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The journal is fostering multidisciplinary research and scholarly discussion on scientific and technical issues in the field of graphic arts and media communication, thereby advancing scientific research, knowledge creation, and industry development. Its aim is to be the leading international scientific journal in the field, offering publishing opportunities and serving as a forum for knowledge exchange between all those interested in contributing to or learning from research in this field.

By regularly publishing peer-reviewed, high quality research articles, position papers, surveys, and case studies as well as review articles and topical communications, the journal is promoting original research, international collaboration, and the exchange of ideas and know-how. It also provides a multidisciplinary discussion on research issues within the field and on the effects of new scientific and technical developments on society, industry, and the individual. Thus, it intends to serve the entire research community as well as the global graphic arts and media industry.

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- Packaging
- Fuel cells and other printed functionality
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- Printed decorations
- Materials science
- Process control

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- Image and reproduction quality
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- Consumer perception and media use
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Submissions are invited at any time and, if meeting the criteria for publication, will be rapidly submitted to peer-review and carefully evaluated, selected and edited. Once accepted and edited, the papers will be published as soon as possible.

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A letter from the Editor

Gorazd Golob
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The first issue of the Journal in 2021 is comprised of four papers. The first original scientific paper is based on a comprehensive study of the effect of jetting shear on the stability of inkjet ink, with a theoretical overview of the ink-jetting physics, ink composition and properties, and the use of novel experimental apparatus used to mimic an inkjet printing process.

The second is a research paper on yellowing of UV varnishes, based on a study of correlations between the yellowing and degrees of polymerization of varnishes with different compositions and characteristics.

The following two papers are case studies, both on challenges related to digital disruption in the printing industry. One is related to the future of multi-national printing ink company active in the Indonesian print media industry. The last one is oriented into analysis and future of book printing houses in Spain.

The Topicalites are bringing an overview of the new publications and news from the field, unfortunately, affected by the pandemic. In the News & more section our editor Markéta Držková (marketa.drzkova@jpmtr.org) made an overview of the recently published patents in the area of printed electronics, together with the news in membership and activities of PRINTING United Alliance, as well as an overview of the research projects of KCL Pilot Plant. In Bookshelf a number of books are presented, some of them on the topics considered at the border of their research field for many traditionally oriented readers of the Journal. However, textile printing, photography, multimedia, book publishing, brand and identity development, design, 3D printing technology, flat panel displays, and materials that can be used as functional printing inks, are key terms that cannot be avoided in our contemporary and future research, covering much more than printing text on paper.

Three academic dissertations are also presented. Johannes Zimmermann defended his thesis on printed electrochemical light cells at the Karlsruhe Institute of Technology. At the Vienna University of Technology, the thesis on advanced additives for radical photopolymerization in UV curable systems was defended by Paul Gauss. Canlin Ou defended his thesis on aerosol-jet printed nanocomposites for thermoelectric generators as a possible new energy harvesting device at the University of Cambridge.

In the Events section, the influence of pandemic is noticeable. Many events, seminars, and conferences were postponed or canceled. Most of them will be held as virtual or online events only, however, some organizers are announcing even face-to-face events. The well-known drupa fair is now planned for 2024, but in April an online event is planned under the name ‘virtual.drupa’. As a part of this virtual edition of drupa in the Topicalities also the ‘Bridging Industry, Education and Research in Graphic Communication, Print and Media’ event is announced.

With the current issue, the Journal reached Volume 10. In the beginning, it was a 'print only' subscription-based publication, distributed mainly to the members of iarigai, the publisher. Since 2016 the Journal is available online and is printed only for subscribers, and since 2020 it is available as an open-access publication at the iarigai website, as a pdf file of complete publication and with access to individual papers and other content, including Topicalities. The individual published papers from the Journal are now available also at the separate website <https://jpmtr.org/>. This should improve the dissemination of the content, access to the wider audience, and also the indexing and status of the Journal in comparison to other scientific journals. Some minor changes and improvements are still expected, however, we at the editorial team are convinced that every positive change and improvement is leading to a brighter future for our research community and the Journal of Print and Media Technology Research.

Ljubljana, March 2021

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Novel device for determining the effect of jetting shear on the stability of inkjet ink

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Abstract

Inkjet printing is a rapidly expanding technology for non-contact digital printing. The focus for the technology has changed from office printing of text and image documents increasingly toward wider applications, including large-scale printing of on demand books and packaging or ultra-small-scale functional printing of microscopic volumes of precious/rare materials formulated for use in precisely printed digitally defined patterning arrays, such as printed diagnostics, flexible electronics, anti-counterfeiting, etc. For efficiency, as well as resource management and conservation, predicting the stable runnability of an inkjet ink remains largely a key unknown. Today the only way to know often means simply trialling it, which at best takes time, and at worst incurs costs rectifying possible equipment damage. We propose a mechanically driven displacement device providing constant high-shear flow rate through an extended capillary. This differs from a standard capillary viscometer, which is commonly pressure driven only and lacks the ability to mimic consistent volume flow inkjetting. The novel method is used to study the aqueous colloidal stability of polymer solution, latex polymer suspensions and complete pigment-containing inks, including a reference pigment only comprising suspension. The results reveal the tendency to build agglomerates, determined by dynamic light scattering particle size distribution, optical and electron microscopy. Liquid phase parameters, including surface tension, and suspension intrinsic viscosity are also studied. Repeated application of high shear is seen to act as a milling process for pigment and agglomerate building tendency for latex binder. Consequences for ink jettability are discussed.

Keywords: ink jettability, ink stability, nozzle blocking, shear-induced aggregation, ink flow testing

1. Introduction and background

Non-contact printing has developed hand-in-hand with the digitisation of text and images, commonly seen in everyday life during the boom era of office printing. Compared with traditional contact printing dating from letterpress through to high-speed offset, flexography and rotogravure, non-contact digital printing, whilst having shown a dramatically rapid development timescale, has had a working lifetime that is extremely short in terms of conveying the written word, and document printing in general is declining rapidly in the face of electronic media. However, its longevity cannot be challenged when it comes to print-on-demand applications and for advanced functional printing, such as flexible electronics, microfluidic point-of-care diagnostics and repetitive laboratory analytics, building biological structures, including tissue and protein cages for constructing human organs and implants, photonic and photovoltaic coatings, etc., enabling complex designs to be formed from low volume availability functional materials (Alamán, et al., 2016; Beedasy and Smith, 2020; Cui, et al., 2012; 2014; Eggenhuisen, et al., 2015; Gao, Li and Song, 2017; Jiang, et al., 2019; Jutila, et al., 2015; 2018; 2020; Kim, et al., 2009; Koivunen, Jutila and Gane., 2015; Koivunen, et al., 2016; 2017; 2019; Matsusaki, et al., 2013; Saarinen, et al., 2014; Sumaiya, Kardel and El-Shahat, 2017; Zönnchen, et al., 2019).

Amongst the array of non-contact digital printing platforms, inkjet offers a broad spectrum flexibility in respect to the printing of small quantities of valuable materials on multiple substrates, a feature that is particularly important in the laboratory and in mass production of components employing functional materials.

Before considering the complexities of the inkjet printing dynamic itself it is perhaps important to remind ourselves briefly of the preparation of an inkjet ink. A typical recipe for an aqueous ink might comprise of:

Solvent 1: ~20 % in the ink; the major part is water (demineralised water, millipore water)

Solvent 2: ~20–35 % in the ink; consisting typically of glycerine, diethylene glycol, polyolefin glycols, such as polyethylene glycol (PEG) and polypropylene glycol (PPG) in small proportions

Surfactant: ~0.02–1 % in the ink; usually non-ionic to prevent disturbance of the anionic stabilising colloidal dispersion system

Binder: ~10 % in the ink; mainly acrylic resins, and considered a very challenging material component in the form of synthetic latex – acts as fixing agent, and is considered perhaps to have the biggest influence on jetting failure

Pigment: ~5 % of the total ink weight if used in preference to dyes, and controls optical and physical properties – dot shape and volume during dewatering and after drying, light absorption and scattering properties; the pigments formulated into inkjet inks are typically dispersed to small particle sizes (between about 50 nm and 200 nm, depending on the application) and need to be colloidally stable in suspension

Humectant: sorbs moisture from the surrounding atmosphere, used to prevent ink drying around printhead plate, nozzle and in recycling (continuous inkjet)

Buffers: to control pH

Biocide: acts to preserve the ink from microbiological contamination

These components are prepared and "madedown" into the ink following a sequence similar to that shown in Figure 1.

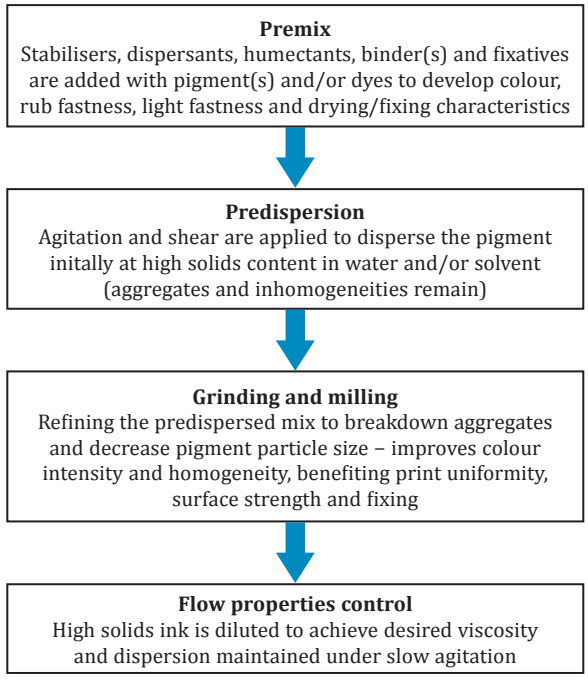


Figure 1: Schematic procedure for makedown of a typical pigment-containing ink

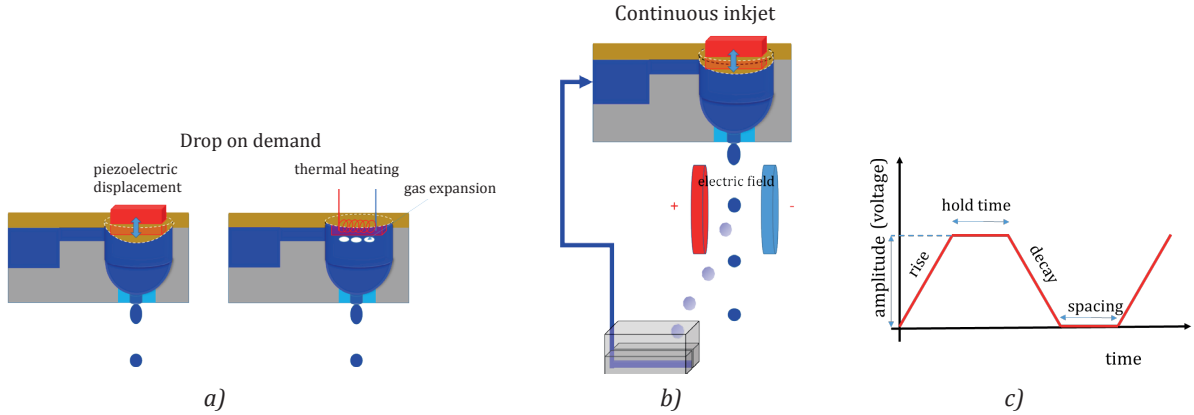


Figure 2: Inkjet technologies commonly used: (a) drop on demand, driven typically either by piezoelectric displacement or heating to expand gas bubbles, (b) continuous inkjet, where the droplets are jetted repetitively and directed either toward the substrate or to recycling via a collecting trough; and (c) an idealised activator voltage waveform

Despite the many advantages that inkjet technology provides, the technique can be marred by runnability-limiting phenomena depending on the nature of the technology itself. As we can see from the schematic of an inkjet printhead, Figure 2, the process is highly dynamic and the forces needed to jet ink are confined within a very small volume.

As we see from the voltage waveform in Figure 2c, the ink is subjected to rapid acceleration and deceleration in response to the applied activator voltage amplitude rise and decay time, repeated consecutively according to the time spacing. This causes the ink to be forced through a narrow nozzle during the voltage hold time, as shown in Figure 2, where the flow regime may be discontinuous between inertial boundary solids depleted plug flow and high-shear viscous flow. For drop on demand the repeated compression and inertial response of retained bulk ink in the ink chamber is experienced many times before the critical ejection through the nozzle, and has been evaluated, at least partially, using exit meniscus imaging in terms of viscoelastic response (Renner and Bircher, 2017), whereas in continuous inkjet the same demanding regime is applied not for one filling of the chamber, but many times as the ink is jetted, fed back to the chamber, exposed to repeated inertial pulses and then jetted again with the possibility of being recycled repeatedly, even when printing has stopped in order to keep the ink in the nozzles from drying and blocking. To bring this into perspective, high-speed jetting is achieved typically by applying a high frequency (~100 kHz) to the piezoelectric displacer, this displaces a volume commonly down to 6 pl (picolitres) – and in more recent times even as small as 2 pl – at 1200 dpi for controlled ejection per droplet, translating to a rate of 6 million drops per minute, all leading typically to an ink consumption of up to 12 dm^3 per hour printing at a substrate surface traverse speed of 6–15 $m \cdot s^{-1}$. Today's ink manufacturers additionally aim to minimise the wetting effect on fibre-based substrates. The more the ink wets and becomes absorbed between and within the fibres, the more the energy needed to dry the ink, and, depending on ink film thickness and the time taken to dry, the droplets can spread undesirably on the substrate surface. This development target promotes further the desire to reduce ink volume, and it is this precision and small volume content applied at high speed that makes the flow regime for the ink highly complex.

It is vital to prevent damage to the printheads caused by changes in the ink over time under such conditions as described above. Should an ink form dry deposits or cause nozzle blockage, the printhead requires cleaning. Experience, though, tells us that cleaning agents are also a suspected culprit in leaving deposits and do not generally work well.

Other runnability-limiting phenomena also exist, such as over-wetting of the nozzle exit or air ingress and entrainment inside the exit, leading to ink build-up around the nozzle and housing plate, resulting, in turn, in droplet volume and trajectory distortion. Humectant is used to retain water in aqueous inks to act against such nozzle build-up and blockage due to evaporation and drying.

The work reported here is not aimed at addressing the whole multiplicity of runnability issues, rather it concentrates on the suspension stability as a response to jetting at high shear, which is primarily responsible for suspension solids-related nozzle blocking (for example: Biswas, Yu and Nierstrasz, 2019; Ebert, et al., 2009; Lee, et al., 2012; Li, et al., 2019; Wheeler, et al., 2014), and resulting in uneven dot distribution and lack of circularity of the printed dot, especially noticeable on smooth non-absorbing substrates. Furthermore, variation in print and colour density parameters, independent of substrate, are often due to inhomogeneous distribution on the surface and contrast between dispersed pigment, flocculated pigment and aggregated pigment. We aim, therefore, to provide some answers to the question: "How can we know an ink works in practice before using it?" Today, the only way is to try it and see.

2. Methods

Here we address why there is the need for a new technique in determining relevant inkjet ink flow behaviour away from the printer itself, and present the ancillary testing methods employed to analyse the results obtained from a constant flow rate device using carefully chosen materials.

2.1 Traditional rheometry – lack of suitability for inkjet

Measurement techniques for determining the rheological properties of liquids and suspensions are historically well established, and based primarily on the analysis of the stress developed in the sample as a function of applied strain. Many geometries and diverse methods for applying strain are available. Two dominant methods exist, (i) consisting of a means of containing the sample under constant volume within a uniform set of boundaries, then coupling one boundary with a driving mechanism to generate controlled displacement as a function of time with a sensor to detect the coupling of the displacement to transmitted stress, and (ii) pressure-driven extrusion through a capillary or slot to observe the volume flow rate as function of pressure and time. In (i) the displacement can be linear, giving a dynamic shearing effect on the sample, or

oscillatory, providing a continuously variable strain amplitude oscillation at a determined frequency, the latter being particularly useful in measuring the viscoelastic response of materials exhibiting a rest-state or strain-induced structure. Rotational instrumentation is accordingly commonly used to study oscillatory behaviour, and when controlled by electronic feedback can also be used as a continuous measure of viscosity under controlled internal stress without applying oscillation. Method (ii) is primarily reserved for observing liquid behaviour under very high shear rates, which can also reveal die-swell behaviour at the exit from the capillary and so including the ability to estimate elastic behaviour. Less commonly used, but nonetheless relevant, (iii) extensional geometry can be used. Essentially, a sample, typically a polymer melt or solution is rapidly extended as a filament under controlled rate, and the thinning to breakage of the filament recorded to reveal a resistance to extension as an extensional viscosity. Combining shear rate, as the rate of change of stress within the sample within these various methods, the material viscosity can be derived (Whorlow, 1992).

The techniques described above are regularly applied to coating suspensions, including printing inks (Hoath, et al., 2009; Tuladhar, 2017; Vadillo, et al., 2010a; 2010b; Yokoi, et al., 2009). Traditional printing technology submits inks to flow, strain and extension in regions of pumping, transfer, film splitting, etc. The ink properties determine its resistance to these applications of strain and extension, and of particular interest is the change of these properties over time. Method (i) in rotational controlled stress mode is an ideal tool to provide "day zero" quasi quality/consistency control information about an inkjet ink before use.

In the case of inkjet in the print application, the ink is either delivered to the substrate as a droplet on demand or as a deflected pathway choosing whether to accept an ejected ink droplet within a continuous stream of such droplets or reject it according to the image requirement. The mechanism used to create the droplet, however, differs fundamentally from those processes familiar in traditional printing methods, such as offset, flexography or gravure. Inkjet technology applies a displacement to the incompressible liquid ink, either via a fixed-response piezoelectric element or a heating device used to expand the ink or a gas bubble within it. The end result is to meet the requirement of extruding a fixed volume of ink from a capillary-like nozzle independent of the ink's rheological properties, which must lie within a given range for the technique to function correctly. The shear rate under these conditions is typically ~10^5 s^{-1} to 10^6 s^{-1}, and, by nature, the applied strain is in the form of a pulse, which can be controlled in terms of amplitude, waveform, and dwell time between each pulse. This force, time and geometrical constriction used to provide a fixed droplet volume thus determines the difference between digital inkjet and classical analogue print technologies, i.e. inkjet is fixed-volume, displacement-driven, whereas traditional printing is ink-responsive pressure-driven. Thus, we see that the method (ii), namely pressure-driven capillary viscometry, fails to replicate the inkjet mechanism designed to deliver a fixed volume in a given time. Why this is the case, is worth discussing in a little more detail.

Capillary viscometry relies on the Hagen-Poiseuille relationship for flow in a pipe

$$Q = \frac{\mathrm{d}V}{\mathrm{d}t} = \frac{\pi R^4 \Delta P}{8\eta l} \qquad [1]$$

where Q is the volume flow rate $\mathrm{d}V/\mathrm{d}t$ of a liquid, having viscosity η, through a cylindrical pipe (capillary) of radius R and length l under an applied pressure difference of ΔP. The observed flow rate is, therefore, responding to the pressure applied as a function of its viscosity. This situation would be useless in inkjet as the flow rate must be a constant. In other words the pressure must rise to the necessary value to extrude a fixed volume of ink in a given time. This can only be achieved using a displacement pump rather than, for example, a gas overpressure. We are forced, therefore, to abandon classical capillary viscometry and design a displacement-driven apparatus to be able to expose an inkjet ink experimentally to the high-shear conditions experienced in application.

2.2 Instrument design – positive displacement

Our design for the experiment is shown in Figure 3. A motor-driven piston expels the ink from a cylindrical syringe and forces it to flow at high shear rate through a capillary. The ink is collected, drawn back into the syringe and so passed a controlled number times repeatedly through the apparatus. A sample can be collected after passage through the capillary and analysed for any change in suspension particle size, surface tension and its intrinsic viscosity. Particle size change is sensitive to particle dispersion state, such as the state of any suspending colorant pigment and/or particulate latex binder, i.e. it reveals flocculation or agglomeration induced by the mechanical stress by showing an increase in size, or the contrary in the case where the induced stress might have actually broken-down any pre-existing structures. Intrinsic viscosity, measured as the flow time required for a given volume of ink to flow through a capillary restriction under gravity (low shear) reveals additionally the condition of any polymer content in relation to the suspension, i.e. a drop in intrinsic viscosity reveals a breakdown in polymer chain length, or it matches the breakdown of sus-

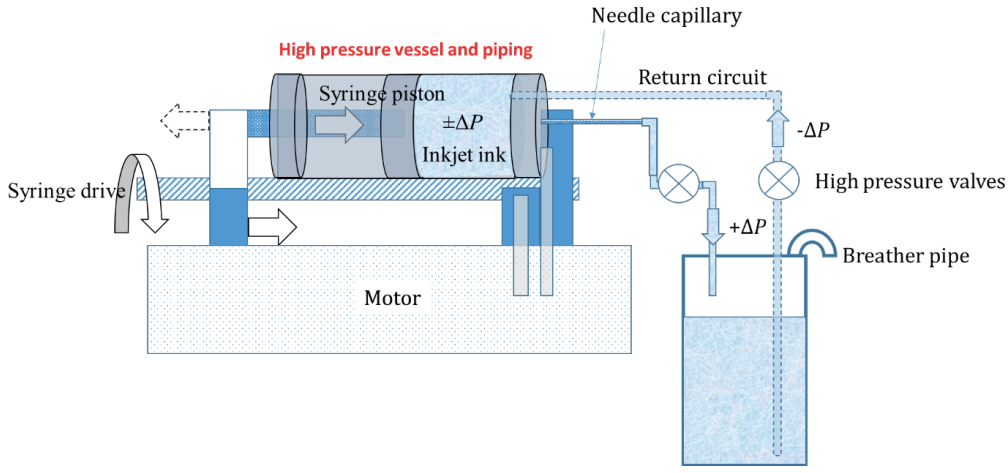


Figure 3: A schematic representation of the experimental apparatus design used to mimic the fixed displacement condition of an ink-jetting process

pension agglomerates, whereas an increase reveals polymer entanglement of structure build within the suspension.

Such polymers exist, for example, as dispersing agents, such as the frequently used polyacrylate dispersant in aqueous inks for ensuring colorant pigment colloidal stability and binding to the substrate, being soluble in the sodium form but precipitated in the calcium form, and, hence, particularly sensitive to contact with divalent alkali metal ions. Other polymers are present frequently as viscosifying agents, humectants, surfactants or as oligomer and monomer residues in latex binder product suspensions. The free polymer content, in particular the presence of surfactant, defines the surface tension of the ink, and any changes to the surfactant itself, or its concentration, that might occur during jetting can be monitored by measuring the surface tension, σ.

The apparatus as installed in the laboratory is shown in Figure 4, and the extrusion of liquid (water in this case) from the capillary and the return flow system is shown in Figure 5.

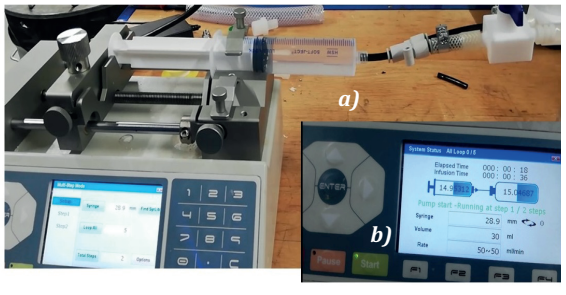


Figure 4: (a) Syringe and motor drive connected to the capillary via a valve, also showing the return flow junction element, (b) motor speed drive controller

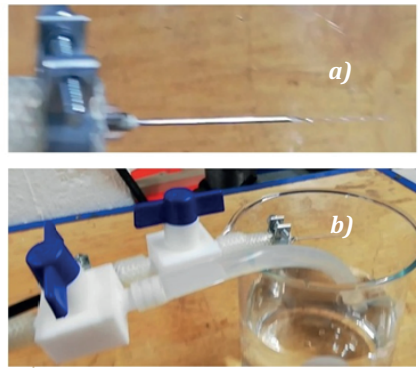


Figure 5: (a) Liquid extruding from the capillary at high speed, (b) return pipe and connection valve system for multiple passes through the syringe

To prevent contamination of the sample a number of precautions needed to be taken. The liquid collection vessel needed to be covered under a sealed film. Sampling was made by mechanical pipette, and each pipette sealed for transportation (Figure 6) to the nearby enclosed laboratory area to perform particle size and intrinsic viscosity analyses – subsections 2.4 and 2.5, respectively.

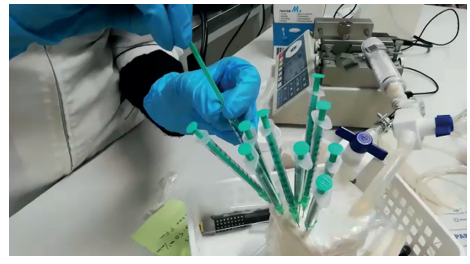


Figure 6: Taking care to isolate samples from contamination using a mechanical sealed pipette, transported in a film-sealed vessel

2.3 Flow analysis

To enable the analytical flow conditions to be determined, the following theoretical background needs to be considered.

Flow rate Q through a capillary is given, as we saw previously, by the Hagen-Poiseuille equation, Equation [1]. Whilst flowing through, the shear rate $\dot{\gamma}$ experienced by the liquid is given by

$$\dot{\gamma} = \frac{4Q}{\pi R^3} = \frac{\left(\frac{4\pi R^4 \Delta P}{8\eta l}\right)}{\pi R^3} = \frac{R\Delta P}{2\eta l} \qquad [2]$$

Thus, the parameters to be adjusted to achieve the desired shear rate at the resulting system flow rate Q are R, l and ΔP, so as to arrive at the representative shear rate of $10^5 \lesssim \dot{\gamma} \lesssim 10^6$ s^{-1}. By finding a conveniently suitable fine capillary, such as used typically in a high shear capillary viscometer, and so knowing R and l, it is then possible to design for the required pressure by displacement.

To calculate ΔP in a syringe one must consider the pressure drop across the capillary, which is given by the Bernoulli expression, and the relationship of pressure to the speed of the syringe piston displacement. The velocity at the end of the capillary, v_2, is given by the ratio of the cross-sectional areas of the syringe A_1 and capillary A_2 (= πR^2) given the velocity before the capillary, v_1, which is the speed of the syringe piston

$$v_2 = v_1\left(\frac{A_1}{A_2}\right) \qquad [3]$$

Applying this in the Bernoulli formula gives us,

$$\Delta P = \rho(v_1^2 - v_2^2) \qquad [4]$$

which is negative, as it is a pressure drop, where ρ is the liquid density, and $v_2 = Q/\pi R^2$.

This then leaves us with the answer from Equation [3] of how large the syringe diameter ($D^2_{\text{syringe}} = 4A_1/\pi$) must be in combination with the adjustable speed of the piston. The piston activator is more controllably run at a slow rate.

Using the equations above we chose the following parameters to work with. A mechanical syringe was chosen that delivers 50 cm^3·min^{-1}
(i.e. $Q = 50 \times 10^{-6}/60$ m^3·s^{-1} = $(5/6) \times 10^{-6}$ m^3·s^{-1}).

We need a shear rate up to $\dot{\gamma} \sim 10^6$ s^{-1}. From Equation [2] we can, therefore, calculate the capillary radius required $\left(R = \sqrt[3]{4Q/(\pi 10^6)}\right) \approx 0.1$ mm, i.e. a capillary diameter of 0.2 mm.

To provide a sufficiently extended period of shear in order to reduce the number of passes needed to obtain a result, a convenient capillary length of 40 mm was chosen. The pressure drop along the capillary length, is then given from Equation [1] as $\Delta P = 47.21 \times 10^3$ Pa, which is approximately equivalent to 0.5 bar. However, in this experimental design it is extremely important to recall that the system is running under constant flow rate, such that the pressure build-up can rapidly increase should there by a blockage or an increase in viscosity either by using a different liquid ink or by an ink that shear thickens – rare but not negligible possibility –, i.e. instead of the case of a normal capillary viscometer, where $Q \propto \Delta P/\eta$, the situation here is a constant displacement apparatus, such that $\Delta P \propto \eta$, which means that a factor increase in viscosity is directly raising pressure by the same factor.

Therefore, it is very important to make the calculation as to what the pressure is likely to be, so that the apparatus is run safely in respect to the material construction. For safety reasons a pressure release valve and/or motor power cut-off sensor should be fitted, and if the liquid properties are not known beforehand, then a protective cover should be installed to contain liquid should there be a vessel or piping failure. Additionally, also pressure-related, the capillary should always point into a receptacle or toward blocking material, in case it should blow out and cause injury. One other non-safety-related issue is to avoid the ingress of air bubbles into the system, as these act to reduce the condition of constant flow rate as the air compresses, and air in ink can also lead to internal drying at the bubble interface, resulting in solids contamination as well as potential oxidation.

2.4 Particle size measurement

Microscopic particles in suspension undergo Brownian motion, which is observed as a translational diffusion rate through the liquid medium using the autocorrelation function over time of the real time varying dynamic laser-light scattering intensity $I(t)$. The decay of the autocorrelation function provides the translational diffusion rate of the particles. This, in turn, is inversely proportional to the ensemble average equivalent spherical diameter (*esd*) of the particle moving at that diffusion rate through the liquid according to the Stokes–Einstein relation

$$esd = \frac{k_B T}{3\pi\eta_{\text{liquid}} D_{\text{translation}}} \qquad [5]$$

where k_B is Boltzmann's constant, T the absolute temperature, η_{liquid} the suspending liquid phase dynamic viscosity, and $D_{\text{translation}}$ the translational diffusion coefficient determined from the e-folding decay Γ of the light scattering autocorrelation function,

$$\int_{\tau=0}^{\infty} \frac{I(t)I(t+\tau)}{I^2(t)} d\tau = e^{-\Gamma\tau}$$

$$D_{\text{translation}} = \frac{\Gamma}{\left(\frac{4\pi n}{\lambda}\sin\frac{\theta}{2}\right)^2} \quad [6]$$

in which n is the refractive index of the particulate material in the suspending liquid, λ the wavelength of the laser light, and θ the angle from the axis at which the scattering is recorded as a function of time, τ. By using multiple iterative deconvolution of the auto-correlation function, supported by software, a particle number size distribution (in %) can be obtained (Zetasizer, Malvern Instruments, UK).

It is important to recognise, as described above, that the particle size data in this study are reported as particle number distributions, based on the scattering volume occupancy effect of each particle in the suspension, which naturally skews the results toward the larger number of finer particles per unit mass of material compared with coarser ones. This differs from most industrial representations, which use individual particle mass concentration, which naturally skews the data toward the coarse particle range. We chose this representation on purpose, so that visual assessment of larger scale agglomeration can be directly compared with optical and electron microscopy. The finer scale structuration, in particular, can be well investigated using the higher resolution of electron microscopy.

2.5 Intrinsic viscosity

The low-shear flow of the ink before and after passage through the displacement pump and capillary was measured as the time taken to flow through an Ostwald glass viscometer, as shown schematically in Figure 7.

