types of streaks, like, for instance, micro streaks other filter settings are required.

2.2.5 Creation of ΔCieL values as streak parameters*

For bright-dark jumps to be directly presented differences of the CieL* values of pixel rows of a defined distance are determined from the filtered pixel row mean value curves.

The absolute amount of these differences is assigned to that point which lies exactly in the middle of the pixel rows participating in the difference formation and can thus be presented in a diagram. Each individual peak in the diagram corresponds to a bright-dark jump within a distance of 5 mm on the printed sheet.

As soon as these ΔCieL* values exceed a certain limit this bright-dark jump will be visible to the human eye. Based on the experiences made in the course of the project it can be said that a ΔCieL* value of app. 0.3 is the limit for the visibility under the conditions described.

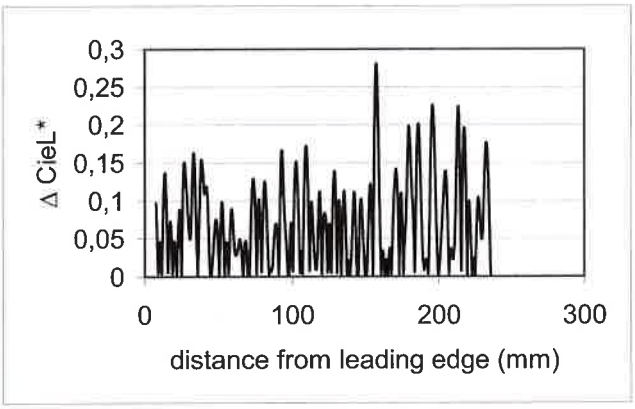


Figure 7: Pixel row mean value differences

The limits will be different for other test criteria (e.g. black printing ink, 50% area coverage) with possibly lower measuring fluctuation. Further studies on this subject are planned.

3. Results

An essentially more exact streak analysis is possible with the new measuring method. The diagram of the pixel row mean value differences clearly shows higher peaks at those points at which streaks or bright-dark edges are visible on the printed sheet. The diagram in figure 10 shows the correlation between visual evaluation and ΔCieL* values calculated with the new method. 18 testers, some of them experts some laymen, took part in the visual evaluation. Their task was to assess the streaks on the basis of contrast differences at a defined edge and to give marks between 1 and 4.

Repeated measurements have proven that the absolute error of the ΔCieL* values produced under the described conditions is ± 0.1.

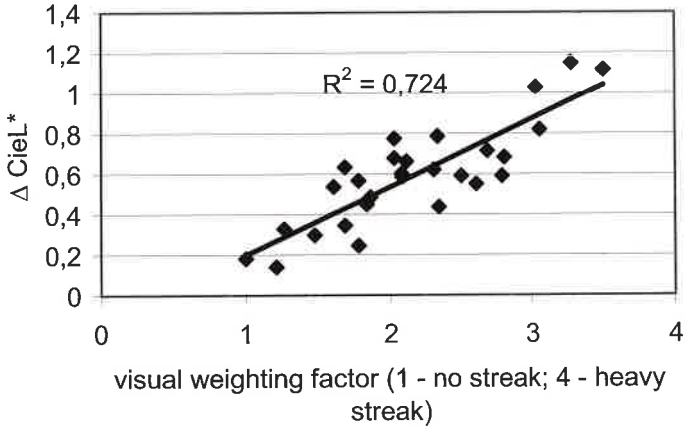


*Figure 8: Correlation visual / ΔCieL**

4. Conclusions

The objective assessment of the quality of printing presses in regard of streaking is possible with the new method.

Precise streak diagrams of sheet sections, whole sheets or of several sheets can be generated with the software integrated in the method. A useful and comfortable tool has thus been created for the development, manufacture or diagnosis of inking and damping units that should be applied for quality assurance both by printing press manufacturers and printers.

References

1. „Handbuch zur technischen Abnahme von Akzidenz-Rollenoffsetmaschinen“, ISBN Nr. 3-88701-177-5, Bundesverband Druck und Medien, Wiesbaden, 1996
2. „Handbuch zur technischen Abnahme von Bogenoffsetdruckmaschinen“ ISBN Nr. 3-88701-178-3, Bundesverband Druck und Medien, Wiesbaden, 1996

Evaluating colour print mottle

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Abstract

Among the most detrimental features of print quality are unintentional spatial reflectance variations in prints, frequently referred to as print mottle. The ability of the human visual system to discriminate between colours makes it sensitive not only to lightness variations, but also to chromatic variations. Previously, several models have been put forward to estimate the amount of lightness variations in prints, but few to measure chromatic variations. In this paper, a new evaluation model, based on a previous achromatic model but generalized to colour, is presented. Printed samples from two sets of simulated prints with various degrees of colour variations and two sets of colour prints from various conventional presses were analysed to evaluate the performance of the new model. The new model gave a result which correlated considerably better with visual evaluation than the achromatic model when the variation was chromatic in character. In practical printing situations, however, the variation does not seem to be mainly chromatic in character and a colour mottle evaluation model may therefore often be redundant.

Keywords

Chromatic variation, colour print mottle, simulation, print quality, visual assessment

1. Introduction

The ability of the human visual system (HVS) to perceive colour makes its receptive not only to variations in grey scale but also to chromatic variations. Several models to estimate the amount of achromatic mottle in prints have been put forward [e.g. Jordan & Nguyen 1986; Johansson, 1993; ISO/IEC 13660:2001], but few approaches consider how to measure the colour mottle.

Hirose (1993) investigate the perceptual characteristics of image noise in colour hard copy images and compared the results with the Visual Transfer Function (VTF) proposed by Sakata & Isono (1977). His results agree well in lightness, but they also suggest that the perceptual characteristics of noise in the chromatic dimensions, a^* and b^*, have a wider band spatial frequency response than Sakata & Isono's VTF.

Mizes (2000) proposes an extension of a graininess metric to colour. The model acknowledges the fact that human contrast sensitivity differs considerably between the three different colour coordinates L^*, a^* and b^* in colour space. A general graininess metric is obtained by separately estimating the variation in the L^*, a^* and b^* channels with respect to human contrast sensitivity, and summing the contributions from each channel.

In this paper, we propose a similar approach for large-scale variations in prints, so called print mottle. The new model is a generalisation to include colour variations of the achromatic model introduced by Fahlcrantz (2003). In the choice of appropriate colour VTF we use the VTF based on Klassen & Goodman (2000) and applied by Mizes (2000). The choice is motivated in an overview of colour contrast sensitivity in the Theory section of this paper. The performance of the new chromatic model is compared to the performance of an achromatic model based solely on L^* in four separate evaluations.

2. Theory

2.1 Colour print mottle evaluation model

Based on the model for stochastic achromatic mottle by Johansson (1993), modifications by Fahlcrantz, Johansson & Åslund (2003), the mathematical contrast sensitivity approximation by Barten (1999) and texture analysis [Jernigan & D'Astous, 1984; Nguyen & Jordan, 1989], a model for the evaluation of systematic print mottle was proposed by Fahlcrantz (2003):

$$M = \frac{1}{\sqrt{R}} \int_{u \in U, \varphi \in \Phi} |N(u,\varphi)|^2 VTF(u)^2 T(u,\varphi) \frac{du}{u} d\varphi \tag{1}$$

where:

M is a prediction of visually assessed print mottle,
$|N(u, \varphi)|^2$ it the reflectance variance at frequency u cycles per degree and orientation φ in the power spectrum,
$VTF(u)$ is a Visual Transfer Function at frequency u cycles per degree,
$T(u, \varphi)$ is a texture enhancement filter based on a Chi-Square measure in the Fourier domain,
U is the integration limits, [0.44, 27.92], in cycles per degree (which corresponds to wavelengths 0.25 - 16 mm at a viewing distance of 0.40 m),
R is the mean reflectance factor level of the print.

In this paper we restrict the model to stochastic mottle and therefore detach the texture enhancement filter, $T(u, \varphi)$, but generalize the model to incorporate not only lightness variations, but also colour variations by carrying out the analysis in the CIE $L^*a^*b^*$ space [CIELAB, 1976]. We also modify the model slightly to obtain a more linear relationship with visual assessment by applying the square root to the whole expression (since (1) has the form of a summation of squares approach).

Fahlcrantz et. al. (2003) suggested a square-root mean reflectance normalisation as a replacement of the original mean reflectance normalisation [Johansson, 1993]. Here the analysis is carried out in the $L^*a^*b^*$ space, which corresponds to a normalisation of $R^{2/3}$. Since the results presented by Fahlcrantz et. al. (2003) yielded only a very small improvement in the correlation with visual evaluation when $R^{1/2}$ was used instead of $R^{2/3}$, we do not add any further compensation for the mean reflectance factor level here.

The variation in each channel, L^*, a^*, and b^* is therefore estimated by the following expression:

$$M_i = \sqrt{\int_{u \in U, \varphi \in \Phi} |N_i(u,\varphi)|^2 VTF_i(u)^2 \frac{du}{u} d\varphi} \tag{2}$$

where

M_i is the prediction of visually evaluated print mottle in channel i,
$i = \{L^*, a^*, b^*\}$,
$|N_i(u, \varphi)|^2$ is the reflectance variance at a frequency of u cycles per degree and orientation φ in channel i,
$VTF_i(u)$ is the Visual Transfer Function for channel i at frequency u,
U is the integration limits, [0.44, 27.92], in cycles per degree (which corresponds to wavelengths 0.25 - 16 mm at a viewing distance of 0.40 m).

A single estimate of the colour print mottle in a printed sample is thus obtained as:

$$M_{total} = \sqrt{M_{L^*}^2 + M_{a^*}^2 + M_{b^*}^2} \tag{3}$$

The new approach, (2), was evaluated by comparing its performance with the achromatic model:

$$M_{L^*} = \sqrt{\int_{u\in U,\varphi\in\Phi} \left|N_{L^*}(u,\varphi)\right|^2 VTF_{L^*}(u)^2 \frac{du}{u} d\varphi} \tag{4}$$

2.2 Choice of colour VTFs

Research on spatial luminance contrast sensitivity has from the beginning been quite consistent and there is today a fairly well established consensus regarding its character [eg. de Valois & de Valois, 1988]. Approximate analytical expressions have also been developed to describe human luminance contrast sensitivity [Barten, 1999; Daly 1992; Jacobson, 1995].

The opposite is however the case regarding spatial chromatic contrast sensitivity. The debate as to whether human colour contrast sensitivity is band pass or low pass has been going on for about 40 years and still lacks proper accord. What is clear however is that human colour contrast sensitivity is much lower than luminance contrast sensitivity at frequencies above 0.5 cycles per degree [e.g. Mullen, 1985; Williams et al. 1993]. In our context, this means that we must choose separate VTFs for each of the L^*, a^* and b^* channels to estimate colour mottle properly.

It has generally been considered that colour contrast sensitivity, in contrast to luminance contrast sensitivity, is low pass rather than band pass [e.g. de Valois & de Valois, 1988]. This view is well anchored in empirical findings by e.g. Van der Horst & Bouman (1969) and later by Mullen (1985). A confirmation of these findings is that Mach bands could not be identified in gradients of varying colour and constant luminance [Van der Horst & Bouman, 1967; Kelly, 1975].

In contrast to this, however, Schade (1958), who was among the first to deal with this problem, reported band pass. Dow (1964) reported chromatic Mach Bands by 3 out of 6 observers. Watanabe, Sakata & Isono (1976) reported some moderate low-frequency attenuation of colour contrast sensitivity at very low frequencies.

Williams et. al. (1993) point out that the drop in neural efficiency at low spatial frequencies leaves room for some lateral inhibition in the chromatic pathways. However, it may be less strong than in the pathway serving isochromatic stimuli. At high spatial frequencies, the fall-off in efficiency is more rapid for isoiluminants with colour variations than for isochromatic stimuli.

The low pass theory has lately been questioned by Guth (1998) who suggests that the luminance and chromatic contrast sensitivity are quite similar, and that existing measurements of colour contrast sensitivity should be compared with luminance contrast sensitivity at a very low luminance. At this level luminance contrast sensitivity is also low pass [Patel, 1965]. With a highly saturated red, however, he shows tentative results suggesting that colour contrast sensitivity is band pass.

Klassen & Goodman (2000) report band pass tendencies at low frequencies, but other late results by Owens et al. (2002) suggest low pass. It is important to notice that Owen's study, together with several of the previously mentioned ones, does not investigate frequencies below 1 cycle per degree (which corresponds to about 1.4 cycles per cm at a viewing distance of 40 cm). The empirical evidence towards band pass suggests that band pass tendencies should start to be visible at about 1 cycle per degree. The controversy may therefore perhaps be partially related to the frequency range within which spatial colour contrast sensitivity has been explored.

We conducted very tentative experiments with highly saturated gratings, such as those suggested by Guth (1998), on a LCD screen. Although it is difficult to obtain isoluminance on a LCD screen, it was confirmed that local luminance within areas corresponding to the pattern frequencies was stable ($\Delta L < 1$, measured with a PR-650 spectroradiometer). Our observations suggests that the colour contrast sensitivity in this case peaks at about 1 cycle per degree, and then falls of very slowly towards lower frequencies. This is in line with both Guth (1998) and Klassen & Goodman (2000), and also with e.g. Watanabe et al. (1976) and Mullen (1985) who detected weak to very weak band pass tendencies.

For practical purposes, the discussion about slightly band pass or low pass is however somewhat less crucial in our case, since we do not consider variations at extremely low frequencies. A slight band pass tendency or a straight low pass relationship will not significantly change the estimation based on (2). More crucial is the relationship between the magnitudes of the L^*, a^* and b^* spatial contrast sensitivities. Mizes (2000) estimates these relationships based on the VTFs by Hirose (1993) as 1:0.34:0.11 and on those by Klassen & Goodman (2000) as 1:0.24:0.12. The discussion concerning low pass or band pass already suggests however considerable differences between the shape of the luminance and the chromatic contrast sensitivity curves, and it would thus be better to establish a relationship between the L^*, a^* and b^* channels for different frequencies, and not to rely on an average over all frequencies.

Upper frequency cut-offs are also of interest. Williams et al. (1993) suggest that the neural spatial bandwidth is the same for S-cone contrast sensitivity and for L-M cone contrast sensitivity, but that chromatic aberrations and the low retinal density of the S-cones nevertheless reduce the spatial performance of the S-cone sensitivity. The visual resolution of the two colour directions, red-green and S-cone, is reported to differ by a factor of roughly two.

Using the VTFs by Klassen & Goodman (2000), presented in Mizes (2000), we calculated the relationship between the L^* a^* and b^* contrast sensitivities for different frequencies. The results of our calculations are presented in Figure 1. The results were slightly modified at high frequencies to ensure proper high frequency cut-offs. The a^* channel was totally attenuated at frequencies above 27 cycles per degree and the b^* channel at frequencies above 16 cycles per degree. These thresholds are reported by Williams (1993) as absolute upper cut-offs for chromatic contrast sensitivity. An alternative to our approach, which would probably serve the purpose just as well, is to use the approximations described by the S-CIELAB approach [Zhang & Wandell, 1996; based on results of Poirson & Wandell, 1993].

Regardless of approach, the relationship established between the L^* a^* and b^* channels will be rather rough, but it should be sufficient to demonstrate the applicability of the model presented in (2). It is probable that these relationships need to be considerably revised not only to account for different observation conditions but also since findings such as those reported by Owens et al. (2002) concerning a difference in sensitivity between variations at a low b^*-value (blue) and variations at a high b^*-value (yellow) suggest that the b^* channel sensitivity is dependent on the coordinates themselves. The construction of precise mathematical approximations for the a^* and b^* channel spatial contrast sensitivities, valid for different observation conditions, may therefore be a very demanding task.

3. Method

To test the new colour mottle model, four separate evaluations were made. In each evaluation, the samples were evaluated visually, with the new colour mottle model, (2) & (3), and with the grey scale model (4).

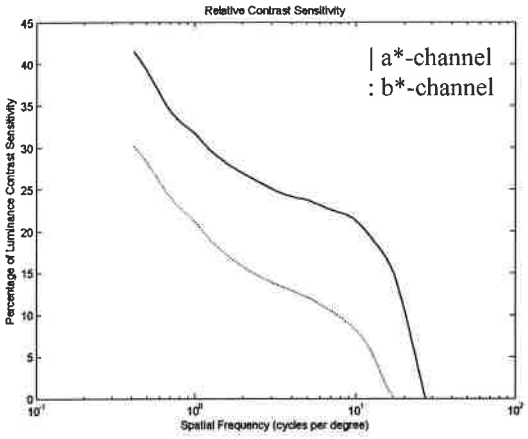


Figure 1: Contrast Sensitivity of the a-channel and the b*-channel relative to that of the L*-channel. The relations are calculated from the results of Klassen & Goodman (2000) presented in Mizes (2000). Luminance level 125 cd/m^2, Sample covering 8.2 degrees of the visual field*

3.1 Evaluation 1 - Simulated grey samples with colour variations

3.1.1 Sample creation

A set of 29 different half-tone grey test patches, reflectance level 32%, was created by digital simulation and then printed on the same substrate with a high quality inkjet printer, Canon BJC-8200. This high quality printer introduces only a very small amount of noise, which can be considered to be similar in magnitude on all the samples. The noise introduced with the digital simulation was therefore the only factor that varied between the samples.

To establish the noise level introduced by the printer, the first patch was left without any simulated contamination. 7 samples were contaminated with various amounts of stochastic noise in the L* coordinate, 7 samples with stochastic noise in the a* coordinate, 7 samples with stochastic noise in the b* coordinate, and 7 samples with stochastic noise in all three coordinates simultaneously.

3.1.2 Visual evaluation

Apparatus. *A digital tablet, such as that commonly used in computer-aided design, was used to record the visual evaluation.*
Observers. 10 persons, 8 male and 2 female subjects, ranging from individuals with no earlier experience of print mottle evaluation to expert judges, participated in the visual evaluation. All the subjects had normal colour vision [Ishihara, 1984].
Procedure. The visual evaluation was conducted on a digital tablet, asking for the magnitude of the generally perceived disturbance level. The subjects were asked to use the whole x-axis of the tablet for the rating, placing the patches with least disturbance close to the origin (lower left corner) and patches with a high level of perceived disturbance far away from the origin (to the right). The positions of the patches were then recorded with a pointing device. The visual evaluation was carried out in a perception laboratory with a homogeneous light source (700lx, 5000K).

3.1.3 Instrumental evaluation

The printed samples were scanned in RGB at 300 ppi with an Epson 1680 pro scanner. The evaluation starts by transforming the RGB image of the scanned prints into the *L*a*b** space. This procedure

involves a colour calibration of the values by a 20-degree polynomial colour calibration approach [Hardeberg, 1999]. The evaluation is then carried out by applying (2) & (3) in the chromatic evaluation, and (4) in the achromatic one.

3.2 Evaluation 2 - Simulated wet-trapping

3.2.1 Sample creation

To evaluate the colour mottle evaluation model in a more practice-like situation, and still maintain a fair degree of control over the sample creation process, 12 samples, 4 red, 4 green and 4 blue, were created by digital simulation, and printed with a high-quality ink-jet printer, Canon BJC-8200. The idea was to simulate a multi-colour printing process situation where spatial density variations in one ink layer influence the transfer of the amount of ink in the subsequent printing station, resulting in a mutual inhibition of inks - an effect that can be referred to as "wet-trapping". The samples were created so that the digital colour coverage was constant all over the patches, 180%, i.e. if 89% magenta was decided by the digital simulation in one pixel in a red patch, 91% yellow was introduced to yield a 89 + 91= 180% total coverage in this pixel. This coverage refers however only to the digital simulation, and not with full precision to the coverage of the final print.

3.2.2 Visual evaluation

Observers. 10 persons, 5 male and 5 female subjects, ranging from individuals with no earlier experience of print mottle evaluation to expert judges, participated in the visual evaluation. All subjects had normal colour vision [Ishihara, 1984].
Procedure. The subjects were asked to rate how disturbing they assessed the inhomogeneity of each patch to be. The subjects were first asked to place the samples in order from least disturbing to most disturbing, and then, by attaching twice as high a value to a patch that was to be considered twice as disturbing as another patch, to carry out a magnitude estimation (Stevens, 1976). The visual evaluation was conducted in a perception laboratory with a homogeneous light source (1400lx, 5000K).

3.2.3 Instrumental evaluation

The instrumental evaluation was carried out according to the procedure described in Evaluation 1, Instrumental Evaluation.

3.3 Evaluations 3 & 4 - Samples printed with conventional presses

To test the applicability of the model to real prints, two series of samples printed with conventional presses were evaluated. The first series of samples used in the third evaluation contained as many as 40 green samples, 100% cyan + 100% yellow, printed in several different printing presses and on several different substrates.

The second series of samples used in the fourth evaluation contained 12 blue samples, 100% cyan + 100% magenta, printed with different printing techniques on different substrates. A detailed description of the test printing from which the samples in Evaluations 3 and 4 originated, can be found in Eidenvall et al. (2001).

3.3.1 Visual evaluation

Observers. In the third evaluation, 13 persons, 8 male and 5 female subjects, ranging from individuals with no earlier experience of print mottle evaluation to expert judges, participated in the visual

evaluation. All the subjects had normal colour vision [Ishihara, 1984]. The fourth evaluation employed 10 persons, 5 male and 5 female subjects, also ranging from individuals with no earlier experience of print mottle evaluation to expert judges. All the subjects had normal colour vision [Ishihara, 1984].

3.3.2 Procedure

The evaluations of the third and fourth sets of samples were conducted as described in Evaluation 2, Visual Evaluation.

3.3.3 Instrumental evaluation

The instrumental evaluation of the third and fourth sets of samples was carried out according to the procedure described in Evaluation 1, Instrumental Evaluation.

4. Results

4.1 Evaluation 1 - Simulated grey samples with colour variations

The results of the first evaluation were mainly intended to verify that the Visual Transfer Functions, based on the Klassen & Goodman (2000) study of human contrast sensitivity presented in Mizes (2000, Figure 4) were applicable in our case.

The linear correlation coefficient between the visual assessment and the colour mottle model (logarithmic transformed values), based on (2) & (3), was 0.97. The correlation coefficient between visual assessment and the achromatic model (logarithmic transformed values), based on (4), was 0.82. The improvement using the colour mottle model instead of the grey scale model was statistically significant ($p = 0.01$). The inter-individual Pearson correlation coefficients were converted to the normally distributed variable 'z' with Fisher's z' transformation and the concordance among observers was calculated as the arithmetic mean of the transformed correlation coefficients [Fisher, 1924]. This mean correlation between observers was 0.90. The correlation coefficient between the two instrumental evaluations, the chromatic and achromatic models, was 0.91. The results are presented in Figure 2.

4.2 Evaluation 2 - Simulated wet-trapping

In the second evaluation the inter-individual correlation coefficient between observers was 0.88 (calculated according to the method described in Results of Evaluation 1). The correlation coefficient between the visual assessment and the instrumental evaluations were 0.98 for the chromatic, and 0.70 for the achromatic model. The enhancement using the chromatic model instead of the achromatic model to predict visual assessment was statistically significant ($p = 0.01$). The correlation coefficient between the two instrumental evaluation approaches in this case was 0.78. The results are presented in Figure 3.

4.3 Evaluations 3 & 4 - Samples printed with conventional presses

The results of the third and the fourth evaluations are presented in Figure 4. In the third evaluation, the correlation coefficient between observers was 0.77. The correlation coefficient between the visual assessment and the chromatic model was 0.80, and between the visual assessment the achromatic model also 0.80. The correlation coefficient between the instrumental evaluation approaches was in the third evaluation 0.99. The corresponding correlations for the fourth evaluation were, 0.90, 0.98, 0.97, and 1.00. The improvement using the chromatic model as a substitute for the achromatic model to predict visual assessment in the third and fourth evaluations was not however statistically significant.

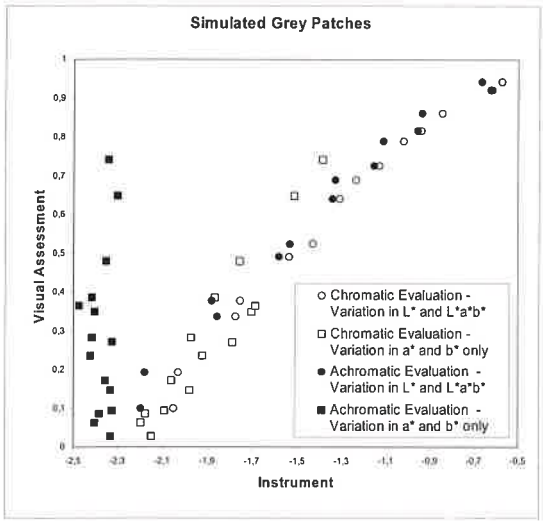


Figure 2:
Simulated Grey Patches - Mean Visual Assessment versus Instrumental Evaluations (logarithmic transformed values). White circles and squares present correspondence between visual assessment and instrumental evaluation based on (2). Black circles and squares show correspondence between visual assessment and instrumental evaluation based on (4). Notice how the samples with simulated variation in the a and b* channels only (black squares) deviate completely in the case of the achromatic instrumental evaluation*

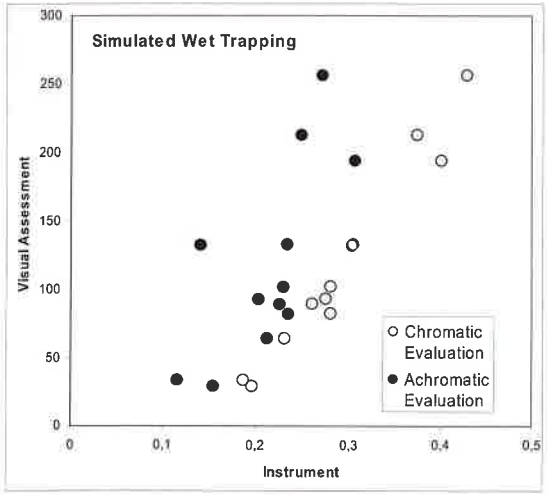


Figure 3:
Simulated Wet-trapping Patches - Mean Visual Assessment versus Instrumental Evaluations. The chromatic measurement model is presented with white circles, and the achromatic model based on L variation is presented with black circles*

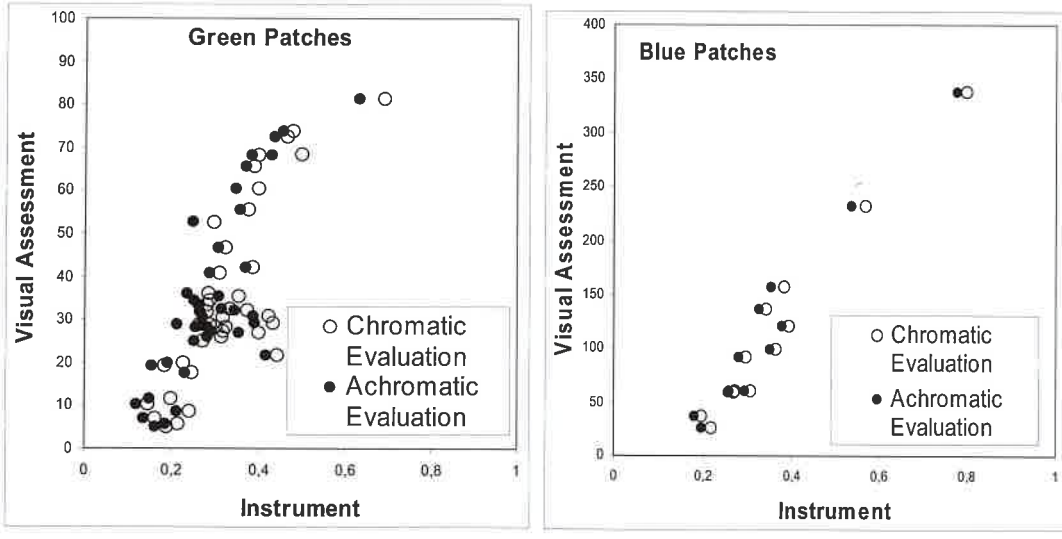


Figure 4: Conventional Test Printing - Mean Visual Assessment versus Instrumental Evaluations. The left hand figure presents the results of the third evaluation and the right hand figure the results of the fourth evaluation (colour mottle measurement model, white circles, and achromatic model, black circles)

5. Discussion

A new model to evaluate colour print mottle based on a generalisation of an achromatic model has been proposed. The performance of the new model has been examined by comparison with the visual evaluation of four different sets of prints. In all cases the agreement between the observers was high.

The first evaluation of the 29 simulated grey samples with different magnitudes of chromatic variation, with and without lightness variations, clearly shows the potential advantage of using a chromatic model instead of an achromatic model. The samples with simulated variation in only the a^* and b^* channels, show a correlation coefficient of 0.06 with the achromatic model but 0.95 with the chromatic model (Figure 2, squares). This suggests that the printed samples of these digitally simulated images indeed have a spatially constant visual lightness character.

Mottle of the kind described by the samples in the first evaluation may also occur in real prints from conventional presses (for example in a 20 + 20 + 20 + 20% CMYK print). Yet, typical colour mottle can probably more often be found in prints where two or more of the four process colours, cyan, magenta, yellow and black, are combined in full tone, or near full tone prints. This situation is considered in the second evaluation where the 12 samples simulating wet trapping were evaluated. The fact that correlations between visual assessment and instrument were in this case 0.98 for the chromatic model and 0.70 for the achromatic model shows that, when mottle was simulated to be chromatic in character, the new model yielded a considerable improvement.

The samples of the third and fourth evaluations were printed in real printing presses. The correlations between the visual assessment and the chromatic and the achromatic mottle evaluation models were here very similar. The immediate conclusion is therefore that little is to be gained by using the chromatic model rather than the achromatic model. However, in both the 3rd and the 4th evaluations, the correlation coefficient between the achromatic model and the new model was virtually 1, i.e. despite the fact that the samples in these two evaluations reveal colour variation, this variation correlates almost perfectly with the lightness variation in the samples. In such a case, a new model can never outperform the old model, no matter how good it may be in its consideration of the colour variations in the prints.

The reason for this correlation with lightness evaluation may be that the intensities of individual process colours in multicolour areas of printed samples generally follow each other, so that the hue stays fairly constant while the lightness varies. This can be the case if the paper shows inhomogeneity in e.g. thickness or roughness leading to spatial variations in dot-gain and density, and hence a mottled appearance. Here an achromatic analysis will be quite satisfactory.

In other cases, the mottle can appear mainly in a late printing station due to successive wetting of the sheet by fountain solution, or in an early print station due to so-called back trapping in later stations. This can lead to mottle which is to a large extent visible as chromatic variations and are underestimated by an achromatic analysis, although they still co-vary heavily with the lightness variations in the print.

Pure chromatic mottle without lightness variations requires two or more inks to co-vary negatively, as was simulated in Evaluation 2, so that the higher intensity in one colour is locally compensated for by a lower intensity in another colour. Wet-trapping phenomena could act in this direction, but the effect is less likely and this is probably the reason why an achromatic analysis of print mottle works well in most cases.

If this explanation accounts for most printing situations and, based on the wide range of prints evaluated here, there are good reasons to believe that this may be so, little will be gained by carrying out colour print mottle evaluation. The variations we visually experience when we, in practice, perceive large-scale

colour variations in prints seem to be almost entirely based on a detection of lightness variations. In addition, one must keep in mind that colour calibration of a scanner is a far more complex and cumbersome operation than achromatic scanner calibration, and it may even fail in some cases [Sokolowski, 2003]. The most rational recommendation must therefore be to not perform colour print mottle evaluation except in cases where it may be expected that the variation can chiefly be said to be in the a^* and b^* coordinates. In such cases Evaluation 1 and 2 decisively demonstrate the inadequacy of an achromatic colour mottle evaluation model, and the merits of using a chromatic model.

6. Conclusions

A new print mottle evaluation model was introduced for the purpose of evaluating colour mottle. The performance of the new evaluation model has in four separate evaluations been compared with the performance of a model based solely on an evaluation of lightness variations. The new model correlated better with visual evaluation than the grey scale model when the variation was mainly chromatic and less in lightness. However, in cases, where the variation in the samples not was of a chromatic character, no difference in performance between the new approach and the approach based solely on lightness variations could be established. Since colour calibration of a scanner is a rather complex and cumbersome operation, which may fail in cases where the samples show e.g. considerable gloss variations, or in cases where metameric issues may influence the calibration [Sokolowski, 2003], we suggest that the instrumental evaluation of colour mottle in practice need only to be performed in cases when chromatic variation can be expected to influence the appearance of the prints considerably. In most cases, our proposed achromatic mottle evaluation approach based on a grey scale image acquisition of the sample, may serve the purpose just as well.

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References

1. Barten, P. G. (1999). *Contrast Sensitivity of the Human Eye and Its Effects on Image Quality*, Bellingham: SPIE Optical Engineering Press
2. Daly, S. (1992). The visible differences predictor: an algorithm for the assessment of image fidelity, *SPIE, 1666*, Human Vision, Visual Processing , and Digital Display III
3. De Valois, R. L. & De Valois, K. K. (1988). *Spatial Vision*, Oxford Psychology Series 14, New York: Oxford University Press
4. Dow, N. W. (1964). Visual Response to Gradients of Varying Colour and Equal Luminance, *Nature, 203*, 215
5. Eidenvall, L., Eriksson, L., Fahlcrantz, C-M., Johansson, P-Å., Klaman, M., Lindberg, S., Norberg, O., Pauler, N., & Westin, P., (2001). *Digital Printing Evaluation 2000/2001*, Stockholm: Framkom, ISSN 1650-687
6. Fahlcrantz, C-M. (2003). Evaluating Systematic Print Mottle, *Journal of Graphic Technology, 1*, 2, 19-28
7. Fahlcrantz, C-M., Johansson, P-Å., & Åslund, P. (2003). The influence of mean reflectance on perceived print mottle, *Journal of Imaging Science & Technology, 47*, 54-59
8. Fisher, R. A. (1924). On a Distribution Yielding the Error Functions of Several Well Known Statistics, *Proceedings of the International Congress of Mathematics, Toronto, 2:* 805-813
9. Guth, S. L. (1997). The Chromatic Contrast Sensitivity Myth, *Proceedings of the 5th Color Imaging Conference*, 23-26

10. Hardeberg, J. Y. (1999). Desktop Scanning to sRGB, *SPIE Proceedings, Color Imaging: Device-Independent Color, 3963*, 47-57
11. Hirose, Y. (1993). Percetual Characteristics of Image Noise in Color Hardcopy Images, *SPIE Vol. 1912*, Color Hard Copy and Graphic Arts II
12. Ishihara, (1984). *Ishihara's test for Colour Blindness, 38 Plates Edition*, Tokyo: Kanehara & Co
13. ISO 13660:2001 (2001). *Information technology - Office equipment - Measurement of image quality attributes for hardcopy output - Binary monochrome text and graphic images*
14. Jacobson, R. E. (1995). An Evaluation of Image Quality Metrics, *The Journal of Photographic Science, 43*, 7-16
15. Jernigan, M. E. & D'Astous, F. (1984). Entropy-based texture analysis in the spatial frequency domain, *IEEE Trans. Pattern Anal. Mach Intell. PAMI-6*, 2, 237-243
16. Johansson, P-Å. (1993). Print mottle evaluation by band-pass image analysis, *Advances in Printing Science and Technology 22*, 403. Pentech Press
17. Jordan, B. D., & Nguyen, N. G. (1986). Specific Perimeter - A Graininess Parameter for Formation and Print-Mottle Textures, *Paperi ja Puu, 67*:6-7, 476-482
18. Kelly, D. H. (1975). Luminous and Chromatic Flickering patterns Have Opposite Effects, *Science, 188*, 371-372
19. Klassen, R. V., & Goodman, N. (2000). Human Chromatic Contrast Contrast Sensitivity Function: Exploration of Dependence on Mean Color, *IS&T 8th Color Imaging Conference, IS&T, Springfield, VA, 2000*
20. Mizes, H. (2000). Graininess of Color Halftones, *IS&Ts NIP16 International Conference on Digital Printing Technologies*
21. Mullen, K. T. (1985). The Contrast Sensitivity of Human Colour Vision to Red-Green and Blue-Yellow Chromatic Gratings, *Journal of Physiology, 359*, 381-400
22. Nguyen, N. G. & Jordan, B. D. (1989). Overview of texture analysis of print and paper, *Paperi ja Puu, 70*(8), 933-944
23. Owens, H. C., Westland, S.. Van de Velde, K., Delabastita, P. , & Jung, J. (2002). Contrast Sensitivity for Lime-Purple and Cyan-Orange Gratings, *IS&T/SID 10th Color Imaging Conference*
24. Patel, A. S., (1965). Spatial Resolution by the Human Visual System. The Effect of Mean Retinal Illuminance, *Journal of the Optical Society of America, 56*, 5
25. Poirson, A. B., & Wandell, B. A. (1993). The appearance of colored patterns: pattern-color separability, *J. Opt. Soc. A., 10*, 2458-2470
26. Sakata, H., & Isono, H. (1977) Chromatic Spatial Frequency Characteristics of Human Visual System (Color Difference Discrimination), *The Journal of ITE of Japan, 31*, 1, 29-35, Jan. 1977
27. Schade, O. H. (1958). On the Quality of Color-Television images and the Perception of Color Detail, *Journal of the Society of Motion Picture and Television Engineers, 67*, 801
28. Sokolowski, K. (2003). *Colour scanner calibration - A Comparison of Different Methods*, Master's Thesis, Stockholm: Royal Institute of Technology, Department of Numerical Analysis and Computing Science
29. Stevens, S. S. (1975). *Psychophysics: Introduction to its perceptual, neural and social prospects*, New York : John Wiley & Sons Inc.
30. Van der Horst J. C., & Bouman, M. A. (1967). On searching for "Mach Band Type" Phenomena in Colour Vision, *Vision Research, 7*, 1027-1029
31. Van der Horst J. C., & Bouman, M. A. (1969). Spatiotemporal Chromaticity Discrimination, *Journal of the Optical Society of America, 59*, 11
32. Watanabe , A., Sakata, H., Isono, H. (1976). Chromatic spatial sine-wave response of the human visual system, *NHK Lab. Note., 198*, 1-10
33. Williams, D., Sekiguchi, N., & Brainard, D. (1993). Color, Contrast Sensitivity, and cone mosaic, *Proc. Natl. Acad. Sci. USA, 90*, 9770-9777
34. Zhang, X. M., & Wandell, B. A. (1996). A spatial extension to CIELAB for digital color image reproduction, *Soc. for Info Disp. Symp .Tech. Digest, 27*, 731-734



A new tool for monitoring the formation of build-up on-line in HSWO

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1. Introduction

On-line information of the press status would provide tools to enhance productivity, runnability and print quality in offset printing. Timely information of the state of the blanket and the interactions between ink, fountain solution and paper would ease the daily life of a printer.

In this work we demonstrate the power of on-line acoustic technique to monitor the status of the printing blanket. The changes in the print quality (e.g. vanishing dots) were easily linkable to the changes in the blanket status.

The acoustic technique has been shown to be an efficient tool for monitoring the film splitting at the printing nip exit [Voltaire, 2006]. It has been shown to be sensitive to variations in ink load, tack, fountain solution content and even paper coating structure (Iwasaki, 1993; Fröberg, 2000). As the the amount of fountain solution in the ink increases, the intensity of the acoustic signal decreases, indicating lower splitting force at nip exits. Likewise the signal decreases when changing from high to low tack ink. Moreover, as shown by Iwasaki et al. already in 1993, the non-image area produces a significantly lower intensity sound than the image area due to weaker cohesive forces. Now based on our data it seems that the same technique can be used to monitor changes in the non-image area.

2. Methods

The printing trials were performed on the 4th printing unit of KCL's Albert Frankenthal A 101 S HSWO press at speed of 6.2 m/s. The press is a double blanket press where the blanket gaps are shifted 180° relative to each other. The trial was run with a model layout (Figure 1b) using two commercial inks: one HSWO [tack: 150 (tack-o-scope, 2min); viscosity: 12.3 (Haake 1000s-1)] and one multipurpose [tack: 110, (tack-o-scope, 2min); viscosity: 9.8 (Haake1000s-1)] ink. Both alcoholic and non-alcoholic fountain solutions were used. Target density for Cyan was D1.5 (GretagMacbeth D196). Both commercial MWC [80g/m^2, PPS-S10 0.95µm, Specular Gloss 64.0 (Tappi 75°)] and pilot coated model LWC-type papers (Table I) were printed.

Acoustic measurement

The microphone comprises of a high level 1/4-inch condenser microcapsule of type 40BE (G.R.A.S ®), with its preamplifier connected to a battery power supply. Digital sampling was performed by a computer coupled to an external Analogue Digital Converter (Data Translation®). The detectable frequency range is 2 Hz-50 kHz, with the upper limit set by the sampling frequency of 100 kHz, and with a maximum tolerable sound level of 168 dB.

Table I: Properties of the LWC-type model papers used in the printing trials

	PAPER1	PAPER2	PAPER3	PAPER4	PAPER5	PAPER7
Grammage (g/m^2)	73	73	76	74	73	75
PPS-10 roughness (μm)	0.90	1.15	0.90	0.85	1.05	0.85
Tack build-up rate[a]	medium	very high	very low	low	high	very low
Surface pore area[c] (%)	8.5	12.1	5.0	9.4	9.9	5.3
Oil absorption (ml/m^2)[b]	2.6	3.2	1.9	2.6	3.5	2.1
Bending, ISO 2493	28	31	39	26	27	33

[a] Tack-on-paper build-up rate with HSWO ink measured with ISIT.
[b] Transferred amount of mineral oil during 10 ms with KCL nozzle applicator.
[c] Calculated with image analysis from HR-SEM cross sections (Pöhler, 2006).

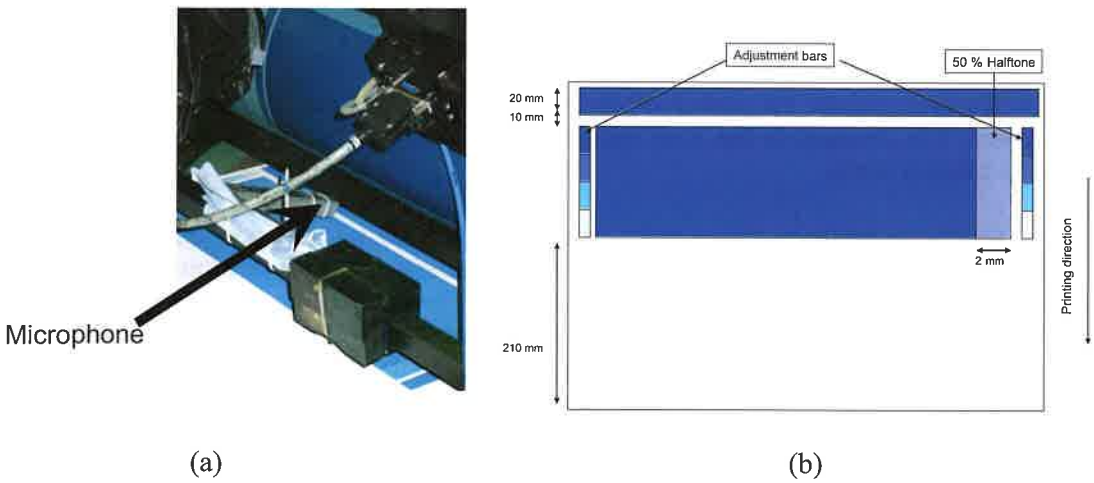


Figure 1: (a) Photograph of the microphone positioned at the nip exit on the upper printing unit during printing and (b) layout used in the trial

The microphone was fixed on the upper side of the printing unit (Figure 1a). In order to maximise the film splitting sound, the microphone was oriented towards the nip exit. Thus, the microphone detected the signal from both image and non-image areas (Figure 2). FFT analysis was performed to obtain the power spectral density (PSD) from the acoustic data. The signal was time filtered in order to separate the image and non-image area behaviour (Figure 2).

3. Results and discussion

One current quality complaint in HSWO printing is the accumulation of build-up on the non-image area of the blanket, which leads to e.g. decreasing dot size, so called vanishing dots. These accumulations are visible to the naked eye after several thounsands of copies. Since the acoustic measurement proved out to be sensitive to small changes in the earlier work, we decided to test wheather it was able to monitor the changes on the non-image area as well. Therefore, an earlier reported data was reanalysed to split the

acoustic signal into sections corresponding to different regions in the print layout. After splitting the signal (see Figure 4) it can be noted that the intensity of sound from the non-image area is changing as a function of the amount of copies printed even though the signal on the image area (reference point paper 1 in the beginning and end of the reel) stay constant. Moreover, the intensity of this phenomenon seemed to be sensitive to the ink type.

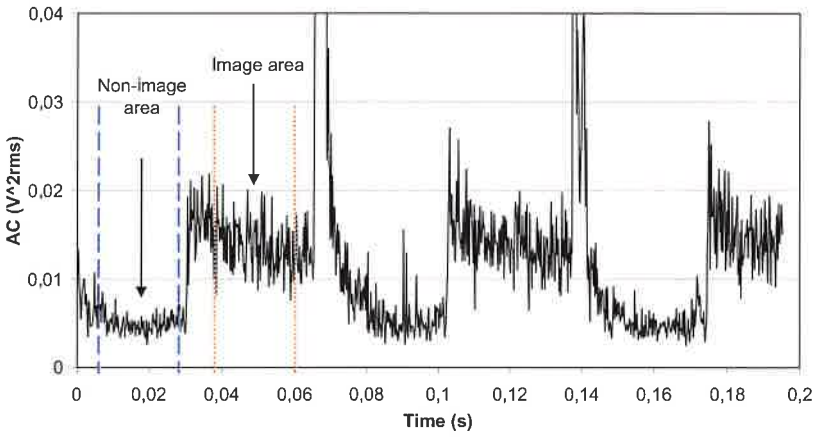
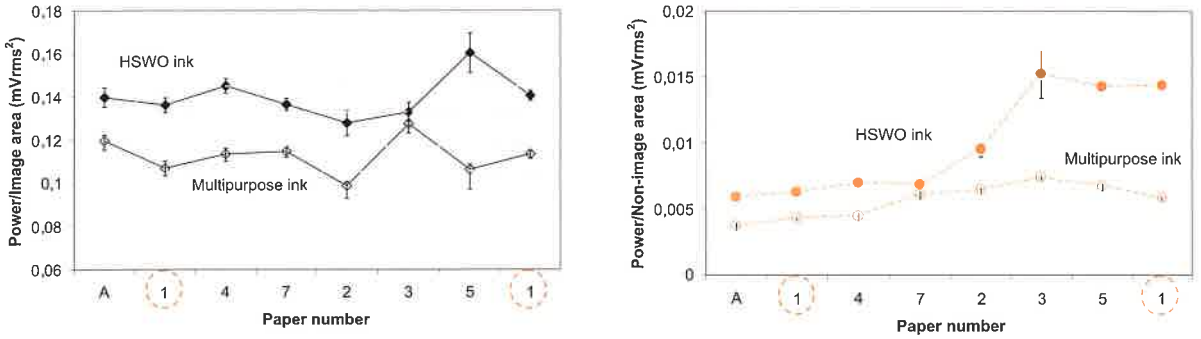


Figure 2: Illustration of identification of non-image and image areas from the signal for the time filtering



(a) *(b)*

Figure 4: Average acoustic powers for two trial runs investigating the effects of two HSWO cyan inks differing in tack: (a) ink-paper contact and (b) blanket-paper contact. The error bars give the standard deviation of 5 time records at each trial point; in all cases the signal is high-pass filtered at 8 kHz. Red circles indicate the reference trial points at the beginning and end of the test point reel. Increase in the signal level of the reference points (paper 1, circuled) is assumed to be caused by accumulation on blanket. Non-alcoholic fountain solution was used

To get further evidence of the usability of the acoustic technique to detect non-image area accumulation, acoustic signals on image and non-image areas were collected at KCL's heatset press with the model layout. Three press settings were used: i) normal conditions, ii) increased ink density (+ 0.2D) and iii) increased ink density with increased FS feed.

Figure 5 depicts how accumulation on blanket affects the acoustic signal. The signals differentiate clearly between the image and non-image area. Moreover, when comparing the non-image area signals of a clean blanket (after wash) with the signal from a blanket having accumulation (at the end of the run) we see that the non-image area signal has increased. Infact, it more resembles that of the image area.

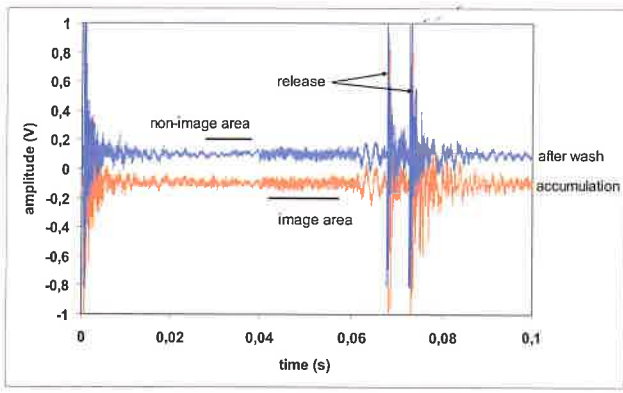


Figure 5: Acoustic measurement signals when there is accumulation on the blanket and after wash. The signals have been shifted in the vertical direction for illustration purposes. Black lines denote the non-image and image area signals, which were used in the analysis

The time dependency of the acoustic signal i.e. how it changes during a trial point is seen in Figure 6 for non-image (squares) and image areas (triangles). The non-image area power clearly monitors the accumulation build-up amount (change in signal about 10 - 20 min after start-up). The image area signal is less affected by accumulation. Note that the printing conditions have a major effect on accumulation rate (increased print density accelerates, increased FS feed retards) and that blanket washing brings the power to the original level.

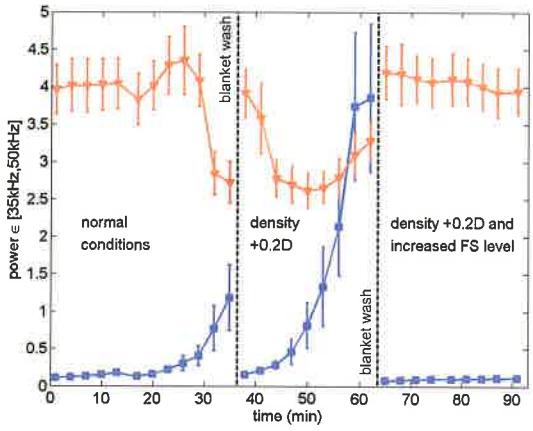


Figure 6: Acoustic power from the non-image (squares) and image area (triangles) when frequency filtering is used. The three settings are i) normal conditions (0 to 37 minutes), ii) density + 0.2D (37 to 64 minutes), and iii) density + 0.2D and increased FS level (64 to 92minutes). Black dotted lines show when the blankets were washed. HSWO ink and alcoholic fountain solution were used in this trial

It was hypothesized that acoustic measurement might even detect accumulation before it affects print quality. To verify this assumption, the corresponding dot gain values from 50% halftone area were measured. Figure 8 shows that in the worst case (high print density) acoustic measurement seemed to correspond with the worsening of print quality in the 50% halftone area.

4. Conclusions

An increase in the acoustic signal in the non-image area was linked to the formation of accumulations on the printing blanket. This phenomena is repeatable, washing of the blankets brings the signal level

back to the original value from which it gradually increases again as the run proceeds. Signal level on the non-image area is typical for a given set of process conditions and materials, especially the feed level of fountain solution and ink properties play a critical role. The increase in FS level on blanket retards the formation of accumulations. Thus, on-line acoustic measurement can be used to monitor the state of the blanket and adjust FS feed to prevent build-up formation. Another way to use acoustic measurement is to use it as a part of the exisiting process control system to optimize the blanket washing cycles, which greatly reduces waste and improves print quality. This helps the printer to keep constant print quality during print runs.

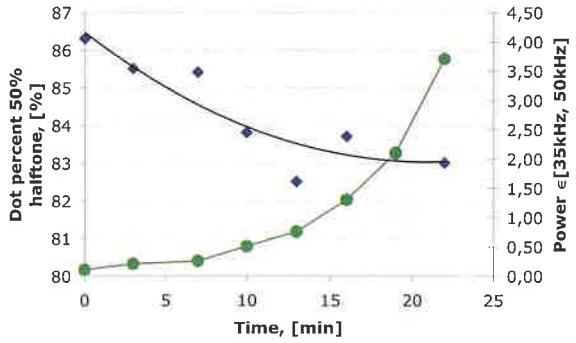


Figure 8: Correlation between changes in the average power and dot percent during printing with increased print density and fountain solution feed. HSWO ink and alcoholic fountain solution were used in these trial points

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References

1. Fröberg, J. C., Voltaire, J., Sundin, M. and Tiberg, F., 2000, *Effect of Ink-Fountain Balance on Ink-Tack Development, TAPPI International Printing anf Graphic Arts Conference, October 2-4 2000, Savannah USA*
2. Iwasaki Y., Takahashi, Y., Yukawa, H. And Okada, H., 1993, *Study on Paper Releasing*
3. *Phenomena in Offset Printing by Acoustic Approach, TAGA Proc., pp. 238-253*
4. Pöhler, T., Juvonen, K. and Sneck, A., 2006, *Coating Layer Microstructure and Location of Binder*
5. *Results from SEM Analysis, 9th TAPPI Advanced Coating Fundamentals Symposium, February 8-10, Turku, pp. 89-99*
6. Voltaire, J., 2006, *Ink Film Slitting acoustics in offset printing, Doctoral Thesis, Stckholm, Sweden, 54p*





5

Color reproduction

Colorimetric device characterization for accurate color image acquisition

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Abstract

We perform the complete characterization of an image acquisition system, using a model-based approach. The objective is to map the recorded device signals to the device-independent color representations CIEXYZ and CIELAB, but also to reconstruct spectral reflectance. The image acquisition system has been specially designed to capture macro images, with the main purpose to study prints and substrates. Besides ordinary RGB-images, it is also possible to capture multispectral images, using a set of 7 more narrow-band filters.

The spectral sensitivity for the CCD-camera is estimated by relating the camera response to measured spectral reflectance for a set of carefully selected NCS colors, using least-squares regression. The principal eigenvector method is used to reduce the noise sensitivity, and *a priori* information on the camera sensitivity function, such as smoothness, positive-valued and uni-modality, is incorporated as constraints. Once the spectral sensitivity for the camera is estimated, the characterization function is inverted to use the recorded camera response to reconstruct spectral reflectance. The results show that using 7-channel images, compared to RGB-images, dramatically increases the accuracy of the inversion. The best results in terms of spectral reconstruction error were obtained by representing the spectral reflectance as linear combinations of a set of basis functions, representing real spectral reflectance. In terms of CIE 1976 color difference ΔE_{ab}, the results were equally good when using the basic pseudo inverse approach, which indicates the accuracy of derived characterization function.

1. Introduction

With the aim to investigate and characterize different properties associated with color printing, we study prints and substrates on a micro-scale level. For this purpose, an image acquisition system has been constructed, specially designed to capture multispectral images with high resolution. With the focus on studies of color reproduction properties, high demands are placed on the images acquired. Beside precision and repeatability, there is also a need to map the acquired, device dependent data, into device-independent representations with high accuracy. We aim to derive mappings to the device-independent color spaces CIEXYZ and CIELAB, but also ways to reconstruct the spectral reflectance of an object, using the recorded device data. Combining colorimetric accuracy, with the spatial resolution of the acquired images, will allow for color measurements in every pixel of the high-resolution images.

To obtain device independent image data of high accuracy, it is necessary to understand the spectral characteristics of all the ingoing components of the image acquisition system, an understanding achieved through the process of device characterization. The forward characterization function describes the color characteristics of the system, and corresponds to the mapping from device-independent color representations to the device-dependent signals recorded. The inverse characterization function compensates for the device characteristics and transforms the recorded device signals into device-independent colorimetric representations. The focus in this study is to derive a complete characterization of the image acquisition system, using a model-based approach. Model-based characterization uses physical models that describe all the components involved in the image acquisition process.

To derive the forward characterization function, spectral measurements are made on the light source and color filters. The spectral sensitivity of the camera, which cannot be derived by direct measurements, is estimated using training a set of color samples with known spectral reflectance. By relating the camera response to the spectral reflectance, the camera sensitivity function is obtained using least-squares regression. To reduce the noise sensitivity in the estimation, we use the principal eigenvector method. We investigate how *a priori* information on properties of the camera sensitivity function (such as smoothness, positive-valued and uni-modality) can be used to improve the accuracy of the estimation. Once the forward characterization function is derived, it can be inverted to derive device independent data from the camera response. We evaluate the results in terms of the RMS difference between reconstructed and measured spectral reflectance, the Euclidian distance in CIEXYZ color space and the CIE 1976 color difference ΔE_{ab}.