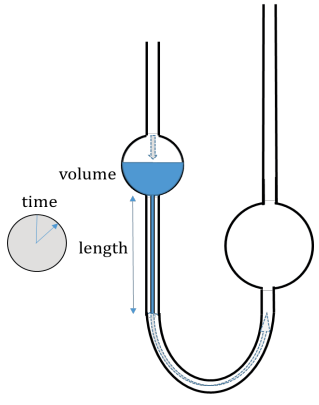


Figure 7: Ostwald viscometer for measuring intrinsic viscosity – time for liquid to pass via the thin capillary restriction is a relative measure of low-shear intrinsic viscosity

The intrinsic viscosity reveals the volume fraction effect of the suspended or dissolved content. Thus, the response of the intrinsic viscosity of the samples to repeated jetting shear reveals the nature of structural elements, as shown schematically in Figure 8, in which a highly dispersed system "day zero" with repulsive interaction manifests a given rest state viscosity, a dynamically induced packing change can result in a higher volume fraction swept out by flocculated particles or coiled polymer, and finally a strongly aggregated material acts as a fewer number of now coarser particles, and, hence, represent a reduced interactive volume fraction.

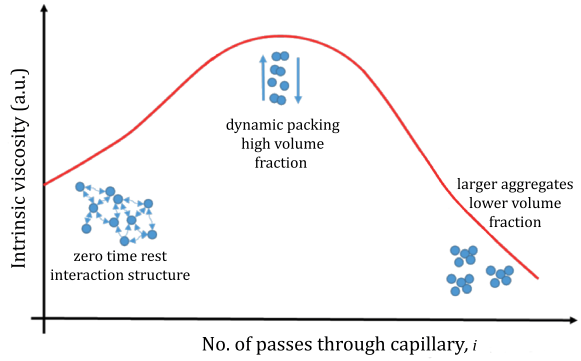


Figure 8: Schematic of the effect of different packing interaction states on intrinsic viscosity

For common ink usage, it is sufficient to follow the typical printhead manufacturer's advice for ink viscosity under these conditions, commonly within the range from 4 mPa·s to 9 mPa·s.

2.6 Surface tension

Ink behaviour when exiting the nozzle and spreading on the printhead plate, as well as wetting the substrate, depends on surface tension (Krainer, Smit and Hirn, 2019). Liquid surface tension can be measured from a bulk liquid sample using the du Noüy ring method. A thin ring of known circumference, typically made from platinum, is lowered into contact with the planar surface of the sample liquid and subsequently slowly raised to form an extended meniscus.

The force F_σ required to raise the ring against the action of the liquid surface tension, corrected for the weight of the ring itself, is related to the surface tension via the length of the contact line on both the inner and outer surface of the meniscus adhering to the ring, namely,

$$\sigma = \frac{F_\sigma}{2\pi D_{\text{ring}}} \quad [7]$$

where D_{ring} is the diameter of the ring used, Figure 9.

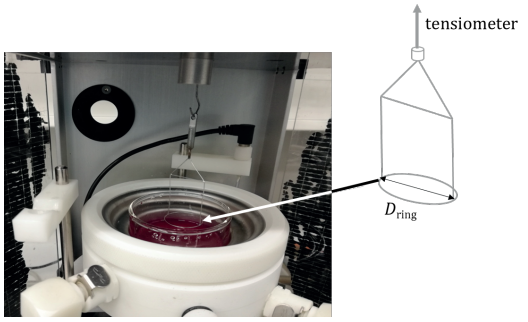


Figure 9: Surface tension measurement using a du Noüy ring tensiometer

2.7 Materials

The materials were collected as best for purpose as could be achieved, given the ubiquitous difficulty of sourcing information on commercial products. The design of sample choice we desired was, nonetheless, more or less catered for, in that we first set out to determine if the experimental concept would actually act out correctly upon trial materials successfully. Therefore, starting with a simple polymer, known to break down under the print dynamic in inkjet, enabled us to gain confidence in the suitability of the test concept (Wheeler, et al., 2014). Once demonstrated, then the task was to move on to the separate components of binder and pigment. Latex binders were suitably acquired by the co-author team and others donated after much searching by a helpful manufacturer's R&D group. Inks proved equally difficult to find, but thanks to one co-author (EK) three "inks" were provided, two based on a couple of the acquired latices and one a "reference" ink comprising a commercial inkjet water-based ink for high-speed digital printing (web speed up to 150–200 m·min^{-1}). The reference ink was developed in cooperation with one particular printhead manufacturer to be suited especially for such extreme rheological conditions.

2.7.1 Polymeric constituents – polyvinyl alcohol and latices

To establish some prior knowledge of the effect of jetting shear on polymeric components of ink, two typical polymer molecules and compound types were studied individually, namely a polymer solution of polyvinyl alcohol (PVOH, MOWIOL® 4-88, M_w ~31 000, Sigma Aldrich), and four latex compound binders. The latex binders were supplied as aqueous dispersions. Two of the latices were formulated by the manufacturer with and without urethane modification (Acrycote® anionic styrene acrylic emulsion AP-600 K and urethane modified AP-600 K-1, supplied by APEC Ltd. R&D Centre, Republic of Korea). Since the AP binders were, respectively, a commercial product and a modified commercial product, necessarily no further detailed information on their polymerisation or manufacture could be divulged by the supplier. The further two latices came from non-disclosable origin, and so are labelled as L1 and L2. In the interests of understanding changes in chemical composition as a function of jetting, all the latex samples were analysed using Fourier transform infra-red (FTIR) spectroscopy (PerkinElmer, Finland Oy) before and after shearing by forming dried films. The films were made by pouring a thin layer of suspension in a Petri dish and then drying at room temperature (25 °C). Flakes of the films (Figure 10) were used for the spectroscopic analysis and yielded spectra as shown in Figure 11.

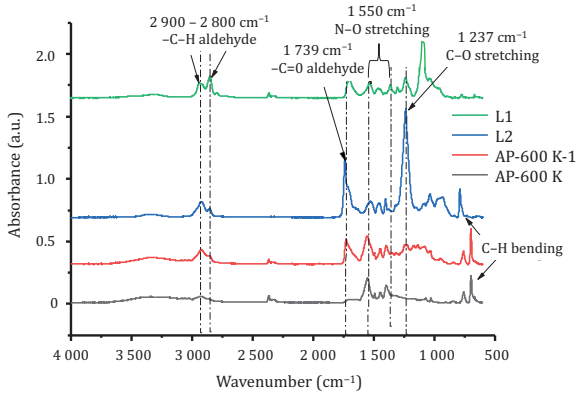


Figure 11: FTIR spectra of the latex binders – the units of absorbance are arbitrary and the stacked spectral plots are of comparable magnitude (processed by spectrum software, PerkinElmer v. 6.3.5)

The latex binders are described in Table 1.

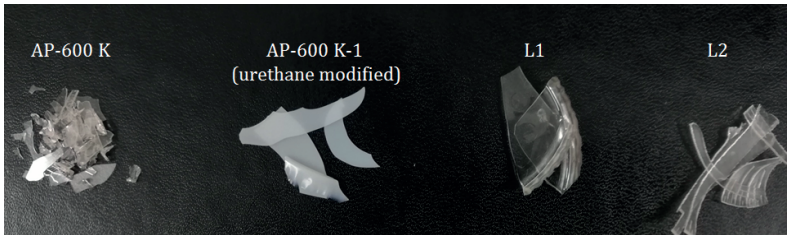


Figure 10: Flakes of dried latex films as used for FTIR analysis

Table 1: Available details of as-supplied and experimental preparation of latex binders

Latices	Initial mass fraction (%)	Mass fraction prepared for passes through capillary pump (%)	Initial pH (as supplied)	Corrected pH for passes through capillary pump
AP-600 K	10.65	5	8.10	8.10
AP-600 K-1	23.43	5	8.25	8.25
L1	36.60	5	7.78	8.35
L2	35.23	5	8.40	8.30

The solids content and pH were adjusted, using deionised water and 0.1 M NaOH, respectively, to represent their solid mass fraction properties present in an ink, typically 5–10 %.

2.7.2 Inkjet inks – complete formulation

Following the analyses of the single components, three commercial pigment-containing ink formulations were tested, which, once again for proprietary reasons, are represented as inks A, B and R from a printing house, where R was termed as the reference ink. Inks A and B, by contrast, were formulated trial inks containing latex L1 and L2, respectively. For these materials little is known about other formulation additives, however since the exercise in the study reported here is to investigate if a method of applying representative jetting shear can reveal characteristics of ink stability/instability, the detailed knowledge of their makeup is, fortunately, less relevant than their generic character. The formulated inks are now in current industrial use, and so can be considered relevant. Table 2 shows the as-delivered solids content of the three inks.

Table 2: Ink solids contents

Ink	Solids mass fraction (%)
A	23.86
B	23.43
R (reference ink)	31.72

2.7.3 X-ray photoelectron spectroscopy

By studying the atomic elemental content using X-ray photoelectron spectroscopy (XPS) the changes in the composition of the surface layer of the ink and influence of shearing after several passes were determined.

3. Results and Discussion

We begin by considering the results from the application of multiple passes of the single component materials, starting with the water soluble PVOH used to determine if the shear regime is sufficient to cause polymer breakage or coiling, as would be expected from the prior-art experience of inkjet printing polymer solutions (Wheeler, et al., 2014). Results from the four latex suspensions are considered in detail, followed by the inks A and B, containing each of them (L1 and L2), respectively, in comparison with the "reference" ink R.

3.1 Polymer breakdown of PVOH in solution under shear

PVOH solution is a typically used adhesive binder in coating formulations. Solubility is controlled by molecular weight and level of hydrolysis, both inversely. Figure 12 shows the effect of increasing number of passes through the pump syringe capillary, where it can be seen that after a low number of passes the polymer chain gel network properties of the polymer at a concentration of 5 000 ppm have been broken down. This structure (Figure 12a) does not rebuild, even after many hours, i.e. the time between shearing, collecting the samples and measuring their intrinsic viscosity.

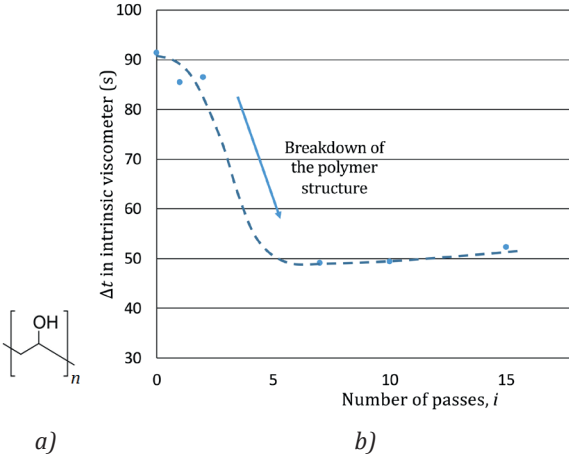


Figure 12: a) PVOH and b) the impact of repeated jetting shear on instrinsic viscosity time interval of PVOH solution (5 000 ppm) – the dashed line is to assist the eye to follow the trends, and could form the first approximation to an experimental function describing the curve

Thus, we can interpret this as a breakdown of the polymer chain. Continued shearing has little further effect, though a slight increase in viscosity might be suspected due to eventual polymer coiling and entanglement.

We can conclude from Figure 12b that the apparatus design is sufficient to reproduce the expected polymer chain breakdown effect of ink jetting on polymer solutions, and thus gain confidence that the procedure can reasonably mimic the forces experienced by an ink during printing.

3.2 Changes in chemical content of latex binders

Figure 13 shows the effect that 20 passes through the syringe capillary has on the chemical makeup of the inkjet ink latices by comparing the FTIR spectra before and after the application of the extrusion (jetting) shear.

The loss of aromatic C-C and N-O after 20 passes (latex AP-600 K-1, dashed circles in Figure 13) through the high-shear regime could be indicative of the constituent styrene and/or species such as nitrosobenzene, which latter can act as a cross-linker during the polymerisation of the latex and/or for increasing strength on drying. Similarly, the loss of signal at ~720 cm^{-1} could relate to a loss of a species such as a hexamine moiety, typically added as a biocide preservative (latices L1 and L2, solid oval in Figure 13). No extra analyses were made to determine the exact nature of the species loss, but the fact that something becomes lost means that it becomes detached in some way from the main polymer into the surrounding liquid, and when the films are formed moves with the liquid (water) to the perimeters of the sample as evaporation proceeds, and thus are no longer present in the polymeric analysis.

3.3 Response of particle size, intrinsic viscosity and surface tension

The results from the designed process of repeated shear are sensitive to the three measured parameters:

(i) particle size, following changes according to the experimentally determined equivalent spherical diameter function *ESD*

$$esd_i = ESD(esd_{i-1}, \dot{\gamma}) \quad [8]$$

where esd_i is the particle size after i passes exposed to a shear rate $\dot{\gamma}$, which is dependent on the previous value esd_{i-1},

(ii) intrinsic viscosity according to the following similar series function

$$\eta_i = H(\eta_{i-1}, \dot{\gamma}) \quad [9]$$

where η_i, the intrinsic viscosity of the ink after i passes, is dependent on the previous viscous condition η_{i-1}, having been exposed to a shear rate of $\dot{\gamma}$, and

(iii) surface tension, similarly, as

$$\sigma_i = \Sigma(\sigma_{i-1}, \dot{\gamma}) \quad [10]$$

The functions *ESD*, H and Σ thus describe the change in stability of the ink as a function of jetting. The starting values esd_0, η_0 and σ_0 are determined prior to the experiment. As we already saw in subsection 3.1, to a first approximation the function H for intrinsic viscosity of the PVOH polymer could be traced at least by eye following the dashed line shown. Should the

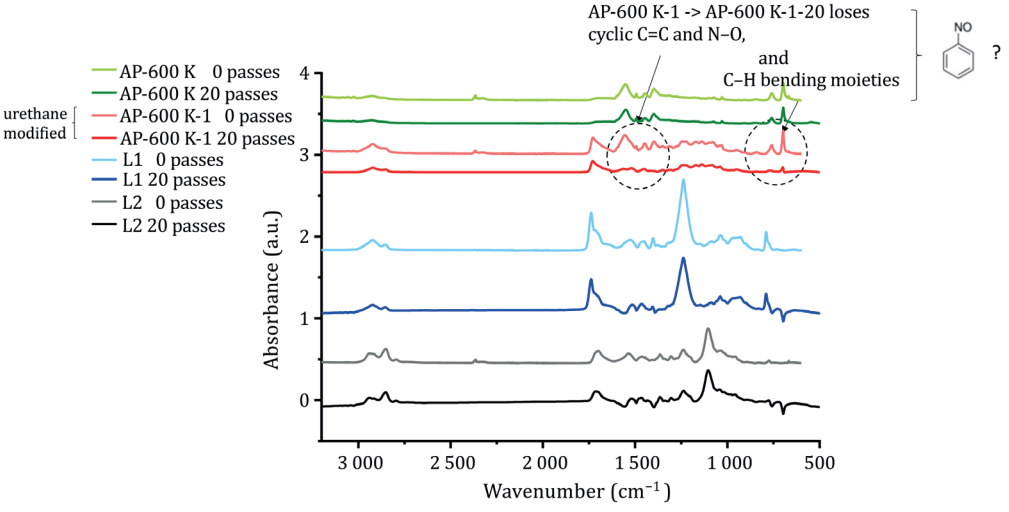


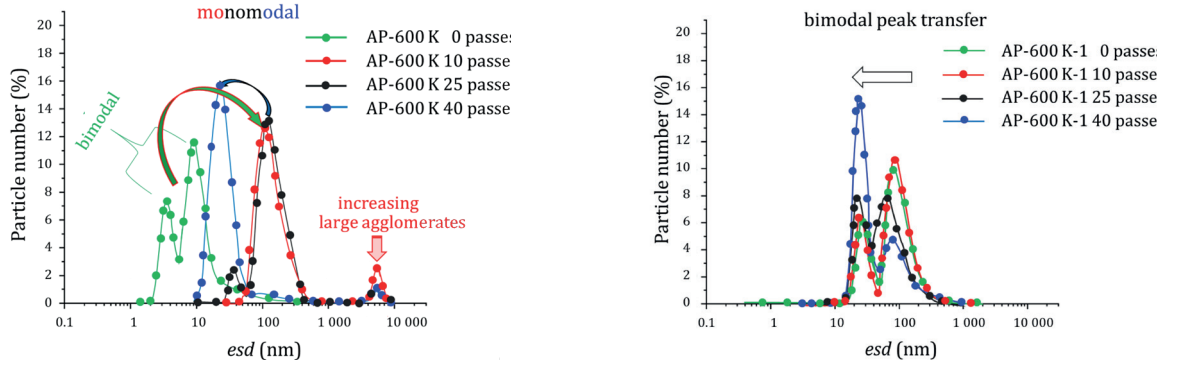
Figure 13: FTIR spectra of the four latex binders comparing the molecular constituents before and after the application of 20 passes through the repeated high shear mechanical syringe (jetting) regime; the units of absorbance are arbitrary and the stacked spectral plots are of comparable magnitude

procedure be used regularly in ink development, then similar experimental traces could be fitted for all three functions – we do not undertake this here since the sampling data are necessarily limited, due to sampling by hand, and would not yield fully reliable representations of the functions, however a fully developed procedure, perhaps a robotic process, would be able to support this approach.

We now report the sensitivity identified for the latex binders and inks in turn to the three parameters, including further observations of relevance.

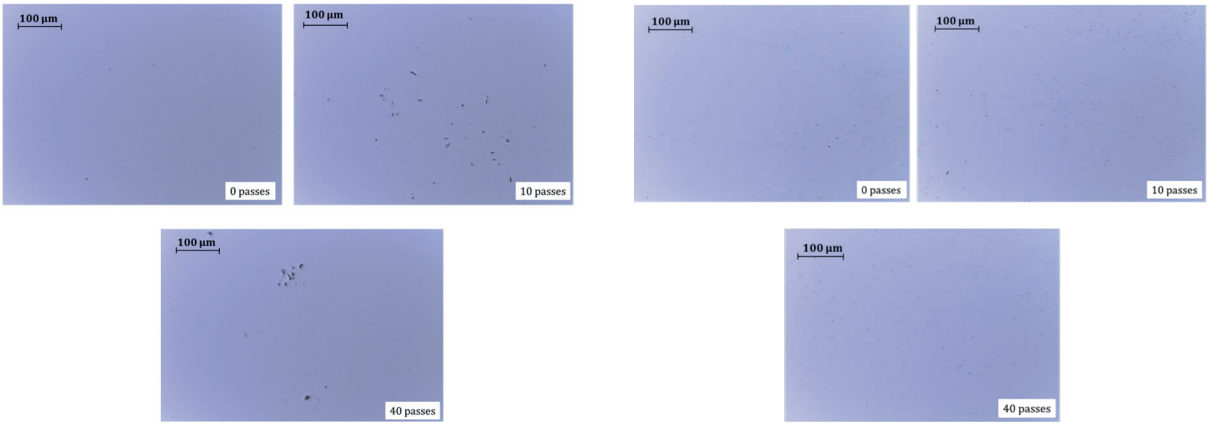
3.3.1 Stability of latex binders

Figure 14 shows the ensemble averaged dynamic light scattering results of particle size (esd_i) for the AP-600 K and AP-600 K-1 latex pair tested for stability during increasing numbers of passes through the mechanical high shear capillary. We can see that there are a number of different responses. AP-600 K (Figure 14a) shows an initial reduction of a starting bimodal into a monomodal distribution, indicative of coagulation, followed by some agglomeration forming large particle sizes as a function of shearing. The reduction to monomodal and increase in size across the logarithmic scale suggests firstly cascade-type joining (coagulation) of particles, initially from 5 nm – so small as to be probably monomer or oligomer residue only – to 10 nm and onward to ~20 nm, and then to an equilibrium between agglomerate building and agglomerate breakdown under high shear at around ~130 nm, with some very large agglomerates building to ~5 000–6 000 nm (5–6 µm). Such large agglomerates could be prime suspects for inkjet nozzle blocking. After 40 passes, however, the large aggregates become broken down again and the size distribution reverts to a single peak a decade finer in size. AP-600 K-1 (Figure 14b), the urethane modified latex, essentially continues to display a strongly discrete bimodal particle size with a progressive transfer of particle occupancy from the coarser branch of the distribution to the finer as a function of progressive repeated shearing, being, interestingly, once again about a decade in size apart.



a) *b)*

Figure 14: Particle size response, esd_i, of latices (a) AP-600 K, and (b) AP-600 K-1 (urethane modified) to repeated passes through the mechanical syringe at high shear



a) *b)*

Figure 15: Optical microscopy of the latex suspensions following the formation of agglomerates as a function of number of passes through the mechanical syringe: (a) AP-600 K, (b) AP-600 K-1 (urethane modified)

Furthermore, we see in Figure 14 that the modification that was made to the latex AP-600 K-1 by adding the urethane moiety has apparently stabilised the latex particles against forming large aggregates. If we refer back to the FTIR spectrum for this latex in Figure 13 we saw that apparently a species becomes lost during repeated shearing. It was speculated that it might be a cross-linking agent. The modification appears to have released this species from the main polymer, and as a result the latex remains significantly more stable against aggregation or flocculation. Additionally, the change in size occupancy might also be related to a breakdown of the polymer cross-linking mechanism (Song and Winnik, 2005).

The agglomeration tendency can be followed physically using optical microscopy of the latex suspensions, Figure 15. The particle sizes observed correspond to the larger particle agglomerates in the light scattering size distribution data in Figures 14a and 14b. The optical resolution limit of ~0.25 μm limits the microscopic observation to random clusters/agglomerates only.

In contrast, in Figure 16, the two latices L1 and L2 show different behaviour as a function of multiple shearing.

The L1, on the one hand, remains quite stable against shear, but at a much larger particle size of ~50 nm, although with the appearance of a smaller size peak after 40 passes at ~12 nm. The L2, on the other hand, shows an initial reduction in particle size, suggesting separation of particles. Noting again the logarithmic scale of particle size (*esd*), the data suggest that the action of shearing on L2 is to break down a likely starting pair-wise particle-particle structure into single particles, i.e. from ~26 nm down to ~13 nm.

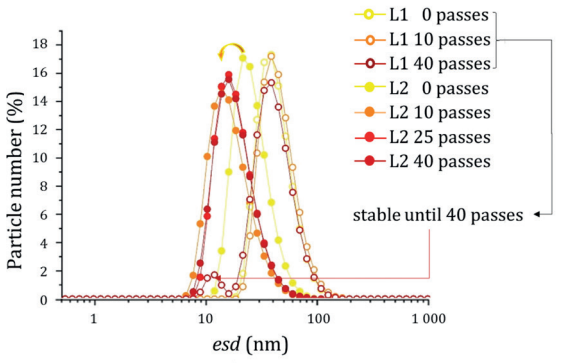


Figure 16: Particle size, esd_i, response of latices L1 and L2 to repeated passes through the mechanical syringe at high shear

The intrinsic viscosity of the latex suspensions is shown in Figure 17, in which it is clear to see that the particle volume flow properties at low shear remain similar for the AP-600 K and the L1 and L2 latices, whereas the urethane modified AP-600 K-1 has a distinctly lower viscosity flow, which may relate to the change in free additive content as seen previously in respect to particle size stability. We may conclude that the presence of a low number of agglomerates is not affecting the intrinsic viscosity. This is a very important finding in that it would be unlikely to identify a runnability problem in an inkjet component simply by considering viscosity measured using a typical printer's viscometer tool.

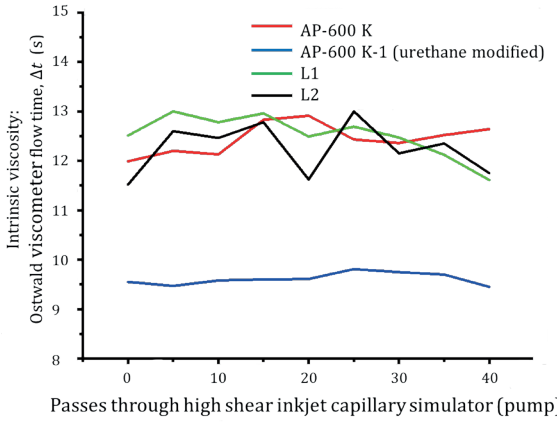


Figure 17: Intrinsic Ostwald viscometer flow time Δt ($\propto \eta_i$) for the four example latices

The surface tension results for the four latices are shown in Table 3. All the samples were measured at a consistent solids content of 5 g·dm^{-3}. The values appear to be very similar except for the latex L1, which shows a higher surface tension – nonetheless relatively low when compared with the much higher surface tension of water, 75 mN·m^{-1} – suggesting that this dispersion probably has less surfactant present, though still an effective amount. The analysis does not deliver any information concerning the hydrophilic nature of the latex particles themselves as the surface tension relates purely to the liquid solution phase only. We also can conclude that the wetting behaviour of the suspension remains constant irrespective of the repeated shearing experienced.

Table 3: Surface tension, σ_i (mN·m^{-1}), of the latex suspensions

Latex	Number of passes through mechanical capillary, *i* 0	10	40
AP-600 K	43.26 ± 0.12	42.49 ± 0.17	42.33 ± 0.10
AP-600 K-1	37.44 ± 0.03	38.11 ± 0.02	37.56 ± 0.04
L1	58.73 ± 0.70	59.37 ± 0.07	59.27 ± 0.02
L2	42.17 ± 0.60	41.94 ± 0.20	42.23 ± 0.10

3.3.2 Inks

Having studied the challenging latex binder component found in many pigmented inks, we now consider the complete pigment formulated inks A (containing latex L1), B (containing latex L2) and R ("reference").

The starting "day zero" size distributions are shown in Figure 18, and the averaged data show that all the inks look alike and fall within the typical size range for a pigmented inkjet ink.

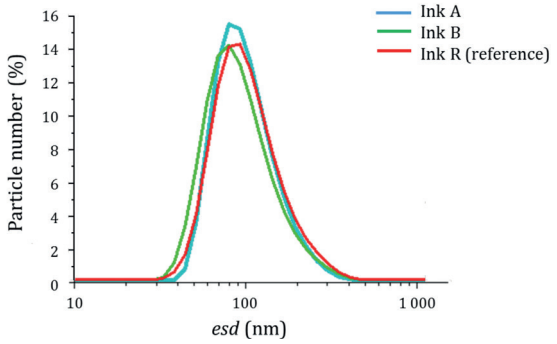


Figure 18: Starting "day zero" particle size distributions of the three inks

The impact of repeated applications of high shear in the mechanical syringe capillary are revealed for the three inks in Figure 19. In all cases the particle size of the contents decreases as a function of passes through the constant flow rate capillary.

Inks A and B behave very similarly, and, as is to be expected across the logarithmic scale in size (Figure 19), while the material becomes either broken down finer or increasingly dispersed, the particle size distribution broadens. This is typical of a grinding/milling process in which hard elastic, and brittle or softer particles coexist, in that the initial close to log-normal distribution becomes progressively skewed to the finer end as the more brittle or softer material grinds preferentially.

If we study the electron microscope images in Figure 20, taken from dried ink films using a field emission scanning electron microscope (FESEM) (Zeiss Sigma VP, Germany), we can notice three effects: (i) in all inks the particle material becomes finer as the number of passes under high shear increases, (ii) aggregates begin to appear as a function of repeated jetting, especially in inks A and B, and (iii) the ink R ("reference") appears not to have a film-forming binder, such as latex, and, as such, is better described as a pigment-only ink, as we see the pigment particles cluster into a random clumped powder distribution during the drying. This clustering is probably related to the "self-binding" design of ink, where the pigment dispersant doubles up as a binder between them on drying, and this, at least partly, explains the clustered form of pigment distribution seen in the micrographs.

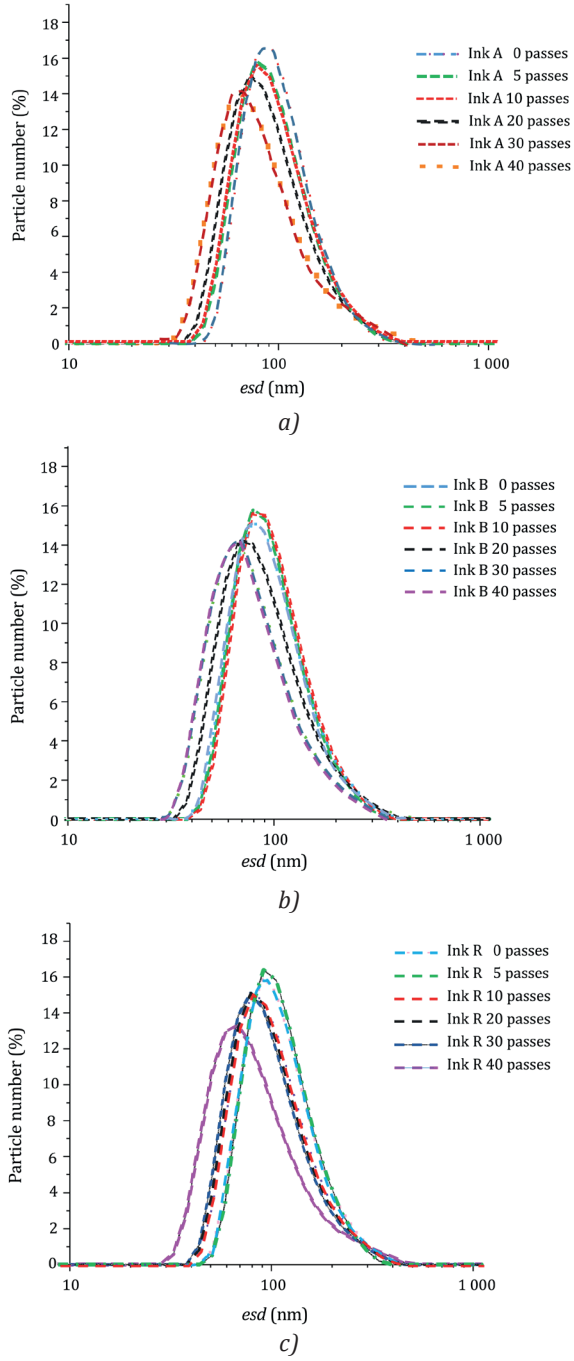


Figure 19: Particle size distribution response to repeated shear through the mechanical capillary; (a) ink A with latex L1, (b) ink B with latex L2, and (c) ink R ("reference")

However, this allows us to make a further important observation since the particle size also becomes finer in ink R, strongly supporting the likelihood of pigment milling continuing during repeated jetting.