2. The image acquisition system

The image acquisition system has been specially designed for acquiring macro images of prints and substrates, with the main purpose of studying micro-scale properties of prints. The images are captured using the monochrome CCD camera Pixelfly HiRes 'ICX205AL', from PCO imaging. The CCD camera, specially designed for scientific imaging, has a resolution of 1360 x 1024 pixels and 12 bit dynamic range. The CCD is of grade 0, which means no defective pixels, and uses digital temperature compensation to reduce noise. The optics used is the APO-CPN 2.8/40 macro system from Schneider Kreuznach. The macro system consists of enlarging lenses, various extension rings and a camera C-Mount adapter, and is designed for macro images in scientific applications.

The substrate is placed on a table, which allows for controlled translation in two directions, and rotation around the optical axis. The illumination is provided using a tungsten halogen lamp and optical fibers, which offers an adjustable and well-controlled angle of incidence, as well as the possibility of using a backlight set-up. Color images are captured sequentially, using filters mounted in a filter wheel in front of the light source. By using this color sequential method, there is no need for any interpolation or de-mosaicing scheme, as the case is in conventional digital cameras. Besides the ordinary RGB-filters, the filter wheel also contains CMY-filters and a set of neutral density filters of various optical density. Furthermore, a set of 7 interference filters allows for the acquisition of multi-channel images. The interference filters, selected with the intention of covering all parts of the visible spectrum with equally spaced pass bands, have center wavelengths, *CWL*, of 400 nm, 450 nm, 500 nm, 550 nm, 600 nm, 650 nm and 700 nm. The *FWHM* (Full Width-Half Maximum) is 80 nm, except for the filter with 400 nm *CWL*, which has 50 nm *FWHM*.

3. Device characterization

Background

There are generally two different approaches for device characterization: model-based and empirical. Model-based characterization uses physical models to describe the process by which the device captures color. In empirical characterization, the mapping is made using a *black box* approach, i.e. without explicitly modeling the device characteristics. By correlating the device response of a large number of test colors to colorimetric values, the characterization function is derived using least squares regression. A common approach is to use polynomial regression from camera RGB values to CIEXYZ [see for example Hong & Lou, 2000]. If the final aim is to derive data in CIELAB color space, it is preferable to convert the camera values directly to CIELAB, than via CIEXYZ [Hardeberg, 2001]. This is because the RMS error minimized in the regression is better correlated to visual color difference in CIELAB than in CIEXYZ color space.

Generally, empirical approaches require a large number of measurements, and the characterization will be optimized only for a specific set of conditions, e.g. the illuminant, the media and the colorant. Once the conditions changes, the characterization should be re-derived to obtain the highest accuracy [see for example Andersson et al, 2003]. This dependence on media and colorant is due to the phenomenon of eye-camera metamerism [Hong & Lou 2000]. For a given set of conditions, however, better results can generally be obtained using empirical techniques than with model based.

We adopt the concept of model-based characterization, because it is more general and allow for measurements on arbitrary combinations of media and colorant. Furthermore, using the model-based characterization gives the possibility not only to convert the images into device-independent color spaces, but also to reconstruct the spectral reflectance of objects. Spectral reflectance is the most accurate representation of the color of an object, and is completely independent of the characteristics of the image acquisition system. From the spectral reflectance data it is possible to convert the data to any color space, as well as rendering the image under different illumination conditions.

Device calibration

Since the accuracy of the characterization will always be limited by the stability and uniformity of a given device, the characterization procedure has been preceded by a thorough calibration of the system. All the components have been controlled with respect to linearity, temporal stability and spatial uniformity. Calibration procedures have been developed, to ensure stability and repeatability, and maintaining the system in a fixed, known state.

Forward characterization

We derive the forward characterization function using a model-based approach, i.e. by modeling the physical characteristics of all the components involved in the image acquisition process. These include: the light source, the color filters, the optics and the CCD-camera. *Equation 1* gives the linear model of the image acquisition system. The camera response, c_k, for the k:th channel is, for each pixel, given by:

$$c_k = \int_{\lambda \in V} L(\lambda) F_k(\lambda) R(\lambda) O(\lambda) QE(\lambda) d\lambda + \varepsilon_k \tag{1}$$

where $L(\lambda)$ is the spectral irradiance of the illumination,
$F_k(\lambda)$ is the spectral transmission of filter k,
$R(\lambda)$ is the spectral reflectance of the object,
$O(\lambda)$ is the spectral transmission of the optics,
$QE(\lambda)$ is the spectral quantum efficiency for the CCD sensor,
ε_k is the measurement noise for channel k, and
V is the spectral sensitivity region of the device.

For the linear model according to *Equation 1* to be valid, requires that the camera response is linear with respect to the incident light, which has previously been verified. The irradiance of the illumination together with the spectral transmission of filter k, and the object reflectance, gives the incoming radiance to the CCD sensor, $I_k(\lambda)$, as:

$$I_k(\lambda) = L(\lambda) F_k(\lambda) R(\lambda) \tag{2}$$

Since it is not straightforward, nor necessary, to separate the spectral transmission of the optics from the spectral quantum efficiency of the CCD camera, we combine them together into the camera spectral sensitivity function, $S(\lambda)$, as:

$$S(\lambda) = O(\lambda)QE(\lambda) \tag{3}$$

Equation 1 then reduces to:

$$c_k = \int_{\lambda \in V} I_k(\lambda) S(\lambda) d\lambda + \varepsilon_k \tag{4}$$

The spectral characteristics of the illumination $L(\lambda)$ and the transmittance of the filters, $F_k(\lambda)$, can be derived by direct measurements, using a spectrophotometer. However, to obtain the spectral sensitivity of the camera, $S(\lambda)$, is not as straightforward, since direct measurements are not possible.

Camera sensitivity estimation

Basically, there exist two different classes of methods to estimate the spectral sensitivity function of a CCD-camera. The first class of methods is based on direct recording of the device response to monochromatic light, using a monochromator. The second approach is to record the devices response to a set of samples of known spectral reflectance and to use least-squares regression to estimate the spectral sensitivity function. The second approach is adopted in this study.

If the spectral data of P samples are collected into an N x P matrix $\mathbf{I}$, with the columns corresponding to spectral measurements of each sample, sampled at wavelengths $\lambda_1, \ldots, \lambda_N$ and the camera response values are collected into a P-vector $\mathbf{c}$, then the linear relationship is given by (compare to *equation 4)*:

$$\mathbf{c} = \mathbf{I}^t \cdot \mathbf{s} + \varepsilon \tag{5}$$

and the optimal spectral sensitivity estimation, $\hat{\mathbf{s}}$, is the one that minimizes the RMS distance:

$$\left\| \mathbf{I}^t \cdot \hat{\mathbf{s}} - \mathbf{c}_i \right\|^2 \tag{6}$$

which is given by:

$$\hat{\mathbf{s}} = pinv(\mathbf{I}^t) \cdot \mathbf{c} \tag{7}$$

where pinv ($\mathbf{I}^t$) denotes the Moore-Penrose pseudo-inverse of $\mathbf{I}^t$. In the absence of noise and with rank ($\mathbf{I}$) $\geq N$ (i.e. with $P \geq N$), the solution is exact up to the working precision (Hardeberg, 2001). Under real conditions, however, the assumption of noise-free image acquisition is not realistic and the pseudo-inverse solution without additional constraints is not often useful.

The problem with the pseudo-inverse (PI) method is that, although the spectral reflectance data in $\mathbf{I}$ is N-dimensional, the true dimensionality of the spectral samples is usually significantly less [Balasubramaninan, 2003]. With the *Principal Eigenvector* (PE) method, the noise sensitivity of the system inversion is reduced, by including only the singular vectors corresponding to the most significant singular values in the spectral autocorrelation function of the training samples [refer to Hardeberg, 2001, for details]. The number of principal eigenvectors included in the inversion controls

the degree of freedom of the camera sensitivity function and should be adjusted depending on the noise level. Eigenvectors of small singular values will amplify the noise in the estimation, since the estimation variance grows inversely with the singular values squared [DiCarlo et al, 2004].

One drawback with the PI and PE methods is that they do not exploit *a priori* information of the known nature of the spectral sensitivity function of an imaging device [Balasubramaninan, 2003]. For example, the spectral sensitivity must always be a positive-valued function, which is usually uni-modal and smooth. These assumptions on the nature of the spectral sensitivity function can be incorporated into the regression as a set of linear constraints, to improve the accuracy of the estimate [Finlayson & Hubel, 1998].

A positive sensitivity function estimate is ensured by the linear constraint:

$$\hat{\mathbf{s}}(\lambda_n) \geq 0, \; for\, n = 1...N \tag{8}$$

The modality refers to the number of peaks in the spectral sensitivity function. Many sensor functions appear to be uni-modal, i.e. having only one single peak, a constraint expressed as:

$$\begin{aligned} \hat{\mathbf{s}}(\lambda_{n+1}) &\geq \hat{\mathbf{s}}(\lambda_n), \; n = 1,...,m-1 \\ \hat{\mathbf{s}}(\lambda_{n+1}) &\leq \hat{\mathbf{s}}(\lambda_n), \; n = m,...,N \end{aligned} \tag{9}$$

When the function only contains the detector sensitivity (i.e. the illuminant is not included) it is generally smooth. This makes it possible to represent the sensitivity function as linear combinations of a set of band-limited basis functions, such as the Fourier basis. We represent the spectral sensitivity function as linear combinations of sine and cosine functions, as:

$$\hat{\mathbf{s}} = \sigma_1 B_1 + \sigma_2 B_2 + ... + \sigma_l B_l \tag{10}$$

where $B_1 = k$, $B_2 = \sin(x)$, $B_3 = \cos(x)$, $B_4 = \sin(2x)$, ...l is the number of basis functions, controlling how smooth the estimated spectral sensitivity function will be, $x = (\lambda - \lambda_{min})\pi/c$ and c is the cycle length used.

An alternative method to ensure a smooth spectral sensitivity function is to add a regularization term, which approximates the second derivative, to the objective function to be minimized [Barnard & Funt, 2002].

Other approaches to derive the camera sensitivity function, not investigated in this study, include the use of neural networks and the method *projection onto convex sets*, (POCS). A set theoretical formulation is used to express the constraints as convex sets, and then generate the sensitivity function by the iterative technique projection onto convex sets [Sharma & Trussel, 1996].

Inverse characterization

After deriving the forward characterization for all the components in the image acquisition system, the known spectral characteristics of the system can be represented by a *spectral transfer function* [Farell, et al, 1999]. The spectral transfer function, $W_k(\lambda)$, describes the spectral characteristics for each channel k, including the illuminant, the camera sensitivity and the filter transmittance, as:

$$W_k(\lambda) = L(\lambda)F_k(\lambda)S(\lambda) \tag{11}$$

Let **W** be the (N x K) matrix where each column describes the spectral transfer function for channel k. Then the camera response $\mathbf{c}_k$ to for a sample with spectral reflectance **r** is given by:

$$\mathbf{c}_k = \mathbf{W}^t \cdot \mathbf{r} \tag{12}$$

When inverting the model, we seek the reconstruction matrix **M** that best reconstructs the spectral reflectance, **ř**, from the camera response, as:

$$\tilde{\mathbf{r}}_k = \mathbf{M} \cdot \mathbf{c}_k \tag{13}$$

The most straightforward approach is to simply invert *Equation 12*, using the pseudo-inverse approach, which gives the reconstruction operator:

$$\mathbf{M}_0 = pinv(\mathbf{W}^t) \tag{14}$$

where pinv($\mathbf{W}^t$) denotes pseudo-inverse of $\mathbf{W}^t$. Generally, the pseudo-inverse reconstruction is sensitive to noise and is not always useful in practical situations. Further more, this method minimizes the Euclidian distance in the camera response domain (i.e. between $\mathbf{c}_k$ and $\mathbf{W}^t$ **R**), which not necessary means that the reconstructed spectra will be close to the real spectra [Hardeberg, 2001].

Another approach is to instead seek to minimize the Euclidian distance between the reconstructed spectrum and the original spectrum. The *a priori* knowledge that the spectral reflectances of typical objects are smooth is exploited. We can assume that the reflectance can be represented as a linear combination of a set of smooth basis functions, $\mathbf{B} = [\mathbf{b}_1, \mathbf{b}_2 \ldots \mathbf{b}_p]$. This gives the reconstruction operator $\mathbf{M}_1$, which minimizes the RMS spectral difference of the reconstructed spectrum, as [refer to Hardeberg, 2001, for details]:

$$\mathbf{M}_1 = \mathbf{B}\mathbf{B}^t\mathbf{W}\left(\mathbf{W}^t\mathbf{B}\mathbf{B}^t\mathbf{W}\right)^{-1} \tag{15}$$

The base functions, **B**, can consist of a set of real, measured spectral reflectances, which then should be representative to the reflectance of samples that is likely to be encountered in the image acquisition system. To reduce the noise sensitivity, the PE-method can be applied to the set of spectral basis, as described earlier. An alternative approach is to simply let **B** consist of a set of Fourier basis functions.

4. Experimental results

Spectral characteristics

The spectral characteristics of the illuminant $L(\lambda)$ and the spectral transmission of the filters, $F_k(\lambda)$ has been derived by direct measurements, see Figure 1. The spectral measurements are performed using the spectrophotometer PR-650 SpectraScan, and are made against a reference white reflectance standard. The spectral data obtained is in the interval 380-780nm sampled at 4 nm intervals, giving N = 101. The spectrophotometer is placed in the same optical axis as the CCD-camera, and the illumination is arranged in the recommended 45°/0° measurement geometry.

Camera sensitivity estimation

The test target of color patches plays an important role in the spectral sensitivity estimation. The large magnification of the macro system makes it difficult to use printed color patches, since the halftone

pattern is visible in the images. We have chosen to use color patches from NCS, created using different pigments, for test targets. A method for selecting those reflectance samples, which are most significant for the estimation of spectral sensitivity, proposed in [Hardeberg, 2001], has been adopted. The 25 NCS colors with most significant spectral reflectance, under the given illuminant, have been selected, out from the 365 colors from the following pages from the NCS Color atlas 96: *B*, *B50G*, *G*, *G50Y*, *Y*, *Y50R*, *R R50B* and *N*.

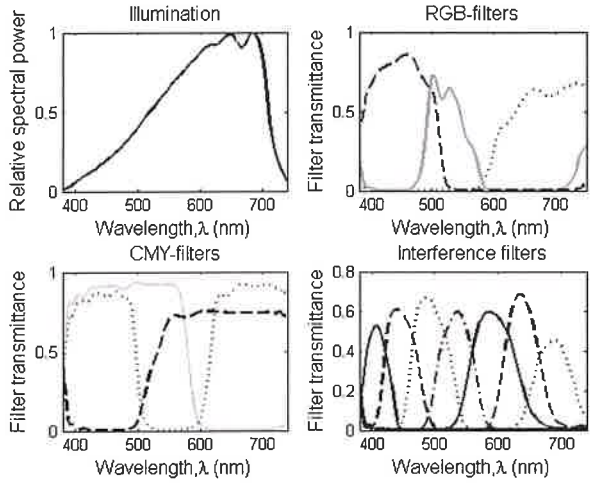


Figure 1:
The measured spectral power distribution for the illuminant and the filter transmittance of the color filters

For the 25 reference color patches, both spectral reflectance data and the corresponding camera response values have been acquired using identical conditions. To reduce random noise, all data are based on 5 measurements, captured at slightly different location. Images are captured using the RGB, CMY and interference filters, i.e. using 14 channels for each color patch, giving $P = 360$. The exposure times have been individual calibrated for each channel to yield maximum digital signal without causing signal clipping, that way optimizing the signal to noise ratio. Before computing the mean value from the images, they are corrected for dark current and electronic gain.

Since the real camera sensitivity function is unknown, the estimated camera sensitivity functions are evaluated by using the forward characterization model to predict camera response values, $\hat{\mathbf{c}}$, from the known spectral data, as:

$$\hat{\mathbf{c}} = \mathbf{I}^{t} \cdot \hat{\mathbf{s}} \tag{16}$$

where $\mathbf{I}$ is the N x P matrix of spectral measurements for each color sample, and $\hat{\mathbf{s}}$ is the estimated camera sensitivity. 20 NCS color patches, independent of the ones used for the estimation, has been used for evaluation, including the data for all 14-color channels, giving. $P = 280$. The predicted camera response values, $\hat{\mathbf{c}}$, are then compared with the real, measured camera responses, $\mathbf{c}$, to compute the estimation errors.

The manufacturers of the optics and CCD camera respectively, have provided data representing 'typical' curves for the CCD quantum efficiency and spectral transmittance of the optics. The manufacturer data have been combined together into the camera sensitivity function according to *Equation 3*. The estimation errors when using the manufacturer data to predict the camera response values from real spectral data was relatively small see Table I. Considering the good quality of the data provided by the manufacturers, the assumption was made that the real function should be similar, i.e. it is most likely both uni-modal and smooth.

The estimated camera sensitivity function considered as the best candidate (see Figure 2) was the result from minimizing the absolute RMS error, using the PE-method with positivity constraint, and Fourier basis to ensure smoothness. The cycle length and number of base functions were not fixed, to allow for more possible candidates of the sensitivity function. Out from the large set of estimations, the best candidate was selected by using the relative RMS error and the uni-modality requirement as selection criterion. It was found that the uni-modality worked better as a criterion for selection, compared to when it was incorporated as a constraint in the regression, which produced unrealistic, flat curves. A note is that there were many estimated camera sensitivity functions that outperformed the selected function in terms of RMS error. They were, however, always less constrained, and could not be considered as realistic candidates for the camera sensitivity function, due to facts such as negative values, non-smoothness and multi-modality. Clearly, there must always be a trade-of between the objective criterion minimized, and what can be considered as a realistic function.

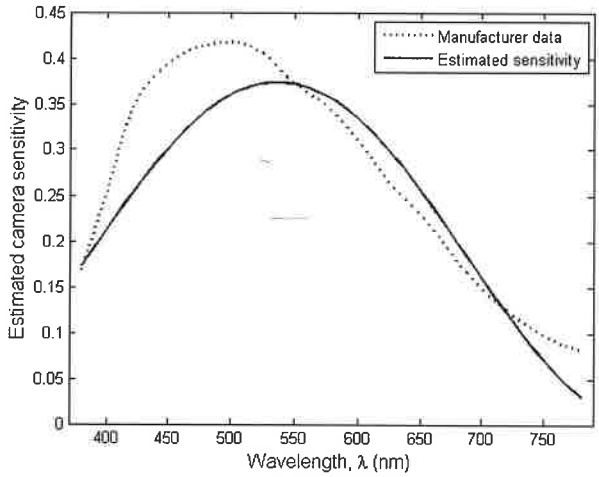


Figure 2:
The estimated camera sensitivity function compared to the sensitivity derived from manufacturer data

The estimation errors for the estimated camera sensitivity function are compared to the manufacturer data in Table I. Clearly, the estimation offers an improvement over the manufacturer data. With a mean estimation error of 0.007 and a maximum error of 0.097 (for camera values in the range [0, 1]), the camera sensitivity estimation must be considered as successful.

Table I: The resulting estimation errors for the estimated camera sensitivity function compared to the data provided by the manufacturer

	Manufacturer data	*Estimated sensitivity*
RMS-error	$5.45\ 10^{-4}$	$2.26\ 10^{-4}$
Relative RMS-error	0.038	0.0149
Mean error	0.012	0.0070
Max error	0.130	0.0965

Reconstructing spectral and colorimetric data

After deriving the camera sensitivity function, all the components of the systems spectral transfer function according to *Equation 11* are known. We have performed experiments on inverting the model according to *Equation 14-15* to derive spectral reflectance from the recorded camera response values, for 25 different

NCS colors. Spectral reflectance data is reconstructed using the operators $\mathbf{M}_0$ and $\mathbf{M}_1$ according to *Equation 14 - 15*, using both multi-channel images (from the 7 interference filters) and ordinary RGB images. As basis functions, **B**, we evaluate both Fourier basis and spectral basis. For the Fourier basis, the best result was obtained using 5 base functions, which is used in all of the following results.

For the spectral basis we use the database made available by NCS, the *Natural Color System*, containing 1750 different colors. The spectral reflectance data available from NCS is in the range 400:10:700 nm, and has been cubically interpolated to 4nm intervals to comply with our spectral measurements. For the results to be directly comparable, the spectral data has been cropped to the range 400:700 nm even for the PI-method and Fourier basis. A note is that, due to the very low energy available from the illuminant at the two ends of the visible spectrum, the data outside this interval is very noisy noise and the reconstruction error decreases significantly by excluding data outside this range.

Even though being generally accurate, it was found that the camera sensitivity function tends to overestimate the response for some parts of the spectrum and underestimate others. This is encountered for by introducing channel dependent normalization factors for the multi-channel images. The normalization factors improved the results when using the multi-channel approach, but had no effect for the RGB images.

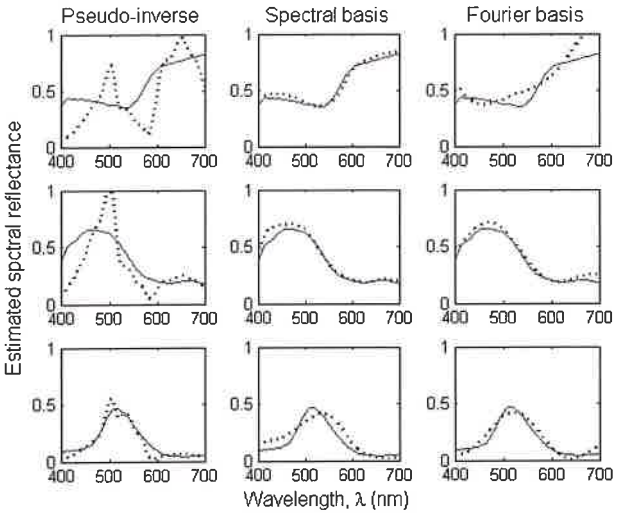


Figure 3:
Reconstructed spectral reflectance using RGB-images. Full lines are measured reflectance spectra, broken lines are reconstructed

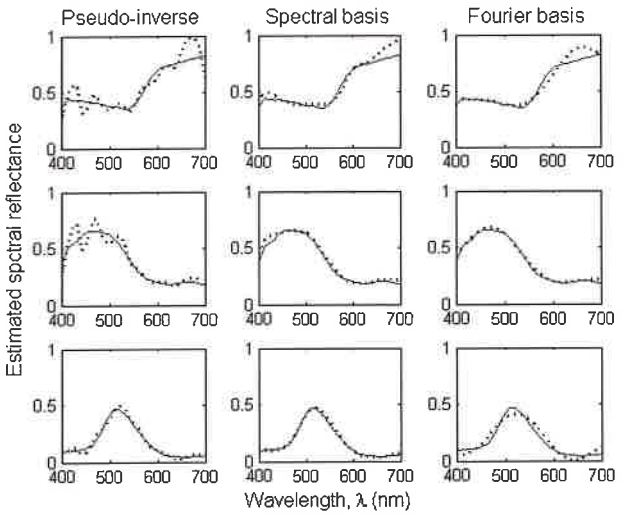


Figure 4:
Reconstructed spectral reflectance using multi-channel images. Full lines are measured reflectance spectra, broken lines are reconstructed

We evaluate the reconstructed spectra, using the RMS spectral reconstruction error, i.e. the Euclidian distance in spectral reflectance space between the original and reconstructed spectra. The mean and maximal RMS difference for the 25 reference colors is given in Table II. The Euclidian difference in CIEXYZ color space and the CIE 1976 color difference ΔE_{ab} are also presented. The colorimetric differences have been computed under the D65 illuminant, using standard formulae [Hunt, 1998]. Figure 3 shows the reconstructed spectral reflectance from RGB-images, using the 3 NCS colors S1030R, S1050B, S1565G, as examples. The corresponding results using multi-channel images are given in *Figure 4.*

Table II: Mean and maximal reconstruction errors, expressed in RMS difference in spectral space, Euclidian distance in CIEXYZ space and ΔE_{ab} in CIELAB color space

Channels / *Method*	*Pseudo-inverse*	*RGB Spectral basis*	*Fourier basis*	*Pseudo-inverse*	*Multi Spectral basis*	*Fourier basis*
RMS max	0.0706	0.0041	0.0392	0.0092	0.0039	0.0040
RMS mean	0.0230	0.0014	0.0120	0.0030	0.0012	0.0011
ΔXYZ mean	13.1	3.98	8.75	1.10	1.33	1.29
ΔXYZ max	23.4	10.4	14.9	3.99	4.81	3.74
ΔE_{ab} mean	15.0	4.17	8.31	1.53	1.82	2.11
ΔE_{ab} max	24.4	15.9	18.7	4.36	4.22	7.27

For the RGB images, the pseudo-inverse solution is virtually useless (Figure 3). The results improve when using base functions, with the best results obtained for spectral basis. However, a mean ΔE_{ab} difference of 4 and a maximal of 14 are to high for the method to be considered as useful for colorimetric measurements. When instead using the 7-channel images, the results improve dramatically (Figure 4). Spectral basis and Fourier basis gives equivalent results in terms of the RMS spectral difference, while the ΔE difference is lower using spectral basis. The pseudo-inverse solution is noisy and has higher spectral RMS difference. However, besides from the noisy fluctuations, the general shapes of the reconstructed spectra follow the real spectra well. This result in colorimetric differences being comparable to the result achieved for the spectral basis and even slightly better. This good performance for the pseudo-inverse solution was somewhat surprising and clearly illustrates the accuracy of the derived characterization model. The result is also a reminder that good performances in terms of spectral RMS difference do not necessary means the best performance in a conceptually meaningful color representation such as CIELAB. A note is that the result was not improved by combining the interference filters with RGB or CMY-filters, thus providing more than 7 channels.

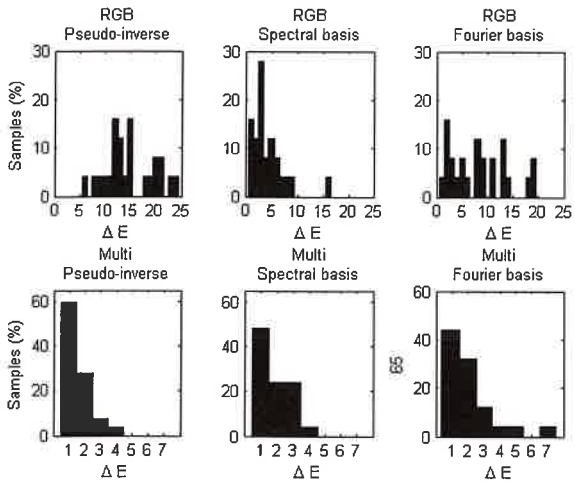


Figure 5:
Histograms of the ΔE_{ab} errors between real and reconstructed reflectance, under the D65 illuminant

Histograms of the distribution of the ΔE errors for the different methods are given in Figure 5. This clearly illustrates the improvement when increasing the number of channels from 3 to 7. For the pseudo-inverse and spectral basis methods, using multi channel images, 96% of the samples give $\Delta E_{ab} < 3$, which is commonly used as a rule of thumb for what is noticeable. With a mean color difference of 1.5 ΔE_{ab} and the maximum 4.4 ΔE_{ab}, the accuracy of the model must be considered as good. A note is that the PI-method, which produces the best result in terms of ΔE_{ab}, is very general, since no basis functions is used, which should be representative for real data. However, if the aim is to reconstruct spectral data, not just colorimetric, it is preferable to use the methods using base functions. The best overall performance is given by the method using spectral basis.

5. Conclusions and future work

In this work we have derived the complete characterization function for an image acquisition system, using a model-based approach. The motivation was to derive accurate mappings from device dependent data to the colorimetric representations CIEXYZ and CIELAB, but also to reconstruct spectral reflectance. The spectral sensitivity of the CCD camera, which is the only component in the imaging chain that could not be characterized by direct measurements, was estimated using a set of 25 carefully selected NCS colors. By relating the measured spectral reflectance of the reference colors to the resulting camera response, the sensitivity function was derived using least squares regression. The principle eigenvector method was used to reduce the noise sensitivity, and *a priori* knowledge on the nature of camera sensitivity, such as positive valued, smoothness and uni-modality, was used as constraints in the regression. When the estimated camera sensitivity function was used to predict the response for a set of test colors, independent from the ones used in the estimation, the mean estimation error was 0.007 and the maximal error 0.097 (for camera values in the range [0, 1]).

After deriving the spectral sensitivity for the camera, the characterization function has been inverted to use the recorded camera response to reconstruct spectral reflectance. The inverse characterization function has been evaluated for RGB data and 7-channel data, using the pseudo-inverse approach, as well as building the spectra from smooth basis functions. Real spectral data from the NCS database, as well as Fourier basis has used. The results show that a good colorimetric accuracy could not be obtained when using RGB data. The best results, using spectral basis, still produced a mean color difference of 4 ΔE_{ab} and the maximal 14 ΔE_{ab}. When using the multi-channel data, the improvement was significant, both in terms of colorimetric differences and in the RMS spectral reconstruction error. The best results in terms of color difference were obtained for the basic pseudo-inverse method, with a mean color difference of 1.5 ΔE_{ab} and the maximum 4.4 ΔE_{ab}. The results using spectral basis were comparable in terms of ΔE_{ab} and significantly better in terms of the RMS spectral difference, compared to the PI-method. Fourier basis produced good results in RMS spectral difference, but slightly worse in terms of color difference, ΔE_{ab}. The results illustrate the fact the RMS reconstruction error in spectral reflectance space, is not necessary closely related to the color difference in a conceptually meaningful color representation, such as CIELAB. The good performance for the pseudo-inverse method illustrates the accuracy of the derived characterization model.

It is possible that the reconstruction of colorimetric data could be improved using empirical approaches, i.e. by direct colorimetric regression to CIEXYZ or CIELAB. However, this comes with the cost that the methods are less general and the parameters have to be derived for each combination of print and substrate. Empirical approaches for device characterization of the system will be investigated in future work, using regression techniques to derive colorimetric data, but also to directly derive spectral reflectance from device data [Solli, et al, 2005].

The results from the physical based characterization of this work will be further evaluated, using a larger set of samples of various media and colorants. We will further investigate if the accuracy can be

improved by using Wiener estimation techniques to take into account the signal dependent acquisition noise [Haneishi, et al, 2000]. The objective is to obtain such accuracy that the instrument can be used for color measurements, both in colorimetric representations and for estimations of spectral reflectance. The combination of colorimetric accuracy and spatial resolution will open up new possibilities, and be of great importance in our further research on color reproduction in printing.

Acknowledgements

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References

1. Andersson, Mattias, et al, (2003). *The Substrate influence on color measurement, Proc, IS&T NIP 19, New Orleans, 2003*
2. Balasubramaninan, Raja (2003). *Device characterization*, in Sharma, Gaurav., *Digital Color Imaging Handbook*, CRC Press LLC, 2003, ISBN: 0- 8493-0900-X
3. Barnard, Kobus & Funt, Brian (2002). *Camera Characterization for Color Research, COLOR research and application, volume 27, number 3, June 2002*
4. DiCarlo, Jeffrey M., et al. (2004). *Emissive Chart for Imager Calibration, The Twelfth Color Imaging Conference: Color Science, Systems and Applications, p. 295-301, 2004*
5. Farell, J. E., et al (1999), *Estimating Spectral Reflectances of Digital Artwork, Chiba Conference of Multispectral Imaging, 1999*
6. Finlayson, Graham D. & Hubel, Paul M. (1998). *Recovering Device Sensitivities with Quadratic Programming, The Sixth Color Imaging Conference: Color Science, Systems and Applications, p. 90-95, 1998*
7. Haneishi, H., et al (2000). *System design for accurately estimating the spectral reflectance of art paintings, Applied Optics Vol. 39, No. 35, pp.6621-6632*
8. Hardeberg, Jon Yngve (2001) *Acquisition and Reproduction of Color Images: Colorimetric and Multispectral Approaches, Dissertation.com, 2001, ISBN 1-58112-135-0*
9. Hong, Gouwei & Lou, M. R. (2000) *A Study of Digital Camera Colorimetric Characterization Based on Polynomial Modeling, COLOR research and application, volume 26, Number 1, February 2001*
10. Hunt, R. W. G (1998). *Measuring Colour, Third Edition, Kingston-upon-Thames, Fountain Press, ISBN 0 86343 387 1*
11. Sharma, Gaurav & Trussell, H. J. (1996). *Set theoretic estimation in color scanner characterization, J. Electronic Imaging, 5(4), p. 479-489*
12. Solli, Martin, et al (2005). *Color Measurements with a Consumer Digital Camera Using Spectral Estimation Techniques, Proc. Scandinavian Conference on Image Analysis, 2005*

Colour accurate imaging of artworks using custom colour reference target for digital camera characterization

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Abstract

When characterizing digital camera for capturing art paintings, the standard targets are often used, resulting in unacceptable differences in reproducing some special colours, so lots of time must be spent in visual editing and colour adjusting in various software applications. To avoid the need for excessive colour editing, and to improve workflow efficiency and colour accuracy, the special colour reference target for digital camera characterization was developed, applied and tested in these research. The object of digitalization was paintings made with gouache paint, so custom gouache reference target (named CGRT) was created for colour accurate digital camera characterization. The results shows that the differences in the colorants (pigments) used and different surface characteristics of the colour reference target used for camera characterization may contribute to the colour difference. The best results can be achieved using reference target with colour samples that have similar spectral properties as colours on paintings being photographed.

1. Introduction

The purpose of this research is to propose a new solution to an old problem - problem of colour accurate reproduction of artworks. The solution involves developing and using object specific test target for digital camera characterization.

Many art galleries, museums and other cultural-heritage institutions, have a long tradition of using analog photography for documenting their collections and producing reproductions of their artefacts. For years, the rules have been created and established in practice, many of them becoming standards. But such standards for digital capture of artworks don't exist. Although, procedures for testing the quality of digital cameras have been established in the recent past, they have not been developed specifically for the direct digital capture of artwork [Smoyer, 2005].

When photographing subjects such as a painting or other original artwork, it is essential to reproduce colours as accurately as possible. For colour accuracy, the most important characteristic of the digital camera are its spectral sensitivities. Ideally, they should closely resemble the human visual system's spectral sensitivities. But, because the colorants which can be used for colour filters in digital cameras are very limited, it is not possible to produce the same spectral sensitivities as those of the average human observer. This is the main reason why colour inaccuracies exist in digital images. Besides on spectral sensitivities of camera sensor, the amount of colour reproduction inaccuracy depends on accuracy of digital camera characterization. Since the spectral sensitivities of the camera cannot be changed, the camera characterization process plays the main role in accurate colour reproduction.

2. Objectives of the research

From previously conducted experiments [Strgar Kurečić, 2005], it was found out that the colour accuracy of the digital camera is considerably impacted by the choice of the colour reference target used for characterization process. Ideally, colour targets should span the colour range of imaged objects and have similar spectral properties, made using similar colorants [Kraushaar, 2005]. For photographic and printed

materials, standard targets are available. The problem is that for art objects (such as paintings), such targets are largely nonexistent [Berns, 2000]. When characterizing digital camera for capturing art paintings, the standard targets are used, resulting in unacceptable differences in reproducing some special colours, so lots of time must be spent in visual editing and colour adjusting in various software applications. To avoid the need for excessive colour editing, and to improve workflow efficiency and colour accuracy, the custom colour reference target for digital camera characterization is developed, applied and tested in these research.

3. Research methods

3.1 Developing an custom gouache reference target (CGRT24)

All criteria for developing custom colour targets for digital camera characterization should be closely connected with objects which will be photographed. In our case, they depend on a type of paint and painting technique in which the originals were painted, what refers to materials used (colorants and surface), spectral properties of colours on paintings and dominant colours. According to an ISO draft working standard (ISO17321, 2005) two basic colour criteria must be followed:

1. All colour samples on target should be representative of scene objects, i.e. colours cannot be reproduced by metamers.
2. Colour samples should cover all regions of the colour gamut of the camera.

Some other characteristics that have to be determined are:

- adequate number of colour samples,
- combinations of hue-lightness-chroma,
- spectral characteristics of colour samples,
- physical characteristics (shape and size of target, and size of colour samples).

	A	B	C	D	E	F
1	PR3	PR4	PY1	PY3	PY3 PG7**	PG7*
2	PB29 PW6	PB29	PB27 PW6	PB27	C (Cyan)	PG7 PW6
3	PV2 PW6	PR173	PY42	PR102*	PR102** PW6	PG8 PW6
4	PW6	PW6 PBk9	PW6 PBk9	PW6 PBk9	PW6 PBk9	PBk9

CGRT24



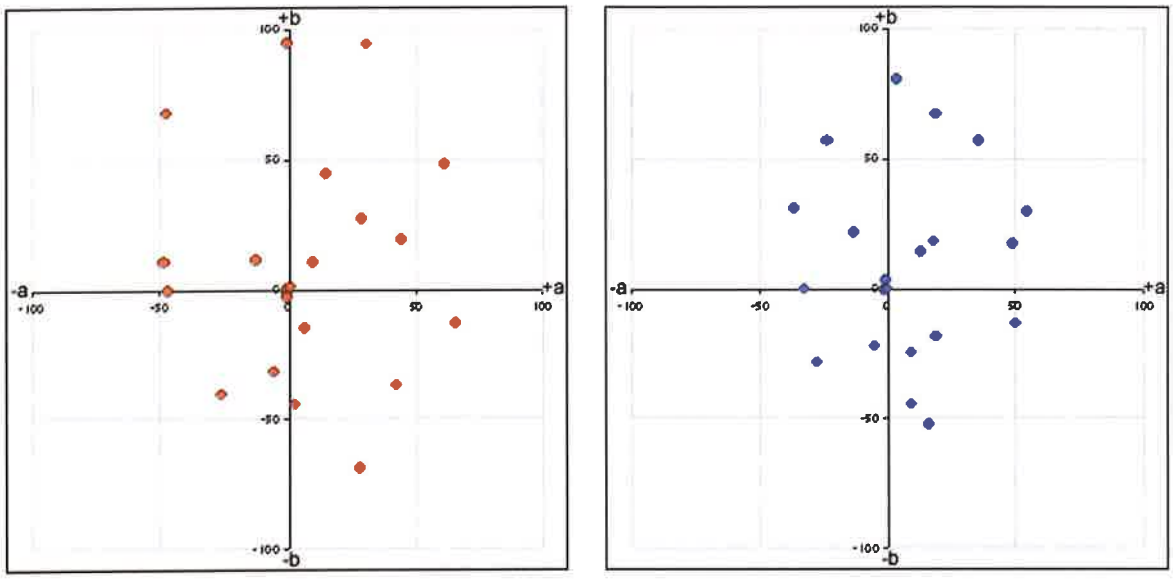
Figure 1: Custom gouache reference target with the list of used pigments

In this research, the objects for digitalization process were paintings made with gouache paint. For this purpose, the colour target was made using the same colorants and same paper as those on paintings being photographed. The 18 Linel 35GT single pigment gouache paints was selected, because they can serve as a representative of different brands of gouache paint made with the same single pigment. The pigments were identified by standardized colour index generic name, a code that identifies each pigment as a specific chemical substance (Figure 1).

Because a chromatic pigment at its maximum chroma can predict mixtures of that pigment with the white pigment extremely well [Mohammadi, 2005], producing colour ramps on target, by varying concentration of chromatic pigment with white, was not necessary. Accordingly, a sample with the maximum chroma was made for each pigment and grey ramp at six lightness levels using PBk9 black and PW6 white pigment.

3.2 Spectral reflectance measurements

After creation, the samples on target were measured using GretagMacbeth Spectrolino spectrophotometer. The CIELAB values for each colour sample were taken by averaging three measurements from a spectrophotometer. Measured values were saved in target description file in Profilemaker PRO 5.02 application. Besides our custom gouache reference target, the two standard colour targets were also used for characterization; GretagMacbeth ColorChecker (with 24 colour samples) and ColorChecker DC (with 237 colour samples). Those targets were also measured with same equipment to get more accurate target-data set. From comparison shown in Figure 2, it could be noticed that CGRT24 target has larger gamut then GretagMacbeth ColorChecker, because colour samples are more saturated.



CGRT24 GretagMacbeth ColorChecker

Figure 2: Comparison of colour samples from CGRT24 and ColorChecker target in CIELAB diagram

3.3 Digital image capture

The setup of the digital camera, object and light source is critical for image capture, so special care should be taken. The lighting illuminating the object needs to be as uniform as possible. Also, lamps used should have the same brightness, colour temperature and constant light emission [Hong, 2001]. According to the GretagMachbeth directions, illumination on the test target should not vary more than 10% and the difference in colour temperature of the light sources should be less than 200K.

In this research, the targets and paintings were photographed in controlled studio conditions, with attention paid to above mentioned terms. The light source used was a pair of Osram Nitrafot B tungsten. The radiometer was used to measure the spectral power distribution of the light sources. Lamps were illuminating target from left and right in a 45° angle, to avoid specular reflections within the camera's field-of-view. Image captures were performed with Nikon D70 digital camera and AF Nikkor zoom lens 35 - 70mm, f/2.8.

Exposure was adjusted by measuring an 18% neutral grey card at the position of the target. When checking the exposure on the histogram of the camera, it is important to avoid any clipped highlights or a peak in the shadows. During the whole period of image capture, exposure (aperture size and exposure time) was fixed. Sensitivity of the system was set to ISO 200. There was not any signal processing such as gamma correction, hue adjustment, sharpening or noise reduction during imaging.

3.4 Digital camera characterization (profile building)

Raw files (12 bits) from camera was converted in TIFF format and then supplied to the Profilemaker software, witch relates camera RGB signals to measured CIELAB values from target, to build a CLUT based transformation structure. In the "Phototask options" in Profilemaker software, the "Reproduction" option was selected, because it does not numerically distort the camera signals in any way. This is important when evaluating profile accuracy. As the three colour targets were used for digital camera characterization (1. CGRT24, 2. ColorChecker and 3. ColorChecker DC), the three ICC profiles were made, named accordingly: CGRT24T, GM24T and GM237T where the number indicates the number of colored samples, and letter T indicate that the profile is for tungsten.

3.5 Evaluation of profiles

The evaluation of profiles was conducted using calibrated CRT monitor (Mitsubishi Diamond PRO 2070^{SB}) as a soft proofing device. The hard proof was made on Epson Stylus PRO 4000 with EFI Colour Proof XF RIP. The accuracy of the profiles was evaluated in two different ways:

Test A. Test of profile accuracy in predicting the characterization target used to build profile.
Test B. Test of profile accuracy in predicting the colours from original painting.

The purpose of Test A. was to ascertain that the prediction errors for the characterization dataset are low. This test was conducted by assigning the profiles (CGRT24T, GM24T and GM237T) to the digital image of our CGRT in Photoshop. Using the monitor as a soft proofing device, colour samples on images with assigned profiles were measured with Spectrolino (direct on monitor) and compared to original target values. Colour differences (ΔE_{94} and ΔE_{00}) for every profile were calculated and compared.

Test B was conducted by choosing 24 different colored areas from digital image of painting. Those colours were formed in samples and save as untagged digital file (without profile). Those areas were measured directly from original painting (using mask with holes at exact coordinates), and compared with values of colour samples with assigned profiles (CGRT24T, GM24T and GM237T), measured from monitor. Those colours were also measured from hard proof prints. Colour differences (ΔE_{94} and ΔE_{00}) for every profile were calculated and compared.

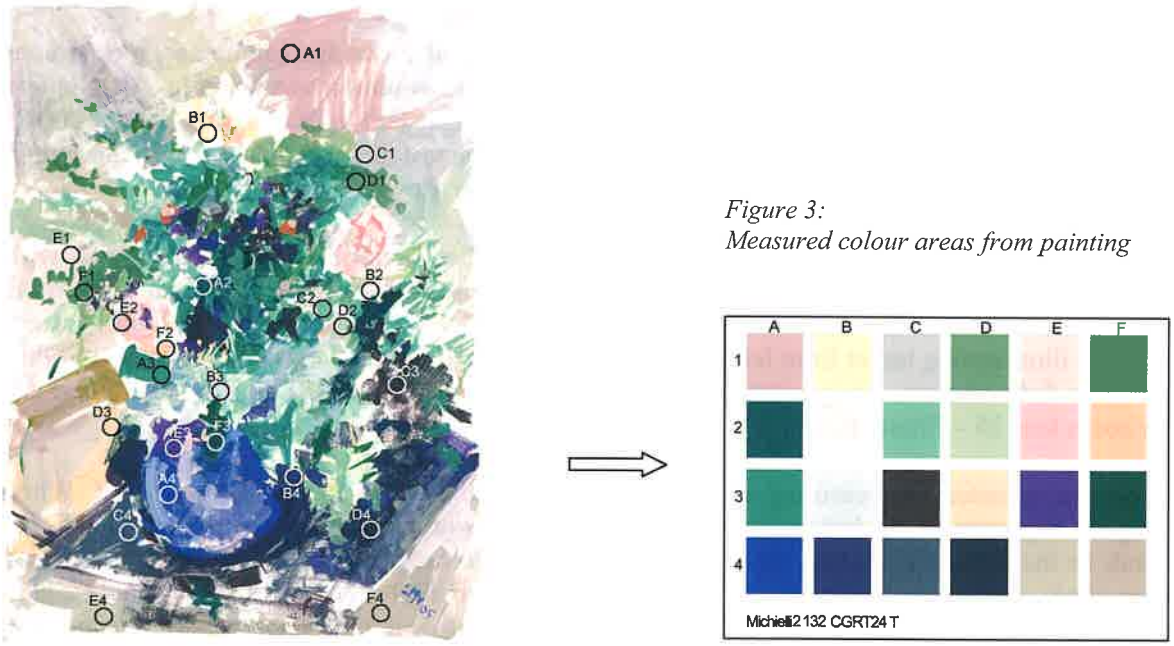


Figure 3:
Measured colour areas from painting

4. Results and discussion

The profiling evaluation results for Test A are shown in Table I (for values measured from monitor) and in Table II (for values measured from print). Accordingly, results gained from Test B are shown in Table III and Table IV. Beside total colour differences (ΔE_{94} and ΔE_{00}), for the purpose of detailed evaluation, the differences in lightness, chroma and hue were also calculated.

Table I: Colorimetrical accuracy of input profiles (soft proof)

Characterization target - CGRT24 (MONITOR)					
Profiles for tungsten illumination (3200 K)	ΔL Average	ΔC Average	ΔH Average	ΔE_{94} Average	ΔE_{00} Average
CGRT24T	0,09	-0,83	3,94	**4,03**	**4,08**
GM24T	-0,66	-5,51	5,03	6,31	6,14
GM237T	-0,21	-1,87	5,75	6,39	6,12

Table II: Colorimetrical accuracy of input profiles (hard proof)

Characterization target - CGRT24 (PRINT)					
Profiles for tungsten illumination (3200 K)	ΔL Average	ΔC Average	ΔH Average	ΔE_{94} Average	ΔE_{00} Average
CGRT24T	-0.72	-5.65	3.65	**4.98**	**5.00**
GM24T	-1.56	-8.39	4.11	6.92	6.84
GM237T	-1.01	-5.90	4.43	6.47	6.26

Table III: Colorimetrical accuracy of input profiles (soft proof)

Painting - Michielli2 (MONITOR)					
Profiles for tungsten illumination (3200 K)	ΔL Average	ΔC Average	ΔH Average	ΔE_{94} Average	ΔE_{00} Average
CGRT24T	1,00	-2,85	5,36	**5,08**	**5,56**
GM24T	-0,04	-4,07	5,00	5,64	6,10
GM237T	0,34	-1,43	5,38	5,38	5,82

Table IV: Colorimetrical accuracy of input profiles (hard proof)

Painting - Michielli2 (PRINT)					
Profiles for tungsten illumination (3200 K)	ΔL Average	ΔC Average	ΔH Average	ΔE_{94} Average	ΔE_{00} Average
CGRT24T	-1,69	-6,83	4,99	**6,78**	**7,02**
GM24T	-2,18	-8,11	4,73	7,44	7,52
GM237T	-1,20	-7,62	5,85	6,95	7,29

As expected, the prediction errors for Test B are higher than that of Test A. Also, the soft proof show smaller colour differences than hard proof prints, because of larger colour gamut of the monitor used.

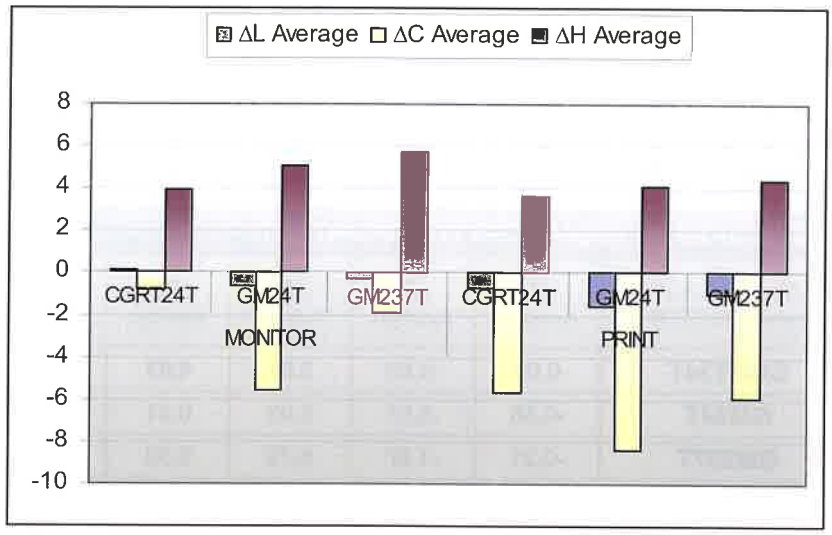


Figure 4: Values of the lightness, chroma and hue differences (Test B)

It is interesting to see that the colour differences on image of painting measured from monitor are mostly caused by errors in hue, and on hard proof print large colour differences are mainly result of errors in chroma.

From the obtained results, it can be noticed that the average color errors are smallest on digital image with the CGRT24T profile assigned. These results proved that the differences in the colorants (pigments) used and different surface characteristics of the colour reference target used for camera characterization may contribute to the colour difference.

The results also showed that having a colour reference target containing more samples does not guarantee better performance. The number of samples in colour reference target is less important then the spectral properties of the colorants used to create target. Using custom developed CGRT24 target with 24 coloured samples, better reproduction results can be achieved, than using standard GretagMacbeth ColorChecker DC with 237 colour samples.

It is also important to accent that those results were achieved without any image or profile editing and colour corrections in software applications.

5. Conclusion

In order to improve the accuracy of digital camera colour reproduction the colour reference target, used in the characterization process, should ideally be made from same materials (colorants and surface) as those used on objects being photographed. Some degree of accuracy can be maintained if the materials and surface textures have some similarities. Otherwise, the conversation from device dependent data to device independent attributes will not be accurate.

Results of this research show that using proposed methodology, the workflow efficiency and colour accuracy can be improved. Also, it is expected that the performance of digital image capture can improve even more using different lighting, witch will be the subject of our future research.

References

1. Smoyer E. M.; Taplin L. A.; Berns R. S., *Experimental Evaluation of Museum Case Study Digital Camera Systems*, in Proceedings of the IS&T Archiving Conference, IS&T, Springfield, 2005
2. Hong G.; Luo R. M.; Rhodes P. A., *A Study of Digital Camera Colorimetric Characterization Based on Polynomial Modelling,* Color Research and Application, pp.76-84, vol. 26, number 1, February 2001, Willey, UK
3. Strgar Kurečić M.; Agić D.; Mandić L., *Digital Camera Characterization using Special Colour Reference Target*, in Proceedings of the 3rd International Conference on Computer Aided Design and Manufacturing, CADAM, Rijeka, 2005
4. Berns R. S., *The Science of Digitizing Two-Dimensional Works of Art for Color-Accurate Image Archives*, Munsell Color Science Laboratory Technical Report, May 2000
5. ISO/DIS 17321-1, *Colour characterization of digital still cameras (DSCs) - Part1: Stimuli, metrology and test procedures*, 2005
6. See http://www.lefranc-bourgeois.com for more information
7. Mohammadi M.; Nezamabadi M.; Berns R.S.; Taplin L.A., *A prototype Calibration Target for Spectral Imaging*, in Proceedings of the 10th Congress of the International Colour Association, AIC Colour 05, Granada, 2005
8. GretagMacbeth, *The Digital Camera Profiling Solution from GretagMacbeth,* http://www.gretagmacbeth.com
9. Kraushaar A., *Test Charts and Photometric Tolerances for Colour Reliable Image Acquision*, in Proceedings from 32nd International IARIGAI Research Conference, Finland, 2005

Spectral-based colour reproduction workflow

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Abstract

Exact and repeatable colour reproduction with high fidelity is one of the main topics in the graphic arts industry. A lot of improvements in this area have been reached so far by standardisation. On the one hand, ICC profiles are applied for matching colours across different devices (e.g. scanners, screens, printers for proofing, printing machines). On the other hand, printing machines used have to be technically well-calibrated. This guarantees well-defined colour fidelity. Nevertheless, some issues remain unsolved, e.g. metamerism or colour gamuts limiting the usable colours.

One promising way to solve these issues is to utilise spectral techniques for recording, handling, and reproduction of colour. Employing spectral techniques implies the absence of metamerism due to the fact that, instead of reducing the colour impression to only three parameters (i.e. RGB or CIELAB), colours are recorded much more precisely. The second advantage of using spectral values for colour recording is that nearly all visible colour impressions can be recorded. There is no significant RGB limitation while recording. The most limiting factor in reproduction is the availability of printing inks to achieve the aspired colour impression. Besides the standardised process colours, spot colours are available to enhance the printing gamut considerably. A spectral algorithm has been developed to calculate colour separation depending on the used inks.

In this paper, the reproduction of a specially prepared original is shown using the spectral approach. The reproduction using the ICC workflow is also done in order to compare these results with the former. In both cases, a printout is done in offset with AM screening.

1. Introduction

Many efforts have been made to reach the level of colour fidelity that can be found in the printing industry nowadays. To show how far these efforts have come, it is advisable to give a short outline of the established colour management workflow at first.

The need of colour management arises whenever the reproduced item claims to be equivalent to an original. In the case of colour management, this refers to the colour impression only, not to the used substrate. Each device used for the reproduction process from scanning or taking a photo to printing has its own limited colour space. The colour gamut of a device contains all colours that can be recorded or reproduced by this device. Due to the fact that there is an incongruity between the colour gamuts using two different devices, the need of colour adaptation arises. One additional problem that might appear is that the basic colours of the devices may also differ. There are devices based on RGB (scanners, digital cameras, screens) while others are based on CMYK (printers). The International Colour Consortium (ICC) has developed a pragmatic solution for this problem. A device independent colour gamut has been chosen for exchanging colour values. This gamut is either the CIE XYZ or the CIE L*a*b* colour gamut. Both can be converted one-to-one. The ICC profile has to be determined for each device describing the conversion rule mathematically from the device's colour values into the device independent colour gamut and vice versa. When using ICC profiles the overall working process indicated in Figure 1 can be established.

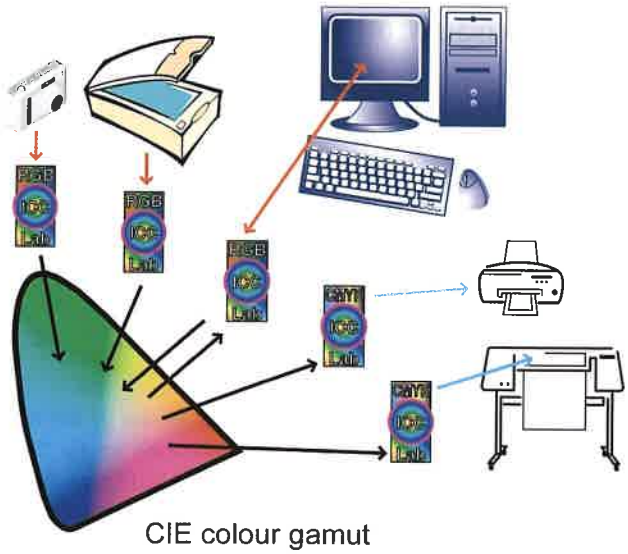


Figure 1: ICC-profile-based colour management applying the device-independent CIE colour gamut. Each transformation rule has to be known for conversion of the colour values

The workflow presented in Figure 1 is based upon the temporal accuracy of the particular device. For scanners or screens this can be assumed after warming up for some time. Nevertheless verifications or recalibrations are needed on a regular basis. Regarding printing devices the situation changes fundamentally. Depending on the respective device, some variations in the printing process are evident. Therefore an inkjet printer, for example, is preferable to an electro-photographic printer as colour proofing device. Taking a look at an offset printing machine, there are a number of possible parameters causing variations in the colour appearance of the printout. Those parameters could be: optical density of the inks, kind of ink used, kind of screening, colour values of primary and secondary colours, registers, optical dot gain; just to name a few. To standardise the offset printing process several ISO standards have been established (ISO 2846, 12647, 13655, EN 61966). These standards are considered to be the basis for comparable printing results when applied correctly. The benefit of these efforts is a minimised deviation in the printouts when using a different printing machine or switching the printing house.