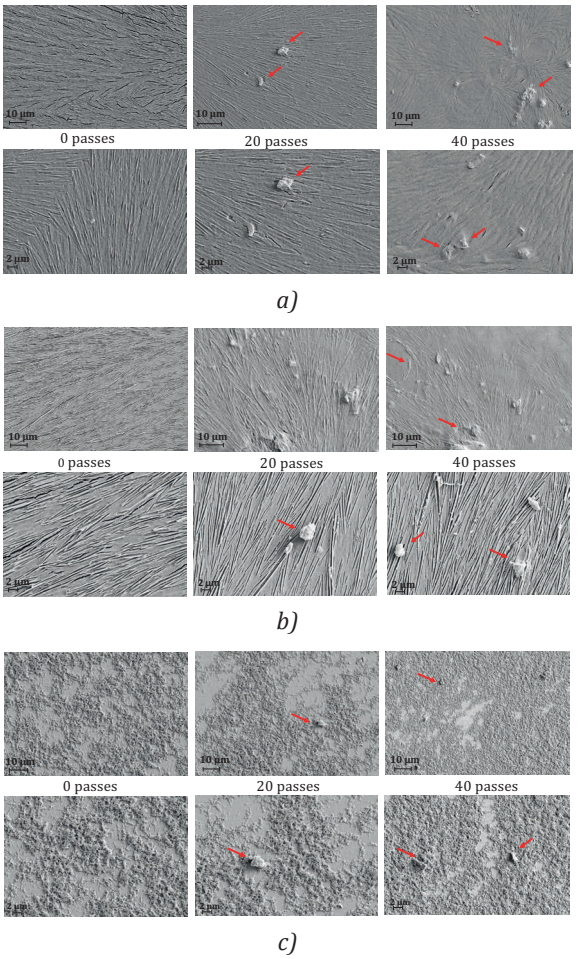
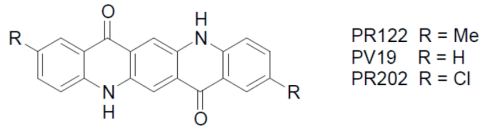


Figure 20: Electron microscope images (FESEM, accelerating voltage 15 kV) of the three inks following the response to repeated exposure to shearing; (a) ink A, (b) ink B, and (c) ink R – the arrows indicate the formation of agglomerates

If pigment continues to be milled in this way in continuous inkjet printing, it will result in increased freshly formed pigment surface area, which, in turn, will adsorb free polymeric material, including excess stabilising dispersant. However, if this continues to a great extent, any excess dispersant will be consumed, such that the freshly milled pigment may not long remain stabilised in colloidal suspension and will flocculate in the stationary state or undergo shear-induced aggregation during jetting. Furthermore, removal of excess dispersant in this way will likely reduce the buffer capacity of the ink against any acidic attack, such as from the action of anaerobic bacteria. Apart from the question of colloidal stability, there might well be expected to be a change in print density and shade. This is clearly a topic for further work.

In the case of a complete ink, such as in A and B, there is a combination of pigment and latex. For example, ink B has a magenta pigment, typically either dimethylquinacridone or dichloroquinacridone, according to the pigment colorant coding PR122 and PR202, respectively, having the formula



where the radical positions R are either unsubstituted hydrogen (H) (defined by the pigment colorant code PV19), methyl (CH_3) or chlorine (Cl). By studying the atomic elemental content using XPS method, it is possible to see if the pigment is concentrating also in the observed aggregates leading to changes in nitrogen, oxygen or chlorine levels. XPS is a surface sensitive technique and does not probe the bulk of the sample due to the material capture of emitted electrons. Thus, if a latex agglomerate were to occur it is likely that the outer surface would then be coated with pigment. Table 4 shows the comparative analysis of the unsheared ink B and an agglomerate formed after 20 passes through the mechanical capillary.

Table 4: Elemental analysis using XPS of ink B "day zero" (unshearded) versus an agglomerate structure

Ink B	**0 passes**		**20 passes**	
Element	Mass (%)	Atomic (%)	Mass (%)	Atomic (%)
N	22.47	25.08	18.08	10.72
O	75.91	74.20	76.61	76.88
Cl	1.62	0.71	5.31	2.40
total	100.00	100.00	100.00	100.00

From the elemental data in Table 4, we can immediately observe the large increase in chlorine (Cl) content, while the nitrogen content reduces, which is probably indicative of a surface concentration of pigment around the aggregate. It is not possible to determine whether the whole aggregate consists of pigment alone, but given the latex agglomeration tendency during shearing it is more likely that an ink containing such agglomerates would concentrate free pigment as a coating on such a sticky material. This is typical, incidentally, of the behaviour of latex binder stickies in papermaking, where the sticky agglomerate is covered by a mineral as a means of preventing the stickies from depositing on the papermachine. The minerals frequently used are either hydrophobic talc or bentonite/montmorillonite nanoclay (Benecke, et al., 2009; Gantenbein, et al., 2009; 2010; Gribble, et al., 2010; 2011).

The observed milling process is also seen in the intrinsic viscosity response, Figure 21, where progressive shearing leads to a steady decrease in passage time

through the Ostwald viscometer. Once again we can note the unusual nature of "ink" R, which also, by these data, suggests it is predominantly pigment only.

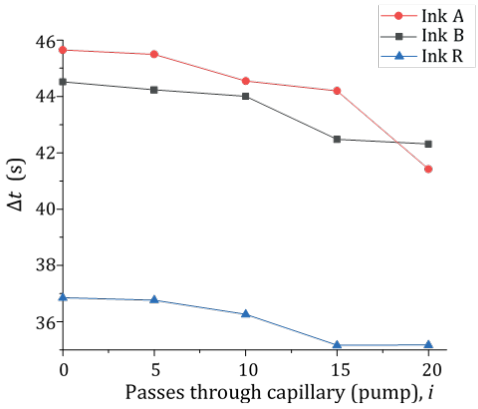


Figure 21: Displaying the steady drop in intrinsic viscosity (passage time through the Ostwald viscometer) as a function of passes through the mechanical syringe capillary

As in the case of the latices, the surface tension values for the inks, Table 5, measured at a solids content of 1 g·dm^{-3}, remain stable also through the shearing process, and lie between the lower and upper latex values, suggesting the presence of a certain amount of surfactant to aid wetting during printing.

Table 5: Surface tension, σ_i (mN·m^{-1}), of the inkjet inks

Ink	Number of passes through mechanical capillary, *i*		
	0	10	40
A	49.94 ± 0.06	49.61 ± 0.05	50.24 ± 0.12
B	50.31 ± 0.09	49.63 ± 0.07	49.67 ± 0.02
R (ref.)	48.41 ± 0.01	49.45 ± 0.08	49.75 ± 0.04

3.3.3 Jettability

The response in respect to particle size is seen as the most critical aspect found in this study, and is logical when considering the challenges of inkjet printing centre almost solely on the behaviour of the ink at the jetting nozzle. The presence of agglomerates or dried material lead to failure of the jet with either reduced droplet ink amount, usually accompanied by distortion of the droplet trajectory, or complete absence of ink altogether. Plate wetting and spreading of ink around the nozzle can also lead to disturbance of the break-away of ink from the printhead. This latter can either be due to problems of surface tension, which interestingly we did not see, or more likely in the light of our results capillarity across the surface of any dry build-up of ink or deposition of agglomerates around the nozzle exit.

Given the focus on agglomeration, it is worth taking a reality check on dimensions. Amongst the latices tested we saw particle sizes ranging from 5 nm to 200 nm. Suppose a printer desires two settings for certain jobs, e.g. 1 pl for the finest functional technical work, including, say, printed electronics, and 1 µl for general book and standard image printing. If we convert these liquid volumes to physical droplet diameters then they are equivalent to $\sqrt[3]{6/\pi \times 10^{-15}} \approx 1.2 \times 10^{-5}$ m and $\sqrt[3]{6/\pi \times 10^{-9}} \approx 1.2 \times 10^{-3}$ m, respectively. In respect to latex size, at least 200–300 spheres of 100 nm diameter could fit into a 1 pl droplet, and as many as 30 000–40 000 such spheres in a 1 µl droplet. However, agglomerates of 10 000 nm (10 µm), such as exhibited by the latex AP-600 K would block pl droplet generation and at least distort, if not also block by further build-up, the production of µl droplets. AP-600 K-1 (urethane modified) by contrast, with its bimodality, would be suitable for, say, down to > 100 pl, despite the particle size changes between the bimodal branches (actually getting finer), and L1 at ≤ 100 nm could be possible to use, like AK-66 K-1, in the upper pl range and certainly for µl droplet work, and their demonstrated stability against agglomeration should ensure satisfactory freedom of nozzle blocking provided no subsequently drying deposition around the nozzle exit occurred. Latex L2 after initial shear to disperse fully the "day zero" state, being then all ≤ 50 nm, should be well suitable for pl work.

As discussed in section 1. Introduction, there are a multitude of parameters, other than colloidal instability to shear, which control inkjet runnability, including the viscoelastic response to the displacement pulse magnitude and frequency in the printhead, exposure to air and drying at the nozzle exit, involving also air ingress during the displacement relaxation cycle, phase separation tendency leading to deposits at chamber walls, etc. Therefore, the novel test and supporting analyses proposed here address a subset, albeit a significant one, of the parameters affecting the dynamic response of the ink, especially particulate-containing ink, which, given the growing trend of using inkjet printing for patterning of functional inks, is increasing rapidly in relevance.

4. Conclusions

The evidence collected suggest that a constant flow rate mechanically driven syringe capillary device can induce the shear-related effects on both polymer and particle agglomerate breakdown as well as particle-particle aggregation via colloidal destabilisation. Such an opportunity to predict the constant flow rate shear-related runnability of inkjet ink in this way could provide a means of reducing on-machine trial time and avoidance of potentially expensive printhead damage.

The study of individual component parts of an inkjet ink, such as latex binder and pigment, separately, reveals the stability of each against repeated jetting shear conditions. Latex is confirmed to be particularly susceptible to both phenomena, showing initial coagulation and agglomerate build, followed by equilibrium breakdown and rebuild of these structures after multiple shearing. In combination with pigment, compound agglomerates have been shown to form, and it is speculated, using elemental analysis, that latex coagulates become covered by pigment, much as sticky deposits in papermaking become covered with mineral particles. Pigment is seen to undergo increased dispersion under initial shear, followed by a milling action during repeated shearing, such that the particle size progressively decreases.

Implications for jettability can be concluded, in that agglomerates are likely to induce nozzle blocking, and milling of pigment is expected to change subsequent print density and substrate coverage performance. It is hoped that using the novel device and procedure reported here, such effects can be readily studied in the future in combination with runnability prediction.

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References

Alamán, J., Alicante, R., Peña, J.I. and Sánchez-Somolinos, C., 2016. Inkjet printing of functional materials for optical and photonic applications. *Materials*, 9(11): 910. https://doi.org/10.3390/ma9110910.

Beedasy, V. and Smith, P.J., 2020. Printed electronics as prepared by inkjet printing. *Materials,* 13(3): 704. https://doi.org/10.3390/ma13030704.

Benecke, F., Gantenbein, D., Schoelkopf, J., Gane, P.A.C. and Gliese, T., 2009. Organic contaminants in recycled paper: a model study of the adsorbent properties of talc for idealised component suspensions. *Nordic Pulp and Paper Research Journal***,** 24(2), pp. 219–224. https://doi.org/10.3183/npprj-2009-24-02-p219-224.

Biswas, T.T., Yu, J. and Nierstrasz, V.A., 2019. Effects of ink characteristics and piezo-electric inkjetting parameters on lysozyme activity. *Scientific Reports,* 9: 18252. https://doi.org/10.1038/s41598-019-54723-9.

Cui, X., Boland, T., D'Lima, D.D. and Lotz, M.K., 2012. Thermal inkjet printing in tissue engineering and regenerative medicine. *Recent Patents on Drug Delivery & Formulation*, 6(2), pp. 149–155. https://doi.org/10.2174/187221112800672949.

Cui, X., Gao, G., Yonezawa, T. and Dai, G., 2014. Human cartilage tissue fabrication using three-dimensional inkjet printing technology. *Journal of Visualized Experiments,* 88: e51294. https://doi.org/10.3791/51294.

Ebert, J., Özkol, E., Zeichner, A., Uibel, K., Weiss, Ö., Koops, U., Telle, R. and Fischer, H., 2009. Direct inkjet printing of dental prostheses made of zirconia. *Journal of Dental Research*, 88(7), pp. 673–676. https://doi.org/10.1177/0022034509339988.

Eggenhuisen, T.M., Galagan, Y., Biezemans, A.F.K.V., Slaats, T.M.W.L., Voorthuijzen, W.P., Kommeren, S., Shanmugam, S., Teunissen, J.P., Hadipour, A., Verhees, W.J.H., Veenstra, S.C., Coenen, M.J.J., Gilot, J., Andriessen, R. and Groen W.A., 2015. High efficiency, fully inkjet printed organic solar cells with freedom of design. *Journal of Materials Chemistry A*, 3(14), pp. 7255–7262. https://doi.org/10.1039/C5TA00540J.

Gantenbein, D., Schoelkopf, J., Gane, P.A.C. and Matthews, G.P., 2010. Influence of pH on the adsorption of dissolved and colloidal substances in a thermo-mechanical pulp filtrate onto talc. *Nordic Pulp and Paper Research Journal*, 25(3), pp. 288–299. https://doi.org/10.3183/npprj-2010-25-03-p288-299.

Gantenbein, D., Schoelkopf, J., Hunziker, P., Matthews, G.P. and Gane, P.A.C., 2009. Efficiency of colloidal pitch adsorption onto phyllosilicates: comparing talc, chlorite and pyrophyllite. *Nordic Pulp and Paper Research* Journal, 24(4), pp. 448–458. https://doi.org/10.3183/npprj-2009-24-04-p448-458.

Gao, M., Li, L. and Song, Y., 2017. Inkjet printing wearable electronic devices. *Journal of Materials Chemistry C*, 5(12), pp. 2971–2993. https://doi.org/10.1039/C7TC00038C.

Gribble, C.M, Matthews, G.P., Turner, A., Gantenbein, D., Schoelkopf, J. and Gane, P.A.C., 2011. Equilibrium coefficients for the adsorption of colloidal stickies onto mineral suspension particulates to improve paper recycling. *Nordic Pulp and Paper Research Journal*, 26(4), pp. 421–427. https://doi.org/10.3183/npprj-2011-26-04-p421-428.

Gribble, C.M., Matthews, G.P., Gantenbein, D., Turner, A., Schoelkopf, J. and Gane, P.A.C., 2010. Adsorption of surfactant-rich stickies onto mineral surfaces. *Journal of Colloid and Interface Science*, 352(2), pp. 483–490. https://doi.org/10.1016/j.jcis.2010.07.062.

Hoath, S.D., Martin, G.D., Tuladhar, T.R., Mackley, M.R., Hutchings, I.M. and Vadillo, D.C., 2009. Links between ink rheology, drop-on-demand jet formation, and printability. *Journal of Imaging Science and Technology*, 53(4): 041208. https://doi.org/10.2352/J.ImagingSci.Technol.2009.53.4.041208.

Jiang, X., Li, W., Hai, T., Yue, R., Chen, Z., Lao, C., Ge, Y., Xie, G., Wen, Q. and Zhang, H., 2019. Inkjet-printed MXene micro-scale devices for integrated broadband ultrafast photonics. *2D Materials and Applications*, 3: 34. https://doi.org/10.1038/s41699-019-0117-3.

Jutila, E., Koivunen, R., Bollström, R. and Gane, P., 2015. Thin layer chromatographic behaviour of dyes during microfluidic transport in functionalised calcium carbonate coatings. In: P. Gane, ed. *Advances in Printing and Media Technology: Proceedings of the 42nd International Research Conference of iarigai*. Helsinki, Finland, 06–09 September 2015. Darmstadt, Germany: iarigai, pp. 255–264.

Jutila, E., Koivunen, R., Bollström, R. and Gane, P., 2020. Fully inkjet-printed glucose assay fabricated on highly porous pigment coating. *Microfluidics and Nanofluidics*, 24(6): 40. https://doi.org/10.1007/s10404-020-02344-4.

Jutila, E., Koivunen, R., Kiiski, I., Bollström, R., Sikanen, T. and Gane, P., 2018. Microfluidic lateral flow cytochrome P450 assay on a novel printed functionalized calcium carbonate-based platform for rapid screening of human xenobiotic metabolism. *Advanced Functional Materials*, 28(31): 1802793. https://doi.org//10.1002/adfm.201802793.

Kim, H.S., Kang, J.S., Park, J.S., Hahn, H.T., Jung, H.C. and Joung, J.W., 2009. Inkjet printed electronics for multifunctional composite structure. *Composites Science and Technology*, 69(7–8), pp. 1256–1264. https://doi.org/10.1016/j.compscitech.2009.02.034.

Koivunen, R., Jutila, E. and Gane, P., 2015. Inkjet printed hydrophobic microfluidic channelling on porous substrates. *Journal of Print and Media Technology Research*, 4(1), pp. 7–17. https://doi.org/10.14622/JPMTR-1413.

Koivunen, R., Jutila, E., Bollström, R. and Gane, P., 2016. Hydrophobic patterning of functional porous pigment coatings by inkjet printing. *Microfluidics and Nanofluidics*, 20(6): 83. https://doi.org/10.1007/s10404-016-1747-9.

Koivunen, R., Jutila, E., Bollström, R. and Gane, P., 2017. Inkjet printed polyelectrolyte patterns for analyte separation on inherently porous microfluidic analytical designs. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 522, pp. 218–232. https://doi.org/10.1016/j.colsurfa.2017.03.001.

Koivunen, R., Jutila, E., Bollström, R. and Gane, P., 2019. Investigating chromatographic interactions in porous pigment coatings between inkjettable polyelectrolytes and model colorant solutions. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 579: 123676. https://doi.org/10.1016/j.colsurfa.2019.123676.

Krainer, S., Smit, C. and Hirn, U., 2019. The effect of viscosity and surface tension on inkjet printed picoliter dots. *RSC Advances*, 9(54), pp. 31708–31719. https://doi.org/10.1039/C9RA04993B.

Lee, A., Sudau, K., Ahn, K.H., Lee, S.J. and Willenbacher, N., 2012. Optimization of experimental parameters to suppress nozzle clogging in inkjet printing. *Industrial & Engineering Chemistry Research*, 51(40), pp. 13195–13204. https://doi.org/10.1021/ie301403g.

Li, Y., Dahhan, O., Filipe, C.D.M., Brennan, J.D. and Pelton, R.H., 2019. Deposited nanoparticles can promote air clogging of piezoelectric inkjet printhead nozzles. *Langmuir*, 35(16), pp. 5517–5524. https://doi.org/10.1021/acs.langmuir.8b04335.

Matsusaki, M., Sakaue, K., Kadowaki, K. and Akashi, M., 2013. Three-dimensional human tissue chips fabricated by rapid and automatic inkjet cell printing. *Advanced Healthcare Mater*ials, 2(4), pp. 534–539. https://doi.org/10.1002/adhm.201200299.

Renner, J. and Bircher, F., 2017. Waveform optimization for piezo drop on demand inkjet printheads by meniscus motion analysis. In: P. Gane, ed. *Advances in Printing and Media Technology: Proceedings of the 44th International Research Conference of iarigai*. Fribourg, Switzerland, September 2017. Darmstadt, Germany: iarigai, pp. 15–20.

Saarinen, J.J., Valtakari, D., Haapanen, J., Salminen, T., Mäkelä, J.M. and Uozumi, J., 2014. Surface-enhanced Raman scattering active substrates by liquid flame spray deposited and inkjet printed silver nanoparticles. *Optical Review*, 21(3), pp. 339–344. https://doi.org/10.1007/s10043-014-0051-8.

Song, J.-S. and Winnik, M.A., 2005. Cross-linked, monodisperse, micron-sized polystyrene particles by two-stage dispersion polymerization. *Macromolecules*, 38(20), pp. 8300–8307. https://doi.org/10.1021/ma050992z.

Sumaiya, S., Kardel, K. and El-Shahat, A., 2017. Organic solar cell by inkjet orienting – an overview. *Technologies*, 5(3): 53. https://doi.org/10.3390/technologies5030053.

Tuladhar, T., 2017. Measurement of complex rheology and jettability of inkjet inks. In: W. Zapka, ed. *Handbook of industrial inkjet printing: a full system approach*. Weinheim, Germany: Wiley–VCH Verlag, Ch. 22. https://doi.org/10.1002/9783527687169.ch22.

Vadillo, D.C., Tuladhar, T.R., Mulji, A.C., Jung, S., Hoath, S.D. and Mackley, M.R., 2010a. Evaluation of the inkjet fluid's performance using "Cambridge Trimaster" filament stretch and break-up device. *Journal of Rheology*, 54(2), pp. 261–282. https://doi.org/10.1122/1.3302451.

Vadillo, D.C., Tuladhar, T.R., Mulji, A.C. and Mackley, M.R., 2010b. The rheological characterisation of linear viscoelasticity for ink jet fluids using piezo axial vibrator and torsion resonator rheometers. *Journal of Rheology*, 54(4), pp. 781–795. https://doi.org/10.1122/1.3439696.

Wheeler, J.S.R., Reynolds, S.W., Lancaster, S., Romanguera, V.S. and Yeates, S.G., 2014. Polymer degradation during continuous ink-jet printing. *Polymer Degradation and Stability*, 105, pp. 116–121. https://doi.org/10.1016/j.polymdegradstab.2014.04.007.

Whorlow, R.W., 1992. *Rheological techniques*. New York, NY, USA: Ellis Horwood.

Yokoi, K., Vadillo, D., Hinch, J. and Hutchings, I., 2009. Numerical studies of the influence of the dynamic contact angle on a droplet impacting on a dry surface. *Physics of Fluids*, 21(7): 072102. https://doi.org/10.1063/1.3158468.

Zönnchen, N., Wenger, R., Mauron, M. and Bircher, F., 2019. Bioprinting of thick, vascularized tissues by inkjet-technology. In: C. Ridgway, ed. *Advances in Printing and Media Technology: Proceedings of the 46th International Research Conference of iarigai*. Stuttgart, Germany, 15–18 September 2019. Darmstadt, Germany: iarigai, pp. 105–115.

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Yellowing of UV varnishes with focus on its temporal behaviour and correlations between intensities and degrees of polymerisation

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Abstract

This work discusses the curing-induced discolouration of UV varnishes, the so-called 'yellowing'. A study of 47 market available acrylic-based UV varnishes from five manufacturers shows that all varnishes exhibit significant yellowing. In order to clarify if yellowing can be exploited for monitoring the cure of the varnishes, three varnishes are analysed in detail, including one low-migration and one photoinitiator-free self-initiating formulation. For this purpose, the applied varnishes are measured with respect to yellowing as well as their actual polymerisation degrees. Both measures are checked for correlations to develop a novel method for monitoring the degree of polymerisation based on colourimetric measurements. Additionally, the temporal behaviour of the yellowing is determined as it is of significant importance when considering a practical usage of the yellowing approach.

Keywords: UV curing, temporal yellowing, discolouration, colourimetry, FTIR-ATR spectroscopy

1. Introduction and background

1.1 Background

A relevant number of print products are UV-varnished to achieve various optical and barrier properties. In some applications, like narrow web label printing, UV curing has reached a predominant position (Etiketten Labels, 2020). Thereby, the polymerisation degree (colloquially spoken: UV curing degree) is of fundamental importance in terms of quality and safety.

From a quality perspective, a certain polymerisation degree is necessary to ensure a good product quality, especially if it comes down to post-press processing aspects. An insufficient curing degree, for example, could cause blocking in the delivery stack or the reel. When considering product safety, within an insufficiently polymerised varnish layer, especially unaffected photoinitiators might tend to migration and could subsequently lead to health/safety issues for operators or even consumers (Green, 2010). Even though the latest-findings indicate that no hazard for consumers is to be expected from sheetfed offset printed products, process control and an adequate degree of polymerisation is still in the interest of all parties involved (bvdm, 2020). For these reasons, several methods to check the quantity/quality of the polymerisation exist in industrial practice. Among them are some methods based on manual tests as well as device-supported methods (ref. section 1.3). Bohn, et al. (2017) presented an alternative approach for indirect cure monitoring based on spectral measurements of the curing-induced discolouration of UV varnishes, the so-called 'yellowing'. They found a correlation between yellowing intensity and exposed UV dose for three common photoinitiators solved in acetone. Furthermore, a correlation between yellowing and actual polymerisation degrees for two laboratory UV varnishes could be shown.

As a logical extension of these findings, this research focuses on industrial varnish systems to determine whether findings of Bohn, et al. (2017) are relevant for industrial print processes. By investigating 47 varnish

systems available on the market, it is the aim to clarify if the yellowing is a relevant variable in commercial varnishes used. Next, three varnishes are analysed in detail to verify a significant correlation between yellowing and the actual polymerisation degree. Also, the temporal progression of the yellowing is examined colourimetrically as a change in yellowing intensities over time. This aspect becomes relevant when yellowing is measured as a process parameter. The studies described are fundamental on the way towards a practical realisation of the yellowing approach as a novel method for monitoring UV curing processes by using common spectrophotometers in the visible spectrum.

1.2 State of the scientific knowledge

The technical principles of UV curing, its related inks and varnishes and other relevant process parameters are widely described in literature, for example in Glöckner, et al. (2008). Therefore, only a brief abstract of UV curing principles and the background of yellowing in particular is given in the following.

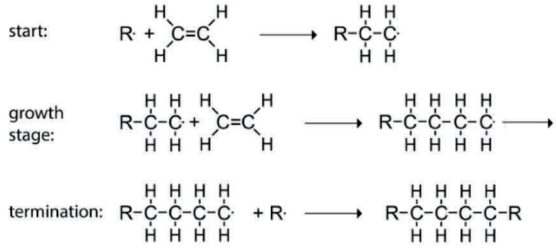

Figure 1: Schematic diagram of the radical polymerisation process (Bohn, et al., 2017)

Most UV varnishes relevant to printing industry are based on acrylates and mainly consist of reactive diluents, binders and photoinitiators. During the process of radical polymerisation, photoinitiators cleave under the influence of UV radiation and form free radicals R· in the start phase. These so-called 'start radicals' initiate the actual polymerisation process by breaking the C=C double bonds of the acrylic monomers and oligomers, which then crosslink in the growth stage to form polymers (Glöckner, et al., 2008). This process ends when all free radicals have reacted. Figure 1 shows the polymerisation process schematically. Besides the free radicals, the UV-induced cleavage of a photoinitiator can result in different photoproducts due to secondary reactions, further scissions and combinations of radicals with parts of the formulation (Green, 2010). These photoproducts have no supporting influence on the polymerisation but can cause a visible discolouration by their specific absorption characteristic in the UV- and the adjacent visible blue region of the electromagnetic spectrum. The findings of Bohn, et al. (2017) are in accordance with increasing yellowing intensities for increasing UV doses observed by Studer and Königer (2001), examining a photoinitiator in combination with a binder. However, this connection is only valid for lower UV doses (less than ~2 000 mJ/cm^2) as the photoproducts, for their part, are sensitive to UV light (Studer and Königer, 2001). Schwalm (2006) also points out that the yellowing can decrease at higher doses. Furthermore, the quantity of formed photoproducts very much depends on the particular photoinitiators and is also proportional to the photoinitiator(s) concentration, relative spectral power distribution of the used light source relative to the photoinitiators absorption spectra, and film thickness (Green, 2010). Schwalm and Green exemplarily showed, that reaction processes can lead to the formation of a broad variety of photoproducts for different photoinitiators. In addition, all other varnish components and even the used substrate as an (unwanted) supply of additional reaction products, might have an impact on the yellowing intensity (Schwalm, 2006; Green, 2010). Due to this potential multicausality, yellowing of a formulation is hardly predictable for a specific application. In this work, the term 'yellowing' is always referring to the UV-curing-induced initial photoyellowing, which needs to be distinct from the yellowing of polymers due to long term aging. The initial yellowing is described as a decrease of certain absorption bands within the first hours after curing (Schwalm, 2006). Figure 2 exemplarily shows the spectral reflectance of a UV varnish on a white substrate in its unpolymerised as well as its polymerised state for two UV doses. The polypropylene (PP) discolouration visible here can be attributed to the varnish, as the substrate does not show significant UV-induced discolouration (cf. section 2.2).

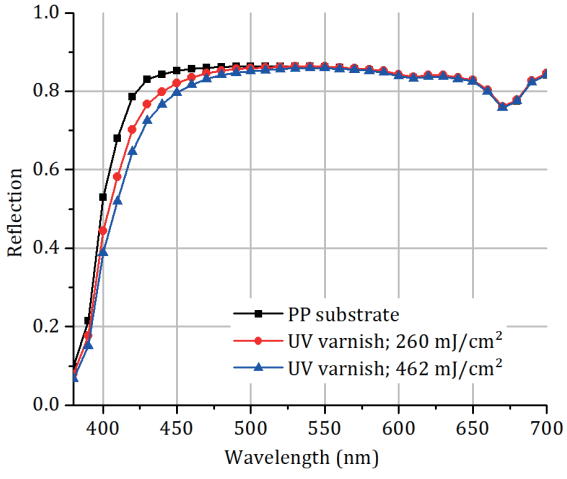

Figure 2: Spectral reflectance of an UV varnish applied on a white PP substrate polymerised with two UV doses; the polymerisation induced yellowing can be seen between 400 nm and 530 nm as a reduction in the reflectivity, i.e., an increased absorption

1.3 Methods to check the polymerisation quantity/quality

Various existing industry-relevant manual methods, such as solvent rub test, tape test, thumb twist test, powder test, and potassium permanganate test, to check cured layers are widely used and described in literature (Glöckner, et al., 2008). Except the last one, all of these have in common that they check different surface properties of a cured layer which are not necessarily related to the actual polymerisation degree. These methods, from some points of view, can be seen as inadequate gap fillers in the absence of a direct measurement of the degree of polymerisation. Besides manual techniques, some device-based methods are available to check various properties of cured layers. Hubergroup offers the NewV cure UV VIS spectrophotometer including the related method and special varnishes. The varnishes contain a marker substance, which is extracted after curing into a liquid. The quantity extracted is determined using the spectrophotometer and represents the curing degree (Schröder, 2019). Fogra offers an automated acetone test called ACET and the Fogra Ushio Cure Check which uses heat and pressure to check cure quality (Rauh, 2007). The UV CURE CHECK of PITSID (2019) determines the coefficient of sliding friction as an indicator for surface cure.

1.4 FTIR as a direct method to determine polymerisation degrees

For molecular spectroscopy purposes like classification and quantification, the Fourier-transform infrared (FTIR) spectroscopy as an analysis technique is widely used. Based on the molecule's interaction with infrared radiation, FTIR allows identification of material compositions, concentrations and functional groups, for instance. Using FTIR in attenuated total reflection (ATR) mode, one can conduct reflection measurements of both solid and liquid samples. The FTIR spectroscopy is a standard method to determine polymerisation degrees on a laboratory level. During the polymerisation process, the C=C double bonds of acrylic molecules split and the monomeric and oligomeric molecules crosslink to polymers. Consequently, one can determine the actual polymerisation degree of a UV varnish layer as a function of the remained C=C double bonds compared to an uncured varnish. The C=C double bonds have distinct absorptions at ~810 cm^{-1} whose intensity is proportional to the number of double bonds contained in a varnish (Glöckner, et al., 2008). To compensate variations in the measurements, it is necessary to perform an internal calibration for each measurement using a spectral band which is not altered by curing. In case of acrylates, the C=O bond absorption at ~1720 cm^{-1} fulfils this requirement (Fernàndez-Francos, et al., 2013). For quantification of a species, the peak heights in the absorbance spectra are determined, starting from their specific baselines. Out of these peak heights, the actual degree of conversion x is calculated by Equation [1] (Fernàndez-Francos, et al., 2013).

$$x = 1 - \frac{(A_{\text{spec}}/A_{\text{ref}})_{\text{cured}}}{(A_{\text{spec}}/A_{\text{ref}})_{\text{uncured}}} \times 100 \qquad [1]$$

where x is a degree of conversion in %, A is absorbance, 'spec' denotes sample species (C=C bond at ~810 cm^{-1}), 'ref' denotes sample reference (C=O bond at ~1720 cm^{-1}), 'cured' and 'uncured' denotes UV irradiated sample and not irradiated sample, respectively.

Figure 3 shows an FTIR-ATR absorbance spectrum of a commercial UV varnish in uncured and cured state. The relevant wavelength bands for quantification of the conversion are marked.