Having reached this level, the next step is to enhance the printer's colour gamut to facilitate a better colour impression by enabling the use of more colour tones. The chosen approach is to replace the primary colours by modified ones with a higher pigment density. These highly-pigmented inks have more extreme primary colour values, so that the entire colour gamut of the printing machine is extended. The outcome is a greater number of colour tones. The brands using this technique are for instance Aniva by Epple, NovaArt by K+E, NovaSpace by K+E, or similar ones.

Sometimes it is required to reproduce a defined colour value when printing. If this value is included in the colour gamut of the printer, it can be reproduced with ordinary process colours either using highly pigmented or ordinary inks. The colour value then varies around a mean value. To avoid this fluctuation, a special spot colour can be used as an additional printing ink to match the required colour value even better. The use of a spot colour is also required if the requested colour value is not included in the colour gamut of the printer. When using a spot colour, one additional separation channel has to be included in the reproduction workflow. This separation channel is only used for the specific spot colour and usually cannot be used as separation channel for any other colour information. If it were possible to use the spot colour also for separation of ordinary colour values, this could lead to greater colour accuracy in the printout.

The overall problem of metamerism is not addressed by the ICC approach. Therefore, metamerism is self-evident in this colour management system.

After analysing the present situation in colour management, the following conclusions can be drawn:

1. The colour management system defines an output colour gamut based on the output device independent of the desired colour gamut. Nevertheless, the colour management system fits the desired colours of the original into the available colour gamut. There is adaptation of the colour gamut of the printer to the desired colours of the artwork. Merely spot colours can be used to print specific colour values.
2. There are spot colours with a colour value outside the ordinary printing colour gamut but these are rarely used. Spot colours are usually not included in the calculation of the separations for ordinary colour tones.
3. Metamerism is evident.

Based on this analysis an alternative workflow is examined in this study. This workflow is based on spectral values, avoiding metamerism because of a more precise colour representation and no reduction of the colour information to just three or four parameters (RGB, CIELAB, CMYK). Applying a spectral colour mixing algorithm that is available in our institute and published in [Hübler, 2005], any primary colour can be used and included for calculating the colour separations.

Due to the steadily increasing processing power of computers available on the market, it becomes possible to handle more than four colour channels per pixel (equal to 4 Bytes). Known spectral recording devices for artwork use 8 to 32 spectral channels with up to 16 Bits resolution per pixel (equal to 8 to 64 Bytes) [Cotte, 2003; Liang, 2004; Hauta-Kasari, 2004; Antonioli, 2004]. Of course, more recording time as well as increased computer power is needed for that. Thus, taking spectral recordings of originals can be considered as the present state of the art. The steps following the spectral recording are more challenging than the recording itself. These steps involve data handling, retouching the picture, and the printout. Most of the viewing devices are based on RGB only. Hence, their colour gamut is smaller than the spectral representation. When the colour gamut of the viewing device is exceeded, a gamut warning should be displayed. It would also be possible to create software tools defining spectral colour values although the viewing device is limited in displaying them adequately.

The most limiting factor in printing is the given colour gamut which is restricted by the used primary colours. In conventional reproduction every workflow step is oriented to fit the available printing colour gamut. The colours are handled according to ICC rendering intents. To minimize its effect on the reduction of the colour gamut in the overall reproduction process, the rendering intent is used in the step of the printout only. Changing the colour gamut is avoided in every intermediate step.

The availability of a colour separation algorithm which utilises the spectral information of the primary colours used for printing allows a selection of primary colours according to the required colour gamut. The limitation in colour gamut is mainly caused by the restricted number of printing inks for spot colours.

In the present study, a spectral reproduction workflow is used. The aim is to create a reproduction on paper of a purpose-built original whose colour impression matches the original. While the main steps of this workflow are basically established, the focus at our institute is on a spectral colour separation algorithm. The main aim is to calculate the colour separation including spot colours instead of handling them as separate channels additionally to CMYK. The algorithm itself can work with spectral colour values. The objective of this research is to demonstrate the whole workflow ranging from colour recording, calculation of the separations to the final printout.

2. Methods

2.1 Introduction

In order to demonstrate the reproduction workflow and obtain a reproduction result, an original is required first. A unique original was created especially for this study. The four spot colours HKS 7 K,

33 K, 41 K, and 53 K (7 K, 33 K, and 53 K are outside the RGB or CMYK gamut) were chosen and painted in overlapping stripes onto a glass substrate using a rubber cylinder. A picture of the created glass art (taken by a digital camera) can be found in Figure 2. The rubber cylinder was uniformly inked using a "Prüfbau Probedruckmaschine" (test printing unit; system Dr. Dürner). The different stripes vary in optical density. This glass art original (size 30 x 30 cm^2) was reproduced using two different workflows: (1) the established ICC profiles for reference and (2) the proposed use of spectral values. Firstly, the ICC based workflow shall be sketched. Afterwards the spectral-based reproduction workflow will be described in detail.



Figure 2:
Glass art created by using HKS spot colours

2.2 The ICC Workflow

The first workflow was entirely based on ICC profiles and standardisation. For our study, the service of a reproduction studio (addprint® KG, Chemnitz, Germany) was used for scanning the glass art with a professional RGB-based flatbed scanner (Linotype Hell Topaz, software: Linocolor 5.1 with ICC profile). Due to the fact that the glass art extends the scanning width of the scanner in transmission mode, the operator decided to use reflectance measurement. Therefore he placed a white paper on top of the glass art. During the scanning process, the gamut limitations of the RGB filters of the scanner became evident. Due to the chosen spot colours most of the colours are not recordable with acceptable colour fidelity. Applying ICC profiles, all recorded colour values were converted into CMYK values, i.e. the colour separation was calculated by the scanning software according to the applied ICC profiles. The separations were then recorded on film (Linotype Hell Herkules) and four printing plates were manufactured. The final printout was done in a standardised process using ordinary CMYK process colours at an offset printing machine (Heidelberg GTO 52) in our printing facility.

2.3 The Spectral-Based Workflow

The second workflow uses only spectral values for colours. To demonstrate the main steps of the workflow, the following sections will address the generation of a spectral digital image, calculation of colour separations, and printing with spot colours. At the current research level no image retouching is included.

2.3.1 Digital Image

The first step was to create a digital image of the glass art represented by spectral values. Due to the fact that no page wide spectral transmission scanner was available, an approximation was used to determine the spectral values of each pixel. This approach was based on the grey level information and spectral values of the full tones. The greyscale of the glass plate was determined by use of a professional flatbed

scanner in transmission mode (Linotype Hell Topaz; 150 dpi, greyscale: 8 bits per pixel). Due to the fact that the same scanner model as in the reproduction studio was used the whole glass plate could not be scanned in one path. The maximum area in transmission can be about 25 x 30 cm^2. Therefore two scans were done with the glass art rotated by 90 degrees. Nevertheless the four corners of 2.5 x 2.5 cm^2 each were still not recordable. So Adobe Photoshop was used to create a synthesised digital composed greyscale representation of the original. The grey level represents the transmitted intensity of light for a localised pixel. This was the basic information to scale the spectral transmission of the used colour to the equivalent optical density. To have the information which colour is at a specific pixel, a second picture was generated indicating by the pixel value the underlying colour. This information is based on the greyscale image created previously. The assignment to the concerning colour was done manually.

The spectral values of the 16 basic colours of the glass art (light source, 4 primary, 6 secondary, 4 tertiary colours, and all four colours superimposed) were recorded using a spectrophotometer in emission mode (GretagMacbeth Spectrolino, 4 mm aperture, NO-filter). A halogen lamp was placed on the opposite side of the glass art for illumination purposes. When the light intensity was too high for a specific colour, it was attenuated by adding neutral grey filters in the optical path. The measured values were aligned according to the used optical density of the grey filter. The results are spectral curves of 36 floating point (16 bits) grid points (range 380 to 730 nm, 10 nm interval).

With a short programme, the generation of the spectral digital image representation was calculated. Therefore, the greyscale digital image (TIFF file format), the pixel spectrum assignment, and the spectra of the basic colours were used to calculate the digital spectral representation line by line and pixel by pixel. The results were saved in a binary file containing a header for Meta data and the floating point spectral data without compression.

The actual used image file had 1765 x 1757 pixels in greyscale (8 bits per pixel). This approximately represents an image of 30 x 30 cm^2 with a screen resolution of 150 dpi. The file size required was about 3.04 MB without compression in TIFF file format. After converting this image into spectral data the size of the data file increased to a volume of 425.9 MB. The growth rate has a factor of 144! This workflow was done without any compression technique for research purposes. Applying a compression technique would decrease the file size drastically.

At this workflow step, the recorded spectral image could be retouched with an adequate software. This interaction was eluded in the present study because the main focus was laid on a high fidelity reproduction of the colours and not on retouching the recorded information. The next step in the reproduction workflow was the colour separation and the raster image process.

2.3.2 Colour Separation and RIP

The colour separation was done pixel-based according to the spectral values. For the test environment, the three spot colours HKS 7 K (orange), 33 K (violet), and 53 K (green) were given as primary colours. The fourth colour HKS 41 K (very dark blue) used for preparing of the glass art is included in the colour gamut of the first three inks and could therefore be omitted as additional primary ink. In addition to the spectral values of all occurring colours, the remission of the paper substrate is needed for calculations. The applied calculation algorithm is called "Free Gamut Technology" algorithm (FGTA). However, FGTA will not be discussed in this paper. Only a very short description of the calculation basics will be given here, because one paper was already published on this topic [Hübler, 2005] and further ones shall be published in the near future.

The FGTA calculates the resulting spectral remittance dependent on the substrate paper and the area coverage of the respective ink. This spectral remittance is adjusted to the required colour value. Due to

the fact that spectral remitting inks are not available yet and the used spot colours have a broad remission regime, the adjustment is done by minimising the colour difference ΔE_{ab}. If spectral remitting inks became available, the FGTA would also be able to do absolute spectral adjustment.

The software executed the raster image process (RIP) after the separation process. As an intermediate step, the dot gain was corrected. These correction curves were determined in advance. The RIP itself was realized with a simple matrix conversion method resulting in a line resolution for the output of about 60 L/cm. This ensured the adaptation of the screen resolution between the digital image (150 dpi) and the film recorder (2540 dpi). The dot shape used was elliptical and all three separations used different screen angles. This was a compromise between the complexities of screening versa the printing result. Recently, Ghostscript [Ghostscript, 2006] has been tested for doing the RIP delivering professional dot shapes.

2.3.3 Printing Process

After calculating these binary separation images, the three data files were stored as 1 Bit Tiff files. These files were the input for the film recorder (Linotype-Hell Quasar) which exposed the separation onto films. The films were then used to produce printing plates by direct copying.

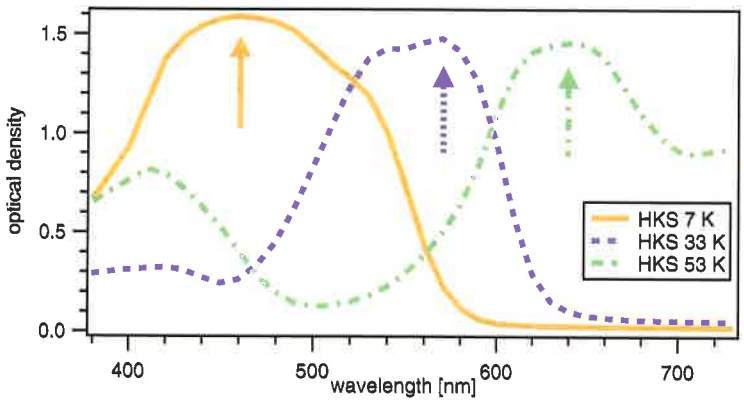


Figure 3: Spectral optical densities of spot colours. The arrows indicate the wavelength of measurement of the optical density during the print process

There have been some investigations about the printing process using spot colours and its parameters. The essential parameters are the optical density and the order of the spot colours applied in the print process. The respective spot colours have been analysed in sample prints using different optical densities. As expected, the colour value differentiates with the optical density. The measurement results are given in Figure 4 in form of an a*b*-diagram. The optical density chosen for printing is indicated in the graph. It is OD 1.6 at 460 nm for HKS 7 K, OD 1.5 at 570 nm for 33 K, and OD 1.5 at 640 nm for 53 K (see Figure 3). In the reference HKS fans, the optical densities are higher (OD 2.0 for HKS 7 K, OD 2.1 for 33 K, and OD 2.0 for 53 K; always at the same wavelength as above). The fluctuations of optical density therefore have only little influence on the printing result.

Conventional densitometers are not capable of choosing the wavelength for measurement freely. Therefore, a spectrophotometer was used. The chosen wavelengths of the applied spot colours are given in Figure 3. The wavelengths used for measuring the optical density are indicated, too. The wavelength with the highest optical density was always chosen because the change of optical density shows the greatest impact there.

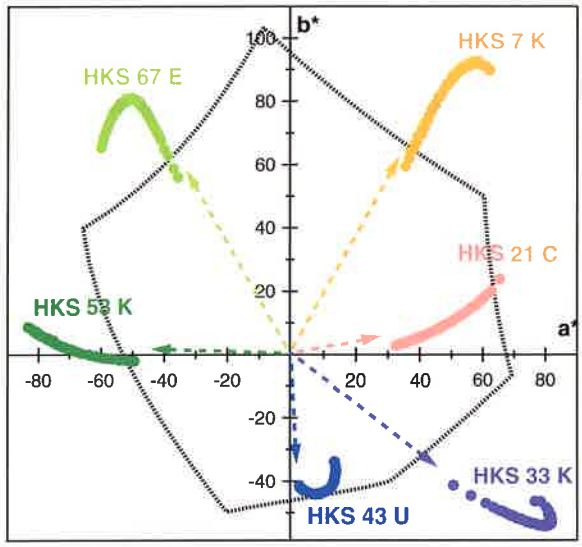


*Figure 4: CIE a*b* diagram of some spot colours printed in different densities. The arrows indicate the direction in which the optical density increases. Furthermore, an ordinary CMYK colour gamut is indicated by the dotted line*

The decision about the order of printing is made according to the viscosities of the inks. Considering these values, the three HKS spot colours were printed in the order HKS 33 K, 7 K, and 53 K. Due to the fact that a Heidelberger GTO 52 with only 2 printing units was used for printing, we decided to use HKS 33 K in the first pass and HKS 7 K and 53 K in the second pass on the next day. So the second ink in the second pass was printed wet onto wet.

In addition to the reproduction of the glass art, an ordinary RGB image was being reproduced using the same FGTA and also the same inks. This reference picture was used to see effects on the colour gamut when replacing process colours by spot colours as primary colours in the printing process. The transformation of RGB values into spectral representation was realized by the spectral information according to a CRT screen remission. The scaling of the spectral information was done according to the RGB values. The RGB picture was reproduced on the remaining part of the film and printing plate which was used to reproduce the glass art original.

3. Results

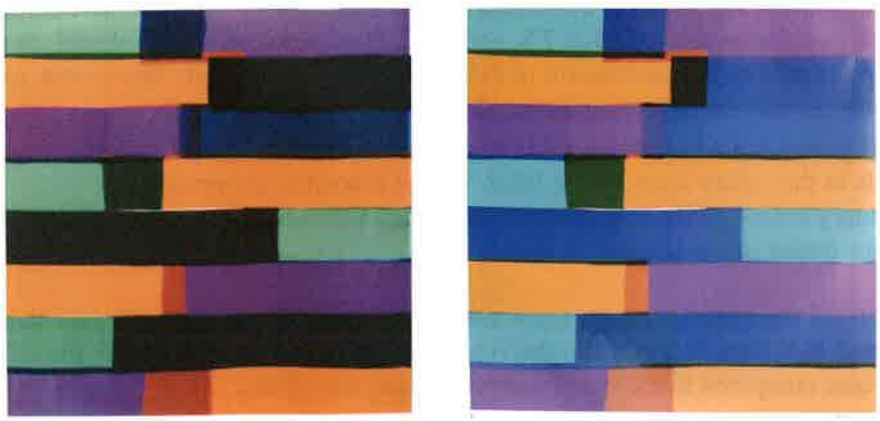


Figure 5: The printouts digitised by a digital camera. On the left hand side the result of the ICC and on the right hand side the result of the spectral reproduction workflow

The aim of the presented investigations has been to compare the printing results using the ICC as well as the spectral reproduction workflow. In this section, the printout results are described and analysed.

The photographs taken of the printouts (in RGB colour space with a digital camera) are shown in Figure 5 to give a visual impression.

To evaluate the results, the primary and secondary colours of the CMYK (marked by a circle) and the spot colour (marked by a square) printouts are given in Figure 6 along with some additional curves.

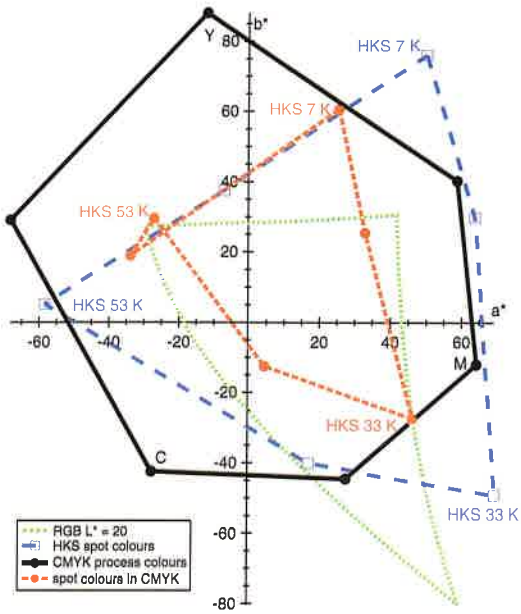


Figure 6:
*CIE a*b* diagram of the primary colours (CMYK, HKS spot colours, RGB with L* = 20)., The spot colours printed in CMYK are also indicated*

The line of the CMYK process colours in Figure 6 indicates the colour gamut achievable in the ICC workflow. The line of the HKS spot colours in Figure 6 indicates the achievable colour gamut. Both colour gamuts are estimations using straight lines between the corner marks. In contrast to the previous two colour gamuts, the line of the RGB in Figure 6 indicates a cut of the RGB colour gamut at L* = 20. This information is helpful for the discussion below. The transformations of the spot colours in the ICC workflow are also given as points and lines of the "spot colours in CMYK" in Figure 6.

As expected due to the chosen spot colours, the ordinary ICC workflow shows its limitations because of its gamut boundaries. The result is the colour gamut indicated by the line "spot colours in CMYK" in Figure 6. The transformations of HKS 7 K and 33 K lead to colour values placed on the edge of the CMYK colour gamut. The transformation of HKS 53 K is placed inside this colour gamut. A closer look at the results reveals the following facts:

1. The colour gamut boundary of the CMYK process colours at about L* = 75.0 (lightness of HKS 53 K) leads to the colour locus where HKS 53 K is placed in the printout.
2. The secondary colour of HKS 33 K and 53 K with a lightness of about L* = 25.0 is limited by the RGB colour gamut of the scanner.

The comparison of the colour gamuts (spot colours in CMYK vs. spot colours) results in the big difference plotted in Figure 6. Therefore the reproduction of the glass art using the ICC workflow is significantly worse compared to the spectral reproduction workflow.

To have one more test case an RGB picture taken by a digital camera is reproduced taking the proposed spectral workflow. This picture and its spectral reproduction are shown in Figure 7.



Figure 7: The printout of a picture taken by a digital camera. The original picture (left) next to the printout of the spectral reproduction workflow (right; digitised by a scanner device)

Both pictures give almost the same optical impression, although the available colour gamuts differ significantly (compare Figure 6). The spectral reproduction is slightly brighter and has a green colour cast. There are several reasons for this. The transformation from RGB to spectral data was realized by a rule of thumb. Additionally, an ordinary RGB scanner was used to capture the printed image. Therefore, minor colour shifts can be accepted particularly because of the demonstration setup. At this stage, the main goal is to demonstrate the workflow rather than to implement the final colour aligned system.

4. Discussion

Analysing the colour gamuts of the printing processes, the one using the three spot colours deviates clearly from that of the CMYK process colours (see Figure 6). Nevertheless, for the chosen RGB picture, this poses no obvious disadvantage.

The glass art has been created to serve as original with colours that are impossible to reproduce using the currently established ICC colour management workflow. Therefore, the big differences between the glass art and the CMYK reproduction are clearly given. In the established ICC workflow, the real bottleneck is the printing process itself, because the RGB-based scanning device has a huge colour gamut compared to the one of the printing process. Indeed, also the RGB colour recording causes loss in colour information. In Figure 8, the colour gamut of an RGB and a spectral scanner [Flaspöhler, 2004] are compared in a horseshoe depiction. From the figure, it becomes evident that the spectral scanning device can capture nearly all of the visible colours, while the RGB scanner is able to detect only part of it.

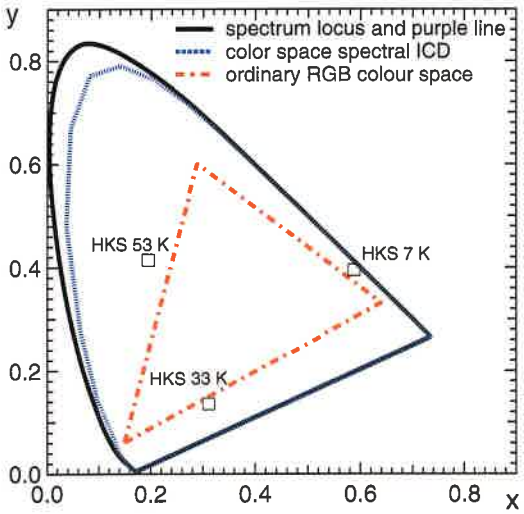


Figure 8: Depiction of a CIE horseshoe with the colour gamut of an RGB and a spectral recording device. Additionally, the colour loci of the used spot colours are displayed

The colours of the original are recordable and also printable in the spectral reproduction approach because for preparing the glass art and for the printed reproduction the same inks are available. Therefore, the reproduction is produced under specialized and unique testing conditions.

The limitations of colour gamuts become evident in the ICC-based reproduction. The resulting printing gamut (see red line "spot colours in CMYK" in Figure 6) is much more limited than the ordinary CMYK colour gamut. Therefore a significant loss in colour accuracy has to be accepted. This can also be seen when comparing Figures 2 and 5 - independent of any limitation in reproduction technique for this paper. These limitations of RGB and CMYK colour gamut do not have to be taken into consideration when spectral capturing techniques are used, because the extent of the colour gamut in spectral scanning is comparable to the gamut of the human reception. The limitation in printing is the lack of adequate printing inks. Only if printing inks that can span the required colour gamut of the digital spectral image are available, a printout is possible. This requirement was fulfilled in the test setup of the present study because of the selection of inks for creating the glass art.

The reproduced RGB digital picture also gives an optical impression of the reproduction potential. Despite the significantly different colour spaces, the reproduction delivers almost the same optical impression as can be seen in Figure 7. To rate the real colour confidence, test images would have to be created. Then measurements can show real deviations between the original and the quality of the reproduction.

This study demonstrates that the spectral workflow is working in general. This was the main focus of our first investigations. During the reproduction workflow, a lot of simple approaches were used: spectral scanning using a spectrophotometer in emission mode, creating spectral values scaling dependent on grey levels, applying FGTA, doing a straight forward RIP, etc. These are some key points which should be improved when developing a more detailed spectral-based reproduction workflow.

5. Conclusions

In general, the spectral recording technique is promoted and established by several research projects. It shows clear advantages over the established RGB/CMYK/ICC workflow, especially with regard to metamerism and limited colour gamut of the recording device.

In the present study, a special test case has been examined. The chosen colours are neither recordable by conventional RGB scanner technique nor printable by ordinary CMYK process colours. Therefore, the limitations of colour gamuts are evident in the scanning and the printing process. Spot colours are often used in advertisement and packaging. At least for these applications, the most widely used approach to overcome these limitations is to use spot colours in addition the four process colours.

Compared to the established ICC workflow, the spectral reproduction technique shows clear advantages. Colours can be recorded with high fidelity despite minor colour gamut limitations (there is actually a small restriction due to the spectral resolution of the measurement device). The used colour separation algorithm as the central component of the reproduction workflow is based on spectral colour descriptions and can hence be adapted to any printing ink. Yet, the availability of inks or the lack thereof remains a limiting factor even in the spectral reproduction workflow.

References

1. Antonioli G., Fermi F., Oleari C., and Reverberi R., (2004), *Spectrophotometric Scanner for Imaging of Paintings and Other Works of Art, Proc. of the 2004 CGIV Conference*
2. Cotte P., and Dupouy M., (2003), *CRISATEL High Resolution Multispectral System, Proc. of the 2003 PICS Conference*
3. EN 61966-7-1, 2002, *Multimedia systems and equipment - Colour measurement and management - Part 7-1: Colour printers - Reflective prints - RGB inputs*
4. Flaspöhler M., Willert A., and Hübler A. C., (2004), *Optical and Colorimetric Characterization of a Micro Mirror Based Spectral Image Capturing System, Proc. of the 2004 CGIV Conference*
5. Ghostscript, *http://www.cs.wisc.edu/~ghost/, last visited: June 28th 2006*
6. Hauta-Kasari M., Miyazawa K., Toyooka S., Parkkinen J., and Jaaskelainen T., (2004), *Spectral Image Acquisition with Rewriteable Color Filters, Proc. of the 2003 PICS Conference*
7. Hübler, Arved, Willert, Andreas, and Flaspöhler, Martin, (2005), *Enhancing Printer Colour Gamut Using Free Gamut Technology, VII. Polygrafický seminar, University Pardubice, pp. 31-37, ISBN: 80-7194-793-8*
8. ISO 2846-1, 1997, *Graphic technology - Colour and transparency of ink sets for four-colour-printing - Part 1: Sheet-fed and heat set web offset lithographic printing*
9. ISO 12647-1, 1996, *Graphic technology - Process control for the manufacture of half- tone colour separations, proof and production prints - Part 1: Parameters and measurement methods*
10. ISO 12647-2, 2004, *Graphic technology - Process control for the manufacture of halftone colour separations, proof and production prints. Part 2: Offset lithographic processes*
11. ISO 13655, 1996, *Graphic technology - Spectral measurement and colorimetric computation for graphic arts images*
12. Liang H., Saunders D., Cupitt J, and Benchouika M., (2004), *A New Multi-spectral Imaging System for Examining Paintings. Proc. of the 2004 CGIV Conference*



How to linearise a multispectral printing system for graphic arts uses?

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Abstract

This paper analyses two linearization methods for a prototypical multi channel inkjet printer. First a multi spectral printing system is explained and set up. This is followed by an introduction to conventional linearization methods of the graphic arts industry. Next, various halftone screens, featured by the modified 7-channel Epson printer used in this study, are examined in conjunction with the pertinent linearization method. Finally, the two linearization methods are evaluated with respect to the spectral accuracy as judged by the Yule-Nielsen modified spectral Neugebauer model (YNSN).

1. Introduction

Linearization processes have been used for decades to set up analogue and digital imaging devices. A good example of such devices are the proofing systems that the graphic arts industry has demanded a great deal from. Therefore these systems have to satisfy very tight requirements. The linearization method, as an integral part of the overall imaging characterization, has to address many needs. For example, it must be very flexible with respect to substrates and inks. With respect to multispectral printing new aspects come into play.

Multispectral printing as considered here is a multi channel ($n > 4$) reproduction of object colours using a digital printing process and having a lower degree of metamerism. In brief, multispectral printing can help to address two unresolved issues in proofing. On the one hand proof prints exhibit a certain amount of colour inconstancy, to be seen clearly when inspecting a proof under different light sources. On the other hand there is a degree of metamerism (illuminant and observer) between the proof and the original that critical customers object to. Both issues could be much improved by using spectral reproduction, in this context considered as the goal of Multispectral Printing. If a proofing system incorporates a high degree of spectral variety one can choose the most colour constant spectra. It should be noted that multispectral imaging is capable of solving many more purposes [1, 2].

Beyond academic use, Multispectral Printing is becoming increasingly interesting for practical implementations in the graphic arts. More and more desktop inkjet printers are capable of printing 7, 8 or even 12 different inks. Generally the additional ink cartridges are filled with diluted cyan, magenta or black inks in order to get a smooth rendition of vignettes and other transitions. Using state of the art out-of-the-box refill products is becoming practical filling up individual inks. Having an inkjet-printer capable of printing dye- and pigment based inks one has an enormous degree of flexibility for setting up a printing system with primaries designed for Multispectral Printing. The linearization method used in this process sets the cornerstone for the setup and plays a substantial role in the overall quality of the multi spectral printing system.

2. Multispectral printing system

Generally speaking a multispectral printing system is based on a conventional digital printing system comprising a printer, appropriate software for driving and controlling the printer and suitable combinations of substrates and inks. The substantial difference is the number of channels used for printing and the aim of spectral reproduction. A multispectral printing system has more than four channels disregarding the diluted inks.

A printer, which is used for multispectral printing, must be very stable. The colour differences apart from lacking homogeneity or short- or long-term repeatability must be as small as possible. In this study an Epson Stylus Pro 7600 has been chosen because of its ability to print both dye-based and pigmented inks. Further selection reasons have been the printing resolution, the excellent registration, the possibilities to add refillable ink cartridges and a convenient and efficient print head cleaning routine.

Usually printing systems are sold with a software driver for Windows and sometimes the Macintosh OS. This driver mostly features sophisticated transformations from RGB-data to the printer channels, known as RGB drivers, for different papers of interest. Some models additionally have a CMYK version in order to bypass the before-mentioned transformation. Nevertheless there is no control of the ink limit, the gradation or the halftone model used; let alone the amount of the diluted inks. Here special proofing RIPs offer distinct advantages. They offer different means for limiting inks and adjusting the gradation in order to achieve a high quality colour transform (e.g. an "ICC printer profile") between the driving values and the resulting tristimulus values. However they hardly give direct access to the individual printing channels because they mostly use the halftone model provided by the printer vendor. Therefore special software is used in this project to control each of the printing channels individually.

The next player for Multispectral Printing is the substrate. Because of unwanted complexity regarding optical brighteners a Schoeller proofing paper (H74261) with no optical brighteners in the ink receiving layer is used. It is a semi-gloss paper having a TAPPI-gloss of 60% and an ISO brightness value of 92.3%. Further aspects such as light fastness, colour bleed, coalescence and ozone fastness are excellent, e. g. measured according to ISO 12647-7 [3]; the coming digital proofing standard.

At this time of the project there are several ink sets to choose from. In the present paper both an out-of-the-box ink set from MIS is used. A comprehensive analysis how to select the proper ink for multispectral printing can be found in [4]. Having individual control over the printing system it is indispensable for operating the inkjet systems in a controlled environment. This was done by the means of a controlled temperature (23°C) and humidity (50% r.h.).

From pixel to nozzle

Nowadays printers meeting the needs for multispectral printing mostly offer multilevel printing incorporating a minimum of 7 channels and a variety of print modes. In this paper direct access to the different printer channels is assumed in order to bypass the halftone model that is usually used to handle to conversion from pixel to nozzle. The halftoning used in this paper therefore must convert multi channel continuous tone values into a multilevel-multichannel bitmap followed by the nozzle-mapping utilized by the printer.

Generally the first parameter of an inkjet system with respect to halftoning is the so-called addressable resolution. Nowadays printers are able to print up to a resolution to 2880 dpi horizontally as well as vertically. The choice of resolution leads to a trade-off between quality and time; to be considered mostly within high-level production environments. Knowing this, the process of halftoning the images can be

done by a multitude of ways, e.g. utilizing a Floyd-Steinberg error diffusion halftoning algorithm or a modification thereof. In this stage of the process it must be known whether printing binary or multi-level wise. In the latter case the halftoning must cope with different planes, usually four levels, for each colorant. Nowadays there are different drop sizes (multiple dot levels) available, commonly ranging from 2 pico litre (pl) up to 20 pl often called "Micro Dot", "Normal Dot" and variations thereof. It's possible to process each plane separately with a single-plane halftone algorithm, but optimizing multiple planes at once can improve quality. Having the binary information for every dot within the halftone grid of the particular printer setup there are again many ways to jet the ink onto the paper; this is often considered nozzle masking.

The next aspect is the printing direction, namely unidirectional and bidirectional printing. While the first one uses only a single pass for jetting ink on paper the bidirectional printing mode splits printing time into equal periods which use the left-right and right-left direction. However, the latter method is rarely used for high quality reproduction. This is mainly due to the fact that a different lay down order of the inks, may result in slightly different overprints. Many inkjet printers use multiple passes to achieve full resolution. In the case of a 2 pass print-mode every second nozzle jets the ink on the paper leading to a improved ink-drying behavior needing twice the time; more passes working accordingly. To mitigate banding, these passes are finely interwoven. The resulting "weaving" patterns are of high spatial frequency and are thus rarely visible. Though a printer firmware offers a variety of mostly proprietary print modes in order to optimally address non-square aspect ratios, interaction between dither microstructure and weaving patterns, multilevel dot generation, processing speed, as well as interactions between microstructures in overlapping planes. These have to be tested manually by means of visual assessment to be described later. A negative example for the interaction between the halftoning and the used print mode can be seen Fig.1.

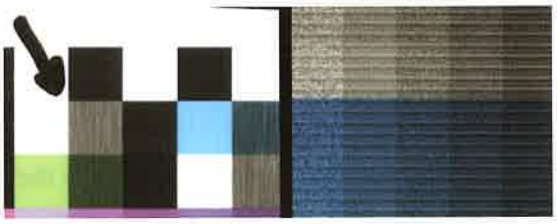


Fig. 1: Left: Example of a bad interaction between halftoning and print mode used; Right: typical banding structure

3. Ink limitation

Before concentration on the relationship between input tone values and the corresponding a ink limitation has been set up. There are many reasons not to print 100% of each channel in order to achieve the outer limit of the colour space. The predominant one is called "hooking". This means that the more ink of one colorant channel hits the paper the resulting trajectory in the CIE a*b* plane get more and more curved; like a hook. Another reason is the missing modulation reaching at a certain amount of ink.

Depending on the optimization criteria there are several ink limits of interest. For digital proofing one will have the closest value to a well-known aim to be simulated, e.g. the primaries of the ISO offset printing standard. Photo printing on the other hand is looking for the largest colour gamut. Having a multispectral printing system the one-dimensional ink limitation turns out to be not sufficient. Overprints incorporating three and more inks will end up printed very dark. The colorant space would therefore be populated very irregularly and inconsistently concentrating around very dark reflectance spectra, let alone the measurement noise. One downside hereby is the ill-posed situation for numerical

iteration methods like quasi-Newton [5] or Newton-Raphson, which tend to be very dependent on the starting values when optimizing in this "black hole". The second one is the reduced degree of spectral variability one will get when not limiting the ink load.

In order to address this problem a multilinear approach has been introduced. An m-channel desktop printer comprise 2m numbers of neugebauer primaries, defining approximately the spectral gamut to be printed with this system. Assuming that the set of valid tone value combinations is bounded by valid neugebauer tone values, a test chart was created comprising $2m^{-1}$ ramps starting at paper white (for a 7-channel printer: $\Psi_0 = \Psi_{paper} = [0,0,0,0,0,0,0]$) and reaching to all of the neugebauer primaries. Each ramp can be written as follows $W_i^j \times \Psi_i$, where Ψ_i, i =1, …, $2m^{-1}$ are the tone values defining the neugebauer primaries (except paper-white) and $W_i^j = j/N$, j=0, …, N are factors defining the subdivision of the ramp. This target has to be printed without any correction in the printer driving software (RIP). After an appropriate drying time of approximately 30 minutes the test chart has to be measured. The next step is the determination of a reasonable value for the maximal acceptable ink limit for each neugebauer primary. These $2m^{-1}$ ink limiting factors Wilimit can be obtained visually considering effects like ink blots or using measurements. For the latter procedure the smallest values Wij can be found by several means e.g. the point above them the densities of the ramp colors do not increase any more. The ink-limiting factors Wilimit fulfilling this criteria could than be stored at the pertinent grid point in a multidimensional array serving as a limit for all tone values going toward the pertinent neugebauer primary. E.g. for the neugebauer primary $\Psi_{127} = [1,1,1,1,1,1,1]$ the ink limiting factor $W_{127}^{limit} = 0.4$ was found to be a tone value combination of $W_{127}^{limit} \times \Psi_{127} = [0.4, 0.4, 0.4, 0.4, 0.4, 0.4, 0.4]$ and a tone value sum of 280 %. The appropriate grid point therefore hosts the value $W_{127}^{limit} = 0.4$. The multilinear ink limitation method can be compared with the neugebauer equations themselves where every grid point (neugebauer primary) holds a weight (e.g. the CIEXYZ tristimulus values). This similarity can be clearly seen in the equation 1 illustrating this approach:

$$\psi_{Limit} = \left[\sum_{i=1}^{2^m-1} a_i(\psi) \cdot W_i^{limit} \right] \cdot \psi \qquad (1)$$

where Wilimit is the ink limitation value for each ramp, a_i represents the demichel equation, m stands for the number of inks and Ψ refers to the tone values.

Visual assessment

Once the ink limit is set for each channel the remaining range between the paper and the solid has to be taken into account. Beside the colour accuracy the smooth rendition of vignettes or gradients is of major interest; sometimes more important than colour. In order to achieve that goal the specific dot placement, discussed in the last section, must be wisely selected. A final assessment can be done by systematically scrutinising all the given printing modes with an appropriate test form. One is depicted in Figure 2.

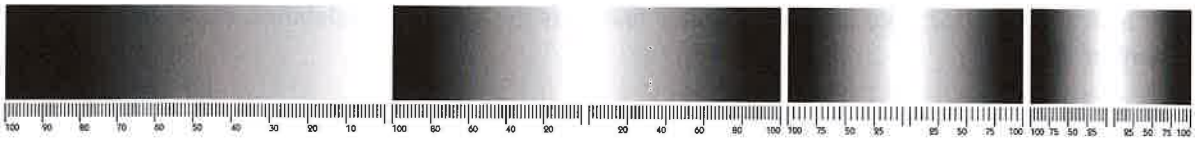


Figure 2: Test target for checking the smooth rendition of gradients (primary ramps in this case)

This approach usually yields reasonable results meaning that no banding or solarisation remains. Sometimes it may be necessary to even interfere into the printer halftone model. In this case the dot

placement as well as the dot size must be manually ascertained for all tone values being on a primary ramp. This is a tedious and time-consuming work requiring access to the particular parts of the printer software. This is not evaluated in this study.

Comparing different linearization methods

The main reason for performing linearization process within an imaging system is to improve the final colour characterisation of the system while achieving visual uniformity. Different objective functions could be used for the individual colorant channels. In the graphic arts, linearization was sometimes used to make equal CMY tone values produce a neutral scale of even CIE L* spacing or variations thereof. Strictly speaking there are many ways to linearise a process as it depends on the unit or dimension to be linearized. For modelling the printing process it is inevitable that the linearization method is invertible because the backward model may need to use it's inverse. This is usually done by the means of one-dimensional look-up-tables (LUTs).

In this study the method using broadband densities and the Murray Davis model minimizing the unweighted RMS-error will be compared against each other. In addition further methods are described being subject to future analysis. In this experiment a spectral dataset, comprising representative samples for offset and gravure printing, as well as a framework for modelling and separating multispectral images has been selected [4, 6]. The test procedure is describe as follows:

1. Perform the multi-linear ink limitation.
2. Print and measure the primary ramps and the neugebauer primaries (using the weights from the previous step).
3. Setup the relationship between the input tone values and the corresponding output according to the pertinent linearization method (relationship between the tone values and the effective area coverage).
4. Conduct the multispectral separation of the spectral dataset (Yule-Nielsen value n is fix for all methods).
5. Convert the effective area coverage back to tone values (DC) and print the samples
6. Measure all the samples and perform a statistical analysis based on spectral and colorimetrical means [7, 8].

Proceed with Step 3

Broad Band Densities

In conventional printing broadband densities, defined in ISO 5-3, are used to setup a baseline for the printing process. This was done by the means of a densitometer or spectrophotometer measuring the pertinent densities (e.g. Status T or Status E). Hence these densities are firstly used to linearise the multispectral printing system. Colorant channels filled with inks as red, green or blue have been linearized with respect to the density giving the highest value.

Murray-Davies model (MD)

Murray first published a simple model to predict output density from input tone value. At the time instrumentation limitations required Murray to work with density. However, it is just as well possible to work with spectral reflectance:

$$R(\lambda) = a * R_{solid}(\lambda) + (1-a) * R_{substrate}(\lambda) \quad (2)$$

where R(λ) is the predicted spectral reflectance factor, Rsolid is the spectral reflectance factor of the solid ink, Rsubstrate is the spectral reflectance factor of the substrate and a denotes the tone value (effective area coverage). For example, if the spectral reflectance is accurately predicted by a specific tone value, that is referred to as the effective tone value ai. This is equivalent to selecting the best portion to scale the spectral reflectance factor of the solid such that is most closely matches the measured spectral reflectance. Tone value is always an estimated value and can be calculated using least square analysis as explained in [9]. This leads to the form:

$$a = \frac{(\vec{R}_{solid} - \vec{R}_{substrate})^T (\vec{R}_{measured} - \vec{R}_{substrate})}{(\vec{R}_{solid} - \vec{R}_{substrate})^T (\vec{R}_{solid} - \vec{R}_{substrate})} \quad (3)$$

where

$$\vec{R}_x = (R_x(\lambda_1), \ldots, R_x(\lambda_N))^T$$

[x = solid, substrate, measured], are discrete reflectances constructed by sampling the continues spectra at N equidistant wavelength in the visible range.

In future studies, further objective functions will be utilized to derive the tone value (effective area coverage), physically meaning the effective relative absorptance. Typical objective functions are the spectral RMS, ΔE_{ab} or ΔE00.

CIELAB coordinates

The coordinates or correlates of the CIELAB colour space constitute a fairly good uniformity. Using this approach the coordinate achieving the highest modulation is used. Mostly this has been CIE L* but for colours like yellow CIE C* does a better job. The last method analysed in the present paper is the so-called "minimum ΔE-method". This is the ΔE_{ab} between the paper and a given tint, divided by the delta ΔE_{ab} between the paper and the solid and seems to work well except when the Magenta exhibits hooking, as it sometimes does.

5. Results

It should be noted that these findings are based on the prototypical multispectral printing system set up in this study. In order to see the difference between the simulation, often used in the literature, and a real print out Table I depict both for the broadband density model. Comparing both models the broadband method performs better than the MD one. It can be clearly seen that both the linearization with respect to the broadband model as well as the Murray-Davies performs bad in comparison to today proofing systems. Here many reasons come into play whereas the halftone and screening failures shown in figure 1 might be the prominent ones.

6. Discussion and Conclusions

Focused on Multispectral Printing two conventional methods have been used for linearizing a prototypical multichannel printing system. It was found that the ink limitation as well as the visual assessment are prerequisites for linearizing a printing system. This is very important for iteration algorithms to minimize noise issued - especially if the ink.

The multilinear ink limitation used in this study turned out to be very effective and simple. Finally two typical linearization models used in the graphic arts have been introduced and evaluated by the means

of the spectral accuracy as judged by the YNSN model and the LRI method for separating the spectral dataset. At this early stage of the project it can be clearly seen that there are a lot of problems to face namely specialized inks, multichannel screening, different forward models, spectral separation, error metric and so forth.

Table I: Spectral and colorimetrical evaluation of the methods used in this study

Method	Mean ΔEab	Max ΔEab	95% Quantile ΔEab	Std of mean ΔEab among observers	Mean ΔE00	Max ΔE00	RMS		
							Mean	Std	Max
Broadband Density - Simulation	1.6	19.9	4.0	0.06	1.1	12.9	0.014	0.0106	0.063
Broadband Density - Measurement	10.3	34.8	10	0.15	7.1	34.8	0.0520	0.0133	0.1345
MD – min(RMS)	15.3	41.3	5.6	0.10	11.8	37.8	0.1328	0.0524	0.283

References

1. B. Hill: Color capture color management and the problem of metamerism (invited). In Proceedings IS&T/SPIE 12th Electronic Imaging Conf., Vol. 3963, San Jose CA, USA, 2000, pp. 3 - 14
2. R. S. Berns, L. A. Taplin, F. H. Imai, E. A. Day, D. C. Day: Spectral imaging of Matisse's Pot of Geraniums: A case study. In Proceedings IS&T/SID Eleventh Color Imaging Conference: Color Science and Engineering, pp. 149-153. Springfield, Va.: Society for Imaging Science and Technology
3. ISO 12647-7:2006: Graphic technology Process control for the manufacture of half-tone colour separations, proof and production prints; Part 7: Processes using digital printing or reproductions made on various traditional printing processes from digital files
4. A. Kraushaar: Practical Ink Selection for Multispectral Printing in the Graphic Arts Industry. In Proceedings of the European Conference on Color in Graphics, CGIV 2006, pp. 176. Springfield, IS&T
5. L. A. Taplin: Spectral Modeling of a Six-Color Inkjet Printer. Center for Imaging Science, RIT, Master Thesis, New York, 2001
6. P. Urban: Spectral-Based Color Separation using Linear Regression Iteration. In Color Research and Application, Vol. 31, 2006
7. Imai, F. H., M. R. Rosen, and R. S. Berns: Comparative study of metrics for spectral match quality. In Proceedings of the First European Conference on Color in Graphics, CGIV 2002, pp. 492-496. Springfield, IS&T
8. J. A. Stephen Viggiano: Comparison of Radiance Ratio Spectra: Assessing a Model's Goodness of Fit. Advanced Printing of Conference Summaries, SPSE's 43rd Annual Conference, 1990, p 222 - 225
9. D. R. Wyble, R.S. Berns: A Critical Review of Spectral Models Applied to Binary Color Printing. Color Research and Application, Vol. 25, 2000, pp. 4-19



Colour tolerances in contract proofing

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1. Introduction

The aim of proofing is to visualize beforehand how the final printed product, when printed in given press conditions, will appear. Proofing can be used to verify that there are no errors in the text or layout, and that the pictures and other colour elements are reproduced in a satisfactory manner. A contract proof accepted by the customer should give a sufficiently accurate indication of the final printed product. Here we are concerned with the correspondence of colours between a hardcopy proof and the print.

In the new soft-proofing systems proofs can be viewed and accepted on appropriately calibrated monitors. Hardcopy proofs, typically printed with ink jet printers, are still more widely used, however. It is recognized that due to a number of factors, such as differences in printing materials, it is very difficult, practically impossible, to always have a perfect colour match between the proof and the print. In this work the goal was to investigate colour tolerances for hardcopy contract proofing.

Currently there is no universal objective definition for the colour tolerances in contract proofing. Problems can arise when the customer, after having accepted the proof, is not satisfied with the print job, claiming that the colours are unacceptably far from those of the proof. In these cases the differences are mainly appraised visually, and it is difficult to come to any definitive conclusions since the arguments are based on individual subjective perceptions. An objective definition for the colour tolerances in contract proofing, based on instrumental measurements, would be helpful to all parties in clarifying cases of this kind. Such a definition could also be used as a target when deciding whether a given proofing system is capable of quality required for contract proofing.

The Ugra/FOGRA Media Wedge has been proposed as a solution to the aforementioned problems. It is likely to currently be the most widely used method for objectively validating digitally printed proofs. The Media Wedge CMYK Version 2.0 is a control strip consisting of 46 colour patches. The Media Wedge is meant to be included in proof layouts, and the colorimetric deviations of the colour patches of a contract proof, compared to the target values of the intended printing conditions, should not exceed certain limits in order for the proof to be a valid contract proof. Specifically, in the user's instructions of the Media Wedge the tolerance for average deviation of all colour patches is defined to be 4 ΔE units in the CIELAB colour space, and the deviation for any individual patch should not exceed 10 units (5 units for the primary colour patches). [Schmitt and Dolezalek, 2004]

However, there are known limitations to the performance of the 1976 CIELAB ΔE equation in predicting perceived colour differences, and despite recent research efforts and development of new colour difference equations many open questions still remain concerning the magnitude of large magnitude colour differences, acceptability of colour differences, and the perceived colour differences in spatially complex colour stimuli (such as typical photographic images). The 1976 equation was intended for predicting the perceptibility of colour differences of uniform colour patches seen side by side on a uniform gray background. The equation is based on the Euclidean distance of two colour stimuli in the CIELAB space. Because the CIELAB space is only approximately uniform, in practice equal ΔE values in different parts of the space do not correspond to perceptual colour differences of equal magnitude. Also, changes in the lightness, hue, or chroma directions have different significance

relative to one another in different parts of the space. Consequently, the perceptual importance of colour difference depends also on the direction of change in the CIELAB space. A number of revised colour difference formulae based on the CIELAB space have been proposed that incorporate different weightings in order to correct the aforementioned non-uniformities. The latest recommendation for industrial colour difference evaluation from CIE is the CIEDE2000 colour difference formula. Revisions like the CIEDE2000 and the previous CIE94 colour difference formula do indeed provide better agreement with certain perceptual data than the 1976 equation, although the number of independent perceptual colour scaling data sets is relatively small and the agreement between different data sets is not complete. [Kuehni, 2003]

In this text ΔE (without a subscript index) refers to colour differences calculated using the 1976 CIELAB colour difference equation. ΔE_{94} indicates values calculated by the CIE94 equation, and differences given by the CIEDE2000 formula are denoted by ΔE_{00}.

Stokes et al. (1992a, 1992b) examined the perceptibility and acceptability tolerances of colour differences in pictorial images shown sequentially on a CRT monitor in a darkened room. They found the perceptibility threshold for pictures to be around 2 ΔE units (calculated as the average over all image pixels), which is at least twice as large as the just noticeable difference for simultaneous comparison of uniform colour patches. The acceptability tolerance was approximately 6 ΔE units. The type of scene depicted in the picture did not have a significant effect on the perceptibility threshold in their experiments, but in the case of acceptability judgements some scene-dependency was evident. In a similar study, Song and Luo (2000) arrived at the tolerances of 2.2 of and 4.5 ΔE units for the perceptibility and acceptability, respectively, of colour differences between pairs of images shown on a CRT display. Their later study suggests that the tolerances are in the same range for printed images [Song and Luo, 2001]. The results of experiments carried out by Johnson and Green (2001), in which the perceived colour differences of uniform printed colour patches were evaluated, suggest that the acceptability threshold would be approximately 4 ΔE units for critical visual evaluation in graphic arts applications.

In this study perceptual colour tolerances in contract proofing for pictorial images were examined by means of psychometric scaling, and the perceptual scale values were compared to values given by colour difference equations, to see how closely they could predict the perceptual data. The psychometric experiments were carried out in order to establish a perceptual scale for a set of digitally printed proofs, the position of a given proof sample on that scale indicating the perceived distance of the proof from the appearance of a reference print sample. The experimental setup is described in section 2. The resulting perceptual scales are presented in section 3 and compared to colour differences calculated by formulas such as the CIELAB ΔE equation from the colour patches of the Media Wedge; the acceptability tolerance for colour deviations in contract proofing was located on the perceptual scale and mapped to the corresponding ΔE value. The implications of the results are further discussed in section 4, and the work summarised in section 5.

2. Experiments

As discussed in the introduction, in order to be useful in practice, an objective definition for contract proof quality would have to have a reasonably close correlation with subjective, perceived colour differences. Therefore appropriate psychometric scaling studies, described below in more detail, were first performed to investigate the perceptual tolerances for colour differences between proofs and prints. These experiments resulted in psychometric scales indicating the perceptual distances of the proof samples from the reference prints. The experiments also allowed the limit for maximum perceived colour difference acceptable for contract proofs to be located on the scale. Objective colour difference metrics (such as the CIELAB ΔE colour difference) calculated for the proof samples based

on spectrophotometric measurements of uniform colour patches included in the test sheets were then compared to the perceptual scale values, in order to find the objective value corresponding to the perceptual tolerance for contract proof colour differences.

Thirteen companies from the graphic arts industry participated in the study, providing the proof samples used in the experiments. The sheets in the Altona Test Suite (2003) were proofed using a number of systems, with various material and colour management parameter choices. 26 proofs simulating coated prints and 22 proofs simulating uncoated prints were produced. Three photographic images from the Altona Test Suite Application Kit were used as reference printed images to which the corresponding images from the proofs were compared visually in the psychometric experiments. The three pictures were a portrait of a woman, an assortment of colourful fruit on blue background, and a whitish egg next to a tree trunk (this low-key picture contained mostly brownish and greenish near-grey colours). Let the pictures be called *woman*, *fruit*, and *egg* for the purposes of this text. All sample pictures, the proofs as well as the reference prints were attached to a black cardboard backing. The cardboard was cut to the shape of the pictures, and was thus not visible around the edges of the picture.

A total of 33 observers took part in the experiments, all of them professionals from the graphic arts industry or related fields. All observers had normal colour vision, as tested before the experiments. The proof samples simulating coated and uncoated prints were evaluated separately in the experiments, each compared to their respective coated or uncoated reference print samples.

In all of the visual assessments the samples and print references were viewed under a light source simulating the D50 standard illuminant in a Just Normlicht Pantone Color Viewing Light booth. With the illuminance of approximately 2000 lux and gray background the viewing conditions fulfilled the requirements set in ISO 3664 for conditions P1 meant for critical evaluation of prints. The observers adapted to the viewing conditions for at least 90 seconds before beginning the experiments. Two kinds of psychometric scaling studies were carried out, the first one to form an interval scale in which the scale value differences between the proof samples would correspond to their relative perceived colour differences from the reference print, and the second one to specify the tolerance range for contract proofs on that scale.

In the first study a rank order experimental method was used. Eight proof sample images were placed in random order around the reference image (the print they were simulating). The observers were asked to indicate the proof that most closely matched the reference in colour. This sample was then removed and the task repeated for the remaining samples until all of them had been removed. The experimental data from this experiment thus comprised of ranking of samples (from 1 to 8) among each set evaluated. A total of 141 sets of eight proof samples were judged (47 for each of the three pictures). The samples comprising each set of eight were randomly selected, and each sample thus appeared in the same set approximately equal number of times with each of the other samples. The experimental setup is shown in Figure 1.

The following instructions were read to the observers before starting the experiment (translated from Finnish):
"*There are 9 image samples in front of you. The picture in the middle is a reference to which the 8 test pictures surrounding it are to be compared. Choose the test picture that best matches the appearance of the reference picture. When you have indicated your choice it will be removed. Then choose the best match to the reference among the remaining test pictures. This will be repeated until no test pictures are left. Note that you should evaluate the similarity of the test pictures to the reference, the choices should not be based on how pleasing the test pictures appear.*"

The aim of this experiment was to estimate the perceived difference between each proof sample and the corresponding reference print. The interval scale derived from the results of this experiment is presented in section 3.



Figure 1: Setup for the rank order experiment. During the actual experiments the surroundings of the light booth were covered with matte gray cardboard

The second psychometric experiment used a category scaling method. The observers compared the proof samples one by one to the print reference, and assigned each sample to one of the three categories labelled as: (1) Excellent proof, (2) Acceptable contract proof, and (3) Not contract proof level. All the observers were familiar with the concept of contract proof. The proof sample being judged was placed below the reference in the light booth. The observer instructions, again translated here from the original Finnish instructions, were:

"*Your task is to compare the given proof samples to the printed reference picture one at a time. Assign each proof sample into one of the three categories based how closely its colours match the appearance of the reference print. The three categories are:*

Category 1: Excellent proof. *The difference between the colours of the reference print and the proof is not noticeable or is just barely noticeable.*
Category 2: Acceptable contract proof: *There is a noticeable difference between the reference print and the proof, but the difference is small enough to be still acceptable for a contract proof.*
Category 3: Not contract proof level. *The proof differs significantly from the reference print, and is not acceptable as a contract proof.*"

This category scaling experiment complemented the rank order experiment, making it possible to locate the boundaries between each category on the interval scale, as described below in section 3. The rank order study by itself does not indicate acceptability of differences, and the category scaling experiment by itself does not necessarily yield a scale with perceptually meaningful intervals.

The spectral reflectance curves were measured from the Media Wedge colour patches in the reference print sheets and the proofs. CIELAB colour differences were calculated between each proof and the reference print that the proof simulated; these are compared to the distances on the perceptual scales in section 3. Black backing was used also in these instrumental measurements, in keeping with the backing used for picture samples presented to the observers.