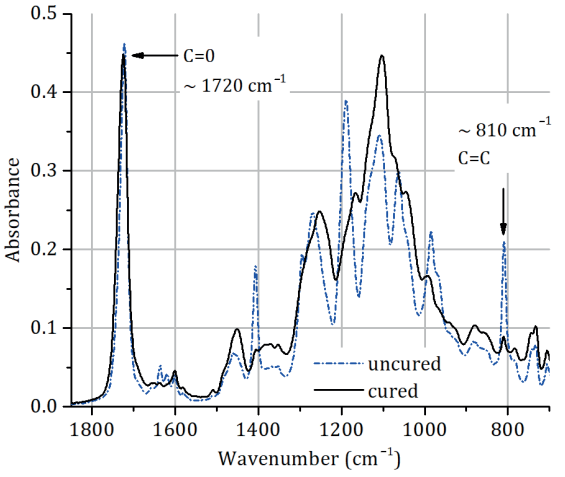

Figure 3: FTIR-ATR absorbance spectra of a UV varnish in uncured and cured state, the crucial bands at 1720 cm^{-1} and 810 cm^{-1} to quantify polymerisation are marked

For practical users of the UV curing, e.g. printers, this method is often seen as an elaborate, cost-intensive and laboratory-only method. For these reasons, it is not directly used in print production, but utilised by some larger companies on a quality assurance level. Thanks to appropriate software, it is just as easy to determine polymerisation with an FTIR as it is to determine colourimetric quantities with a spectrophotometer. Therefore, in the opinion of the authors of this article, at least the complexity aspect is worth a discussion.

2. Methods

2.1 Materials

In total, 47 samples of typically distributed UV varnishes have been obtained from five European varnish producers for conventional curing with medium

pressure mercury lamps and application via flexo print units. Our goal was to obtain a broad field of samples, representing current practice. The samples include high glossy and matte varnishes and all intermediate levels, varnishes for special application like anti-static protective varnishes and finishing of digital prints, varnishes for thermal transfer, embossing and several other demands. Low-migration (LM) systems are among these varnishes and also systems which are free of additional photoinitiators but containing self-initiating monomers. We assign a number to each varnish and provide Table 1 with basic characteristics like LM, glossy and matte. As a concession to the supplier, we do not provide brand names. Out of this range, three varnishes are selected for a deeper investigation of actual polymerisation degrees as well as the temporal progression of their yellowing (highlighted in Table 1). These varnishes were selected in order to represent different categories and yellowing intensities from our sample field.

Table 1: Sample field of 47 UV varnishes with allocated ID, manufacturer (Manuf.) and basic characteristics (Charac.) glossy (g) and matte (m), LM and self-initiating LM (LM+)

ID	Manuf.	Charac.	ID	Manuf.	Charac.
1	A	g	25	B	g
2	A	g	26	B	m
3	A	g	27	C	g
4	A	g	28	C	g
5	A	g, LM	29	C	g, LM
6	A	g	30	C	m, LM
7	A	m	31	C	m
8	A	m	32	D	g, LM
9	A	g	33	D	g
10	A	m	34	D	g, LM
11	A	g	35	D	g
12	A	g	36	D	g
13	A	m	37	D	g
14	A	m, LM	38	D	g
15	A	g, LM	39	D	m
16	A	g, LM+	40	D	m
17	A	g, LM+	41	E	g
18	A	m, LM+	42	E	g, LM
19	A	g, LM+	43	E	g, LM
20	A	g, LM+	44	E	g
21	B	g, LM	45	E	g
22	B	g	46	E	g
23	B	g	47	E	m
24	B	g	/	/	/

2.2 Application

For the wide investigation of the 47 varnishes, application is done with a 12 µm rod wire in order to enable an efficient sample generation. For the investigation of correlations and temporal progression, an IGT Printability Tester F1 in flexo mode is used. Its anilox roller has a nominal pick-up volume of 16 ml/cm^2. All varnishes are applied on a white 250 µm PP substrate, which is not affected by UV radiation in its colour (white point for M2 mode, D50, 2°: CIELAB 94,1; −2,04; 0,94). The tests were carried out under laboratory conditions. All samples have been stored at 21 °C under exclusion of light between measurements.

2.3 Colourimetrical analysis

The colour measurements are done with a Konica Minolta FD-7 spectrophotometer in 45°/0° geometry, M2 measurement mode, D50 illuminant, 2° CIE standard observer, 10 nm wavelength pitch, 3 mm measuring spot configuration. According to its spectral characteristic, yellowing can be expressed within the CIELAB colour space as change of the b^* coordinate. Calculation of Δb^* occurs in accordance with ISO/CIE 11664-6:2014 (International Organization for Standardization, 2014). For measuring the temporal progression of the yellowing, the time gap between curing and first measurement is fixed to ten seconds.

2.4 FTIR-ATR readings

A PerkinElmer Spectrum Two FTIR with ATR accessory is used to determine the acrylate conversion. The spectrometer measures in a spectral bandwidth of 8300–350 cm^{-1} (1204–28571 nm) and uses a versatile diamond crystal in the ATR top plate. The macros for an automated quantification process are written with PerkinElmer Spectrum Quant software. Each sample is measured three times whereby each measurement automatically consists of the average of four single measurements. Each sample is measured for yellowing and polymerisation at identical spots.

2.5 UV conveyor belt dryer

For curing the samples, the laboratory UV unit Technigraf AKTIPRINT MINI UV equipped with a standard medium-pressure mercury UV lamp is used. The emission spectrum of this type of lamps can be seen in relevant literature, for example in Green (2010). The UV source emits an irradiance of 441 mW/cm^2 in the entire UV range for an electric input power of 120 W/cm. We use UV doses from 462 mJ/cm^2 to 110 mJ/cm^2.

Variations of the UV doses are realised by different conveyor belt speeds in a range of 20 m/min to 4 m/min. Both irradiance and the resulting UV doses are measured with an Opsytec UVPAD E spectral radiometer. This device covers a wavelength range from 240 nm to 480 nm. We only consider the UVC, UVB and UVA range up to 400 nm for power data.

3. Results

3.1 Yellowing of market available UV varnishes

Figure 4 shows all analysed varnishes in their unpolymerised and their polymerised state for two UV doses. Inherent colours of all varnishes differ from the substrate's white point and all varnishes show significant yellowing with clearly different intensities within the sample field. For further evaluation we define Δb^*_i as the inherent varnish colour and Δb^*_c as the yellowing intensity for a UV dose of 462 mJ/cm², related to Δb^*_i.

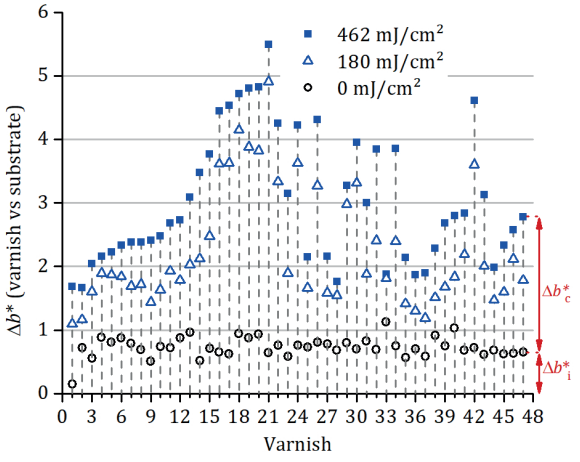

Figure 4: CIELAB Δb values of 47 UV varnishes for three UV doses of 0, 180 and 462 mJ/cm² (141 samples), Δb^*_c and $\Delta b^*_i$are exemplarily indicated for varnish 47*

Our knowledge of the varnishes consists only of the manufacturer's characterisation and is therefore limited to the properties we described in the materials section. During the analysis, we find the greatest yellowing intensities in the sample field for LM varnishes. Figure 5 shows diagrams containing all varnishes from two manufacturers, including 10 LM and 15 non-LM varnishes. The LM systems are shown with blue dashed line, non-LM with red dotted lines. These findings are representative for the other 22 varnishes of three manufacturers. We have reduced the legend of the left diagram and show results in two diagrams for better clarity.

The sample field can also be categorised by the surface properties glossy or matte. Figure 6 shows in two diagrams the varnishes already depicted in Figure 5, but here we differentiate between glossy (blue dashed lines) and matte (red dotted lines) varnishes. Based on this categorisation, no pattern can be identified. We could not identify any other categorisation.

In Table 2, the sample field is categorised by LM, non-LM, glossy and matte varnishes and the yellowing is quantified by mean Δb* values in order to highlight our findings. The glossy varnishes surpass the matte ones in their average yellowing intensity. This is due to the fact that most of the LM varnishes are categorised as glossy and, thus, significantly raise the mean value. To compensate for this distorted representation, we have added the categories glossy and matte excluding LM varnishes.

Table 2: Yellowing properties of the sample field based on arithmetic mean of Δb^*_i and Δb^*_c values, categorised by LM and surface properties glossy and matte

Varnish category (quantity)	$\bar{x}\ \Delta b^*_i$ *(substrate vs varnish unpolymerised)*	$\bar{x}\ \Delta b^*_c$ *(varnish unpolymerised vs polymerised)*
all (47)	0.73	2.29
LM (15)	0.73	3.33
non-LM (32)	0.73	1.80
glossy (35)	0.73	2.37
matte (12)	0.74	2.05
glossy, non-LM (23)	0.72	1.89
matte, non-LM (9)	0.77	1.89

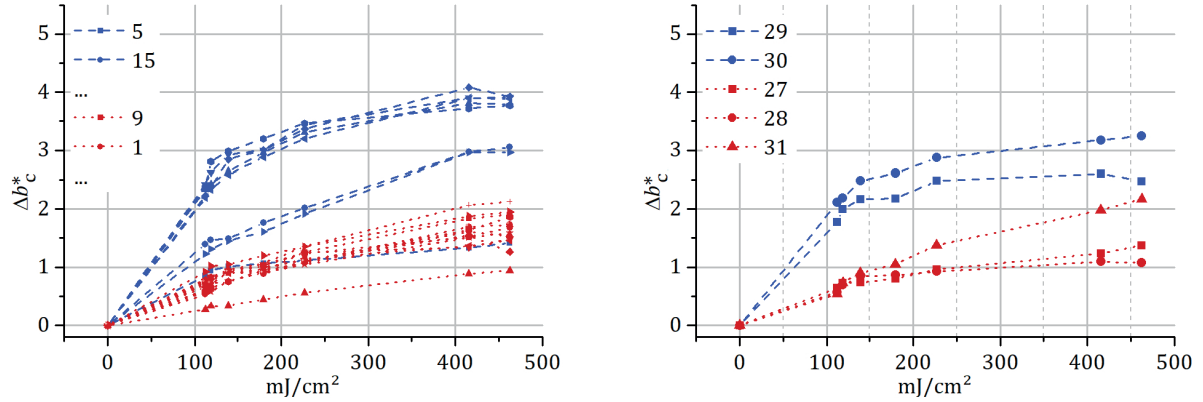

Figure 5: CIELAB Δb^*_c values of 25 UV varnishes, non-LM (dotted) and LM (dashed), from two manufacturers for eight UV doses ranging from 0 to 462 mJ/cm²; LM varnishes show the trend for higher yellowing intensities

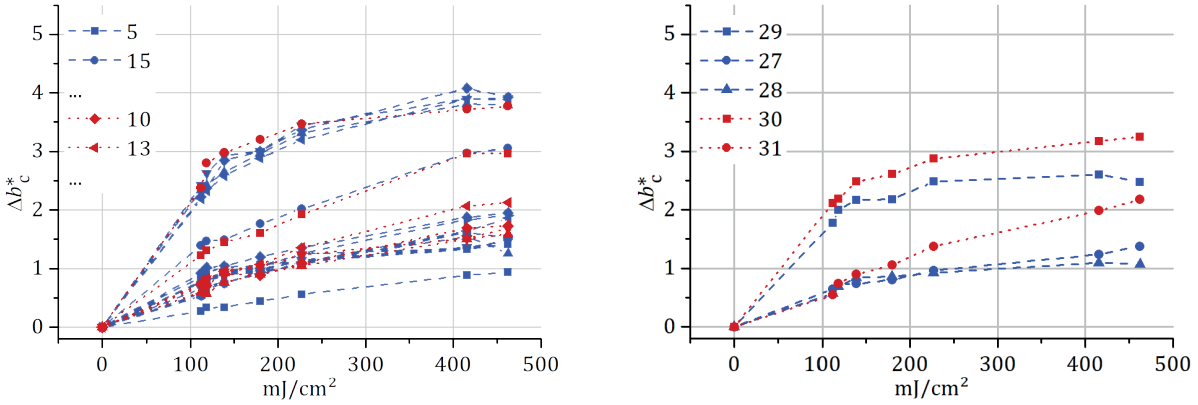

Figure 6: CIELAB Δb^*_c values of 25 UV varnishes, matte (dotted) and glossy (dashed), from two manufacturers for eight UV doses ranging from 0 to 462 mJ/cm²; no trend can be identified

Figure 6 shows that for some varnishes even an increase of the UV dose from 415 mJ/cm² to 462 mJ/cm² does not lead to an intensified yellowing. The same can be observed for varnish 5 and 19 in Figure 7 (cf. section 3.2), where the three crowded data points at the upper end of the regression line indicate that increasing the dose does not further increase polymerisation. This is because the varnishes have reached their polymerisation maximum for our curing condition.

3.2 Correlation between yellowing and polymerisation

Figure 7 shows the relationship between b^* value and polymerisation degree for three varnishes cured with 15 different UV doses. The varnishes differ significantly in yellowing intensities, but linear correlations are apparent for all of them. Based on Figure 7, one can ascertain a significant relationship between the acrylate's conversion and discolouration of the UV varnishes.

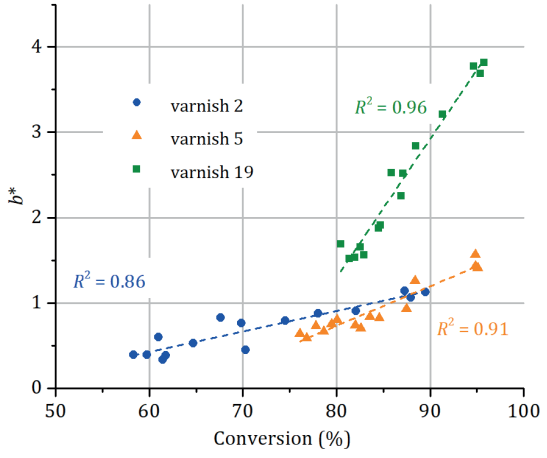

Figure 7: Correlation between yellowing as CIELAB b^* value and acrylates conversion for three UV varnishes cured in 15 UV doses ranging from 110 to 462 mJ/cm; coefficients of determination R^2 are given

Despite high coefficients of determination R^2 values, deviations from the ideal linear course can be seen. The sample generation and the measurements have multiple potential sources of errors like variations in varnish layer thickness, measurement of yellowing and polymerisation at non-identical spots, white point variations of the substrate, influence of morphology changes on colour measurements, penetration depth of the ATR measurements and measuring device errors. We do not conduct a complete error analysis as we primarily want to determine whether there is a fundamental connection between yellowing and polymerisation or not. Regardless of any measurement errors, a linear correlation can be established between the two variables. Of course, measurement errors are crucial in questions of practical measurability. We are aware of potential sources of errors and will consider them in a future validation of the approach.

3.3 Temporal behaviour of the yellowing

Figure 8 shows the temporal progression of the yellowing of varnishes 2, 5 and 19 for a period of 24 hours after initial curing.

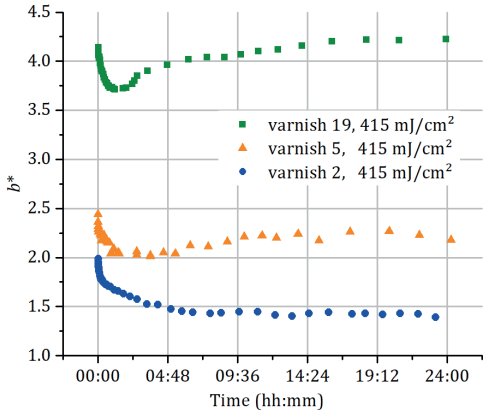

Figure 8: CIELAB b^* values for UV varnishes 2, 5, 19 for a time range of 10 s to approx. 24 h after curing

In the first two hours after curing, the measurement intervals are small as the yellowing changes rapidly, while intervals become greater with progressing time. When comparing the trends of the varnishes, clear differences can be seen. While varnish 2 shows an exponential decay, varnish 5 decreases in the first two hours and then, after two hours of stagnation, increases again to approach its initial b^* value. Varnish 19 shows this effect intensified and even reaches its initial yellowing after about 19 hours. All varnishes remain stable after a period of 24 hours.

4. Discussion

In the following, the results are discussed successively, each followed by an estimation of its relevance to the yellowing approach.

Although yellowing is undesirable and manufacturers have been searching for non-yellowing formulations for decades, all used varnishes show a curing-induced distinct yellowing with a mean Δb^*_c of 2.29. One can also see significant Δb^*_i values due to the application of the unpolymerised varnishes to the substrate. As well as laminations and other coatings, the presence of a varnish layer influences the visual and measurable colour due to several optical effects like scattering, refraction and absorption. However, from a colorimetric point of view these effects mainly influence the brightness and not the chromaticity (Stiene, Urban and Rodriguez-Giles, 2019). Therefore, the changes in b^* values can be attributed to the inherent colour of the varnishes.

With regard to yellowing, especially the 15 LM systems stand out by showing the highest intensities with a mean Δb^*_c of 3.33, compared with a mean Δb^*_c of 1.80 for non-LM varnishes. In general, the reasons for the yellowing potential of a varnish are to be found in the chemistry of its components and are not subject of this work. However, it seems conceivable that it is more difficult for manufacturers to focus on low-yellowing LM-formulations because there are less permitted photoinitiators for LM systems. The chemical industry will certainly continue research here.

The intensive yellowing signal of modern LM systems contributes to the yellowing approach in a way that a good measurability is crucial for the approach. As product safety is always an issue to be improved, LM varnishes are expected to gain market share. In addition, until there is certainty about the hazard potential of UV varnishes, the use of LM systems is also in line with the precautionary principle. Analysing the category glossy/matte, no pattern can be identified. In the absence of more detailed information about the composition of the varnishes we could not identify other categories. However, a precise knowledge of the composition presumably would allow us to draw closer conclusions about the interaction of different components regarding to their yellowing.

Based on our findings, we can state out that curing-induced yellowing is a potentially relevant parameter while working with UV varnishes, in particular against the backdrop of rising demands on colour quality.

Linear correlations between yellowing and polymerisation can be seen in Figure 7. As already mentioned at the end of section 3.1, in Figures 5, 6 and 7 we can see maximum yellowing and polymerisation, which we cannot increase further with our curing conditions. In other conditions, e.g. in an inert environment or using higher irradiances, the particular polymerisation maximum could potentially be increased. Thinking about a novel approach for monitoring UV print productions based on colour measurements, a reliable measurability is crucial. The weak yellowing of varnish 2 could make it difficult to realise measurements for this particular varnish. This must be investigated in further research under practical conditions taking into account an error analysis.

The temporal yellowing progressions of the three different varnish systems do not allow general statements for conventional or LM systems in their entirety. However, they demonstrate exemplarily that yellowing is a dynamic effect in the first 24 hours after curing and can go well beyond a simple decay after cross-linking. Especially in the time right after curing, the yellowing alters quickly. Since the time gap between curing and measurement is ten seconds, it can be concluded that the yellowing is even greater directly in the delivery of the dryer. This short period of time is probably not relevant for most practical processes, but may have an influence when working with inline colour measuring devices and comparing to manual measurements at the printing press. We have already described above that a varnish as an additional layer has an influence on the colour appearance. Furthermore, and that's characteristic for UV varnishes, yellowing can bring in a specific discolouration, which is not limited to changes in brightness and also is time-dependent. Hence, concerning colour measurements of UV cured products, the intensity and temporal behaviour for a specific varnish as well as the time of measurement should be considered to obtain consistent colour measurements.

5. Conclusions

This investigation shows significant yellowing for all varnishes considered. The yellowing is a dynamic effect that shows changes in the first 24 hours after the initial

curing. For one varnish it decreases within a few tens of minutes in a nearly exponential manner and then remains stable, whereas other varnishes show a yellowing rebound a few hours after an initial decrease. Linear correlations between yellowing intensity and degree of polymerisation are exemplarily determined for three UV varnish systems of the categories conventional, low-migration and self-initiating low-migration. There are no indications why linear correlations should not be valid for other common varnishes. The yellowing intensity of a varnish also depends on its layer thickness. Following Lambert-Beer law, this connection is of logarithmic character. Knowledge of the influence of both polymerisation and layer thickness on yellowing intensities opens the possibility to predict yellowing for any layer thickness and degree of polymerisation. To achieve this objective, future work could investigate the measurability of yellowing in practical processes, take a closer look at correlations under different circumstances, and, fundamentally, deal with a possible implementation of the yellowing approach. Another interesting field is the discolouration of UV inks. Considering what is known so far, beneficial use of the actually unwanted yellowing of UV varnishes seems possible.

References

Bohn, D., Dattner, M., Wahl, F. and Urban, P., 2017. Determination of the UV-curing degree of thin films by crosslinking byproducts of reacted photo initiators in the UV-A & VIS-region of the spectra with actual polymerization degrees obtained from NIR-readings. In: *Proceedings of the 69th Annual Technical Conference of Technical Association of Graphic Arts*. Houston, TX, USA, 19–22 March 2017. Warrendale, PA, USA: TAGA, pp. 167–188.

bvdm, 2020. *Studie: UV-Druckerzeugnisse keine Gefahr für Verbraucher*. [online] Available at: <https://www.bvdm-online.de/presse/pressemitteilungen/2020/studie-uv-druckerzeugnisse-keine-gefahr-fuer-verbraucher/> [Accessed 15 December 2020] (in English: *Study: UV print products no danger for consumers*).

Etiketten Labels, 2020. UV-Lampen – vielfach totgesagt und trotzdem quicklebendig. *Etiketten Labels*, [online] 10 August. Available at: <https://www.etiketten-labels.com/etiketten-labels/uv-lampen-vielfach-totgesagt-und-trotzdem-quicklebendig/>, [Accessed 15 December 2020] (in English: UV lamps – often pronounced dead and yet still alive).

Fernàndez-Francos, X., Kazarian, S.G., Ramis, X. and Serra, À., 2013. Simultaneous monitoring of curing shrinkage and degree of cure of thermosets by attenuated total reflection Fourier transform infrared (ATR FT-IR) spectroscopy. *Applied Spectroscopy,* 67(12), pp. 1427–1436. https://doi.org/10.1366/13-07169.

Glöckner, P., Jung, T., Struck, S. and Studer, K., 2008. *Radiation curing: coatings and printing inks*. Hannover, Germany: Vincentz Network.

Green, W. A., 2010. *Industrial photoinitiators: a technical guide*. Boca Raton, FL, USA: Taylor & Francis.

International Organization for Standardization, 2014. ISO/CIE 11664-6:2014 Colorimetry – Part 6: CIEDE2000 Colour-difference formula. Geneva, Switzerland: ISO.

PITSID, 2019. Operating Manual: UV CURE CHECK for checking the curing degree of UV print products. [pdf] PITSID Polygraphische innovative Technik Leipzig GmbH. Available at: <https://www.pitsidleipzig.com/fileadmin/files/messgeraete/uv-cure-check/uv-cure-check-operating-manual.pdf> [Accessed 15 December 2020].

Rauh, W., 2007. Is the UV coating hard enough? *KBA Process*, 4(1), pp. 22–23.

Schröder, R., 2019. Härtungskontrolle im UV Bogenoffsetdruck. In: *VDD-Jahrestagung 2019 „Gedrucktes effizient trocken"*. Köln, Germany, 22 November 2019 (in English: *Curing control in sheetfed UV offset*).

Schwalm, R., 2006. *UV coatings: basics, recent developments and new applications*. Amsterdam, London: Elsevier.

Stiene, T., Urban, P. and Rodriguez-Giles, J.M., 2019. Prediction of lamination-induced colour shifts for UV offset printings by using a heuristic approach as well as machine learning techniques. *Journal of Print and Media Technology Research* 8(4), pp. 199–207. https://doi.org/10.14622/JPMTR-1912.

Studer, K. and Königer, R., 2001. Initial photoyellowing of photocrosslinked coatings. *European Coatings Journal,* 1–2, pp. 26–33.

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Scenario planning development for a multi-national printing ink company facing digital disruption in Indonesian print media industry

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Abstract

The rapid development of digital technology gives disruptive influences on the value of goods or services. New media communication technology offers media convergence that provides accessible speed, flexibility, and updated information. The existence of print media has become less common in the market. This affects all print media industry suppliers, including a printing ink company. The company will get decreasing revenue, especially if most of its current revenue comes from print media ink sales. Digital disruption is a certain thing, but uncertainty in print media arises because of the pros and cons of using digital devices for children's education, the freedom of online journalism that provides doubtful information, and the emergence of community media. The printing ink company also needs to prepare itself by making a strategy for the future that is full of those uncertainties. In this case, scenario planning can help the company to manage the uncertain future so that they can quickly adapt to the changes or the critical situations in the future and manage the complexity of turbulence, uncertainty, novelty, and ambiguity, that happen in the current Covid-19 pandemic. The key focal issue of this research is how digital disruption in the print media industry in Indonesia will affect a multi-national printing ink company over the next five years. The research involved experts from a multi-national printing ink company, a magazine publisher, a university, a digital printing consultant, a business consultant, and a disrupted public transport provider. Through intensive focus group discussion applying iterative reframing and re-perception, many driving forces were identified, two critical uncertainties were defined, and a scenario framework was created. The four scenarios came up as the result of the interaction between limited or widely available global ink supply and changes in people's behavior from conventional to digital media. These scenarios describe future challenges for the print media industry in Indonesia that are very dynamic. The company must be able to respond to emerging scenarios and adapt the strategies accordingly.

Keywords: future scenarios, uncertainty, pandemic, business strategy, management

1. Introduction and background

1.1 Digital disruption in print media Indonesia

Digital disruption happens when a new digital technology with a new business model has a disruptive influence on the value of goods or services and changes consumer behavior (Chan, 2016). Recently, Gojek has become an Indonesian decacorn startup and a leading technology group of platforms serving millions of users in Southeast Asia (Gojek.com, n.d.). They influence people in the cities to change their way of how to use public transportation from the traditional way that often involves a high bargaining service price to the digital way that provides a low fixed service price.

People's behavior in searching information is also changed from the traditional way by reading papers to the digital way by browsing electronic news. Based on media consumption surveys in 65 countries in 2010 and 2014 that were published by ZenithOptimedia, the internet has been gradually replacing traditional media (Richter, 2015). The Reuters Institute affirmed that print media started down in 2014 in the US based on a survey of 2,269 US news consumers in the period of 2012–2017 (MarketingCharts.com, n.d.). In Indonesia,

the decreasing number of print media circulation for all segments were started in 2015 (Zuhra, 2017). It is hard to get print media such as newspapers and magazines in public currently. On the other hand, electronic news and electronic magazines are flying over through mobile applications from one to another at very low cost or even for free. Another analysis based on the Indonesian Publishers Association's (SPS) data shows that in the last four years, there were 404 media publishing closed and there were 850 remaining publishing in 2017 (Wiwoho, 2017). With the same decreasing rate continuing for the following years, it concludes a rough prediction that the remaining age of a newspaper in Indonesia is only nine years, which is 2026.

Unfortunately, the current Covid-19 pandemic will boost high digital consumption and abandon print media. Pandemic pushes people to access digital media instead of reading print media. In March 2020, the first month of the Covid-19 pandemic in Indonesia, the number of health site visitors increased 53 % compared to previous data in February 2020 (Aninda, 2020). On the other hand, the Deputy Chairman of the Indonesian Press Council, Hendry Bangun, assessed that print media are most affected by the coronavirus or Covid-19 among other types of mass media. To PRFM 107.5 Radio on 21 April 2020, Hendry said "All business fields are under heavy pressure, including mass media, especially print media because it coincides with a rising dollar, loss of advertising, and fewer purchases" (Firmansyah, 2020). Some provinces in Indonesia implement restrictions on business activities as well as people movement limitations. The business restriction period during the Covid-19 pandemic and the economic contraction accelerate the fall of many print media companies.

Out of obvious trends that lead to the extinction of the print media industry, limited print media companies may exist in the future. Reading competencies are changing with the use of digital technologies, but people still see the benefits of reading with paper which they continue to use, especially to convey private emotions and intimate feelings (Vincent, 2016, p. 97). The ability of print media companies to change their business model or their dynamic capabilities dealing with media convergence may happen. Media convergence offers the integration of multimedia communication for compelling user experience and uploading additional content as important advantages compared to print (Fedorovskaya, et al., 2016, p. 133). Online community and offline events are engagement platforms as vehicles to build a story that creates a good experience (Viljakainen, Toivonen and Seisto, 2016, p. 155). The fact is that even during the Covid-19 pandemic, long-distance learning still requires printed books that can be borrowed from school or bought by students (Slameto, 2020). This may continue in the future but also may not.

1.2 Multi-national printing ink company

The company in this research is a multi-national printing ink company in Indonesia. The company is a subsidiary of a global ink supplier that has more than 150 branch offices, sales offices, distributing warehouses and representatives worldwide, and delivers high-quality printing ink solutions to customers. The parent company fully supplies ink products to be sold in the Indonesian market through trading business activity only. The majority of the business in Indonesia is offset ink supply to mostly media printing companies and some packaging printing companies. It was around 60 % of the total sales volume in 2019. The company claims to have 20 % of the market share in Indonesia's offset printing industry. Web ink sales volume reflects specifically the market segment of high-volume media printing such as newspapers, books, magazines, flyers, and brochures. It was 46.93 % of the total sales volume in 2017 and went down to be 44.37 % of the total sales volume in 2019. In the second quarter of 2020, it was continuously down to 28.76 % of the total sales volume after Joko Widodo, the President of the Republic of Indonesia, declared national status under the non-natural disaster of the Covid-19 pandemic in April 2020.

1.3 Research background

The print media industry is not in the process of its death but is coming to terms with uncertainty and rapid technological change (Barthelemy, et al., 2011). Past European analysis of the consumption of print media and their digital equivalents depicted a complex configuration (Nossek, Adoni and Nimrod, 2015, p. 381). In the current situation, the print media industry and printing ink companies who face impacts of digital disruption may come up with new approaches to such complex problems added by the Covid-19 pandemic. The broader condition disrupts the activity of the people and the business entities and changes the established rules to be the new norm. This pandemic creates unpredictable situations due to the complexity of turbulence, uncertainty, novelty, and ambiguity called TUNA (Ramírez and Wilkinson, 2016). Scenario planning is part of strategic planning that relates to the tools and technologies for managing the uncertainties of the future (Ringland, 1998).

Scenario planning is a methodology that uses the inherent human capacity for imagining futures to better understand the present situation and to identify possibilities for new strategies (Ramírez and Wilkinson, 2016). Since Herman Kahn began developing scenarios for the Air Defense System Missile Command, a large-scale early warning system in the 1950s (Bradfield, et al., 2005, p. 798), many methods and approaches have been introduced. There are Schwartz' eight steps of the scenario building process (Chermack, Lynham

and Ruona, 2001, pp. 17–19), Schoemaker's ten steps of scenario planning (Schoemaker, 1995, pp. 28–30), The Causal Layered Analysis that introduces four layers of scenarios (Inayatullah, 1998, p. 820), Shell 2001 Global scenarios that consist of four phases (Shell, 2008, p. 25), TAIDA method for scenario planning (Lindgren and Bandhold, 2003, p. 47), Harvard's five stages of scenario planning (Garvin and Levesque, 2006), the five steps of Transformative Scenario Planning (Kahane, 2013, p. 20), Oxford Scenario Planning Approach (Ramírez and Wilkinson, 2016), and further development of transformative scenario planning that consist of three phases (Bøjer, 2018, pp. 7–14).

The scenario planning application example is on Shell 2001 Global Scenario. The scenario project began in September 1999, developing two scenarios with the same assumption that global economic growth would continue but with different patterns of globalization which are dominated by global elites in the Business Class scenario or by the people of the heartlands in the Prism scenario (Shell, 2008). Shell is able to adapt quickly or build new scenarios when facing emerging risks and crises, such as the invasion of Kuwait, Iraq, and the prospect of a global influenza pandemic triggered by a new flu virus (Ramírez and Wilkinson, 2016). Another example of a scenario planning application is in Philips Lighting B.V. They explored how people may experience cities in 2035 and constructed four scenarios (Fablab, Sandbox, Resort, and Campsite) from two driving forces of access to information and adapting to rapid change. These four scenarios help Philips Lighting to think about how the future may change and challenge their assumptions (van der Weijden, et al., 2017).

1.4 Research questions and limitations

This research is limited to develop scenario planning for a multi-national printing ink company as one of the printing ink suppliers in Indonesia. The discussion will focus on the key focal issue of the company in the middle of digital disruption in the print media Indonesia, the scenario framework creation, the strategic imperatives, and the activities that should be conducted by the company to address the future challenges. The development of scenario planning involved a small group discussion that consisted of experts from the internal and external environments. The scope of print media business in this research comprises newspapers, magazines, books, and a big volume of promotions such as flyers and brochures. With the shortage of research time and small number of stakeholders involved in this research, the result of this research is the best scenario planning that researcher can provide and the company or other stakeholders may conduct further deeper development if required.

2. Methods

This research adopted five stages of scenario planning introduced by David A. Garvin that consist of orientation, exploration, scenario creation, option consideration, and integration (Garvin and Levesque, 2006). This is exploratory research using qualitative data that was collected through four Focus Group Discussions (FGD) in October and November 2020.

Table 1 describes the series of FGDs involved nine experts from a university, a publisher, a digital printing consultant, a business consultant, a disrupted public transport provider, and a multi-national printing company. The scenario creation was conducted with iterative reframing and reperception as an Oxford Scenario Planning Approach (Ramírez and Wilkinson, 2016). The FGD series allowed participants as learners to change their individual perceptions to a broader environment that never crossed their minds. In this scenario planning development, external environments in the political, economic, sociocultural, technological, envi-

Table 1: Focus Group Discussions participants

No.	Level	Organization	Work experience
1	Senior Manager	Multi-national printing ink company	23 years of experience and also active in the printing community
2	Manager	Multi-national printing ink company	14 years of experience
3	Supervisor	Multi-national printing ink company	12 years of experience
4	Supervisor	Multi-national printing ink company	15 years of experience
5	Lecturer	University	7 years of academic experience
6	Chief Editor	Publisher	17 years of experience
7	Manager	Digital printing consultant	20 years of experience
8	Director	Business consultant	22 years of experience in two multi-national printing ink companies, 13 years of experience as a business executive coach and author of business books
9	General Manager	Public transport provider	21 years of experience

ronmental, and legal factors called PESTEL framework and TUNA impacts are dynamic. For the company to sustain its competitive advantage, any fit between its internal strengths and the external environment must be dynamic (Rothaermel, 2017, p. 123). Dynamic capabilities relate to the capability of the company to sense and seize any opportunities, to navigate any threats, to combine and reconfigure its assets for building long-run value by responding to changing customer needs (Teece, 2009, p. 54). The dynamic capability framework introduced by Einar Lier Madsen provides an understanding of how the company can explore and exploit its external and internal resources (Madsen, 2010). Even though this research involves the subjective interpretation of an expert team, the objective analysis of the theoretical framework is also applied.

3. Results

3.1 Driving forces

The expert team explored external factors around the key focal issue that consist of trends, emergencies, ignored things, and uncontrolled forces that influence the company's future. Table 2 describes that 17 driving forces were discussed during exploration and scenario creation. The driving forces will create future scenarios for the print media industry in Indonesia and may impact a multi-national printing ink company that has a trading activity in Indonesia over the next five years. During FGDs, the driving forces were analyzed and grouped into clusters as illustrated in Figure 1. The clusters show potential alternative futures to be shaped as a scenario framework. The extinct print media cluster and the limited optimism cluster are contradicting frames that help the research to create a contrasting future whose differences make a difference to decision-makers (Schwartz, 1991). In addition, the global ink group domination cluster indicates a dependency on the global supply chain which adds to the uncertainty that a company at a country level faces.

The massive use of digital technology, pandemic, changes in people's behavior, online journalism, and global penetration from digital-based companies will lead to extinct print media in the future. Digitalization is happening in various sectors and replacing the position of print media in delivering information, news, and knowledge to the public. The public is not only a media user but also a source of information in the media and it is free for anyone to share news online. In the current pandemic conditions, people are forced to maintain social distances, work from home, and long-distance learning, which prioritizes internet usage that is safer from viruses. Changes in people's behavior from conventional media to digital media will take place also as generations change. Global competition campaigns such as paperless issues give another impact on the weakening of the position of the print media in the future.

Experts believe that limited optimism about the sustained print media may happen over the next five years. The trust of the media community, both domestically and abroad, is the support for the print media as a part

Table 2: Driving forces involvement in Focus Group Discussions

No.	Driving forces	Exploration		Scenario creation	
		FGD1	FGD2	FGD3	FGD4
1	The massive use of digital technology	✓		✓	✓
2	Pandemic	✓		✓	✓
3	Changes in people's behavior	✓	✓	✓	✓
4	Freedom of online journalism	✓	✓	✓	✓
5	Global competition from digital-based companies	✓	✓	✓	
6	Trust from media stakeholders, especially from the community	✓		✓	✓
7	Lean organization of print media	✓	✓	✓	
8	Government regulations in formulating the educational curriculum	✓	✓	✓	✓
9	Awareness of emerging health problems due to digital media consumption	✓	✓	✓	✓
10	Geopolitics			✓	✓
11	Global ink network support	✓	✓	✓	✓
12	Changes in market orientation	✓	✓	✓	
13	The existence profit as the last stand to support print media	✓		✓	✓
14	Availability of internet connection in remote areas	✓		✓	✓
15	The emergence of media convergence	✓		✓	✓
16	The need for environmentally friendly products	✓	✓	✓	
17	Investment in climate support from political parties through Omnibus law (2020)	✓	✓	✓	

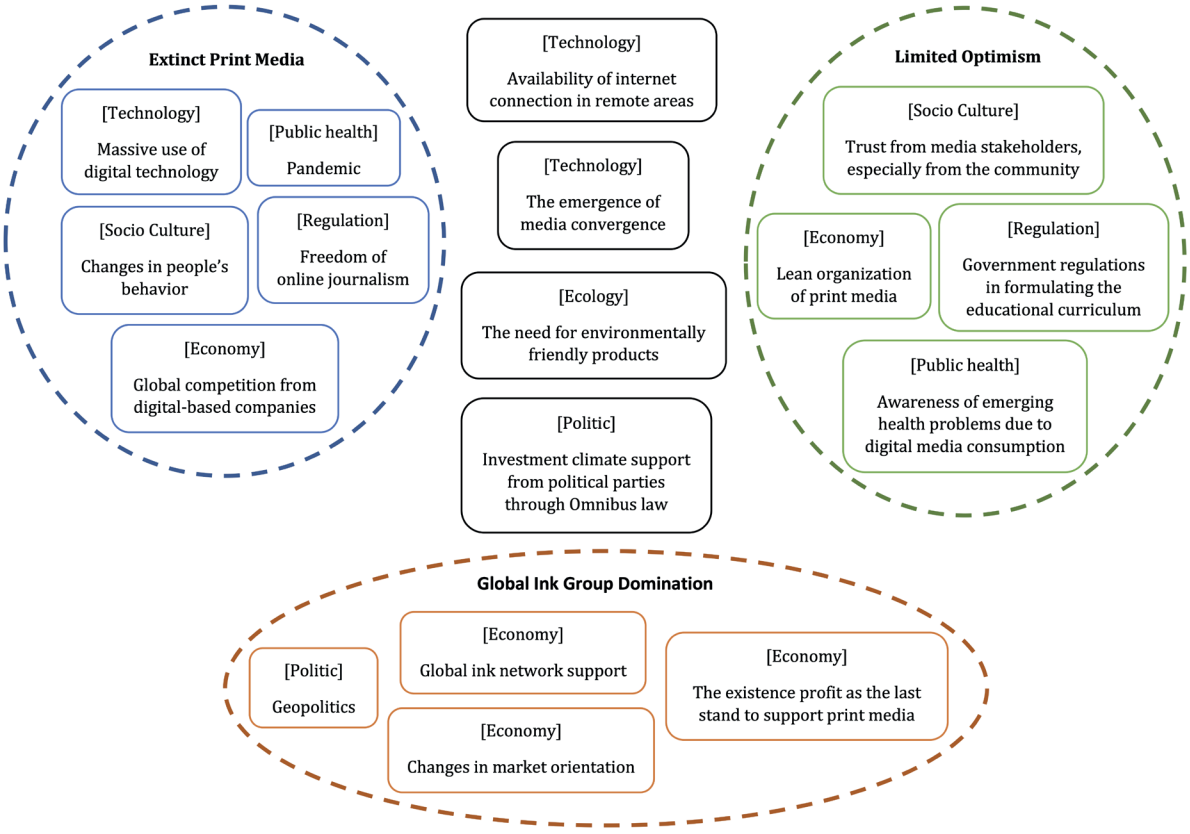

Figure 1: Driving force clusters

of media convergence. Print media companies are also trying to minimize losses by downsizing and restructuring their organizations. In the education sector, students still require printed books for studying especially for elementary, junior, and senior high schools, even in the current pandemic. Despite the government's effort to make electronic schoolbooks (so-called *Buku Sekolah Elektronik* or BSE in Indonesian term) available so that students can download them for free, it is less effective in regions with a poor internet connection and lack of access to computers or other digital devices. The printed version of the books is still preferable. The parents also limit their children in the use of the digital device as unhealthy behavior on the consumption of digital media will cause health complaints such as the influence of children's brain development, eye fatigue, and so on.

Experts recognize that the global ink group drives its subsidiaries to contribute to a global future. The local ink company is controlled by the global group where the materials still depend on global supply. As it relies on international trade, the geopolitical risk will create a level of supply stability worldwide. The global ink group will also observe the emerging print-on-demand market and growing packaging market. The global decision will also provide their subsidiaries at the country level whether the company can continue and be the last stand that supplies the ink to the remaining print media industry.

Outside the three clusters, experts put other driving forces in the middle of the clusters. Availability of internet connections in remote areas and media convergence provide an uncertain future that may create limited optimism or lead to extinct print media. The trend of going green stops forest destruction as a raw material resource for the paper while managing hazardous and toxic waste may address both digital and print media. A similar case is for investment climate support. Omnibus law supported by political parties may also encourage digital technology adoption of startups as well as global ink supplier domination in the Indonesian market.

3.2 Scenarios creation

There were 16 driving forces identified in the initial exploration stage and one driving force, geopolitics, arose in the scenario creation stage when the experts reframed and challenged the initial scenario framework. The initial framework was constructed with two initial critical uncertainties based on expert team rank in appendix A. The two highest critical uncertainty

scores, pandemic, and global ink network support represent two factors that have high importance and high uncertainty so those are the potentially to be developed as an initial scenario framework for print media future.

The expert team tried to challenge the initial combination of pandemic and global ink network. It is realized that without the pandemic, the changes in people's behavior will happen as generations change. The pandemic factor is the only accelerator for the changes. Changes in people's behavior are one of the uncertain factors that have a high impact on the company. The combination of government regulation and the market that creates four scenarios in the emerging media trend exploration (Picha Edwardsson and Pargman, 2014) is less relevant in this research as digital disruption leads the media market to adopt advanced digital technology and government regulation will align with the technology adoption as well. Experts argue that regulation will follow the development of technology in the end. Digital disruption on transportation, for example, a startup called Gojek, was at first against the prevailing regulation on public transportation but in the end, the government allows them to be an alternative of public transportation in Indonesia.

The research describes global ink network support as the availability of global ink supply. From the supply chain perspective, a trading company is at much greater risk because the supply chain has become more interdependent, complex, and vulnerable to temporary or long-term disruption (Blos, Wee and Yang, 2010). The limited global ink supply happened in the current Covid-19 pandemic. The global ink supply chain faces a container shortage that incurs extra costs, delays, and difficulty in managing stocks. The company that relies on global ink supply, without having the ability to produce ink locally, fails to meet local ink demands. Local ink products may have a chance to establish their market and strengthen their position. Moreover, local governments always encourage industries to use local sources. Indonesia has a lot of resources that many industries can explore and exploit. Government policies such as high import tariffs or by nature of high exchange rates lead industries to utilize their local resources. The global ink supply term is more coherent in applying the scenario framework than a global ink network term. It offers a contrast of limited and widely available global ink supply. Limited global ink supply reflects the attraction of the use of local resources while widely available global ink supply reflects reliable global resources. This research proposes scenarios constructed by the interplay of the global ink supply chain and the changes in people's behavior that is relevant for a multi-national printing ink company with only trading activity in Indonesia. The scenario framework, illustrated in Figure 2, creates four contrasting quadrants from the combination of global and local factors as well as the combination of supply and demand factors.

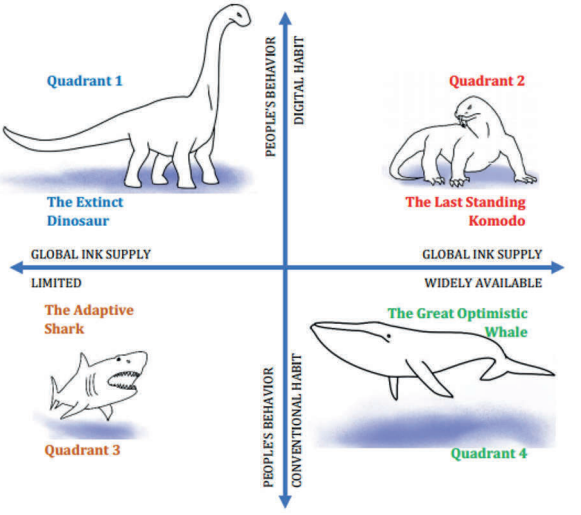

Figure 2: Scenarios of the future print media in Indonesia for a multi-national printing ink company

3.2.1 The extinct Dinosaur

Indonesian people are getting used to digital media and are leaving print media. Print media is becoming scarce. People only demand a few high-quality prints but the print media industry in Indonesia is unable to run its business. There is no certainty of high-quality ink supply even though the paper is still available. Long periods of global issues such as another new pandemic and geo-political tensions create obstacles to international trading. The global ink group prefers to secure ink supplies for the potential printing segment which can still thrive in the situation of limited international trade. Import activity becomes less as the government increases import tariffs or high exchange rates impact negative exposure. The extinction of print media is increasingly evident being eroded by the massiveness and development of digital technology adoption in remote areas. The government and private sectors work together to provide solutions to the lower society. The development of digital technology has succeeded in addressing the concerns of health problems and making it easier for the older generation to adapt. There will be no more newspapers, print magazines, print books, and print flyers. There are only digital news, e-magazines, e-books, and e-flyers. Print media will be remembered as part of the history of the past human civilization.

3.2.2 The last standing Komodo

The massive use of digital technology in Indonesia is supported by the increasing distribution of the internet network to the villages, the affordable ownership

of digital devices, and enabling people to easily access the internet. Society is increasingly connected one to another freely so that certain communities that have the same orientation are formed. Amid the long-term easing of geopolitics between countries in the world, global access is increasingly open. The community becomes a global force that shapes and maintains certain beliefs and values, including the existence of a global community that still respects print media as part of media convergence in the hustle and bustle of the digital world. The print media industry is lean and able to survive with the continued supply of high-quality inks and high-quality paper, moreover, the selling price is absorbed. The community specifically provides an environment for print media that offers exclusive value as a cultural heritage that needs to be preserved.

3.2.3 The adaptive Shark

Tensions exist at the global level and the national level. High geopolitical risks and other global issues over a long period have led to a fragile global ink supply chain. Domestic tensions also arise when the exchange rate is high and import tariffs limit local companies from importing ink or its raw materials from other countries. Indonesian people still require print media, but the ink is not available even though the local paper sources are still reliable. The development of local conventional print media ink still requires further research on the economic local resources of raw materials. Conventional printing technology is encouraged to meet the needs of print media. The production of local ink which has low quality can be an acceptable alternative for national print media users. Digital printing is coming into the picture of the race to offer technological solutions that are forced into a long run while its ink supply and the printing cost become a big issue. Digital inks have the same problem as conventional ink in terms of their import dependency. The fast adaptation of local printing ink technology, both digital and conventional, is the key to win in this competition.

3.2.4 The great optimistic Whale

People are still not satisfied with the use of digital media, especially in the education sector. The use of digital media is avoided because it is feared that it will interfere with children's development. Elementary to high school education is still constrained by an uneven internet network and the inability of the lower society to buy digital devices and their internet quota. The government is considered to be slow in overcoming this gap, while private investment is still very limited. The older generation still maintains their habit of using print media. The government realizes that print media is still needed by the people and provides room for the sustainability of the media printing business. Long-term conducive global conditions also ensure the sustainable availability of imported ink and domestic paper. The Indonesian print media industry has great optimism that it will survive in certain sectors under the role of the government and take advantage of the lack of satisfaction with the use of digital media in these sectors.

3.3 Early warning signals

Some indicators can signal an emerging scenario. Recognizing these indicators will give early warning alarms to the company so that they are ready to implement corporate activity to fit the scenario. The early warning signals that distinguish one scenario from another are presented in Table 3. There are four indicators of changes in people behavior factors and three indicators of global ink supply factors.

The first indicator is the population who accesses the internet, and that the threshold percentage is 70 % of the total population of Indonesia. The Central Bureau of Statistics (BPS) Indonesia provides the percentage of individuals with access to the internet in 2019 is 47.69 % of the 244 million population aged 5 years old and above (Sari, Utoyo and Anggraini, 2020). Considering the productive ages of 15 to 64 years old, which is 181 million people in 2019 (Badan Pusat Statistik, 2020), the number of individuals in the productive ages who access the internet is low. People will be more dependent on digital media if all individuals in the productive ages access the internet that is around 74.18 % of the 244 million population aged five years old and above. The emergence of this digital habit may consider 70 % of the total population accessing the internet already.

The second indicator is the number of villages with strong signal receptions of cellular phones. This reflects internet access available in remote areas in Indonesia. BPS provides 58,194 villages or 69.33 % of total villages in Indonesia have strong signal receptions of cellular phones in 2019 (Sari, Utoyo and Anggraini, 2020). The more villages in Indonesia have strong signal receptions of cellular phones, the more chances to access the internet, and the more people depend on digital media. In the current state, it is not strong enough to declare that the majority of Indonesian people have access to digital media and many sectors still require the conventional way. Therefore this research proposes 80 % of total villages having strong signal receptions of cellular phones as the threshold percentage to reflect digital penetration in Indonesia. The increase from the current coverage state of 69.33 % to 80 % indicates a major shift that may have a significant impact on people's behavior.

Table 3: Early warning signals

Factor	Indicator	Source	Dinosaur	Komodo	Shark	Whale
Changes in people's behavior	The population who accesses the internet	Annual BPS publication	≥ 70 % (high)	≥ 70 % (high)	< 70 % (low)	< 70 % (low)
	Villages with strong signal receptions for cellular phones	Annual BPS publication	≥ 80 % (high)	≥ 80 % (high)	< 80 % (low)	< 80 % (low)
	Web printing machine installments in the last two years	Marketing team	none	none	1–6 units (rare)	> 6 units (many)
	Government project for printed books and papers	Marketing team	none	none	exist	exist
Global ink supply	Import tariff for print media inks	Government regulation	≥ 10 %	< 10 %	≥ 10 %	< 10 %
	Geopolitics	Government statements	hampered (high)	normal (low)	hampered (high)	normal (low)
	Raw material issue	Import planner	≥ 1 month	< 1 month	≥ 1 month	< 1 month

The third indicator is web printing machine installment in the last two years. The web printing machine is a representation of big print media volume. Rare installments of brand new or used web printing machines indicate the emergence of Shark scenario when the demand for print media is high, but the ink supply is less. Small quantity ink supply fits the small printing volume capacity of a sheetfed printing machine. It limits investment in web printing machines only for compromised lower print quality of large print media volumes such as black and white school books. The number of rare installments can consider up to six press units of web printing machines. When many web printing machines are installed, it indicates the emergence of Whale scenario that there is optimism on print media sustainability. The number of many installments can be considered more than six press units of web printing machines. If no printing machine was installed in the last two years, it indicates the emergence of digital habit that people are leaving print media consumption and switching to digital media. The company should record this activity by collecting data through the marketing team and its channels.

The fourth indicator is the existence of government projects for printed school books aid and papers. National elections require ballot papers, but if the government has adopted electronic elections using digital technology, ballot papers are no longer required. It is the same indication of the school books project. If the government has pushed the schools to utilize electronic books available on the internet, then students are more dependent on digital media. Current ballot papers and school book aid projects indicate people still have conventional habits. The company should be able to monitor and sense these signals from government officers or through the associations.

The fifth indicator is import tariff. Based on the minister of finance regulation no 6/PMK.010/2017 on stipulating the goods classification system and imposing import duty on imported goods, import duty of pigments and inks are in the range of 0 % to 5 %. Increasing import duty affects increasing ink price or absorbing the cost by ink company. Import tariffs of more than 10 % indicate local sources offer more attraction than global group sources.

The sixth indicator is geopolitics that involves the country where the mother plants are located. Big printing ink manufacturers are global players and raw materials such as pigments and resins are traded internationally involving both the US and China. The major suppliers of petroleum resins as the main print media ink vehicles are from the US, China, Vietnam, and France. Global companies with international trade with both the US and China will have the potential to face obstacles when there is trade war tension or direct bilateral conflict to one of them. Import and export activities have a chance to be hampered by high geopolitical risk.

The seventh indicator is a raw materials issue. The company should monitor the availability of ink supply from mother plants. Stock planners have to communicate intensively to mother plants and ask for clarification on any delays in dispatching. Mother plants' information on raw materials issues and difficulty in manufacturing are important to be noticed and indicate instability of global ink supply. This causes a bad ink stock shortage for the company. The emergence of a limited global ink supply may take more than one month to resolve raw materials issues.

As the future is dynamic, the company should monitor early warning signals. The company can appoint people in charge for capturing the population who

accesses the internet and the number of villages with strong reception signals of cellular phones from annual BPS publication, recording number of web printing machines installment every quarter, recording government projects existence for printed books and papers every semester, recording every movement of import tariffs, capturing every event of geopolitics that involves the mother plants' country, and capturing every event of raw material issues. The integration of monitoring emerging scenario signals to the company's activity will guide the company to always be on the appropriate track.

4. Discussion

4.1 Scenario implications and options

Each scenario gives its implications to the company and provides the available options that consider the current state of the company. The print media market tends to be stagnant in the Whale scenario while others indicate it has shrunk and even become extinct. The company has some options on each scenario where the print media market still can contribute to the revenue or focus on other markets such as the packaging ink market and the digital ink market to survive and grow.

The implications in Dinosaur are the loss of a significant source of revenue, the lack of reliable human capital and new technological knowledge, and the dissolution of a company by the parent company. The available options for the company are maximizing sales achievement in other market segments, developing local ink products, and exploring the chances of getting support from the other subsidiaries of the parent company to penetrate the potential market in Indonesia. Dinosaur challenges the development of local packaging ink that is one of the core competencies of the parent company. This core competency provides the ability of the company to explore and exploit the resources faster.

Komodo has similar people's behavior as Dinosaur but there is a community environment that sustains the special needs of high-quality print media supported by the global supply. There are decreasing revenue and hard competition on the shrinking print media ink market. The company may consider product diversification with three options. First, product diversification on conventional ink technology and continuing to supply the print media industry. Second, product diversification in digital printing ink supplied by other global digital printing ink manufacturers. Third, product diversification on both conventional and digital ink technologies. Many challenges arise in the Komodo scenario. The decision of being the last standing print media ink supplier in Indonesia challenges the global cost leadership strategy. Product diversification on digital printing ink also is not easy as it requires new competency building for the company although the supply is widely available in the global network.

The uncertainty of the ink supply from imports in the Shark scenario can disrupt the business relationship and losing customers' trust. The company has difficulty competing with the local product from competitors. Regaining customer trust should be taken such as providing extra service to save ink usage, reuse leftover inks, and reduce print waste on a daily operational basis. Another option is establishing a local innovative R&D team that focuses on developing print media ink from available local resources. This local innovative product formulation from local resources is the challenge in the Shark scenario. It requires an R&D project collaboration and manufacturing activity for print media ink.

In the Whale scenario, the print media market tends to be stagnant while the parent company demands business growth. The price issue is the only selling point that can be played in the competition among media ink suppliers in Indonesia. The options are being a print media market leader with a cost leadership strategy, creating a business commitment, and customer engagement. The company may approach printing media companies who have international relationships that may provide export. Whale challenges to be a market leader in Indonesia for print media ink and expanding to the export market.

4.2 Strategic imperatives

The implications and options enable the company to formulate strategic imperatives that apply to most of the scenarios. A strategic imperative consists of activities that change the current state of the company to be better prepared for the future. This research proposes the strategic imperatives that will change the state of the company from insufficient R&D to innovative R&D, from selling conventional inks only to also selling digital inks, and from trading activity to manufacturing activity. The strategic imperative activities also are required to be adapted as the emergence of the scenario. An annual management meeting determines the situation based on the monitored signals and which adjustments the company should make to the strategic activities that are summarized in appendix B. The company is expected to be ready to face any scenario that happens and continue to grow and perform at the end of or after five years.

4.2.1 Innovative R&D

Investment in human capital becomes important and contributes to growth. People's knowledge in the company becomes tangible as well as intangible resources

that can be captured, stored, and shared to produce the innovation. A successful R&D team not only generates innovative ideas but also transfers these newly created concepts through the organizational system for economic gain (Thamhain, 2003). Recruiting R&D people who have expertise in packaging technology for both offset printing and gravure printing is necessary. The company should provide R&D facilities to support the research projects. The R&D team collaborates the research projects with other parties such as graphics schools and universities for local development projects.

In the first year, the company forms an R&D team by recruiting experienced people from other competitors. The R&D team should be able to handle a research project on conventional ink formulation of both print media ink technology and packaging ink technology. Basic laboratory instruments should also be provided, whatever the scenario emerges. In the following years, team building and specific laboratory instruments purchasing will refer to the scenario. Dinosaur or Komodo lead R&D project on packaging ink technology while Shark or Whale lead R&D project on print media ink technology. Collaborative research projects with other parties such as graphic schools and universities also follow the same direction.

4.2.2 Product diversification

Product diversification enables the company to serve the broader market even though it requires building a new core competency for the company. The performance of product diversification may be contingent both on the specific home country environment and time period (Benito-Osorio, Guerras-Martin and Zuñiga-Vicente, 2012). The abundance of natural resources in Indonesia and the five year period provide a chance for the company to perform local product diversification. As the future challenges of the print media in Indonesia are very dynamic, the company must have dynamic capabilities that do not only offer print media inks but also packaging inks and digital printing inks to the markets.

Assessing potential domestic ink markets and global suppliers for new ink markets is conducted in the first year and the third year whatever the scenario emerged. This includes feasibility studies to support business proposals on product diversification for the following years. The business proposal includes conventional ink market development by global ink supply and a new digital ink market development by a partnership with a global digital ink manufacturer. In the second year, if the scenario is Whale or Komodo, the company can generate stocks for new conventional ink products immediately from the global ink supply. If the scenario is Dinosaur or Komodo, it will need further study to prepare a partnership agreement and ask for the parent company's approval. This partnership activity can only be implemented in the third year if there is any Dinosaur or Komodo signal.

4.2.3 Local ink manufacture

Local manufacture will secure continuity in ink supply to customers; moreover, the local R&D team works on local resource consumption. Design global–manufacture local (Kostakis, et al., 2015) can also be considered in conventional ink manufacturing as the global ink company has its global ink technology while local markets have local varieties of printed products. The company can propose a local manufacturer for offset printing ink or gravure printing ink after the R&D team shows the progress of the research project on it. The proposal includes the option of partnership with a local ink or paint manufacturer for production facilities only or building own ink production facilities.

There will not be any local ink manufacturing activity in the first two years. The only possible time to establish a local ink production is in the third year if there is a positive result from the R&D team in terms of local ink formulation. It will be difficult to be ready for future challenges in the next five years if establishing a local manufacturing facility starts in the fourth and fifth year. This activity only applies to Dinosaur, Komodo, and Shark scenarios. If the Dinosaur signals are strong and the R&D team has been successful in a local packaging ink formulation, then a local ink manufacturing facility can be proposed to the parent company and start to be executed after their approval. If Komodo signals emerge in the third year, the local ink manufacture will open to produce finished ink from the intermediate product supplied by global ink manufacturing in case of local R&D projects fail to search economic raw materials locally. If the Shark emerges in the third year and R&D has been successful in a local print media ink formulation, then a local ink manufacturing facility can be proposed to the parent company and started to be executed after their approval as well. This activity required a strong sense of early warning signals in the third year.

5. Conclusions

The focal issue of this research is how digital disruption in the print media industry in Indonesia will affect a multi-national printing ink company over the next five years. Scenario planning development identifies many driving forces and creates some alternative frames for future digital disruption. Four scenarios are constructed by a combination of limited or widely available global ink supply and the changes in people's

behavior from conventional media to digital media. The extinct Dinosaur describes the domination of digital technology and the print media industry no longer exists anymore. The last standing Komodo describes a small room in the high-quality print media industry supported by its community amid a full digital lifestyle. The adaptive Shark describes the innovative pace of resolving imbalanced supply and demand in print media. The optimistic Whale describes limited print media sustainability amid the failure of digital technology to serve public needs.

Through scenario planning development, the company can realize the future implications and prepare the strategy to face it. Three strategic imperatives should be conducted by the company to address future digital disruption in print media in Indonesia. Those are local innovative R&D building, product basket development for both conventional packaging and digital printing inks, and business activity expansion from trading to manufacturing. The strategic imperative activities also are required to be adapted based on monitored signals and which adjustments the company should make to the strategic activities. The company may introduce this scenario planning approach to the parent company and propose to use it as a basis of the company's strategy. Scenario planning development can be implemented globally to have the ability to adapt quickly or build new scenarios when facing emerging risks and crises at the global, regional, and country-level.

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References

Aninda, N., 2020. Konsumsi media online konsumen Asia meningkat selama pandemi. *Lifestyle*, [online] 14 May. Available at: <https://lifestyle.bisnis.com/read/20200514/220/1240779/konsumsi-media-online-konsumen-asia-meningkat-selama-pandemi> [Accessed 24 October 2020].

Badan Pusat Statistik, 2020. *Jumlah penduduk menurut kelompok umur dan jenis kelamin 2019: penduduk dan ketenagakerjaan*. [online] Available at: <https://www.bps.go.id/indikator/indikator/view_data_pub/0000/api_pub/58/da_03/1> [Accessed 7 December 2020].