3. Results

From the combined rank order results experimental proportions for each pair of samples were calculated, based on how many times sample A was ranked higher than sample B (and thus assessed to better match

the reference). These experimental proportions were treated as proportions resulting from a paired comparison experiment, and Thurstone's Law of Comparative Judgement, Case V was applied to the experimental data to derive an interval scale for the perceived colour differences of the samples. The Law of Comparative Judgement is based on the assumption that the observers' judgements follow a normal distribution. The distances on the perceptual scale are estimated in the units of standard deviates, z, derived from the pair-wise experimental proportions between samples. The scale values (z-scores) represent the perceived distance from the reference, the sample with the highest scale value being closest in appearance to the reference, similarity decreasing with decreasing scale value. Since there were unanimous judgements for some of the samples (zero-one proportions indicating that there was no confusion between observations for these samples) Thurstone's law could not be directly applied. There was, however, sufficient confusion between neighbouring samples throughout the range from the best to the worst proofs so that an interval scale could be derived by using Morrisey's least squares solution. Thurstone's law and Morrisey's least squares method are described in more detail by Engeldrum (2001).

In Figure 2 the interval scale values are shown for the 26 proofs simulating coated prints, calculated separately from the judgements of each of the three pictures. Figure 3 depicts the corresponding scale values for the 22 proofs simulating uncoated prints. In both cases the results are similar for all three pictures, most picture-wise differences being insignificant compared to the relatively large spread of scale values between different proofs. Such was the case also for the results of the category experiment (not plotted here). Therefore interval scale values calculated from the combined judgements of all three pictures are used in the following analysis.

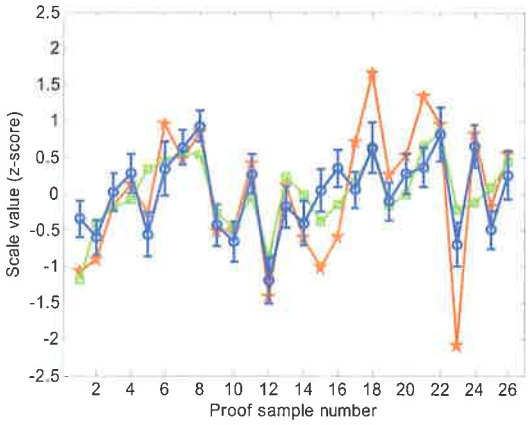


Figure 2: Interval scale values (z-scores) for proof samples simulating coated prints. Scale values for the picture woman *are marked with circles, scale values for* fruit *with squares, and scale values for* egg *with stars. 95% confidence intervals for scale value differences are shown for the* woman *samples*

An ordinal scale for the samples was derived by simply calculating the average of category values assigned to each sample. As stated earlier, the main purpose of this experiment was to locate the transition point from acceptable to unacceptable contract proofs in the scale derived from the rank order experiment. The ordinal scale derived from the category experiment cannot by itself be assumed to indicate the relative perceptual distances between the samples as accurately as the interval scale.

By comparing the scales from the two experiments the acceptability tolerance for contract proofs could be set in the interval scale, as shown in Figures 4 and 5 for proofs simulating coated and uncoated prints, respectively. Despite the less rigorous analysis involved with the second experiment the two scales were in close agreement with one another, the order of samples on both scales being similar, which supports the validity of the results. The acceptability tolerance was set at the point where the average category for samples in the second experiment was 2, and this point was mapped to the interval scale from the first experiment, as indicated by the dotted lines in Figures 4 and 5. The

proof samples included in the experiment and the corresponding proofing systems and setups they represented were thus located on a perceptual interval scale with an acceptability limit for contract proofs. Slightly less than half of the proof samples fell within the tolerance range for contract proofs. It should be noted that some of the proofs were experimental in nature, with unusual ink/paper combinations, and therefore the data does not entirely reflect the performance of proofing systems actually used in the industry.

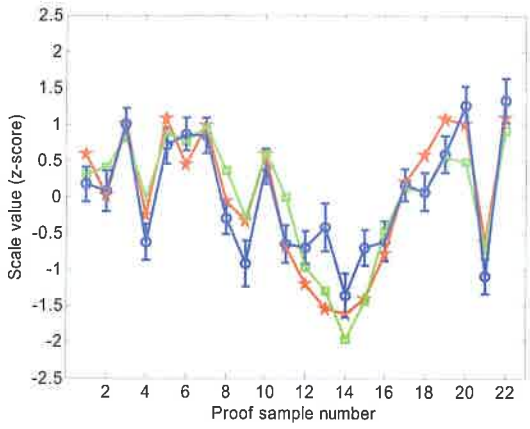


Figure 3: Interval scale values (z-scores) for proof samples simulating uncoated prints. Scale values for the picture woman *are marked with circles, scale values for* fruit *with squares, and scale values for* egg *with stars. 95% confidence intervals for scale value differences are shown for the* woman *samples*

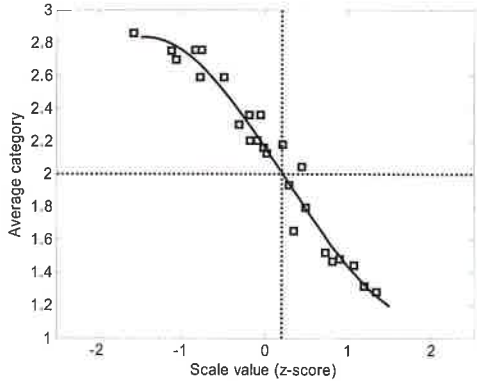


Figure 4: Average category versus interval scale values for the proof samples simulating coated prints

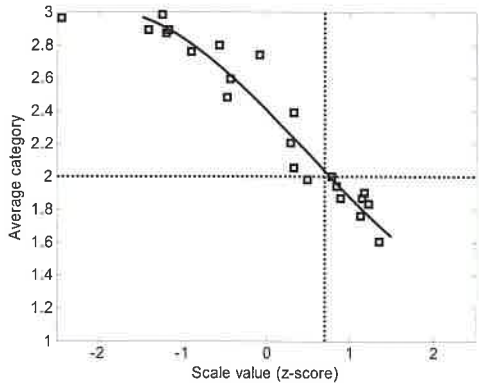


Figure 5: Average category versus interval scale values for the proof samples simulating uncoated prints

The average CIELAB ΔE values calculated between the Media Wedge patches of the proofs and the reference prints are compared to the perceptual scale values in Figures 6 (proofs simulating coated prints) and 7 (proofs simulating uncoated prints). Some proofs simulating uncoated prints with large colour differences (average ΔE between 10 and 20) were excluded from the analysis and the graph of Figure 7. The error bars again depict the 95% confidence intervals for the scale value differences. The solid line fitted to the data has a negative slope, since higher scale values indicate perceptual similarity to the reference print while increasing ΔE naturally predicts increasing colour difference. Although there is considerable spread in the data, the correlation coefficient r = - 0.62 between the ΔE's and the psychometric scale values for proofs simulating coated prints still indicates significant negative linear correlation between the two. The linear correlation is slightly stronger for proofs simulating uncoated prints, with correlation coefficient r = - 0.77. Using the line fitted to the data, the previously established acceptability threshold was mapped from the psychometric scale to the corresponding average ΔE value, as indicated by the dotted lines. This resulted in ΔE acceptability tolerances of approximately 5 and 4.4 for the proofs simulating coated and uncoated prints, respectively.

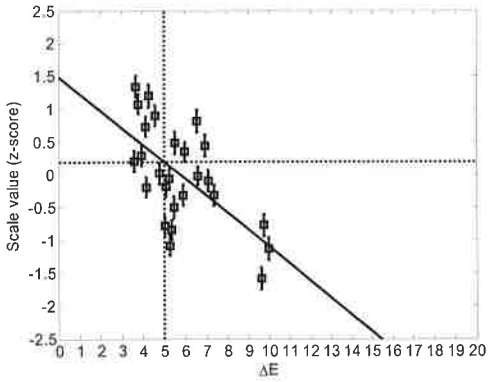


Figure 6: Interval scale values versus CIELAB ΔE for the proof samples simulating coated prints

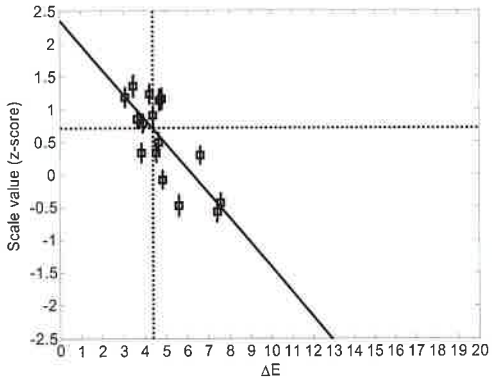


Figure 7: Interval scale values versus CIELAB ΔE for the proof samples simulating uncoated prints

Average colour differences were calculated between the Media Wedge patches in the proofs and prints also using the CIE94 and CIEDE2000 formulas, and compared to the perceptual scale values in the same way as the CIELAB 1976 ΔE values above. Figure 8 shows the graph for the ΔE_{94} and scale values of proofs simulating coated prints and Figure 9 for ΔE_{00} and scale values of proofs simulating coated prints. The spread of data around the lines and the correlation coefficients of r = - 0.58 (CIE94) and r = - 0.59 (CIEDE2000) for proofs simulating coated prints and r = - 0.74 (CIE94) and r = - 0.76 (CIEDE2000) for proofs simulating uncoated prints, indicate that the performance of all three colour

difference formulae was very similar in predicting the perceived colour differences between the proofs and prints. The acceptability threshold for both CIE94 and CIEDE2000 was around 3 units, as indicated by the dotted lines in Figures 8 and 9.

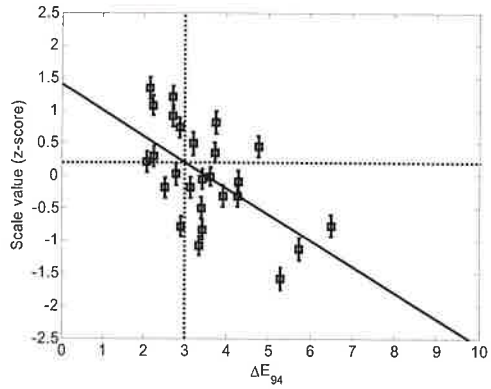


Figure 8: Interval scale values versus ΔE_{94} for the proof samples simulating coated prints

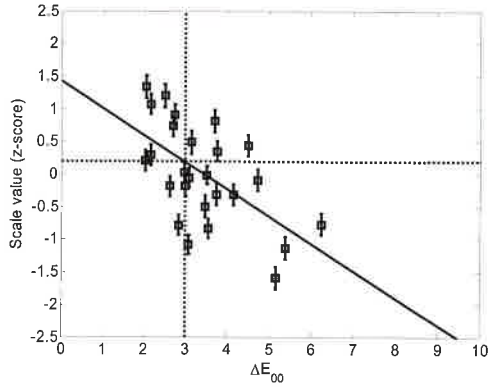


Figure 9: Interval scale values versus ΔE_{00} for the proof samples simulating coated prints

4. Discussion

The results described above are not surprising, and are in line with earlier studies. As stated in the introduction, based on measurement and visual evaluation of printed patches of uniform colour, Johnson and Green (2001) suggested that an acceptability threshold of 4 for the standard 1976 CIELAB colour difference, or 3 when either the CIE94 or the CIEDE2000 formula was used, would be appropriate for graphic arts. Our results with pictorial images support the use of approximately same average colour difference values, 4 or 5 ΔE units, as acceptability thresholds in contract proofing. This tolerance value is in the same range as the average acceptability tolerance found in other studies of colour reproduction of pictorial images [Stokes et al., 1992a, 1992b; Song and Luo, 2000, 2001]. 4 ΔE units in the CIELAB colour space is also the tolerance for average deviation of all colour patches given in the Media Wedge user's instructions [Schmitt and Dolezalek, 2004].

It should be noted, however, that the correlation between the average ΔE of the Media Wedge patches and the perceptual scale for colour differences of pictorial images in the proofs, although significant, was far from perfect. This was also an expected result, as there was no reason to expect that any colour difference equation intended for predicting perceived colour differences in uniform colour fields could

precisely predict the perceived difference in pictures. CIE94 or CIEDE2000, being likewise designed for uniform colour fields, did not appear to offer any advantage over the 1974 equation in this respect.

Direct colorimetric measurement of images by scanner-based methods, although more difficult and cumbersome to use and implement in practice, would make it possible to apply new kinds of algorithms for image difference evaluation, to also take the context and spatial properties (size, shape, background, etc.) of colour elements into account. S-CIELAB (spatial CIELAB) is an example of an algorithm that combines spatial filtering to colorimetric differences, in order to better predict the perceived differences between images [Zhang and Wandell, 1996]. The iCAM framework, combining colour appearance and spatial vision modelling, could also be applied to image difference evaluation [Fairchild and Johnson, 2004]. Morovic and Sun (2002) showed how improved predictions of perceived colour differences in images could be achieved by taking into account certain parameters based on the colorimetry of the two images being compared.

It should also be noted that none of the algorithmic methods mentioned above take into account the content of the image, as interpreted by the human observer. Especially when dealing with the acceptability of colour differences that are well above the perceptibility threshold, the dependency of the acceptability tolerance on the content of the scene shown in the picture is likely to increase. For example, greenish skin-colour reproduction would likely be more objectionable to most observers than a reddish reproduction, even if the colour differences were equally perceptible. Our category experiment results showed only slight scene-dependency of the acceptability of colour differences, however. The fruit picture generally received slightly better scores (lower average of category numbers) than the woman and egg pictures from the same proof sheet. This could indicate more critical judgement of the colour differences in the skin tones in the woman picture and the nearly neutral, brownish grey colours in the egg picture, but could also be partly due to possibly greater variation in the reproduction of the mid-tones (mid-tones occur more frequently in the woman and egg pictures than in the saturated fruit picture). (Note that unlike in most other studies the type of colour difference was not systematically varied in this case.) The scene-dependencies were in most cases insignificant, however, and analysis of the judgements for any one of the three pictures individually would not have resulted in an acceptability threshold appreciably different from the one that was calculated from the combined judgements. Acceptability may have a significant scene-dependency for certain types of colour differences in individual cases, however, even though the average effect was found to be relatively small in these experiments.

Summing up the above considerations, average deviation of 4 ΔE units measured from a test target such as the Media Wedge can be taken as an appropriate acceptability threshold for contract proofing, and it should guarantee that the differences between the prints and proofs remain within acceptable tolerances, *on average*. Simple average ΔE, however, cannot predict the visual effect of complex interactions between the type of colour variations, scene content in pictorial images, and the interpretation of the scene and its colours by the observer, and therefore subjective perception of acceptability may differ in individual cases, even if the value of the ΔE metric is in the same range. From the practical point of view, validation of proofs by instrumental colorimetric measurement of an appropriate test target is still the most straightforward method, and despite the shortcomings discussed above, simple average ΔE seems to be the best choice currently available for defining objective tolerances for contract proofing by a single figure.

5. Conclusions

Acceptability of colour differences in contract proofing was studied by psychometric experiments involving subjective visual judgements of pictorial images. A perceptual scale of colour differences between proofs and reference prints was compared to colour differences calculated from measurements

of colour patches included in the proofs and prints by three colour difference formulas based on the CIELAB colour space. Based on this comparison, an appropriate tolerance for average colour deviation of the colour patches in contract proofing was found to be approximately 4 units when the 1976 CIELAB colour difference formula was used, or 3 units for either of the CIE94 or CIEDE2000 formulas. Significant but incomplete correlation was found between the perceptual differences between the proofs and prints and the average colour difference values given by the three formulas, suggesting that the average colour difference value can be used as a guideline in judging the validity of a proof but cannot be expected to precisely predict perceived acceptability of colour differences in individual proofs containing pictorial images. No significant differences were found between the performances of the three colour difference formulas in predicting the perceived differences in images.

References

1. Altona Test Suite Application Kit (2003), *Documentation*. http://www.altonatestsuite.com/
2. Engeldrum, P. G. (2001), *Psychometric Scaling: A Toolkit for Imaging Systems Development*, Imcotek Press
3. Fairchild, M. D., Johnson, G. M. (2003), *The iCAM framework for image appearance, image differences, and image quality*, Journal of Electronic Imaging, Vol. 13. p. 126-138
4. ISO 3664:2000, *Viewing Conditions-Graphic technology and photography*, ISO
5. Johnson, A. J., Green, P. J. (2001), *The CIEDE2000 colour difference formula and its performance with a graphic arts data set*, Advances in Colour Reproduction: 28th Conference of IARIGAI, Montreal, Canada
6. Kuehni, R. G. (2003), *Color Space and Its Divisions: Color Order from Antiquity to the Present*, John Wiley & Sons, Inc
7. Luo, M. R., Cui, G., Rigg., B. (2001), *The Development of the CIE2000 Colour-Difference Formula: CIEDE2000*, Color Research and Application, Volume 26, Number 5. p. 340-350
8. Morovic, J., Sun, P.-L. (2002), *Visual Differences in Colour Reproduction And Their Colorimetric Correlates*, The Proceedings of the 10th IS&T/SID Color Imaging Conference, p. 292-297
9. Schmitt, U., Dolezalek, F (2004), *UGRA/Fogra Media Wedge CMYK V2.0: Instructions for use* http://www.mediawedge.com
10. Song, T., Luo, R. (2000), *Testing Color Difference Formulae on Complex Images Using CRT Monitor*, The Proceedings of the 8th IS&T/SID Color Imaging Conference, p. 44-48
11. Song, T., Luo, R. (2001), *Colorimetric Thresholds for Printed Images*, The Proceedings of the 9th IS&T/SID Color Imaging Conference, p. 219-223
12. Stokes, M., Fairchild, M. D., Berns, R. S. (1992a), *Precision Requirements for Digital Color Reproduction*, ACM Transactions on Graphics, 11(1992)4, p. 406-422
13. Stokes, M., Fairchild, M. D., Berns, R. S. (1992b), *Colorimetrically Quantified Visual Tolerances for Pictorial Images*, TAGA/ISCC Proc., Vol. 2, p. 757-777
14. Zhang, X. M., Wandell, B. A. (1996), *A spatial extension to CIELAB for digital color image reproduction*, Proceedings of the SID symposium 27. p. 731-734

Print quality evaluation and applied colour management in heat-set web offset

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Abstract

This paper aims to investigate print quality in heat-set web offset by applying colour management. In particular it looks at the colorimetric properties of five heat-set web offset presses in order to evaluate the appropriate colour separation approach, either by applying individual separation profiles or by using industry standard profile such as ISOwebcoated.icc. The key method underlying the work described here relies on obtaining colour measurements to determine the repeatability of each participant in terms of colour differences. Furthermore the variation between the five heat-set web offset printing processes and the variation according to the colorimetric values of the ICC profile "ISOwebcoated" are important parts of the quantitative evaluation. According to the colour measurements two custom ICC profiles were generated and applied to four test images, which were printed of the five heat-set web offset presses in a second test run. Furthermore the industry standard ICC profile "ISOwebcoatd" was applied too. A psychophysical experiment was carried out to determine naturalness of the reproductions made according to the three profiles applied. Finally the results of the study indicate the performance of the appropriate profile applying to the five heat-set web offset presses to obtain significant best print quality.

Keywords

Colour management, colour measurement, print quality assessment, process control, psychophysical methods

1. Introduction

Although process control for the production of half-tone colour separations, proof and production prints are clearly defined in ISO 12647-2:2004 often printing processes show major variations, which affect the appearance of print. Essentially, there are two different approaches considering printing press convention, namely optimized or standardized press behaviour. A fully optimized press is all about maximizing its capability in terms of lowest possible dot gain, highest ink densities and best contrast the individual printing press can achieve without regards to any external specifications or standards. Such individual parameters can create unique press condition, which requires custom ICC profiles to create the appropriate separations. Another approach is to make the press conform to a certain reference or standard such as ISO 12647-2:2004. By using the second approach and by standardising the behaviour of the press industry standard ICC profiles can be used.

Recently, five of the largest Norwegian heat-set web offset printing plants started a collaboration to evaluate their common print quality and print control to strengthen their position in the heat-set market. Due to the print-on-demand concept, parts of a total publication edition can be printed in different print locations. However, the appearance of the total print edition must be identical. Therefore the variations of the five heat-set web offset printing plants had to be verified to determine the appropriate adjustments. The project is named "webicc" and the five participants are AllerTrykk, Hjemmet Mortensen Trykkeri (HMT), Aktietrykkeriet, Norprint and Ålgård.

The aim of the presented work is to evaluate five heat-set web offset printing presses in terms of their conformance to specified values, in accordance with the requirements of ISO 12647-2:2004.

Furthermore, the assessment of each individual printing press and the variation within the five participants are important parts of this study, in order to evaluate the appropriate colour separation approach, either by applying individual separation profiles or by using industry standard profile such as ISOwebcoated.icc. In order to obtain the defined goals, the "webicc-group" in collaboration with the Norwegian Color Research Laboratory has carried out this print quality project.

The next section of this paper will introduce the experimental method used for evaluating the print quality. Then the data analysis performed on the experimentally obtained data will be described, followed by a presentation of the results. Finally the implications of the results will be discussed and ideas will be suggested for future work.

2. Research method

Various studies and research have been done in the field of print quality and repeatedly it has been concluded as a very complex issue. The subject has been discussed at various conferences [see e.g. Hardeberg and Skarsbø, 2002; Nussbaum *et al.,* 2004].

Principally there are two different approaches to assess image quality. The first approach is by measurement, using instruments to determine values for the various quality factors. The second method is based on observation, using psychophysical experiments to gather the judgement of human observers. For instance, the pair comparison method is a robust approach where observers are asked to compare the perceptual magnitude between two stimuli (or pairs of stimuli). This method is based on Thurstone's «law of comparative judgement» [Handley, 2001; Gescheider, 1985].

Considering the print quality evaluation in this study both methods have been applied, using quantitative analyses based on colour measurements and psychophysical experiments (Figure 1).

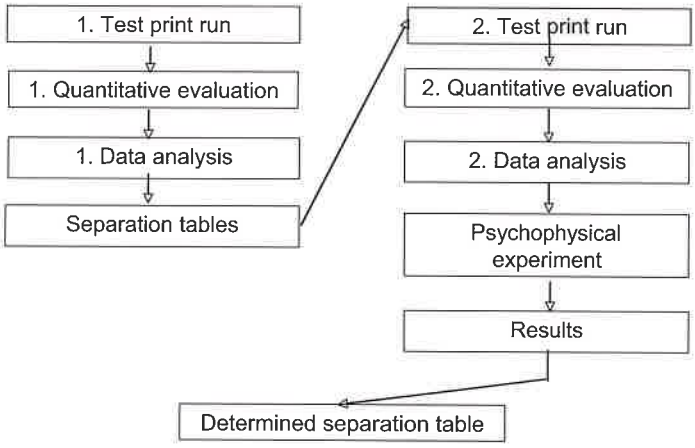


Figure 1: Overview of method

2.1 Quantitative evaluation

The purpose of the following test is to determine the print run repeatability of each participant of the "webicc" project. Furthermore the variation between the five heat-set web offset printing processes and the variation according to the colorimetric values of the ICC profile "ISOwebcoated" are important parts of the quantitative evaluation. Hence, the characterization test target ECI2002 was used in this work. As seen in Figure 1 two test print runs with four months interval were carried out in

this project. The colour measurement data from the first test print run were the source to generate two custom printer profiles, which were applied in the second test print run.

Considering the substrate, a paper manufacture supplied all the participants with the appropriate paper, type 3, 70 g/m^2. The ink set colours used in the test was supplied by two manufacturers according to ISO 12647-2:2004. The colour measuring conditions were according to ISO 13655:2000, geometry 45/0, 2°observer, CIELAB system. For documentation all measuring were made on white backing. Considering colour difference calculations ΔE^*_{ab} values were computed between individual measurements and the "ISOwebcoated" colorimetric values. The arithmetic mean, standard deviation and maximum of the resulting colour difference distributions were then computed.

The quantitative evaluation has been achieved on the basis of data gathered in an experiment involving colour measurement. The Short-term repeatability performance of the measuring instrument (GretagMacbeth Spectrolino) has a mean ΔE^*_{ab} of 0,02 (10 measurements at 10 sec. interval on white). Hence the instrument can be considered to have a high degree of repeatability. The mean repeatability error of the reference measuring set-up was ΔE^*_{ab} of 0,17 (equal test print measured two times).

2.2 Psychophysical experiment

The aim of the psychophysical experiment was to determine naturalness of the reproductions made according to different web coated prints. As a result of the colour measurements of the first test run two ICC profiles were generated, namely, "webicc" and "custom". Consequently the psychophysical experiment was carried out according to the test prints of the second test print run. In addition to the two custom profiles the "ISOwebcoated" ICC profile was applied to each test image and printed in the five hest-set web offset printing plants. The properties of the three applied ICC printer profiles are:

- ISOwebcoated: Based on the offset characterization table "FOGRA28L.txt" valid for the following reference printing conditions relating to the international standard ISO/DIS 12647-2:2003.
- Webicc: ICC profile according to the average measurement values of all five heat-set web offset printing plants (Profiling tool: GretagMacbeth, ProfileMaker 5.0.4, predefined separation settings "Offset").
- Custom: ICC profile (5 individual profiles) according to individual measurement values of each heat-set web offset printing plant (Profiling tool: GretagMacbeth, ProfileMaker 5.0.4, predefined separation settings "Offset").

The source profile of the test images was "AdobeRGB(1998)". Considering the conversion options the Adobe (ACE) CMM and the relative colorimetric rendering intent has been used.

Four test images were chosen to contain a range of different types of pictorial content and tonal and chromatic variety as shown in Figure 2. The chosen images represent typical the type of images used in weekly magazines.

The images were simultaneously viewed side by side, as shown in Figure 3 and no anchor stimuli were used as a reference. The viewing set up was based on the standard condition of the graphic art industry ISO, 3664, vertical geometry 45°, background grey, light source D50 simulator, light intensity 100%. The images were viewed in a darkened room (lights off) and the images, approximately 10 cm x 15 cm in size, were viewed from a distance of approximately 65 cm.

A total of 27 observers (16 experts and 11 naive) with normal colour vision and ages from 20 to 64 took part in the experiment. Each observer was required to make 3 pair-wise comparisons per image (4) and per web offset process (5), a total of 60 comparisons. Note that the comparisons were carried within each individual web offset press. The law of comparative judgement was applied and the method used was

pair comparison judgement [Engeldrum, 2000]. The observer's task was to decide which of the two prints in the viewing cabinet was most preferred in terms of naturalness. In a study by Morovic (2002) naturalness is defined as an attribute, which is determined by identifying the locations of prototypical memory colours such as "skin", "grass" and "sky" in colour space (which represent a wider range of naturally occurring colours) and then assessing image colours in relation to these.



Figure 2: Four test images: camera, couple, portrait and house. The images "camera" and "portrait" are reproduced with the permission of "Ole Jakob Bøe Skattum". The image "couple" is reproduced with the permission of "Se og Hør" and the image "house" with the permission of "Hjemmet Mortesen AS - Hytteliv"



Figure 3: Viewing arrangement for psychophysical experiment

3. Results

As mentioned previously the aim of this work is to evaluate five heat-set web offset printing presses in terms of their conformance to specified values, in accordance with the requirements of ISO 12647-2:2004. Furthermore, the assessment of each individual printing press and the variation within the five participants are important tasks to evaluate the appropriate colour separation approach, either by applying individual separation profiles or by using an industry standard profile such as "ISOwebcoated.icc".

3.1 Results of the quantitative evaluation

The Color Research Laboratory received test prints from all five "webicc" participants and measured a total of six (3 recto printing and 3 verso printing) test charts (ECI2002) per test print run from each participant to evaluate their colorimetric properties.

To determine the variation in terms of colour stability over time the quality factor repeatability is required [Morovic and Nussbaum, 2003]. Figure 4 shows the performance of the short-term repeatability

of each participant. According to the first test print run the colour differences were calculated between the average of the six measurements and each individual measurement. Apparently, participant "Norprint" shows the best performance with a mean ΔE^*_{ab} 1.2 units. Although the other four participants present larger variations the results are still within an acceptable tolerance (Mean ΔE^*_{ab} between 1.5 and 2.0 units).

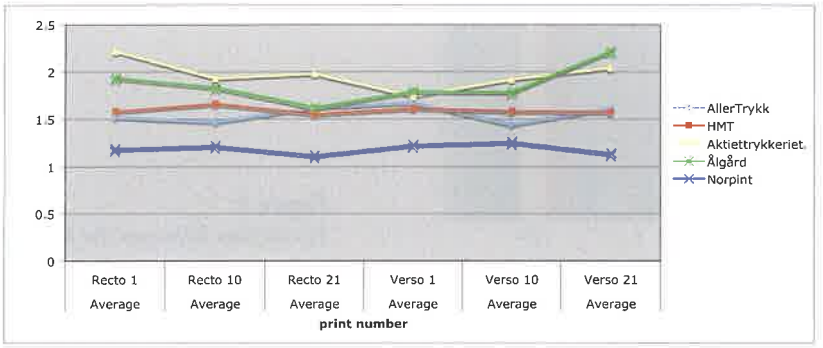


Figure 4: Short-term repeatability performance of each participant

To determine the long-term repeatability performance from each participant colour measurement data from the first test print run and colour measurement data from the second test print run has been compared. As mentioned before the two test print runs were carried with four months interval. As expected the results in Table I show higher variations in terms of colour differences. However, as already seen in the short-term repeatability participant "Norprint" shows again the best performance in the long-term repeatability with a mean ΔE^*_{ab} 1.92 units. On the other hand participant "HMT" presents the largest variation with a mean ΔE^*_{ab} 6.48 units.

Table I: Long-term repeatability performance of each participant

	AllerTrykk	HMT	Aktietrykkeriet	Norprint	Ålgård
Mean	2.68	6.48	3.92	1.92	4.53
STDEV	1.67	3.68	1.79	1.3	1.78
MAX	10.85	19.03	12.36	7.08	9.81

It is important to point out that the first test print run has been carried out according to individual "in-house" density standards defined by each participant in the "webicc" project. These density values are unknown and not available to publish. For the second test print run the "webicc" group has defined a "webicc" density standard, which is required to obtain by each participant. The "webicc" densities of dry solids were measured without polarizing filter. The values are for black 1.4, cyan 1.25, magenta 1.2 and yellow 1.1.

Another approach to assess the colorimetric properties is to analyse the variations between the five heat-set web offset printing processes in the first test print run. Figure 5 presents the colour difference between the average measurements of all five heat-set web offset plants and each individual participant. Notice, that participant "HMT" shows the largest difference (mean $\Delta E^*_{ab} > 4$ units) and participant "Norprint" illustrates the smallest difference.

An important part of the evaluation is to analyse the variation between all five "webicc" participants and the colorimetric values of the "ISOwebcoated" ICC profile. According to the results given in Table II, the participant "AllerTrykk" shows the best match (mean $\Delta E^*_{ab} < 5$ units) and participant "HMT" presents the largest difference (mean $\Delta E^*_{ab} > 8$ units). Note that all the measurements from the first test

run were carried out according to individual "in-house" density standards. Although paper type 3 was used in the project minor variations in terms of colour differences (Table III) according to ISO 12647-2:2004 and "ISOwebcoated" were detected which also may contribute to the overall colour differences.

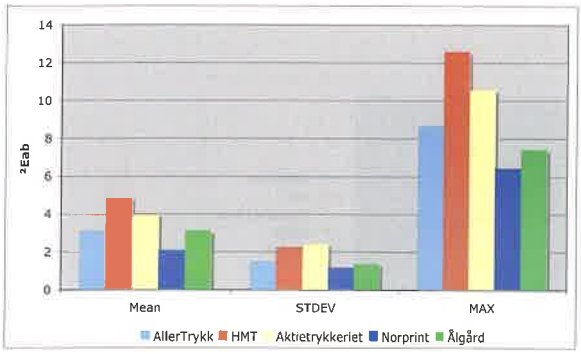


Figure 5:
Variations between the five participants

Table II: Colorimetric colour differences between each heat-set web offset plants and ISOwebcoated values

	ISOwebcoated	ISOwebcoated	ISOwebcoated	ISOwebcoated	ISOwebcoated
	AllerTrykk	HMT	Aktietrykkeriet	Norprint	Ålgård
Mean	4.97	8.15	7.09	6.39	6.69
STDEV	2.64	3.97	3.64	3.51	3.26
MAX	13.76	21.11	17.55	16.67	18.26

Table III: CIELAB coordinates for paper type 3

	L*	**a***	**b***
ISOwebcoated	92.4	-0.7	1.5
webicc	90.2	0.3	-0.7
ISO 12647-2:2004	92	0	5
Tolerance	±3	±2	±2

Another way of looking at the colour differences between colour measurement data of each participant and the data of the "ISOwebcoated" profile is to consider the colour patches with the highest fluctuations. Figure 6 shows the colorimetric colour differences between each heat-set web offset plant and the "ISOwebcoated" values including the worst 10% colour differences of the colour patches which are outlined in yellow.

Looking at the CIELAB values for the primary colours cyan, magenta, yellow and black specified in ISO 12647-2:2004 the differences between the actual values and the nominal values must not exceed the tolerances shown in Table V. Table IV presents the CIELAB values for the primary colours from all five "webicc" participants, "ISOwebcoated" and the ISO 12647-2:2004 specification. Moreover the Table shows colour differences calculated between the participants, "ISOwebcoated" and the ISO 12647-2:2004 from the first test print run (1.TP) and the second test print run (2.TP). As expected "ISOwebcoated" is within the tolerance values $\Delta E_{ab} < 5$ units for all four primary colours. For the primary colours cyan and black all five "webicc" participants show reasonable results in terms of tolerances. Only participant "HMT" shows colour differences above the CIELAB tolerances. On the other hand the performance of all five participants is rather poor for the primary colours magenta and yellow comparing to the "ISOwebcoated" CIELAB values. Note that the target value *b** for the primary colour yellow in ISO 12647-2 is defined by b* = 94. Apparently, none of the participants is able to obtain an appropriate match. Consequently the colour differences in yellow are rather high for

all participants. This has also been confirmed, in Figure 6 where the worst 10% colour differences of the colour patches are outlined in yellow, which are typically in the area of yellow, magenta and red.

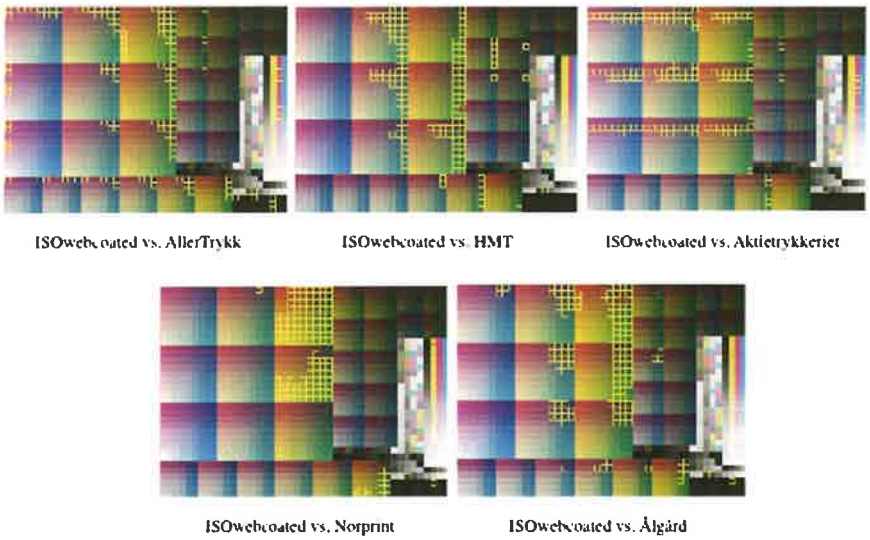


Figure 6: The worst 10% colour differences outlined in yellow between each heat-set web offset plant and "ISOwebcoated"

Table IV: CIELAB coordinates for paper type 3 according to measurements on white backing (ISO 12647-2:2004)

		Cyan		Magenta		Yellow		Black	
		1.TP	2.TP	1.TP	2.TP	1.TP	2.TP	1.TP	2.TP
		House density	webicc density	House density	webicc density	House dens	webicc density	House dens	webicc density
AllerTrykk	L*	57.5	-55.1	49.2	49.1	83.9	84.5	22.1	21.2
	a*	-35.4	-36.1	68.9	69.7	-3	-3	1.8	1.5
	b*	-41.2	-43.8	-8.8	-7.2	83.1	85.2	3.2	2.8
	ΔE^*_{ab}	**4.6**	**1.9**	**10.7**	**8.9**	**12.1**	**9.9**	**4.2**	**3.4**
HMT	L*	50.6	55.6	46.6	50.9	82.9	84.3	13.8	25.1
	a*	-35.9	-35.4	72.1	66.1	-0.6	-2.4	0.7	2
	b*	-46.6	-43.3	-2.6	-8.6	81.5	82.1	0.7	4.5
	ΔE^*_{ab}	**5.5**	**2.8**	**4.6**	**13**	**14.3**	**13**	**6.3**	**7.1**
Aktietrykkeriet	L*	56	60.3	50.6	50.6	83.8	84.7	23.2	22.9
	a*	-34.8	-33.7	66.3	67.1	-2.5	-2.8	1.1	1
	b*	-42.7	-39.7	-9.5	-7.8	82.1	77.5	2.5	0.9
	ΔE^*_{ab}	**3.6**	**8.1**	**13**	**11**	**13.1**	**17**	**4.2**	**3.2**
Norprint	L*	56.9	56.2	47.6	47.8	84.4	83.6	18.9	20.4
	a*	-37.8	-37.6	70.1	70	-3	-2.1	0.1	0.4
	b*	-42.7	-43	-6.5	-5.8	76.7	79.2	1.8	2
	ΔE^*_{ab}	**2.3**	**1.6**	**8.3**	**7.8**	**18.0**	**16**	**2.1**	**2.1**
Ålgård	L*	55.8	57.6	48.9	49.5	84	85	21.8	22.6
	a*	-37.2	-36.1	68.4	67.2	-2.4	-3.3	1.6	1.7
	b*	-44	-41.5	-7.4	-8.3	80.4	75.3	2.9	1.7
	ΔE^*_{ab}	**1.1**	**4.1**	**9.9**	**11**	**14.6**	**19**	**3.8**	**3.5**
ISOwebcoated	L*	55.5		46.2		85.8		17.6	

	a*	-38.6		71.2		-2.9		0.6	
	b*	-44.7		-1.7		93.3		0.3	
	ΔE^*_{ab}	**1.0**		**5.0**		**3.5**		**2.5**	
ISO 12647-2	L*	55		49		89		20	
	a*	-38		75		-4		0	
	b*	-44		0		94		0	
		< CIELAB tolerances				> CIELAB tolerances			

Table V: CIELAB tolerances (ΔE^*_{ab}) for the solid tones of primaries according to ISO 12647-2:2004

	Cyan	Magenta	Yellow	Black
Deviation	5	5	5	5

Figure 7 shows the colour gamut projection of the five heat-set web offset presses and the ICC profile "ISOwebcoated" onto the a*b*-plane according to the level of lightness L* = 50.

The data used in this task are based on colorimetric measurements, which have been analysed and visualised by the icc3d application [Farup *et al.*, 2002]. The Figure to the left (Figure 7A) illustrate the gamut projection of the five heat-set web offset presses according to the first test print and the Figure to the left (Figure 7B) presents the gamut projection of the second test print with "webicc" density. It can be seen that the "ISOwebcoated" profile has a slightly larger colour gamut than the five participants of the "webicc" project.

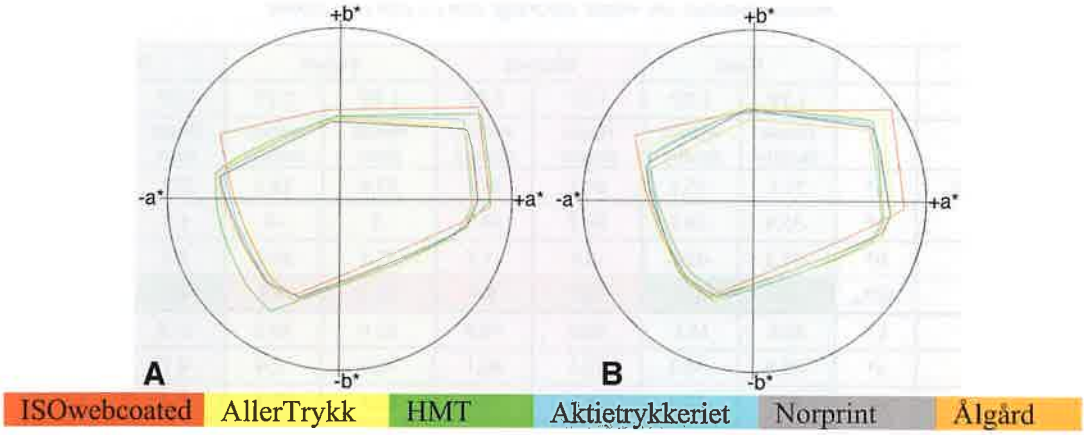


*Figure 7: 2D colour gamuts comparison of the five heat-set web offset presses and the ICC profile ISOwebcoated onto the a*b* - plane according to the level of lightness L* = 50*
***A)** First test print run according to "in-house" densities*
***B)** Second test print run according to "webicc" density*

Note that the size of the colour gamut of the five participants has changed from the first test print to the second test print. Remember that the density values from the first test print run are not identical to the density of the second test print. Furthermore variations in terms of long-term repeatability affect the colour gamut too. However, as seen in Figure 7B the improvement of the "webicc" density values results in a closer match to the "ISOwebcoated" colour gamut. Particularly participant "HMT" shows in the first test print (Figure 7A) a much larger gamut in the green blue area. Further the largest colour differences between "ISOwebcoated" and the "wecicc" participants observed previously in the primary colours magenta and yellow (Table IV) can also be seen in the colour gamut comparison in Figure 7.

The three-dimensional CIELAB plot in Figure 8 reveal the colour gamut properties of the "ISOwebcoated" profile and the "webicc" profile which contains the average measurement values of all five heat-set web offset printing plants. The plot shows obvious limitations of the webicc profile in high-saturated colours such as yellow and magenta. While the "ISOwebcoated" profile has some minor limitation in the blue area comparing to the "webicc" profile.

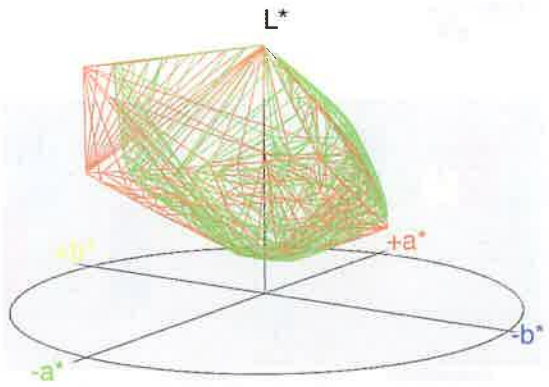


Figure 8: 3-D comparison of the "ISOwebcoated" colour gamut (wireframe red) and the "webicc" colour gamut (wireframe green)

Another way of looking at the size of colour gamuts is by considering the gamut volume. The size of colour gamuts, quantified as the volume of the convex hull [Morovic, 2003] of the gamut in CIELAB colour space was derived from the test prints of both test print runs of the five heat-set web offset presses and the ICC profile ISOwebcoated.

Table VI: Comparison of the approximate relative gamut volumes of the five heat-set web offset presses and the ICC profile "ISOwebcoated"

Participants:	1. Test print House density		2. Test print Webicc density	
	CIELAB volume	Relative volume	CIELAB volume	Relative volume
ISOwebcoated	436'900 unit	100%	436'900 unit	100%
AllerTrykk	432'646 unit	99%	472'158 unit	108%
HMT	482'392 unit	111%	437'106 unit	101%
Aktietrykkeriet	423'847 unit	97%	423'556 unit	97%
Norprint	415'451 unit	95%	422'646 unit	96%
Ålgård	428'605 unit	98%	382'246 unit	87%

The density changes from the first test print run ("house-density") to the second ("webicc" density) affect the gamut volume. It can be seen in Table VI that AllerTrykk provides the largest gamut volume (even 8% larger than the "ISOwebcoated") in the second test print run, whereas the volume given by participant "Ålgård" is 87% of that given by "ISOwebcoated". Although participant "HMT" has shown the largest mean colour difference comparing to "ISOwebcoated" as seen in Table II, the relative gamut volume is virtually equal to that of the "ISOwebcoated". This reinforces the fact that colour differences say something more specific about individual colours whereas relative gamut volumes refer to their ranges.

3.2 Results of the psychophysical experiment

The following are the results in terms of z-scores, which have been obtained in the psychophysical experiment. For each image and heat-set web offset printing plant the 3 x 3 matrices of comparisons

results for each observer were arranged over the 27 observers and transformed into z-scores. The precisions of the experimental results are described in terms of 95% confidence interval (CI), which is calculated using equation (1) using the mean (R), standard deviation (σ) and the number of observations (N). Using case V of the method proposed by Thurstone, the standard deviation of the z-scores is assumed to be $\sigma = 1/\sqrt{2}$.

$$95\%\ \text{confidence interval} = R \pm 1.96\frac{\sigma}{\sqrt{N}} \quad (1)$$

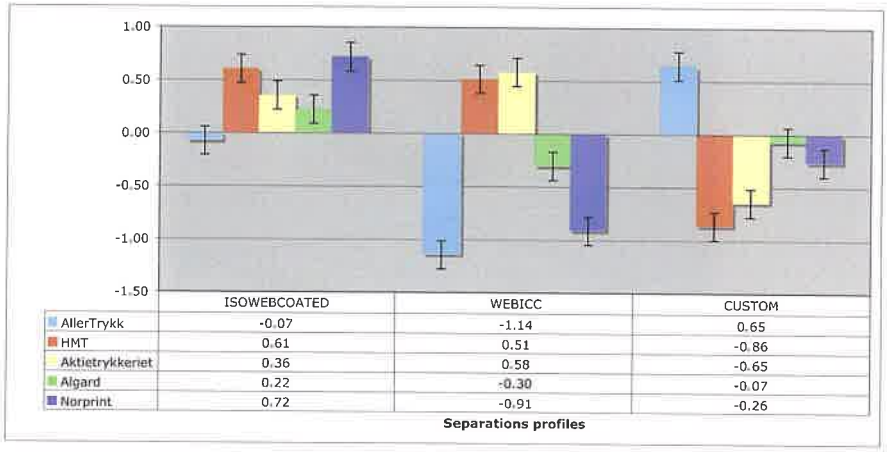


Figure 9: Pair comparison z-scores for each heat-set web press and separation (The error bars represent 95% of population distribution)

Figure 9 presents the results in terms of z-scores for each heat-set web press. For the number of images and observations, CI was calculated to be ± 0.13. Except for the printing plant "AllerTrykk" the profile "ISOwebcoated" shows the best performance for the other four printing plants. The profile "custom" was ranked significantly best and the profile "webicc" significantly worst for "AllerTrykk". Note that the profiles "ISOwebcoated" and "webicc" do not indicate a significant difference in terms of preferred naturalness. It is interesting to note that despite a large colour difference in the quantitative evaluation (Table II) between the colorimetric values of the participant "HMT" and the profile "ISOwebcoated" the performance with the ISOwebcoated profile ranked significantly best. On the other hand considering the long-term variation between the first test print run and the second test print run the participant "HMT" has shown the largest colour difference. Hence the "custom" profile for "HMT" performs worst.

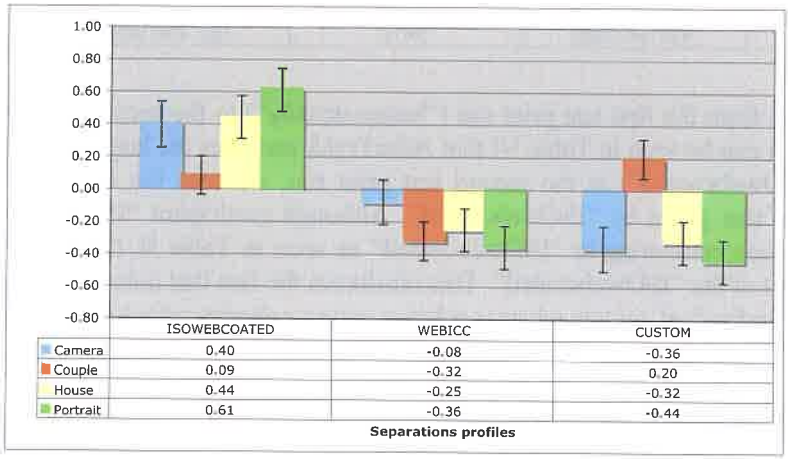


Figure 10: Pair comparison z-scores for each type of image and separation (The error bars represent 95% of population distribution)

Considering Figure 10 the experimental results identify the profile "ISOwebcoated" as the separation, which scored significant best for the images "Camera", "House" and "Portrait". For the image "Couple" the profile "custom" performed best in terms of preferred naturalness. Considering the images "Camera", "House" and "portrait" the profile "custom" shows a lower performance comparing to the profile "webicc". However there is no significant performance difference between the profile "webicc" and the profile "custom".

Table VII: Ranking of separation profiles for each image (1 = best, 3 = worst)

Image	ISOWEBCOATED	WEBICC	CUSTOM
Camera	1	2	3
Couple	2	3	1
House	1	2	3
Girl	1	2	3
Overall	**1**	**2**	**3**

Table VII gives the ranking of the performance of the three separation profiles for the four images. As it can be seen the profile "ISOwebcoated" was significant best and the profile "webicc" was second and the profile "custom" was third respectively. Figure 11 presents the results in terms of z-scores for all four images and all five webicc-project participants. For the total number of images, heat-set web offset presses and observations, CI was calculated to be ± 0.06. Notice, overall, the "ISOwebcoated" profile performed significant best. Although the results don't show a significant difference between the "custom" and the "webicc" profile the "custom" profile performed second best.

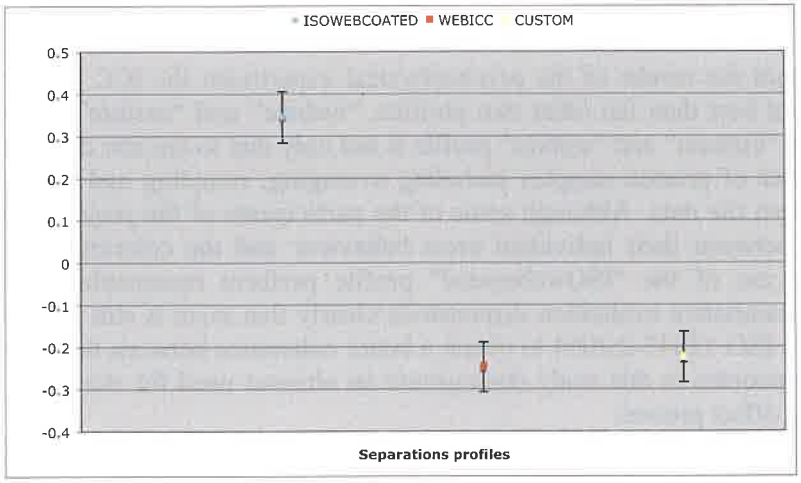


Figure 11: Overall z-scores for the three separation profiles

4. Discussion

Considering the colorimetric results and the colour differences between the individual printing plants and the colorimetric data of the "ISOwebcoated" profile (Table III) it might be expected that a custom profile will perform best. However, it is worth pointing out that the characterization data for generating the "ISOwebcoated" profile were obtained by measuring a large number of printed samples including averaging, rounding and further adjustments to smoothen the data. Although the results of the repeatability of the individual presses have shown reasonable performances small deviations in the print process can cause unwanted variations in the appearance of the print by using custom profiles. As seen in Figure 9 the "webicc" profile performs similar comparing to the "custom" profile. Due to the fact that the "webicc" profile is related to a larger number of measurements comparing to the "custom" profile the

behaviour is similar to the "ISOwebcoated" profile considering the smoothness, which tolerates larger variation than the "custom" profile. Furthermore it must be mentioned that the profile "webicc" and the profile "custom" were generated using GretagMacbeth ProfileMaker 5.0.4 whereas the profile "ISOwebcoated" has been generated using Heidelberg Printopen 4.0.5.2. Although the predefined separation settings "Offset" in ProfileMaker 5.0.4 has been chosen, which is, according to GretagMacbeth, compliant with the specifications laid down by FOGRA and ISO 12647-2 for glossy and matt papers the separations using by "ISOwebcoated" gives a results with a much stronger GCR (grey component replacement) degree. The test images "camera" and "portrait" contain large areas with neutral colours, which might be easier exposed to print variations and finally affect the appearance of the print. Hence the reproductions made with the "ISOwebcoated" profile gives better print results in terms of preserving grey balance. Note, based on the psychophysical experiment the results shown in Figure 10 demonstrate a significant best performance for the test images "camera" and "portrait" reproduced by the "ISOwebcoated" profile.

It is worth pointing out that in the beginning of the project a generic Norwegian heat-set web offset profile has been considered for application in the Norwegian market. However, the Norwegian Color Research Laboratory argued very soon to make the presses conform to a certain reference or standard such as ISO 12647-2. As a result of the present study it is possible for all participants of the "webicc"-group" to adopt the industry standard profile "ISOwebcoated". Nevertheless to preserve the daily printing conditions and to match the colorimetric requirements of the adopted standard profile it is highly recommended press control according to the standard ISO 12647-2.

5. Conclusions and perspectives

As can be seen from the results of the psychophysical experiment the ICC profile "ISOwebcoated" performs significant best than the other two profiles, "webicc" and "custom" respectively. The poor performance of the "custom" and "webicc" profile is not only due to the low degree of GCR. Rather a much larger number of printed samples including averaging, rounding and further adjustments are required to smoothen the data. Although some of the participants of the project still show significant colour variations between their individual press behaviour and the colorimetric values of the ISO 12647-2:2004 the use of the "ISOwebcoated" profile perform reasonable results. However, the outcomes of the quantitative evaluation demonstrate clearly that there is still potential to improve the target values of the ISO 12647-2:2004 to obtain a better coherence between the "webicc" participants. Furthermore the outcomes in this study demonstrate an obvious need for standardising the behaviour of the heat-set web offset presses.

Finally, it is of interest to consider other potential directions for further work in the field of print quality assessment. Colour difference metrics for image quality assessment has been used widely for various applications. However there is not very often a strong correlation between the objective evaluation and the visual assessment. Furthermore the interpretation of the complete image quality assessment considering the colour difference calculation is dependent on the application and the acceptance. The acceptability threshold considering print quality assessment is defined as a vague concept and one that depends strongly on application and industry. Moreover, a further quality metric, which could be considered more suitable for the heat-set web offset printing process, is a tolerance threshold.

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References

1. Engeldrum P. G. (2000) *Psychometric Scaling, A Toolkit for Imaging Systems Dvelopment*, Imcotek Press, Winchester USA, 1st ed
2. Farup I., Hardeberg J. Y., Bakke A. M., Kopperud S. and Rindal A. (2002). Visualization and interactive manipulation of color gamuts. In *Proceedings of IS&T and SID*'s 10th Color Imaging Conference: Color Science and Engineering: Systems, Technologies, Applications, pages 250 - 255, Scottsdale, Arizona
3. Gescheider G. A. (1985) *Psychophysics, Method, Theory, and Application*, Second Edition, Lawrence Erlbaum Associates, ISBN 0-89859-375-1, 152
4. Handley J. (2001) Comparative Analysis of Bradley-Terry and Thurstone-Mosteller Paired Comparison
5. Models for Image Quality Assessment, *PICS 2001*, 108-112
6. Hardeberg J. Y. and Skarsbø S. E. (2002) Comparing color images quality of four digital presses. *Proceedings of the 11th International Printing and Graphic Arts Conference*, Bordeaux, France
7. ISO (2004) ISO 12647-2:2004 *Graphic Technology - Process control for the production of half-tone colour separation, proof and production prints*
8. ISO (2000) ISO 13655:2000 *Graphic Technology - Spectral measurements and colorimetric computation for graphic arts images*
9. ISO (1999) ISO 3664:1999 *Viewing conditions - Prints, transparencies and substrates for graphic arts technology and photography*
10. Morovic J. (2003) Gamut mapping. *In Digital Color Imaging Handbook.* S. Sharma, CRC Press, pp 639-685
11. Morovic J. (2002) Colour gamut mapping. *In Colour Engineering Achiving Device Independent Colours*, P. Green and L. MacDonald, John Wiley & Sons Ltd, pp 297-317
12. Morovic J. and Nussbaum P. (2003). Factors Affecting The Appearance Of Print On Opaque and Transparent Substrates, Journal of Imaging Science and Technology, *JIST* 47 #6
13. Nussbaum P., Hardeberg J.Y. and Skarsbø S.E. (2004) Print quality evaluation for governmental purchase decisions, In *Proc IARIGAI Conference*, Copenhagen, Danmark
14. Thurstone L. L. (1927) A law of comparative judgement. *Psychol. Rev.*, 34, 273-286



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