Barthelemy, S., Bethell, M., Christiansen, T., Jarsvall, A. and Koinis, K., 2011. The future of print media: Capstone report 2011. *The Future Leadership Institute,* [online] Available at: <https://fli.institute/2011/12/23/the-future-of-print-media/> [Accessed February 2021].

Benito-Osorio, D., Guerras-Martin, L.Á. and Zuñiga-Vicente, J.A., 2012. Four decades of research on diversification: a literature review. *Management Decision*, 50(2)., pp. 325–344. https://doi.org/10.1108/00251741211203597.

Blos, M.F., Wee, H.M. and Yang, J., 2010. Analysing the external supply chain risk driver competitiveness: a risk mitigation framework and business continuity plan. *Journal of Business Continuity & Emergency Planning*, 4(4), pp. 368–374.

Bøjer, M., 2018. *Transformative scenario process: how stories of the future help to transform conflict in the present*. [pdf] Berlin, Germany: Berghof Foundation. Available at: <https://berghof-foundation.org/library/transformative-scenarios-process-how-stories-of-the-future-help-to-transform-conflict-in-the-present> [Accessed February 2021].

Bradfield, R., Wright, G., Burt, G., Cairns, G. and Van Den Heijden, K., 2005. The origins and evolution of scenario techniques in long range business planning. *Futures*, 37(8), p.p. 795–812. https://doi.org/10.1016/j.futures.2005.01.003.

Chan, S., 2016, The age of digital disruption. *Digi Vue Consulting*, [online] 27 November. Available at: <http://digivue.io/2016/11/27/the-age-of-digital-disruption/> [Accessed 6 October 2020].

Chermack, T.J., Lynham, S.A. and Ruona, W.E.A., 2001, A review of scenario planning literature. *Futures Research Quarterly*, Summer, pp. 7–31.

Fedorovskaya, E., Hickerson, A., Desai, S. and Cheng, F., 2016. The RocReadaR – a system for transmedia news publishing using augmented reality. *Journal of Print and Media Technology Research*, 5(2), pp. 133–143. http://dx.doi.org/10.14622/JPMTR-1606.

Firmansyah, R., 2020. Dewan pers sebut media cetak paling terdampak pandemi Corona. *Prfmnews*, [online] 21 April. Available at: <https://prfmnews.pikiran-rakyat.com/nasional/pr-13369688/dewan-pers-sebut-media-cetak-paling-terdampak-corona> [Accessed 21 October 2020].

Garvin, D.A. and Levesque, L.C., 2006. *A note on scenario planning*. Boston, United States of America: Harvard Business School Publishing.

Gojek.com, n.d. *About us.* [online] Available at: <https://www.gojek.com/about/> [Accessed 19 December 2020].

Inayatullah, S., 1998. Causal layered analysis. *Futures*, 30(8), pp. 815–829.

Kahane, A., 2013. Transformative scenario planning: a tool for systematic change. *Social Space*, 6, pp. 16–22.

Kostakis, V., Niaros, V., Dafermos, G. and Bauwens, M., 2015. Design global, manufacture local: exploring the contours of an emerging productive model. *Futures*, 73, pp. 126–135. http://dx.doi.org/10.1016/j.futures.2015.09.001.

Lindgren, M. and Bandhold, H., 2003. *Scenario planning: the link between future and strategy*. New York, United States of America: Palgrave Macmillan.

Madsen, E.L., 2010, A dynamic capability framework: generic types of dynamic capabilities and their relationship to entrepreneurship. In: S. Wall, C. Zimmermann, R. Klingebiel and D. Lange, ed. *Strategic reconfigurations: building dynamic capabilities in rapid innovation-based industries*. Cheltenham, United Kingdom: Edward Elgar Publishing Limited.

Marketingcharts.com, n.d. *US news consumption sources*. [online] Available at: <https://www.marketingcharts.com/reutersinstitute-us-news-consumption-sources-2012-2017-jun2017> [Accessed 6 October 2020].

Nossek, H., Adoni, H. and Nimrod, G., 2015. Is print really dying? The state of print media use in Europe. *International Journal of Communication*, 9, pp. 365–385.

Omnibus law, 2020. "Omnibus law" on job creation has been enacted. *Investment Policy Monitor*, [online] 2 November. Available at: < https://investmentpolicy.unctad.org/investment-policy-monitor/measures/3567/indonesia-omnibus-law-on-job-creation-has-been-enacted> [Accessed February 2021].

Picha Edwardsson, M. and Pargman, D., 2014, Explorative scenarios of emerging media trends. *Journal of Print and Media Technology Research*, 3(3), pp. 195–204.

Ramírez, R. and Wilkinson, A., 2016. *Strategic reframing: the Oxford scenario planning approach.* Oxford, United Kingdom, Oxford University Press.

Richter, F., 2015. The internet is gradually replacing traditional media. *Statista,* [online] 2 June. Available at: <https://www.statista.com/chart/3519/media-consumption/> [Accessed 6 October 2020].

Ringland, G., 1998. *Scenario planning: managing for the future*. New York, United States of America: John Wiley & Sons.

Rothaermel, F.T., 2017. *Strategic management.* 3rd ed. New York, United States of America: McGraw-Hill Education.

Sari, E., Utoyo, S. and Anggraini, L. eds., 2020 *Telecommunication statistic in Indonesia 2019*. Jakarta, Republic of Indonesia: BPS-Statistics Indonesia.

Schoemaker, P.J.H., 1995. Scenario planning: a tool for strategic thinking. *Sloan Management Review*, 36(2), pp. 28–30.

Schwartz, P., 1991. *The art of the long view: planning for the future in an uncertain world*. New York, United States of America: Currency Doubleday.

Shell, 2008, *Scenarios: an explorer's guide*. The Hague, the Netherlands: Shell International BV.

Slameto, 2020. 5 Fakta pendidikan di tengah wabah korona. *Detiknews*, [online] 8 April. Available at: <https://news.detik.com/kolom/d-4969335/5-fakta-pendidikan-di-tengah-wabah-corona> [Accessed 19 December 2020].

Teece, D.J., 2009. *Dynamic capabilities & strategic management*. Oxford, United Kingdom: Oxford University Press.

Thamhain, H.J., 2003. Managing innovative R&D teams. *R&D Management*, 33(3), pp. 297–311. https://doi.org/10.1111/1467-9310.00299.

Viljakainen, A., Toivonen, M., and Seisto, A., 2016. Digitalisation and service business model innovation in media. *Journal of Print and Media Technology Research*, 5(2), pp. 145–158. https://doi.org/10.14622/JPMTR-1514.

Vincent, J., 2016. Students' use of paper and pen versus digital media in university environments for writing and reading – a cross-cultural exploration. *Journal of Print and Media Technology Research*, 5(2), pp. 97–106. https://doi.org/10.622/JPMTR-1602.

van der Weijden, A.-M., Chraibi, S., Rajagopalan, R., Lekse, D., Lunz, M., Dannemann, E., Cherenack, K., Stainthorpe, J., Fleuren, M., Mason, J. and Aliakseyeu, D., 2017. *Future of Cities.* [pdf] Philips Lighting Research. Available at: <http://images.philips.com/is/content/PhilipsConsumer/PDFDownloads/Global/ODLI20170921_001-UPD-en_AA-Philips-Lighting-Scenario-Planning-Cities-1.pdf> [Accessed February 2021].

Wiwoho, L.H. ed., 2017. Berapa lama lagi usia koran di Indonesia?. *Kompas.com*, [online] 7 July. Available at: <https://nasional.kompas.com/read/2017/07/07/18590671/berapa.lama.lagi.usia.koran.di.Indonesia?page=all> [Accessed on 6 October 2020].

Zuhra, W.U.N., 2017. Pertumbuhan oplah koran: melambat, melambat, menurun. *Business Media*, [online] 8 February. Available at: <https://tirto.id/pertumbuhan-oplah-koran-melambat-melambat-menurun-ciy7> [Accessed 6 October 2020].

Appendix A: Driving force rank

No.	Driving forces	Uncertainty score	Impact score	Critical uncertainty score
1	*Pandemic*	*31*	*30*	*61*
2	*Global ink network support*	*24*	*33*	*57*
3	The existence profit as the last stand to support print media	26	29	55
4	Freedom of online journalism	21	33	54
5	The need for environmentally friendly products	24	30	54
6	Investment climate support from political parties through Omnibus law	24	30	54
7	The massive use of digital technology	18	35	53
8	Global competition from digital-based companies	17	36	53
9	Availability of internet connection in remote areas	18	35	53
10	The emergence of media convergence	20	33	53
11	Lean organization of print media	22	31	53
12	Government regulations in formulating the educational curriculum	21	32	53
13	Changes in people's behavior	18	34	52
14	Trust from media stakeholders, especially from the community	23	29	52
15	Awareness of emerging health problems due to digital media consumption	27	25	52
16	Changes in market orientation	15	35	50

Driving force rank was conducted by distributing a questionnaire to the expert team based on the second FGD. There were nine respondents. The scores are calculated based on the degree of uncertainty and the degree of impact on every driving force as follows:
1 = Low
2 = Low to Moderate
3 = Moderate
4 = Moderate to High
5 = High
Uncertainty score and impact score could range from 9 (as the lowest) to 45 (as the highest)
Critical uncertainty score from 18 (as the lowest) to 90 (as the highest)

Appendix B: Activity plan on strategic imperatives

Strategy	Activity	Year 1	2	3	4	5
General	Monitoring early warning signals	DK SW	DK SW	DK SW	DK SW	DK SW
Building innovative R&D	Forming R&D team	DK SW	DK SW	DK SW		
	Providing R&D facilities	DK SW	DK SW	DK SW		
	Collaborating R&D projects with other parties		DK SW	DK SW	DK SW	DK SW
Developing product basket	Assessing potential ink markets in Indonesia including a feasibility study	DK SW		DK SW		
	Assessing global suppliers for new ink markets including feasibility study	DK SW		DK SW		
	Proposing product diversification plan including the choice of inhouse development or strategic alliances through a partnership		DK SW	DK SW	DK SW	DK SW
	Establishing partnership agreement with global digital ink manufacturer and local packaging ink company (in case of partnership for the saleable product)			DK S	DK S	DK S
	Generating stocks for new conventional ink products provided by global group (in case of in-house development)		K W	K W	K W	K W
Establishing local manufacture	Proposing local manufacture plan including the choice of inhouse development or strategic alliances through partnership or acquisition of a local ink manufacturer			DK S	DK S	DK S
	Establishing partnership agreement with other ink or paint manufacturer (in case of partnership for production facilities)			DK S	DK S	DK S
	Establishing acquisition process of a local packaging ink manufacturer (in case of acquisition)			DK S	DK S	
	Establishing local conventional ink manufacture including licenses, human resources, infrastructure, and equipment (in case of in-house development)			DK S		

Remarks: D = Dinosaur, K = Komodo, S = Shark, W = Whale

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Coming face to face with innovation and digitization: the case of book printing in Spain

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Abstract

This paper deals with how technological change and digitization in the Spanish book printing sector are challenging existing business models and encouraging printers to modify their product portfolio and core competencies. This research analyzes the impact of digitization on the business models of Spanish book printing houses. The case studies conclude that: a) book printing houses, although aware of the necessary digital transformation, continue to maintain the traditional business model alongside the new one, b) customers are the main driving force for digital transformation in book printing houses, c) there is a trade-off between cultural and environmental policies as drivers of the paradigm shift in book printing houses and d) the digital context is a motivating factor for book printing houses to integrate vertically downstream.

Keywords: core competences, cultural policy, digital transformation, book printing house, business model

1. Introduction

Technological changes have influenced book production, mainly through the computerization of printing processes (Tian and Martin, 2010; Steinberg, 2017; Brillenburg Wurth, Driscoll and Pressman, 2018; Zimmermann, Ferreira and Carizzo Moreira, 2019), and have driven the development of digital printing, providing book printing houses with a more efficient and flexible tool to meet the new demands and requirements of the market: shorter print runs, printing on-demand and customization of print copies, among others (Gallagher, 2014; Wilson-Higgins, 2017).

The printing industry – one of the most technically advanced and complex – faces significant technology management challenges, particularly since the emergence of innovations, such as, among others, the new digital workflows or digital printing technologies. This pace shows no sign of slowing and seems to have sped up in recent years. The printing industry could now be said to be in a state of almost continual change. Nonetheless, many of those problems display significant opportunities for the analysis and further development of solutions (Prakhya and Hull, 2006). The introduction of new technologies and the Internet in book printing houses significantly improved their production processes and communication with their customers (Longhi and Rochhia, 2014; Clark, and Phillips, 2019). Accordingly, a new online printing model appears, characterized by Internet sales and the digital printing system. There is an unfolding of the channel, so both channels coexist simultaneously: the 'offline' with the 'online' (Wang, Tsai, and Chang, 2016; North and Kumta, 2018). Internet sales have meant for book printing houses the possibility of connecting with a new customer profile beyond their area of geographical influence and increasing its efficiency by shortening delivery times (Minguela-Rata, Arias-Aranda and Opazo-Basáez, 2014; Świerczek, 2014; Wang and Disney, 2016). Nowadays, more and more book printing houses allow the production of books ordered on the Internet without the publisher having to go to the book printing house (or conversely) with a file to print since it is possible sending it through File Transfer Protocol (FTP).

Innovation and technological change in book printing houses increasingly depend on technologies and standards external to this industry (Benghozi and Salvador, 2016; Fleischmann, Daniel and Welters, 2017; Grodach, O'Connor and Gibson, 2017; Protogerou, Kontolaimou and Caloghirou, 2017). Digital printing or new printing

materials, such as mineral paper, would be examples of how book printing houses adopt innovations from more technical sectors (Zimmermann, Ferreira and Carizzo Moreira, 2016; Schulte-Holthaus, 2018). In this regard, it can be noted that the most frequent is the adoption of innovations, basically, from the world of technology, and managing the implementation of new technology efficiently and effectively will be, thus, a critical success factor in the printing industry (Prakhya and Hull, 2006).

The transition to digital technologies of book production has influenced trades and professions, which, until relatively recently, were significant in graphic arts, such as linotypists or proofreaders, among others. Procedures that were recently highly labor-intensive have been automated, digitized, and replaced by workers skilled in the use of digital-based technologies. In this case, there is a process of creative destruction associated with new companies, new technologies, and qualified human resources. Creative destruction generates the possibility of new businesses within the book printing houses, such as on-demand printing and online title management, while, on the other, it displaces processes from conventional to digital printing. Those book printing houses best adapting to the publishing market dynamism will be the ones sustained over time. As said above, two printing formulas coexist: conventional and digital.

One of the relative advantages of digital printing, in comparison with conventional printing, has to do with cost reduction in short print runs: in digital printing, the unit cost is fixed and independent of the number of printed copies, while in conventional printing, the unit cost per copy diminishes according to print runs, which places digital printing as an ideal option for short print runs (Kranz and Picot, 2016).

The academic literature underlines that technological changes can redefine any industry where inserted and modify its pre-existing business models (Christensen, 1997; Bindra, Parameswar and Dhir, 2019), but also stresses that the changes operated are gradual and go through different stages before the consolidation of a new dominant paradigm or productive model (Abernathy and Utterback, 1978; Dodgson and Gann, 2018). On the other hand, the little existing research on digitization in graphic arts has been based mainly on describing changes in production processes, but not on their impact on business models. (Magadán Díaz and Rivas García, 2019).

A study of the impact of digitization on book printing houses' business models is the general goal of this research, and the specific objectives focus on finding answers to the following questions: a) how does digitization affect the business models of book printing houses?; b) how do book printing houses adapt to the new private demand needs?; c) to what extent can public policies influence changes in the book printing paradigm?; and d) does digitization lead book printing houses to integrate vertically downstream?

Innovation is not a choice but a need in this era of rapid changes in the printing industry. The printing industry is the perfect one to analyze rapid technological changes and problems associated with these and develop methods for overcoming all those difficulties, guaranteeing technical changes proceed appropriately (Prakhya and Hull, 2006).

The study is structured as follows: the second section offers the theoretical framework; the third section describes the case study; the fourth section includes the main findings derived from the analysis and, finally, the fifth section summarizes the conclusions reached.

2. Theoretical framework

This section presents the leading theories on business models, digitization, and innovation management, which constitute the conceptual and analytical framework for carrying out case studies in this work.

2.1 Business models

A business model defines how organizations create and deliver value to their customers and structures the market in which runs, placing themselves within a value chain composed of suppliers, intermediaries, and customers (Amit and Zott, 2001; Teece, 2010; DaSilva and Trkman, 2014; Spieth, Schneckenberg and Ricart, 2014; Wirtz, et al., 2016; Foss and Saebi, 2017; Mazzarol and Reboud, 2020). In short, a business model: i) represents the operative architecture behind the value chains and supply of a product, and ii) facilitates both the understanding and the response given by organizations to the market and its needs (Foss and Saebi, 2018).

Digital transformation and technological change – in the book printing sector – not only foster new ways of presenting their products through digital printing but also favor the development of new business models, among which online sales can be highlighted (Peng, 2016; North and Kumta, 2018; Wirtz, 2019). The joint result of all these changes for organizations is the need to adapt their respective business models to make profitable the changes derived from technological innovations (Sabatier, Mangematin, Rousselle, 2010; DaSilva and Trkman, 2014; Spieth, Schneckenberg and Ricart, 2014; Wirtz, et al., 2016; Foss and Saebi, 2017; Mazzarol and Reboud, 2020).

Companies belonging to sectors that are considered mature – such as graphic arts – should be dynamized and adapted to improve both their competitiveness and their sustainable development in the face of environmental changes, so it is necessary to study the interactions among innovation, digitization, and business model in the framework of the current economy (Andreini and Bettinelli, 2017; Afuah, 2014; Visnjic, Wiengarten and Neely, 2014; Martins, Rindova and Greenbaum, 2015; Evans, et al., 2017).

It is significant to highlight the role of an open innovation culture within organizations (Stanko, Fisher and Bogers, 2017; Enkel, Bogers and Chesbrough, 2020). Business organizations will be able to detect new business opportunities, either from within their structures or in collaboration with other digital organizations, driving the transformation of mature sectors with new products, services, techniques, and ideas, that is, with new logics for value creation (Viljakainen, Toivonen and Seisto, 2016; Massa, Gianluigi and Tucci, 2018; Majchrzak and Malhotra, 2020).

2.2 Knowledge and innovation

Knowledge and innovation are the main factors for today's organizations, as they represent the essence of their competitive advantage and promote changes in business models to better adapt to environmental conditions (Luong, et al., 2017; Magadán Diáz and Rivas García, 2019). The redefinition of an existing business model demands the capability to produce or absorb new knowledge (Afuah, 2014; Hsieh and Wu, 2019; Snihur and Wiklund, 2019).

Innovation is a fundamental source of competitive advantages for business organizations, promoting, at the same time, the sectoral development in which they locate (Schumpeter, 1934; Dodgson, 2018; Malerba and Pisano, 2019). However, innovation processes depend on the size of an organization: a) to make bigger R+D+I (Research, Development, and Innovation), b) to hire technically qualified personnel, and c) to compensate for the risks from the investment in R+D+I with higher sales (Schumpeter, 1934). From the knowledge perspective, innovation is supposed to be a paramount factor in any production process and a source of value-generating competitive advantages with cumulative effects (Alvarez and Barney, 2017; Dayan, Heisig and Matos, 2017). One of these innovation sources is the business organizations' ability to access and strategically manage knowledge, also known as absorption capacity (Reid, et al., 2018; Patel, 2019; Kafouros, et al., 2020).

Knowledge and innovation in the graphic arts sector are increasingly dependent on technologies and standards that are external to this industry, which will boost the search for open innovation in companies from the graphic arts sector, both via knowledge overflow and via agreements with specialized organizations (Benghozi and Salvador, 2016; Fleischmann, Daniel and Welters, 2017; Grodach, O'Connor and Gibson, 2017; Magadán Diáz and Rivas García, 2019; Protogerou, Kontolaimou and Caloghirou, 2017).

2.3 Print digitization

The impact of the Internet and digitization on economic systems causes very different effects among diverse industries depending on whether they integrate technical changes into their respective production processes or not. For organizations integrating technical changes, this can mean gains in productivity, while for non-integrators it implies just the opposite, to the point that the sectoral transformation operated by the organizations integrating change ends up undermining the old existing business models of the organizations outside such impacts, and that finally see themselves close to closure (Martin and Tian, 2016; Magadán Diáz and Rivas García, 2019). In sum, the transition from offline to online portfolio products will pose critical challenges and changes for the graphic arts industry (Mohammed Ali, et al., 2019; Gallagher, 2014).

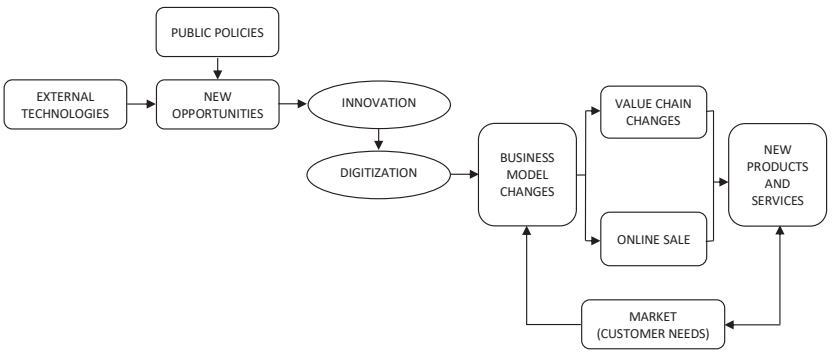


Figure 1: Research and conceptual framework of the case study

2.4 Research and conceptual framework

Once analyzed the theoretical framework to study the impact of digitization on printing business models, Figure 1 provides the research framework for this study. This research and conceptual framework show the relationships among the following aspects: the adoption of technology, adaptation to market needs, the influence of public policies and their effects on the value chain, and possible vertical integration.

From the research and conceptual framework shown in Figure 1, it is proceeded to present the case studies together with the findings obtained.

3. Case studies: digitization in Spanish book printing houses

This section presents the case studies conducted on the digitization of three Spanish book printing houses, according to their size, and the Spanish context.

3.1 The Spanish context

Spain is one of the European countries with the largest number of companies and production volumes in the graphic industry. It is a very atomized sector, with numerous companies: 13 032 companies linked to graphic arts that employ 56 830 people (INE, 2019), with companies of very small size, with an average workforce of three people in 70 % of cases. They are usually family businesses and of domestic capital, although, in recent years, some investment funds are joining the graphic industry (CESCE, 2017).

The communities with the highest weight in the graphic arts sector are Madrid (23 %) and Catalonia (22 %), followed by Andalusia (11 %) and the Community of Valencia (10 %). There are also a few large companies and leading positions: the first five companies in the sector absorb 10 % of the market share and are integrated into international groups (CESCE, 2017).

Firstly, customers of book printing companies benefit from the existence of an excess of supply in the market and, secondly, by the little or almost no differentiation in the quality of the products and services offered. Consequently, changing the printing service provider does not imply a significant opportunity cost. This industry suffers an excess of capacity (oversupply), causing closures and concentrations and forces the remaining book printing houses to be more productive.

Although the graphic arts sector has generated 5 523 million euros (CESCE, 2017), the number of companies operating in Spain has been reducing since 2008. Many of these companies merged with others to survive, mainly due to their low production and profitability. This decline was more pronounced since the Great Crisis of 2008, experiencing a hard adjustment in recent years, with the disappearance of small-sized companies and a meaningful diminishing in production, motivated by the reduction of advertising investment and publishing activity.

A circumstance that contributes to the shortening of book printing activities is the spread of information through digital media (Davis, 2014; Wolford, 2016). Digital distribution of information and e-publishing has reduced the volume of production of the book printing houses (Cherian, 2015). Only analyzing the reduction of print runs published in Spain, for example, while in 2016 the average print run was 2 749 copies, in 1997 it was of 6 670 copies, which has meant a reduction of 59 % (Magadán-Diáz and Rivas-García, 2020).

Increasing production costs (machinery, paper, ink, and energy) and changing customer needs explain the fall in turnover in Spanish book printing houses. Hence, more and more companies in the sector focus on new online business models allowing them to: a) diversify their offer, b) streamline their production processes, and c) optimize costs.

The book printing sector in Spain is evolving and innovating permanently, which is an essential process to guarantee the survival of companies that operate in a highly complex, dynamic, and hostile environment given the high intra-sectoral competitiveness that forces an update and improvement of their processes, increasingly oriented to digital printing – one of the fundamental sectoral innovations of recent years.

3.2 Case method

The method used to carry out the empirical study is that of the case study method. This approach is fundamentally interpretive (Cresswell, 2003) and fits the scope and objectives of this research because it offers the possibility of explaining or understanding a phenomenon, a process, or a combination of these (Corbetta, 2003).

This methodology turns out to be very suitable when the key questions are what (description), how, and why (application) in the generation of a theory (Snow and Thomas, 1994).

From the vast academic literature on the case study method, its foundations, and applications, must be underlined works and studies such as those of Eisenhardt (1989), Chetty (1996), Gerring (2007), Simons (2011), Yin (2011) or Elman, Gerring, and

Table 1: Description of cases of study

Company	Named as	Operating years	Legal form	Employees rank	Turnover rank (in millions of €)
Book printing house 1	P1	59	Individual company	5–25	0.6–1.5
Book printing house 2	P2	28	Limited liability company	5–25	1.5–3
Book printing house 3	P3	66	Public limited company	25+	6–30

Mahoney (2016). These works are considered seminal in an updated approach to the case study method, both in understanding and implementation.

The case study method has been applied to business management research on business cooperation associations and agreements (Wilson and Vlosky, 1997; Yin, 2009), on managerial and organizational processes (Grunow, 1995; Mintzberg, 1973) or related to operations management (Ketokivi and Choi, 2014), among others. In this context, we have chosen to use this methodology to develop the empirical analysis since the case study is one of the fundamental research strategies within the qualitative field, especially concerning organizational change and innovation (Brown and Eisenhardt, 1997; McCutcheon and Meredith, 1993; Pettigrew and Whipp, 1991; Van de Ven and Poole, 1990).

The book printing houses that make up this study were selected according to a criterion of convenience (accessibility and profile sought for the set of cases); therefore, given the difficulty of accessing professionals in this field, only those who could effectively contribute to the questions of this research were selected, a necessary condition in the case studies (Cresswell, 2003; Miles, Huberman and Saldaña, 2013).

In a case study, there should be a cross-check of data sources, which guarantees: a) its constructive validity, since the use of different data sources and analysis methods will allow a more accurate picture of the subject studied, and b) the possibility of replicating, with analogous researches, to confirm or refute the findings obtained (Bartlett and Vavrus, 2016; Elman, Gerring and Mahoney, 2016; Gummesson, 2017).

Among the different methods of evidence collection, this research used the following: a) search and review of documents of the book printing houses analyzed (documentary shreds of evidence like advertising, catalogs, reports, and memorandums of the companies analyzed, as well as financial data, among others), and b) conducting structured interviews (face to face or via Skype). All this collection process responds to the methodological need for an informative triangulation that assesses the alignment of the responses obtained from the book printing houses to the existing documentary evidence and is publicly available.

As said above, the method used to carry out the empirical study is the case method, as it is considered that two primary conditions or dimensions are met for its implementation: a) the type of questions that are sought to answer with the development of this investigation facilitates the application of the case study and b) the problem addressed is novel and complex enough to require an approach through this method (Yin, 2014; Ridder, 2017; Roseli Wünsch Takahashi and Araujo, 2019).

This research selected three book printing houses – using, as said, a convenience sampling –, named as P1, P2, and P3. Next, the profile of each organization studied is summarized (see Table 1).

Three interviews were conducted from October to November 2019, with representatives of each one of the three selected book printing houses and carried out by the authors of this research; of those, one was in person (face to face), and the rest was by Skype. The questions formulated were broad enough so that those responsible interviewed could freely delve into the issues raised. These open questions, despite having made the analysis more complex, have allowed us to achieve a much richer and more nuanced interpretation.

The questionnaire was prepared following Josselson (2013), considering, among others, the following recommendations: a) predominance of open versus closed questions; b) design questions that promote the narrative discourse of the interviewee so that the information flows naturally and organically; c) avoid the abuse of questions that require an answer to a 'why' and force an intellectualization process of the interviewee that should be carried out by the person conducting the research; d) take into account how the interviewee expresses himself when addressing a question or proposed topic to better assess his position on the question.

Finally, a narrative approach was adopted to convey the results of the analysis, seeking to establish a connection between the themes. This narrative was paired with the bibliographic references, seeking validation of the results collected in the theoretical framework. This process culminated in reaching the main theoretical and practical implications of this research, described in the final observations of this study.

3.3 Digitization at a company level

To understand the challenges and opportunities in the graphic arts industry in Spain related to digitization, it is proceeded to the case studies of three reference printers, according to their size.

3.3.1 P1 book printing house

The P1 book printing house, established in 1958, takes the legal form of an individual company. It offers conventional and digital printing services in short runs and on-demand. It was a pioneer in Spain in introducing digital printing and variable data over 21 years ago. Since the 1980s, P1 integrated pre-press, printing, and post-press services into its organization, being the first book printing house in its environment to incorporate a binding machine so as not to have to outsource this phase of the process and thus provide better service to its customers. Although P1 retains conventional printing, this only accounts for 10 % of the total workload currently.

Since 1994, P1 has a web page that offers the presentation of the company and compliance with the privacy policy but does not offer an online quote request (only provided by email), or access to product catalogs, or access to price lists, or file delivery via FTP. Together with conventional printing services, P1 also offers, in addition to content digitization, the transformation of files into ePub or PDF format.

The P1 company has a brand for self-publishing, a downstream vertical integration, which its manager describes as *'one more service we offer to our customers. We facilitate the procedures of the ISBN, and it comes out with a stamp without appearing author-editor, but, for me, that is not an editorial*', admits that, *'although we were the first to introduce a digital book printing house in Spain, we still maintain an offset printing machine, but that we hardly use*' and finally concludes *'right now, 90 % of our turnover comes from digital printing*'.

The manager of P1 points out that, for the moment, *'we only produce paper books, from a copy up to those that our customers wish'* and that *'once finished, we deliver it to them'* and adds *'It is we who manage the ISBN and the legal deposit. The book comes out with our stamp, which we created for it*'. Although they do not publish, for the moment, e-book, *'we offer our customers the possibility of generating the e-file in ePub or PDF so that later they can upload it to some platform of e-books*'.

Its manager highlights the quality of printing obtained, which is comparable to the print quality of an offset machine, noting that '*with the new digital machines it is very difficult, with the naked eye, to know whether it is digital printing'*. One of the brakes that have made digital printing no longer extend is that *'digital printing machines cannot standstill. For each copy we print, a percentage is paid to the equipment manufacturer plus a fixed fee, so you must ensure a good workflow and set the prices per sheet printing to avoid financial problems'*, and points out that many book printing houses have suffered bad moments and have even closed as a result of *'an aggressive pricing policy to attract customers so that the digital machine did not stop, but without covering costs'*. Finally, the manager of P1 stresses that the future of book printing unavoidably goes through digital printing.

3.3.2 P2 book printing house

The P2 book printing house has a history of 28 years. Established in 1992, it adopts the legal form of a limited liability company. With net equity of 320 000 euros, the turnover of P2 moves in the range of 1.5 and 3 million euros in 2019. However, the CEO of P2 acknowledges that the trend of its turnover was downward since 2014, with a fall estimated at approximately 6.5 %. The P2 printing house has a powerful web page that shows: a) the presentation of the company, b) the request for online quotes, c) the monitoring of the evolution of the order, d) the possibility of sending files via FTP, and e) compliance of the privacy policy. Together with conventional and digital printing services, it also offers, in addition to the digitization of content, the possibility of making e-books with the incorporation of multimedia content adaptable to any reading device. The P2 has its FTP server for the reception of files using the client/model and works so that each publishing company can send them through this system. All the aforementioned tasks are performed by offering quotation request services through its website and with real-time response. For this, users must be registered as customers, who are provided with a digital identification and a password. Once the budget has been provided, users have the option to place the order or leave it. For more than four years, P2 offers publishers the possibility of distributing and marketing their funds, both those of paper and e-books, managing the relationship with digital platforms, and offering sales control tools. It stands out that those who are making more use of this distribution tool are those who self-publish. So far, P2 has not developed its publishing label.

Although the book printing house began its journey with conventional printing, its CEO points out that *'our book printing house is fully digital'*. Also, it is highlighted that the print quality achieved has nothing to envy to an offset machine: *'the introduction of digital machines has allowed us to do more work in less time and improve the service we offer to our customers'*, to which adds that *'digital printing is very fast, the ink comes out dry and can be bound instantly. If offset printing was done, the job would take at least three days because you must generate the plates, print, let the ink dry to avoid rubbings, and, in the end, bind*'.

The P2 has taken another step and is positioning itself as an online book printing house. Its CEO underlines that *'the future of book printing goes through digital printing'*, and acknowledges that *'we have made a great investment, both in the new digital machinery and in a portal with all the technology available at the moment*' aimed at *'offering a close deal, more competitive prices, reducing delivery times of the final product to the customer and expand our catalog of products and services*'. At the moment, P2 offers graphic design, layout, processing, and transformation services to any format (ePub, Mobi, among others) so that it can be read on e-devices, as well as the management of the marketing of e-books on Amazon, Apple, Book House, Kobo. According to its CEO, *'we are a living company, in constant movement to live up to the current markets and cover all their needs*' and, besides, announces that the online tracking of shipments and a virtual library will be launched for books, both in paper or digital format, of *'those publishing companies with which we reach an agreement*'. The CEO of P2 admits that cannot say what has been the most outstanding innovation, although *'perhaps it is the computerization of the entire production process*' and recognizes that innovations carried out in P2 are focused both in processes and in products, although without specifying in detail.

3.3.3 P3 book printing house

The P3 book printing house, established in 1954, has the legal form of a public limited company. With a registered capital of 60 000 euros, the turnover of P3 moves in a range between 6 and 30 million euros in 2019. It offers solutions for sheet-fed offset printing, web offset, and digital printing. The P3 company has opted for the finished product and thus, since the 1990s, has incorporated folding and binding systems in the plant so as not to depend on other external companies, shorten delivery times and control the quality offered to customers. Also, at that time, P3 integrated services of pre-press, printing, and post-press. It has been a pioneering book printing house in going out to the foreign markets at the end of the 1990s, with entrenched customers in France, Germany, Italy, Belgium, Portugal, Holland, and Morocco, allowing P3 to create an international department and undertake, from the quote request and the order of production, the monitoring, and compliance in time and form of the entire production process, thus giving an immediate service and maintaining maximum control of production. According to its manager, *'we have had dare to go beyond national borders, building over time a reputation based on consolidated knowledge, reliability, financial strength, the willingness to innovate and experiment*', and stresses that the future of book printing goes through digital printing.

The P3 has also become an online book printer where customers can calculate the printing price of a book, brochure, or catalog. According to the manager of P3, *'we are aware that the company has to be in continuous renovation to be able to compete with the same weapons in an increasingly close league, where the digital technology implemented in this sector was sweeping those companies that resisted to adapt to the new digital environment*', adding that *'the market always rewards those organizations that invest in the incorporation of new technologies and that assume technological change*'.

The P3's commitment to online printing has allowed it to reduce fixed costs, improve customer accessibility and shopping experience. According to its manager, *'customers access our website, select the products and the quantity wished from each one and finalize their purchase choosing the place and term of delivery*'. Having an online-based business model, P3 has had to create a strong enough infrastructure to support all the daily orders received, forcing to have a team of software engineers to support and maintain the technological modules, which in turn is driving the growth of the company. The P3 can manage, in just one day, a volume of up to 4 500 orders, from printing a single copy to 800 copies. According to its manager, *'we can meet any demand, from the urgent printing of a book or catalogs to the careful edition of a book with luxury finishes*' and assures that the future of book printing involves developing digital printing and having an online service of book printing.

Currently, P3 is committed to environmental sustainability by researching and developing printing on new ecological materials, such as stone paper or plant paper, using recycled paper to print customer orders, and using ecological inks, that is, replacing the polluting components by others more environmentally respectful. In this sense, P3 invests in ecological printing systems, such as the LED-UV system, which eliminates pollutants such as mercury or ozone, among others, thereby reducing the ecological footprint.

The manager of P3 underlines that *'the book printing house has made a deep digital and technological trans-*

formation that has allowed it to expand its service offer and adapt existing ones to new market demands'. In short, '*the coexistence of the online world, new management applications and traditional sales teams have profoundly modified this business*', because '*it has generated significant integration, automation, and complimentary services needs for our customers*'.

4. Discussion of findings

The answers obtained to the research questions initially formulated are summarized in Figure 2 where the location of findings within the research and conceptual framework is shown.

The first finding (F1) stresses that the book printing houses have recognized the need for digitization within their business models but have not yet fully traveled that path and recognizing the need to do it. The second finding (F2) refers to the fact that there is an insufficient adaptation from book printing houses to private demand needs. The third finding (F3) shows a significant impact of public policies on the change in the printing paradigm. Finally, the fourth and last finding (F4) underlines that digitization is driving book printing houses to integrate vertically downstream.

Next, the findings obtained from the case study performed are discussed.

4.1 Digitization in existing business models

First, the book printing houses studied have begun to explore new digital products but with little progress in aspects such as the following: a) the building of interoperable digital infrastructures, b) the definition of industrial standards, and c) the development of joint distribution systems.

Second, the Internet and mobile connectivity are changing the printing business model and, therefore, how book printing houses and customers interact: shortening the production process, reducing delivery times, or expanding online services, are some effects derived from the adaptation of the business model of the book printing houses analyzed.

Third, although the printers studied are clinging to the traditional business model and distribution networks, they are making several incursions to explore new business opportunities such as digital printing and online printing. Many of the initiatives of a digital nature promoted in the book printing houses studied are still limited and fragmented in terms of internal organization. In any case, printers are receptive to the phenomenon of digitization. The Spanish publishing printing houses analyzed combine several business models. However, the traditional model remains dominant.

Fourth, the book printing houses analyzed are aware of the need to incorporate new specialized talent that provides the new skills necessary for the transformation of their respective business models, so to extract maximum performance from all technological developments, they must invest a lot, either in training, or in the attraction of that qualified personnel, since the control of the variables of the new context of the printing business will no longer depend on the 'physical' or 'manual' ability of the person, but on their technological knowledge to fix properly the appropriate parameters to each support and printing difficulty. In short, the new printing model will use less 'touch' and more 'brain'.

4.2 Insufficient adaptation to private demand needs

Firstly, the most critical issue faced by printing companies is, without a doubt, the one related to delivery times: since customers perceive print work as a homogeneous product – given the similarity in quality offered by the printers in the sector together with low-priced and competitive prices that are not very differentiated –, these tend to demand increasingly shorter

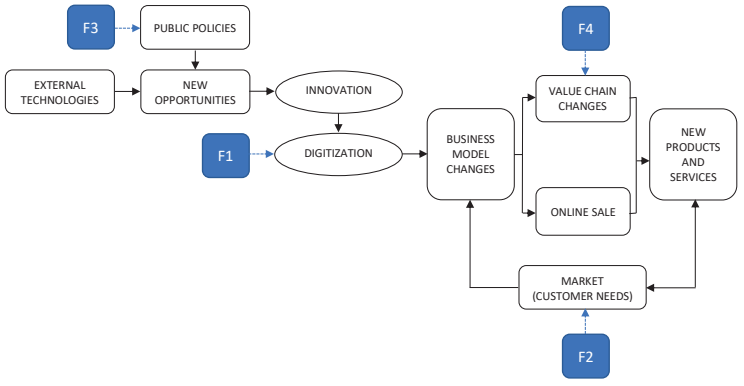


Figure 2: Location of findings within the research and conceptual framework

delivery times and opt for those printers that are capable of performing the work within that timing. A tendency that presses the book printing houses to offer the development of a work from days to hours avoiding the bottlenecks associated with a simple template reinforcement at certain stages of the printing work.

Secondly, to offer competitive prices and reduced delivery times, it is necessary to implement automation in the various processes of printing work. Automation is seen as the only possible way to survive in the market. From the perspective of those responsible for the book printing houses studied, there is no other way.

Thirdly, the print runs continue to shorten. To produce short print runs cost-effectively, it is imperative to use software that automates the entire workflow, from design to billing, through shipping; and all with the minimum human intervention, which implies both an adaptation and innovative effort in each of the phases of the printing process.

4.3 Public policies and change of book printing paradigm

How book printing houses relate to innovation, technical change, digitization, and their impact on existing business models, can also be understood from the public policies surrounding the graphic arts sector. Specifically, there are two kinds of influences on book printing paradigms: a) promoted by cultural policies and b) promoted by environmental policies.

Firstly, cultural policies promote publishing projects to favor all links in the publishing value chain, which implies a priority commitment to paper format over the digital. Failure to do so would, from a political perspective, turn its back on three links in the value chain: book printing houses, middlemen (distributors), and bookstores. Whether public resources address publishing projects with no favoring the paper format, then their effects on those three links – in their traditional version – would be null.

Second, environmental policies promote a paradigm shift from the printing business model to digital printing and online processes using less polluting raw materials to make it more sustainable and environmentally responsible.

4.4 Digitization and vertical integration

The development of digital printing and new technologies will lead to the book printing houses being able to grow their business model through the vertical integration downstream, assuming a publisher role and even a commercial function through the online sale. Digital transformation – in the opinion of the book printing houses analyzed – will continue to be a priority in their respective agendas, searching for greater efficiency and better positioning of their product and service portfolios.

Finally, the graphic arts sector – unlike what happens in other sectors analyzed by academic literature – develops a type of strategy around its digital transformation not oriented towards the formation of barriers to market entry for other potential external competitors, which, presumably, may favor adequate assimilation and adoption of both adaptive and disruptive innovations.

5. Conclusions

The graphic arts sector in Spain is immersed in an increasingly digital reality, which implies a redefinition of production processes and a constant rethinking of the business model.

The book printing houses studied are absorbing digital knowledge to try to position and respond adequately to changes in the market and changing technologies. However, they acknowledge not fully exploiting the full potential of new digital technologies through their respective business models.

The technologically motivated book printing houses are concerned with introducing process innovations to increase its efficiency, both in product development and in its commercialization: digital printing or new printing materials, such as mineral paper, would be some examples of how they adapt to the printing innovations coming from more technical sectors.

The introduction of new technologies and the Internet in the printing houses: a) significantly improves communication with their regular customers, b) makes it possible to connect with a new customer profile beyond their geographical range of action, and c) increases their efficiency by shortening times of delivery. As a result of all this, a new online book printing model appears characterized by Internet sales and the digital book printing system. Thereby, there is an unfolding of the channel so that offline and online printing coexist together.

The studied book printing houses find that users of their services have different expectations of digital products compared to their analog predecessors. The data provided by the book printing houses show the changes experienced in their respective companies are produced not by their initiative but by the necessary customer orientation, which makes them their reason to innovate, forcing the book printing houses to permanent evolution in products and services.

There is a trade-off between cultural policies, consolidating the traditional printing model against environmental policies, driving a sustainable model that favors the digital transition in graphic arts.

The book printing houses – as the first link in the publishing value chain – have a significant incentive for a forward vertical integration based on self-publishing, avoiding, among others, the costs associated with the search for authors or those related to the negotiation of the publishing contract. Finally, this incentive for a forward vertical integration seems to be independent of its size.

Finally, the trends that will mark the sector will be: a) a better adaptation to customer demands, with a product customization and faster deliveries, b) a growing investment in digital technology, c) a higher environmental responsibility, with the use of recyclable products and of less impact on the environment and d) a necessary search for workers with new skills and abilities that can use tools such as the use of artificial intelligence, big data, and that allow improving the productivity of printing processes.

In conclusion, digitization manifests itself as a fundamental piece for the graphic arts sector to improve its productivity and profitability. It is not only a question of taking full advantage of the broad possibilities of digital printing but also about increasing the efficiency of printing processes thanks to the automation and use of resources offered by digital marketing, the big data, or the implementation of the web-to-print so that the printers adapt adequately to the demands and requirements of the client.

Though this research has focused on the printing industry, this case method approach can be applied to any industry undergoing rapid or continuous change to take a snapshot that helps understand not only the impacts derived from innovation and technical change but to draw a future profile of trends from a strategic management perspective.

References

Abernathy, W.J. and Utterback, J.M., 1978. Patterns of industrial innovation. *Technology Review,* 80(7), pp. 41–47.

Afuah, A., 2014. *Business model innovation: concepts, analysis, and cases*. Abingdon, UK: Routledge.

Alvarez, S.A. and Barney, J.B., 2017. Resource-based theory and the entrepreneurial firm. In: M.A. Hitt, R.D. Ireland, S.M. Camp and D.L. Sexton, eds. *Strategic entrepreneurship: creating a new mindset.* Hoboken, NJ, USA: Wiley, pp. 87–105.

Amit, R. and Zott, C., 2001. Value creation in e-business. *Strategic Management Journal,* 22(6–7), pp. 493–520. https://doi.org/10.1002/smj.187.

Andreini, D. and Bettinelli, C., 2017. Business model definition and boundaries. In: *Business model innovation: from systematic literature review to future research directions.* Cham, Switzerland: Springer International Publishing, pp. 25–53.

Bartlett, L. and Vavrus, F., 2016. *Rethinking case study research: a comparative approach.* London, UK: Routledge.

Benghozi, P.-J. and Salvador, E., 2016. How and where the R&D takes place in creative industries? Digital investment strategies of the book publishing sector. *Technology Analysis & Strategic Management,* 28(5), pp. 568–582. https://doi.org/10.1080/09537325.2015.1122184.

Bindra, S., Parameswar, N. and Dhir, S., 2019. Strategic management: the evolution of the field. *Strategic Change,* 28(6), pp. 469–478. https://doi.org/10.1002/jsc.2299.

Brillenburg Wurth, K., Driscoll, K. and Pressman, J. eds., 2018. *Book presence in a digital age.* London, UK: Bloomsbury Publishing.

Brown, S.L. and Eisenhardt, K.M., 1997. The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organizations. *Administrative Science Quarterly, 42*(1), pp. 1–34. http://dx.doi.org/10.2307/2393807.

CESCE, 2017. *Informe sectorial de la economía española: papel y artes gráficas, 2017*. [online] Available at: <https://issuu.com/cesce.es/docs/isectorial_09-papel_artes_graficas_> [Accessed February 2021].

Cherian, J., 2015. Emergence of digital publishing – a great challenge to the print publications. *Procedia Economics and Finance*, 23, pp. 576–586. https://doi.org/10.1016/S2212-5671(15)00361-5.

Chetty, S., 1996. The case study method for research in small- and medium-sized firms. *International Small Business Journal*, 15(1), pp. 73–85. https://doi.org/10.1177/0266242696151005.

Christensen, C.M., 1997. *The innovator's dilemma: when new technologies cause great firms to fail.* Boston, MA, USA: Harvard Business School Press.

Clark, G. and Phillips, A., 2019. *Inside book publishing.* 6th ed. Abingdon, UK: Routledge.

Corbetta, P., 2003. *Metodología y técnicas de investigación social.* Madrid: McGraw-Hill Interamericana.

Cresswell, J.W., 2003. *Research design: qualitative, quantitative, and mixed methods approaches.* Thousand Oaks, CA, USA: Sage Publications.

DaSilva, C.M. and Trkman, P., 2014. Business model: what it is and what it is not. *Long Range Planning,* 47(6), pp. 379–389. https://doi.org/10.1016/j.lrp.2013.08.004.

Davis, R.H., 2014. Business economics and the printing industry. *Business Economics*, 49, pp. 122–126. https://doi.org/10.1057/be.2014.9.

Dayan, R., Heisig, R. and Matos, F., 2017. Knowledge management as a factor for the formulation and implementation of organization strategy. *Journal of Knowledge Management*, 21(2), pp. 308–329. https://doi.org/10.1108/JKM-02-2016-0068.

Dodgson, M., 2018. *Technological collaboration in industry: strategy, policy and internationalization in innovation*. Abingdon, UK: Routledge.

Dodgson, M. and Gann, D., 2018. *Innovation: a very short introduction.* Oxford, UK: Oxford University Press.

Eisenhardt, K.M., 1989. Building theories from case study research. *Academy of Management Review,* 14(4), pp. 532–550. https://doi.org/10.2307/258557.

Elman, C., Gerring, J. and Mahoney, J., 2016. Case study research: putting the quant into the qual. *Sociological Methods & Research,* 45(3), pp. 375–391. https://doi.org/10.1177/0049124116644273.

Enkel, E., Bogers, M. and Chesbrough, H., 2020. Exploring open innovation in the digital age: a maturity model and future research directions. *R&D Management,* 50(1), pp. 161–168. https://doi.org/10.1111/radm.12397.

Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E. A. and Barlow, C. Y., 2017. Business model innovation for sustainability: towards a unified perspective for creation of sustainable business models. *Business Strategy and the Environment*, 26(5), pp. 597–608. https://doi.org/10.1002/bse.1939.

Fleischmann, K., Daniel, R. and Welters, R., 2017. Developing a regional economy through creative industries: innovation capacity in a regional Australian city. *Creative Industries Journal*, 10(2), pp. 119–138. https://doi.org/10.1080/17510694.2017.1282305.

Foss, N.J. and Saebi, T., 2017. Fifteen years of research on business model innovation: how far have we come, and where should we go? *Journal of Management,* 43(1), pp. 200–227. https://doi.org/10.1177/0149206316675927.

Foss, N.J. and Saebi, T., 2018. Business models and business model innovation: between wicked and paradigmatic problems. *Long Range Planning,* 51(1), pp. 9–21. https://doi.org/10.1016/j.lrp.2017.07.006.

Gallagher, K., 2014. Print-on-Demand: new models and value creation. *Publishing Research Quarterly,* 30(2), pp. 244–248. https://doi.org/10.1007/s12109-014-9367-2.

Gerring, J. (2007). *Case study research: principles and practices.* Cambridge, UK: Cambridge University Press.

Grodach, C., O'Connor, J. and Gibson, C., 2017. Manufacturing and cultural production: towards a progressive policy agenda for the cultural economy. *City, Culture and Society,* 10, pp. 17–25. https://doi.org/10.1016/j.ccs.2017.04.003.

Grunow, D., 1995. The research design in organization studies: problems and prospects. *Organization Science*, 6(1), pp. 93–103. https://doi.org/10.1287/orsc.6.1.93.

Gummesson, E. (2017). *Case theory in business and management: reinventing case study research.* London, UK: SAGE Publications.

Hsieh, Y.-J. and Wu, Y.J., 2019. Entrepreneurship through the platform strategy in the digital era: insights and research opportunities. *Computers in Human Behavior,* 95, pp. 315–323. https://doi.org/10.1016/j.chb.2018.03.033.

Miles, M.B., Huberman, A.M. and Saldaña, J., 2013. *Qualitative data analysis: a methods sourcebook.* Thousand Oaks, CA, USA: SAGE Publications.

INE, 2019. Estadística estructural de empresas: sector industrial. [online] Available at: <https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=estadistica_C&cid=1254736143952&menu=ultiDatos&idp=1254735576715> [Accessed February 2021].

Josselson, R., 2013. *Interviewing for qualitative inquiry: a relational approach.* New York, NY, USA: The Guilford Press.

Kafouros, M., Love, J.H., Ganotakis, P. and Konara, P., 2020. Experience in R&D collaborations, innovative performance and the moderating effect of different dimensions of absorptive capacity. *Technological Forecasting and Social Change,* 150: 119757. https://doi.org/10.1016/j.techfore.2019.119757.

Ketokivi, M. and Choi, T., 2014. Renaissance of case research as a scientific method. *Journal of Operations Management,* 32(5), pp. 232–240. https://doi.org/10.1016/j.jom.2014.03.004.

Kranz, J.J. and Picot, A., 2016. Internet business strategies. In: J. Bauer and M. Latzer, eds. *Handbook on the economics of the internet.* Cheltenham, UK: Edward Elgar Publishing, pp. 365–384.

Longhi, C. and Rochhia, S., 2014. «Ceci tuera cela»? Dynamique des changements dans l'industrie du livre. *Revue d'économie industrielle,* 145(1), pp. 121–154. https://doi.org/10.4000/rei.5761.

Luong, H., Moshirian, F., Nguyen, L., Tian, X. and Zhang, B., 2017. How do foreign institutional investors enhance firm innovation? *Journal of Financial and Quantitative Analysis*, 52(4), pp. 1449–1490. https://doi.org/10.1017/S0022109017000497.

Magadán Diáz, M. and Rivas García, J., 2019. Digitalización y modelos de negocio en la industria editorial española. *Journal of Technology Management & Innovation,* 14(1), pp. 63–72. https://doi.org/10.4067/S0718-27242019000100063.

Magadán-Diáz, M. and Rivas-García, J.I., 2020. La industria editorial española: dos décadas clave de transformación y cambio (1996–2016). *Economic History Research,* 16(2), pp. 1–15. https://doi.org/10.33231/j.ihe.2020.04.003.

Majchrzak, A. and Malhotra, A., 2020. What is crowdsourcing for innovation? In: *Unleashing the crowd: collaborative solutions to wicked business and societal problems.* Cham, Switzerland: Palgrave Macmillan, pp. 3–46.

Malerba, F. and Pisano, G., 2019. Innovation, competition and sectoral evolution: an introduction to the special section on industrial dynamics. *Industrial and Corporate Change,* 28(3), pp. 503–510. https://doi.org/10.1093/icc/dtz017.

Martin, B. and Tian, X., 2016. Books, bytes and business: the promise of digital publishing. New York, NY, USA: Routledge.

Martins, L.L., Rindova, V.P. and Greenbaum, B.E., 2015. Unlocking the hidden value of concepts: a cognitive approach to business model innovation. *Strategic Entrepreneurship Journal,* 9(1), pp. 99–117. https://doi.org/10.1002/sej.1191.

Massa, L., Gianluigi, V. and Tucci, C., 2018. Business models and complexity. *Journal of Business Models,* 6(1), pp. 59–71. https://doi.org/10.5278/ojs.jbm.v6i1.2579.

Mazzarol, T.W. and Reboud, S., 2020. Planning, business models and strategy. In: *Entrepreneurship and innovation: theory, practice and context.* Singapore: Springer, pp. 191–225.

McCutcheon, D.M. and Meredith, J.R., 1993. Conducting case study research in operations management. *Journal of Operations Management,* 11(3), pp. 239–256. https://doi.org/10.1016/0272-6963(93)90002-7.

Minguela-Rata, B., Arias-Aranda, D. and Opazo-Basáez, M., 2014. Processes integration and e-business in supply chain management. In: F. Martínez-López, ed. *Handbook of strategic e-business management*. Berlin, Germany: Springer, pp. 217–236.

Mintzberg, H., 1973. *The nature of managerial work.* New York, NY, USA: Harper & Row.

Mohammed Ali, N.A., Azahari, M.H., Mohd Rosnan, S. and Sumarjan, N., 2019. The digital printing technologies and survival of the commercial printers in Malaysia printing industry. *Journal of Printing Science and Technology,* 56(1), pp. 18–23. https://doi.org/10.11413/nig.56.18.

North, K. and Kumta, G., 2018. Knowledge management: value creation through organizational learning. Berlin: Springer.

Patel, P.C., 2019. Opportunity related absorptive capacity and entrepreneurial alertness. *International Entrepreneurship and Management Journal,* 15(1), pp. 63–73. https://doi.org/10.1007/s11365-018-0543-2.

Peng, Y., 2016. Mobile and digitally-mediated publishing strategies in China: an overview of evolving business models. *Publishing Research Quarterly, 32*(3), pp. 247–260. https://doi.org/10.1007/s12109-016-9467-2.

Pettigrew, A. and Whipp, R., 1991. *Managing change for competitive success.* Oxford, UK: Blackwell.

Prakhya, S.H. and Hull, C.E., 2006. The six facets model of technology management under conditions of rapid change: a study in the pre-media segment of the printing industry. *International Journal of Innovation and Technology Management*, 3(4), pp. 407–420. https://doi.org/10.1142/S0219877006000867.

Protogerou, A., Kontolaimou, A. and Caloghirou, Y., 2017. Innovation in the European creative industries: a firm-level empirical approach. *Industry and Innovation*, 24(6), pp. 587–612. https://doi.org/10.1080/13662716.2016.1263551.

Reid, M., Marion, T.J., Hultink, E.J. and Barczak, G., 2018. Open innovation, IT orientation, and external collaboration: implications for the use of new media and social networking IT in new product development. In: S. Nambisan, ed. *World scientific reference on innovation: Vol. 3, Open innovation, ecosystems and entrepreneurship : issues and perspectives*. Singapore: World Scientific Publishing, pp. 37–76. https://doi.org/10.1142/9789813149083_0003.

Ridder, H.-G., 2017. The theory contribution of case study research designs. *Business Research,* 10(2), pp. 281–305. https://doi.org/10.1007/s40685-017-0045-z.

Roseli Wünsch Takahashi, A. and Araujo, L., 2019. Case study research: opening up research opportunities. *RAUSP Management Journal,* 55(1), pp. 100–111. https://doi.org/10.1108/RAUSP-05-2019-0109.

Sabatier, V., Mangematin, V. and Rousselle, T., 2010. From recipe to dinner: business model portfolios in the European biopharmaceutical industry. *Long Range Planning,* 43(2–3), pp. 431–447. https://doi.org/10.1016/j.lrp.2010.02.001.

Schulte-Holthaus, S., 2018. Entrepreneurship in the creative industries. In: E. Innerhofer, H. Pechlaner and E. Borin, eds. *Entrepreneurship in culture and creative industries: perspectives from companies and regions.* Cham, Switzerland: Springer, pp. 99–154.

Schumpeter, J.A., 1934. *The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle*. Cambridge, MA, USA.: Harvard University Press.

Simons, H., 2011. *El estudio de caso: teoría y práctica.* Madrid, Spain: Ediciones Morata.

Snihur, Y. and Wiklund, J., 2019. Searching for innovation: product, process, and business model innovations and search behavior in established firms. *Long Range Planning,* 52(3), pp. 305–325. https://doi.org/10.1016/j.lrp.2018.05.003.

Snow, C.C. and Thomas, J.B., 1994. Field research methods in strategic management: contributions to theory building and testing. *Journal of Management Studies*, 31(4), pp. 457–480. https://doi.org/10.1111/j.1467-6486.1994.tb00626.x.

Spieth, P., Schneckenberg, D. and Ricart, J.E., 2014. Business model innovation – state of the art and future challenges for the field. *R&D Management,* 44(3), pp. 237–247. https://doi.org/10.1111/radm.12071.

Stanko, M.A., Fisher, G.J. and Bogers, M., 2017. Under the wide umbrella of open innovation. *Journal of Product Innovation Management*, 34(3), pp. 543–558. https://doi.org/10.1111/jpim.12392.

Steinberg, S.H., 2017. *Five hundred years of printing.* Mineola, NY, USA: Dover Publications.

Świerczek, A., 2014. The impact of supply chain integration on the "snowball effect" in the transmission of disruptions: An empirical evaluation of the model. *International Journal of Production Economics,* 157, pp. 89–104. https://doi.org/10.1016/j.ijpe.2013.08.010.

Teece, D.J., 2010. Business models, business strategy and innovation. *Long Range Planning,* 43(2–3), pp. 172–194. https://doi.org/10.1016/j.lrp.2009.07.003.

Tian, X. and Martin, B., 2010. Digital technologies for book publishing. *Publishing research quarterly,* 26(3), pp. 151–167. https://doi.org/10.1007/s12109-010-9164-5.

Van de Ven, A.H. and Poole, M.S., 1990. Methods for studying innovation development in the Minnesota innovation research program. *Organization Science*, 1(3), pp. 315–335. https://doi.org/10.1287/orsc.1.3.313.

Viljakainen, A., Toivonen, M. and Seisto, A., 2016. Digitalisation and service business model innovation in media. *Journal of Print and Media Technology Research*, 5(2), pp. 145–158. https://doi.org/10.14622/JPMTR-1604.

Visnjic, I., Wiengarten, F. and Neely, A., 2014. Only the brave: product innovation, service business model innovation, and their impact on performance. *Journal of Product Innovation Management,* 33(1), pp. 36–52. https://doi.org/10.1111/jpim.12254.

Wang, C.-C., Tsai, L.-S. and Chang, C.P., 2016. Trade-off among online, offline, and online-to-offline business models: a perspective based on the four Ps of product characteristics. *International Journal of Electronics Communication and Computer Engineering,* 7(4), pp. 234–240.

Wang, X. and Disney, S.M., 2016. The bullwhip effect: progress, trends and directions. *European Journal of Operational Research,* 250(3), pp. 691–701. https://doi.org/10.1016/j.ejor.2015.07.022.

Wilson, E.J. and Vlosky, R.P., 1997. Partnering relationship activities: building theory from case study research. *Journal of Business research,* 39(1), pp. 59–70. https://doi.org/10.1016/S0148-2963(96)00149-X.

Wilson-Higgins, S., 2017. *The impact of print-on-demand on academic books.* Cambridge, MA, USA: Chandos Publishing.

Wirtz, B.W., 2019. *Digital business models: concepts, models, and the Alphabet case study.* Berlin, Germany: Springer International Publishing.

Wirtz, B.W., Pistoia, A., Ullrich, S. and Göttel, V., 2016. Business models: origin, development and future research perspectives. *Long Range Planning,* 49(1), pp. 36–54. https://doi.org/10.1016/j.lrp.2015.04.001.

Wolford, C., 2016. *Commercial print: strategies for improving profit in a contracting market.* Master of science research project. University of Oregon. Available at: <http://hdl.handle.net/1794/22338> [Accessed February 2021].

Yin, R.K., 2009. *Case study research: design and methods.* 4th ed. London, UK: Sage Publications.

Yin, R.K., 2011. *Applications of case study research*. 3rd ed. London, UK: Sage Publications.

Yin, R.K., 2014. *Case study research: design and methods.* 5th ed. London, UK: Sage Publications.

Zimmermann, R., Ferreira, L.M.D.F. and Carrizo Moreira, A., 2019. Strategic fit between innovation strategies and supply chain strategies: a conceptual study. *International Journal of Value Chain Management,* 10(3), pp. 258–273.

TOPICALITIES

Edited by Markéta Držková

CONTENTS

News & more

Recently granted patents in the area of printed electronics

This brief overview presents the patents retrieved for the searched term "printed electronics" and published since the beginning of 2020. Among over 500 patents, the most represented are the U.S. (37 %), Chinese (21 %) and Korean, Japanese and European (each above 10 %) ones. The rest comprises the Taiwanese, Canadian, Australian, Russian, Spanish, German and Luxembourgish patents. The inventions relate to a wide range of fields and applications. This fragmentation is reflected in the number of assignees; there are less than 20 % of assignees with more than one patent from this selection, and only a few of them with more than five. Both academic and commercial sectors are represented, with the assignees in the latter ranging from global corporations to small companies. The following sections present those with the most entries in the list.

TactoTek

This company is a spin-off from VTT, Technical Research Centre of Finland, and develops the technology for injection-moulded structural electronics, seen as a manufacturing method that uses less plastic and reduces greenhouse gas emissions. The most recent one among its numerous patented inventions is US 10,849,235 B1 Method of manufacture of a structure and structure, filed in May 2020, which presents different approaches to producing a functional electronics assembly by using a suitable forming process. The other patents granted during past months include, for example, US 10,642,433 B2 Multilayer structure with embedded multilayer electronics, US 10,675,834 B2 Integrated multilayer structure for use in sensing applications and method for manufacturing thereof, US 10,827,609 B2 Ecological multilayer structure for hosting electronics and related method of manufacture, and US 10,928,583 B2 Illuminated multilayer structure with embedded light sources.

Xerox Corporation

The Xerox patents related to printed electronics deal with various topics. These include CA 3 006 257 C Memory cells and devices, fabricated on a flexible substrate and utilising a ferroelectric memory layer and an adhesive layer comprising a crosslinked mixture of acrylic polyol, an alkylene urea-glyoxal resin and an acid catalyst, which are already protected by US 10,115,785 B1. Memory cells are described also in US 10,593,684 B2 Printed electronic devices exhibiting improved yield, being achieved by suitable modifications of contact pads. Another application shows US 10,799,042 B2 Point-of-purchase (POP) display that includes a printed electronic device and other components necessary for its use, while it can be shipped as flat panels or sheets as usual POP displays. Yet another one is presented in US 10,821,658 B2 Conductive three-dimensional articles, prepared by printing using a proper combination of structural material and conductive ink.

Some of the most recent Xerox patents further develop the inventions concerning the composition of inks and layers for printed electronics applications, presented in this section in JPMTR Vol. 9, No. 1 (2020). These include

PRINTING United Alliance grows further

Less than one year since SGIA, the Specialty Graphic Imaging Association, and PIA, Printing Industries of America, merged and became PRINTING United Alliance on 1 May 2020, another merger was announced this January. Idealliance, originally organised as the Computer Section of the Printing Industries of America in 1966, soon renamed to the Graphic Communications Computer Association, later to the Graphic Communications Association (GCA), and then turned into an independent association called the International Digital Enterprise Alliance in 2001, became a part of PRINTING United Alliance on 1 March 2021.

Idealliance will continue to operate and provide its services as a division of PRINTING United Alliance, expanding its efforts in providing global standardisation, training and certification programmes to all graphic communication professionals in the printing and packaging supply chain. The numerous technical guidelines and specifications of Idealliance are classified into four sectors. Those for print media creation, production and workflows include, among others, the ECG (Expanded Color Gamut) project, XCMYK, an expanded-gamut CMYK printing method, PrintWide, a new large-gamut CMYK dataset, SWOP (Specification for Web Offset Publications), G7 specifications for achieving grey balance, and GRACoL guidelines and resources, such as colour settings, ICC profiles, characterisation data sets, control wedges, etc. Those for cross-media, digital-asset creation, management and publishing include, for example, PRISM Metadata and Controlled Vocabularies. The remaining specifications are provided for either mail supply, fulfilment and postal services or paper supply chain.

Activities of KCL Pilot Plant

KCL Pilot Plant, one of the 15 ATI (Advanced Technologies for Industry) Technology Centres in Finland as currently listed on the EU's ATI project website, provides services and expertise in biomaterial processing, mechanical pulping, stock preparation, paper making, coating, calendering, printing, finishing, laboratory testing, and process design and building. Adapting to the ongoing pandemic situation, KCL Pilot Plant offers a remote video-stream connection employing mobile cameras placed on commonly agreed locations in the process, in addition to appropriate communication via a trial-specific platform.

The company now takes part in the new EU project INN-PRESSME, the open innovation ecosystem for sustainable plant-based nano-enabled biomaterials deployment for packaging, transport and consumer goods. This four-year project, which started on 1 January 2021, is coordinated by VTT, Technical Research Center of Finland, and funded as one of the four projects under Horizon 2020 topic 'Open Innovation Test Beds for nano-enabled bio-based materials'. With 27 partners from nine European countries involved, it aims at replacing petroleum-based products with bio-based packaging, energy and vehicle solutions and other consumer goods by supporting European companies to scale up their nano-enabled biomaterials and processes with reduced risks and accelerated market access. KCL Pilot Plant contributes its services of recycling testing for fibre-based materials.

KCL Pilot Plant also newly offers printing-trial services for the packaging and board customers on an 8-colour reel-fed flexographic printing press, in addition to the offset and inkjet lines. The machine enables trial-specific modifications of print layout, ink type and viscosity, anilox rolls, printing plates, and parameter settings according to particular needs in printability studies of packaging paper and board substrates.

US 10,899,940 B2 Interlayer printing process, where an interlayer is deposited and cured on a substrate before depositing and curing a conductive metal ink composition to form a solid metal trace, and US 10,723,887 B2 UV curable interplayer for electronic printing (the name as filed and published), claiming a multilayer structure comprising the interlayer between a substrate and a conductive layer formed from a UV-curable composition. Other types of compositions are claimed as well, such as US 10,577,515 B1 Dielectric ink composition, which is UV-curable and suitable for inkjet or aerosol-jet printing, US 10,767,069 B2 Aqueous carbon nanoparticle ink composition for resistors, and compositions with eutectic metal alloys, namely US 10,800,948 B2 Conductive adhesive compositions and method for the same, with gallium, tin and indium, US 10,843,262 B2 Compositions comprising eutectic metal alloy nanoparticles and US 10,947,424 B2 Adhesive composition comprising eutectic metal alloy nanoparticles, both the latter with bismuth, tin and indium.

Beijing Dream Ink Technology

This company develops the technology for printing liquid metal instead of conductive polymers or nanoparticle materials. The technology is protected by several Chinese patents and utility models, including, among others, CN 107 337 964 B Colored liquid metal printing ink and preparation method thereof, CN 210 478 087 U Printed electronics and printed electronics manufacturing system, CN 211 868 913 U Desktop printing inking device, and CN 210 143 156 U Circuit substrate and flexible film circuit.

NTN Corporation

While the main product range of NTN comprises bearing products and precision machinery, attention is also paid to research and development in other fields. This is reflected in a series of recently granted patents dealing with a fine-coating method using a special needle mechanism capable to deposit materials having a wide viscosity range, including a high-viscosity liquid containing metal powder. This microscopic coating technology, described, for example, in JP 6 835 506 B2 Liquid coating unit and liquid coating device and JP 6 799 046 B2 Coating method and coating equipment, is primarily intended for pattern correction, more particularly for repairing a broken portion of a wiring pattern formed on a substrate. However, as stated in NTN Report 2020, in collaboration with Osaka University towards the development of cell chips, the coating of high-viscosity solutions containing cells onto the chips can be achieved with this technology.

South China University of Technology

Among the numerous Chinese patents granted to this academic organisation, those related to printed electronics describe conductive ink formulations, such as CN 107 739 554 B Rapid-gelation zirconia ink-jet printing ink and preparation method and application thereof and CN 108 587 326 B Silver nanowire transparent conductive ink and preparation method and application thereof.

Stora Enso

The patents recently granted to Stora Enso in several European and American countries cover different methods used in the production of printed electronics, such as US 10,887,998 B2 Method and an arrangement for producing electrically conductive patterns on substrates, or their applications.

Bookshelf

Handbook of Image Engineering

This handbook builds on the author's experience in the education and research of image engineering, the field which is understood as an overall framework and system for the comprehensive research and integrated application of various image technologies. Near ten thousand entries of the handbook, which covers the common concepts, related principles, practical technologies, and specific methods, are systematically organised into parts, chapters, sections and subsections. Each chapter and section begins with a concise definition based on selected references that can be used as the source for further reading. The entries are based on recent literature, providing the appropriate explanations, examples, analyses, and discussions. The text is supported by numerous figures, tables, and formulas. The cross-references to other entries are marked in bold or, where suitable, literally specified at the end of a given entry. All terms are listed in the index having almost a hundred pages.

The first part provides image fundamentals. Its eight chapters introduce image basics, engineering, acquisition devices and modes, digitisation, display and printing, storage and communication, together with the related knowledge comprising basic mathematics, statistics and probability, signal processing, tools, and means.

The second part, with over 450 pages the longest one, deals with image processing. In 14 chapters, it presents pixel spatial relationship, image transforms, point and mask operations for spatial domain enhancement, frequency domain filtering, image restoration, repair and recovery, reconstruction from projection, coding, watermarking, and information security, colour and video image processing, and multi-resolution image.

Twelve chapters of the third part are dedicated to image analysis, introducing segmentation, edge detection, object segmentation methods, segmentation evaluation, object representation and description, feature measurement and error analysis, texture, shape and motion analysis, image pattern recognition, and biometric recognition.

The fourth part explores image understanding, a high level of image engineering. Eleven chapters deal with the theory of image understanding, 3D representation and description, stereo vision, multi-image and single-image 3D scene reconstruction, knowledge and learning, general image matching, scene analysis and interpretation, image information fusion, content-based retrieval, and spatial-temporal behaviour understanding.

Finally, the fifth part combines other relevant entries, with seven chapters on related theories and techniques, optics, mathematical morphology for binary images and grey-level images, visual sensation and perception, application of image technology, and an overview of international organisations and standards.

Author: Yu-Jin Zhang

Publisher: Springer
1st ed., January 2021
ISBN: 978-981-15-5872-6
1 999 pages, 790 images
Hardcover
Available also as an eBook

Functional Textiles and Clothing 2020

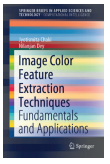
Editors: Abhijit Majumdar, Deepti Gupta, Sanjay Gupta

Publisher: Springer
1st ed., December 2020
ISBN: 978-9811593758
219 pages, 74 images
Hardcover
Also as an eBook

This volume presents the selected papers from the 2nd International Conference on Functional Textiles and Clothing held at the Indian Institute of Technology in New Delhi, India, in February 2020. The contributions are divided into four parts that deal with testing, characterisation and instrumentation, functional and protective clothing, functional printing and finishing, and sustainable production and supply chain. The topics in the third part include photoluminescent printed fabrics to aid nighttime navigation, statistical optimisation of fire protective finishing of jute fabric, application of protective finishes on denim with analysis of its multifunctional performances, and development of eco-friendly multifunctional textiles.

Image Color Feature Extraction Techniques
Fundamentals and Applications

Authors: Jyotismita Chaki, Nilanjan Dey

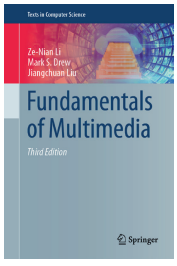


Publisher: Springer
1st ed., June 2020
ISBN: 978-9811557606
95 pages, 53 images
Softcover
Also as an eBook

This book from SpringerBriefs in Applied Sciences and Technology covers the colour feature extraction techniques used in content-based image retrieval. The first chapter introduces colour spaces and models, colour quantisation methods, and both pseudocolour and full-colour image processing. Three chapters then review the histogram-based, MPEG-7 and other image colour features. The applications of image

Fundamentals of Multimedia

The third edition of this comprehensive textbook on multimedia appeared 17 years after the original and 7 years after the second one. The content of the current edition is substantially revised and updated to reflect the rapid growth and evolution in the field, including the topics such as 360° video, new-generation social, mobile and cloud computing for human-centric interactive multimedia, and deep learning for multimedia processing. On the other hand, the structure of the book remains mostly unchanged. The first part introduces the topic, including the components of multimedia, appropriate software tools and issues in multimedia production; also, it provides the basics of multimedia data representations, from graphics, images and colours to video and audio. The second part reviews the multimedia data compression, i.e. the algorithms for lossless or lossy compression, image compression standards, video compression techniques, video coding using MPEG, H.264 and H.265 standards as well as a new H.266 standard, and audio compression techniques. The third part covers multimedia communications and networking, from network services and protocols to multimedia content distribution using the internet, including wireless and mobile networks. Also, the chapter on cloud computing for multimedia services was moved into this part from the fourth one, which was renamed and contains a new chapter on augmented and virtual reality, besides those dealing with online social media sharing and content-based retrieval in digital libraries.



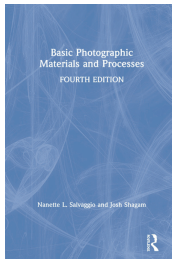
Authors: Ze-Nian Li, Mark S. Drew, Jiangchuan Liu

Publisher: Springer
3rd ed., February 2021
ISBN: 978-3-030-62123-0
849 pages, 390 images
Hardcover
Available also as an eBook

Basic Photographic Materials and Processes

Published 11 years after the previous edition, the current one, co-authored by Josh Shagam, was significantly revised and reorganised to provide a solid technical background on the current photography. The first section explains the fundamentals of image capture, namely light and photometry, optics, digital camera technology, photographic exposure, lens filters, and motion video. The second one covers image processing, dealing with demosaicing and interpolation, digital asset management, digital tone reproduction, software filters, camera characterisation, image quality, and image compression. The last one reviews the basics of output, from colour vision and colour management to display technology, printing and physical media.

Authors: Nanette L. Salvaggio, Josh Shagam

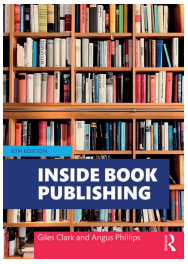


Publisher: Routledge
4th ed., October 2019
ISBN: 978-1-138-74436-3
384 pages, 390 images
Hardcover
Available also as an eBook

Inside Book Publishing

The current edition of this highly informative and praised book with many reprints and translations was published over 30 years since the first one appeared in 1988 and five years after the previous edition. Among major changes in the book publishing industry since the fifth edition from 2014, the authors highlight the slowing growth in the sale of ebooks and the fast-growing sales of audiobooks, the strong increase in self-publishing, disruption in the sale of printed textbooks in the US, and open-access publication moving into the area of academic books. On the other hand, they mention the resilient sale of printed books, prospering children's publishing and publishers retaining their authors.

The book introduces the publishing industry and markets, major business trends, digital transformations, adaptation and innovation, and tracks the development of modern trade publishing in the UK. Next, it explores publishing for educational, academic and professional markets, and provides the characteristics of the main publishing sectors. The following four chapters deal with creating and protecting value in publishing, the author, self-publishing and agents, commissioning, the author contract and editorial development. Further, the text details the processes and techniques used in the design and production of books, their marketing, sales and distribution, with rights sales discussed in the next chapter. One chapter presents the sales channels for books in the UK. Finally, the last one reviews how to get into publishing. Besides a glossary, the text is complemented by contributions from industry experts on a wide range of relevant topics, including the new ones dealing with the global audiobook market, crowdfunding, self-publishing, and the role of the agent, among others.



Authors: Giles Clark, Angus Phillips

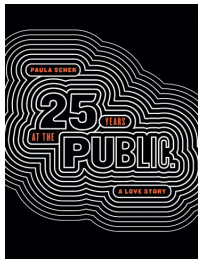
Publisher: Routledge
6th ed., August 2019
ISBN: 978-1-138-57438-0
420 pages
Hardcover
Available also as an eBook

Twenty-Five Years at the Public
A Love Story

In this volume, Paula Scher presents a quarter-century of the brand and identity development for the Public Theater in New York, including design roughs as well as hundreds of finished posters and other matter – not only printed but also integrated into the theatre's facade and interior.

Author: Paula Scher

Publisher: Princeton Architectural Press
1st ed., September 2020
ISBN: 978-1-61689-864-9
256 pages, 400 images
Softcover



colour features in the recognition and detection of selected elements are presented in the last chapter.

Advances in Design, Music and Arts

Editors: Daniel Raposo, João Neves, José Silva, Luísa Correia Castilho, Rui Dias

Publisher: Springer
1st ed., September 2020
ISBN: 978-3030556990
717 pages, 273 images
Hardcover
Also as an eBook

This large volume comprises the papers accepted for the 7th Meeting of Research in Music, Arts and Design, EIMAD 2020, which was held last year in May as an online event. The content is organised into four parts. The first one covers the topics from the area of design, communication and education, such as the creative graphic thinking and contemporary graphic representation, semantic analysis of brand mark creation, research project management in communication design, technological empowerment of communication designers, the magazine case study in printing laboratories practices, and digital transformation at school of arts and design accelerated by the COVID-19 pandemic.

Graphic Design Play Book
An Exploration of Visual Thinking

Authors: Sophie Cure, Aurélien Farina

Publisher:
Laurence King Publishing
1st ed., June 2019
ISBN: 978-1786273963
80 pages, 150 images
Softcover

In this book with the appropriate quality of design and production, the authors provide entertaining and creative exercises that convey the basic principles of graphic design and help to develop visual thinking. Its four sections deal with typography, posters, signs, and identity.

Introduction to Flat Panel Displays

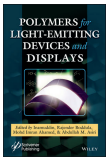
Authors: Jiun-Haw Lee, I-Chun Cheng, Hong Hua, Shin-Tson Wu

Publisher: Wiley
2nd ed., September 2020
ISBN: 978-1119282273
376 pages
Hardcover
Also as an eBook

The new edition of this guide covers the advances in technologies for flat panel displays and improvements in their performance achieved during twelve years since the original publication in 2008, including the development of head-mounted displays for virtual and augmented reality applications. The updated and extended text now comprises the chapters with an overview of flat panel displays, related colour science and engineering, thin-film transistors, liquid crystal displays including those enhanced with quantum dots, light-emitting diodes, organic light-emitting devices, reflective displays, fundamentals of head-mounted displays for virtual and augmented reality, and touch panel technology.

Polymers for Light-Emitting Devices and Displays

Editors: Inamuddin, Rajender Boddula, Mohd Imran Ahamed, Abdullah M. Asiri



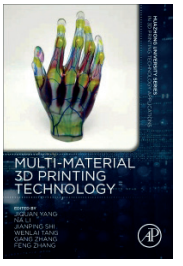
Publisher:
Wiley-Scrivener
1st ed., May 2020
ISBN: 978-1119654605
288 pages, Hardcover
Also as an eBook

This new book reviews the applications of polymer light-emitting devices and displays, devices made by solution processing, modelling and design of new organic derivatives for highly efficient blue emitters, light-emitting diodes utilising conjugated polymers or electrospun materials, luminescent polymer light-emitting devices and displays, polymer liquid crystal devices and displays, and hybrid inorganic–organic diodes emitting white light.

Multi-material 3D Printing Technology

This book is intended for engineers as well as researchers in the area of advanced 3D printing technologies that enable the fabrication of heterogeneous objects. The introductory chapter outlines the classification of such objects, their characteristics and applications, as well as the technologies for their design, manufacturing and prototyping. The particular focus is on the modelling aspects, covered in four chapters. These include 3D models and data formats, static modelling of heterogeneous objects with a description of methods used for the acquisition of network nodes, voxel-based and contour-based modelling, modelling for dynamic heterogeneous objects, where the authors discuss material and functional models, mapping of geometric structure and materials, multi-material property representation, and dynamic material change design, as well as the visualisation of models, i.e., colour file formats and material mapping visualisation methods, among others. The following two chapters present the materials and technologies used for 3D printing of heterogeneous objects, while the applications of heterogeneous parts based on 3D printing are presented in the last one. Among the materials, the text describes different types of 4D printing materials, conductive materials, and biological 3D printing materials. The examples of utilisation include a number of applications in the areas of biomedical engineering, defence engineering, industrial manufacturing and manufacturing of functional parts.

Authors: Jiquan Yang, Li Na, Jianping Shi, Wenlai Tang, Gang Zhang, Feng Zhang

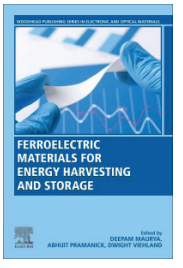


Publisher: Academic Press
1st ed., February 2021
ISBN: 978-0-08-102991-6
232 pages
Softcover
Available also as an eBook

Ferroelectric Materials for Energy Harvesting and Storage

Contributed by several authors and author teams, this book provides the fundamental background on ferroelectrics and related materials and then, in eight chapters, explores the topics of solar energy harvesting, thermal energy harvesting, vibration-energy harvesting from structures leveraging flexoelectricity (with polarisation induced by strain gradient), modelling and identification of nonlinear piezoelectric material properties for energy harvesting, wind-energy harvesting using piezoelectric materials, biomechanical energy harvesting with piezoelectric materials, the harvesting of stray magnetic field for powering wireless sensors, and ferroelectric ceramic capacitors for electrical energy storage, both lead-based and lead-free.

Editors: Deepam Maurya, Abhijit Pramanick, Dwight Viehland



Publisher: Woodhead Publishing
1st ed., October 2020
ISBN: 978-0-08-102802-5
372 pages
Softcover
Available also as an eBook

Bookshelf

Academic dissertations

Printed Electrochemical Light Cells Based on Biocompatible and Biodegradable Materials

Doctoral thesis – Summary

Author:
Johannes Zimmermann

Speciality field:
Photonic Materials and Devices

Supervisor:
Gerardo Hernandez-Sosa

Defended:
6 February 2019, Karlsruhe Institute of Technology, Light Technology Institute Karlsruhe, Germany

Language:
German

Original title:
Gedruckte elektrochemische Leuchtzellen auf Basis von biologisch kompatiblen und biologisch abbaubaren Materialien

Contact:
johannes.zimmermann@innovationlab.de

Contributing to the research on sustainable electronics, this thesis was focused on light-emitting electrochemical cells based on biomaterials. They consist of a single active layer that can be deposited from the liquid phase and thus can be produced cost-efficiently by printing techniques. The aim was to develop light-emitting devices, which are substantially based on biocompatible and biodegradable materials, mechanically flexible, and produced by digital printing to enable easy modification of the layout without increasing the production costs.

The dissertation provides the theoretical background on the electronic properties of organic semiconductors, the charge injection process, the structure, working principle, and types of light-emitting electrochemical cells, as well as the methods for optoelectrical measurements. After specifying the selected materials, ink formulation, fabrication and characterisation methods used, it systematically deals with the properties of biomaterial-based solid-state electrolytes and their combination with commercially available emitters, their utilisation in the active layer and optimisation of its performance, and finally the fabrication and properties of partially or fully printed light-emitting electrochemical cells employing the studied biomaterials. For the best performing system comprising Super Yellow with poly(caprolactone-co-trimethylene carbonate) and tetrabutylammonium bis(oxalato)borate, a maximum luminance of approx. 12 000 cd/m^2, a turn-on voltage of 3.7 V, a maximum efficiency of about 2 cd/A and an operational lifetime of over 100 hours were achieved with a reference electrode system on the glass. In the case of fully printed light-emitting electrochemical cells on an ultrathin biocompatible Parylene C film, these parameters achieved the values of 900 cd/m^2, 6.7 V, 1 cd/A and over 8 hours, respectively.

Advanced Additives for Radical Photopolymerization

Doctoral thesis – Summary

Author:
Paul Gauss

Speciality field:
Chemistry – Photopolymerisation

Supervisors:
Robert Liska
Patrick Knaack

Defended:
26 March 2019, Vienna University of Technology, Institute of Applied Synthetic Chemistry Vienna, Austria

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The aim of this thesis was to develop a new generation of non-aromatic initiator systems as an alternative for potentially hazardous aromatic ketone initiators. This topic is important, among others, for food packaging and medical applications of UV-curable systems, which require biocompatible and harmless photoinitiators. The second goal was to find new chain transfer agents to further improve the material properties of radical photopolymers.

After introducing the basics of radical photopolymerisation and defining the objectives, the dissertation is organised into two main parts describing the research on novel photoinitiators and chain transfer reagents, respectively, with the experimental details provided in the last part. The work documents a comprehensive approach. In the search of new photoinitiators, 23 compounds in total were selected among both the commercially available ones and those to be synthesised. All were classified into five groups comprising the simple aliphatic α-ketoesters, compounds derived by the modification of the ester moiety, compounds derived by the modification of the alpha carbonyl, long-wavelength UV initiators, and long-wavelength visible light

initiators. Next, the work describes the methods used to synthesise the required compounds. The preliminary curing tests with 19 compounds that were either available or successfully synthesised then showed nine of them to be active as photoinitiators, with each group represented by at least one. These compounds were further investigated and compared with the reference photoinitiators. The tests employed the UV-Vis characterisation and photo-DSC measurements in different monomer systems (an acrylate system, methacrylates, and also hydrogels) and at different wavelengths, UV-aging of polymers, photolysis studies to provide more information about initiation mechanisms, and the cytotoxicity by cell incubation tests. The work presents a new class of initiators with high reactivity and colour stability of the resulting cured polymers, where a high potential to replace the standard Norrish type II initiators is seen especially for the simple ketoesters, such as ethyl pyruvate (ethyl 2-oxopropanoate). A similarly thorough approach was applied in the case of studies dealing with the control of chain transfer, investigating new reagents based on oxy-acrylates for the addition–fragmentation chain transfer and cyclohexadienes for the chain transfer by hydrogen abstraction.

Doctoral thesis – Summary

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Aerosol-Jet Printed Nanocomposites for Flexible and Stretchable Thermoelectric Generators

The focus of this thesis was on thermoelectric generators that are expected to become one of the important energy harvesting technologies. These devices are based on thermoelectric materials producing an electric current when subjected to a temperature gradient. The work addresses the lack of such materials being suitable in terms of performance, energy conversion efficiency, processability, cost and harmlessness, as well as with respect to the required mechanical properties of the resulting device. The solution employs organic–inorganic thermoelectric nanocomposites and adopts a material engineering approach to achieve desirable properties concerning both the thermoelectric performance and intended applicability of thermoelectric generators. The dissertation identifies the challenges and provides the theoretical background on energy harvesting, thermoelectrics, microscale additive manufacturing techniques, functionally graded thermoelectric materials, and approaches to produce stretchable thermoelectric generators. In the next chapter, it presents the methods used within the work, from nanomaterial fabrication and structural characterisation to printing, ink preparation, post-processing, measurements, and tests, up to the finite element analysis and thermoelectric generator fabrication. The selection of materials includes poly(3,4-ethylenedioxythiophene) poly(styrene-sulfonate) (PEDOT:PSS) as the organic polymer matrix, Bi_2Te_3 and Sb_2Te_3 as inorganic nano-fillers for the enhancement of Seebeck coefficient at or near room temperature, and multiwall carbon nanotubes for the improvement of electrical conductivity. The aerosol-jet printing was chosen as a scalable technique enabling mixing different ink materials in situ to form nanocomposite structures and dynamically optimise their composition and properties. Attention was also paid to post-processing treatment to further enhance the thermoelectric properties. The work presents the successful fabrication of high-performance and, at the same time, flexible thermoelectric generators based on Bi_2Te_3/Sb_2Te_3 nanocomposites and their further improvement by incorporating multiwall carbon nanotubes, which also increased the mechanical flexibility and fatigue robustness. As the next step, compositionally graded thermoelectric composites were developed to ensure better performance across the entire intended temperature range. Finally, free-standing stretchable thermoelectric structures were produced.

Events

Virtual.drupa

https://virtual.drupa.com
20–23 April 2021

The traditional drupa fair is now planned for 2024, eight years since the previous edition. After several changes of dates due to different reasons, the in-between event for the print industry organised by Messe Düsseldorf is held online, in four days only. The live content is divided into three sections – first, the conference area with the programme based on four global trend topics identified as artificial intelligence, circular economy, connected consumer and platform economy; second, the exhibition space with online showrooms for the presentation of innovations and products; and third, the networking plaza for business meetings and matchmaking with visitors and exhibitors worldwide.

The breadth of coverage is well illustrated by the list of web sessions by topic, which includes, in alphabetical order, 3D printing, additive manufacturing, best case, branding, brand story, design, fashion, functional printing, future technologies, green printing, Industry 4.0, inkjet, interior decoration, multisensory marketing, packaging, packaging production, printed electronics, robotics, screen printing, security printing, smart and intelligent packaging, sustainability, textile printing, and workflow automation.

The conference area offers sessions in two parallel streams and with three confirmed keynote speakers. The keynotes on the first and last day of virtual.drupa, both by Michael Gale, deal with artificial intelligence. Their topics are 'Small steps and giant leaps for your AI in a circular economy', discussing necessary decisions and showing the simple steps based on thousand case studies, and 'The AI opportunity – A dawn of a new age for you with the right AI schematic', with a virtual facility to simulate where and how AI can help change the economics of a business. On the second day, the keynote by James Sommerville named 'The creative business model of tomorrow. The cusp of another revolution' explores the ways to work as distributed teams and networks and to keep the business model human-centred to create a competitive edge for growth. The third day of virtual.drupa, 22 April, features the keynote 'All change: Implications of the climate megatrend for the printing industry' by Gabrielle Walker, as part of the World Earth Day.

After the keynote opening each day, the conference programme continues with live lectures and panel discussions on five virtual stages. The topics explored at the drupa cube include artificial intelligence, sustainability, printed electronics and smart packaging. The schedule for the dna – drupa next age – offers, among others, two lectures on BigContentData, the project identifying new chances and approaches for print and media companies made possible through digitalisation, an introduction of the Print Your Future project aimed at attracting a new skilled workforce for quality jobs to the European graphical sector, co-coordinated by Intergraf, and the presentation of ColorNet, a novel software solution that utilises artificial intelligence to optimise the display of brand colours during live sporting events, which was developed at the Clemson University.

The calendar of events is still changing

Again, several events presented in the previous JPMTR issue had to be rescheduled, many events cancelled for 2021 at all. Now, some of the June events are planned to be held in a non-virtual format. That being possible would be great news.

FORUM 2021

https://www.flexography.org
11–14 & 18–21 May 2021

The programme of this year's FORUM of the Flexographic Technical Association offers more than 20 technical presentations and discussions in 9 sessions, with efficiency being the main focus. This time, also the INFOFLEX 2021 exhibition takes place as a virtual event on 12–13 & 18–20 May.

HOPV21
13th Conference on Hybrid and Organic Photovoltaics

http://www.nanoge.org
25 and 28 May 2021

This established event is held online for the second time, offering over 20 invited speakers and a scientific programme with oral and electronic poster presentations. In addition, a pre-conference workshop, Maestro Perovskite Research Seminar, can be attended on 24 May. Its topics are perovskite materials and devices, namely the single and multi-junction solar cells and light-emitting devices, and perovskite technology upscaling. Four weeks earlier, on 29–30 April, the conference on Organic Materials in Perovskite-Based Optoelectronic Devices is held, also online.

ESMA Events

Being still limited to the online activities, the European Specialist Printing Manufacturers Association offers during spring two online ESMA Academy courses on industrial digital printing – in German on 18–20 May and in English on 8–10 June 2021. Besides this established training, the ESMA experts are involved in the touchpoint textile at the virtual.drupa, presenting there. among others, the roadmap of textile printing with respect to the emergence of digital printing in various applications from soft-signage to sportswear and fast fashion to home textiles.

Understanding Inkjet Conference 2021

Appleton, Wisconsin, USA
8–9 June 2021

The focus of this IMI event is on the inkjet capabilities, applications, selection and implementation. The topics of its two-day schedule include the inkjet technology for production printing, inks, drying and curing technologies, software for print quality optimisation, media handling for the on-demand printing, new market opportunities beyond traditional printing, matching applications with the right inkjet technology, end users' views, and the real-world experiences with implementation.

The London Book Fair 2021

London, UK
29 June – 1 July 2021

In 2021, The London Book Fair celebrates its 50-year anniversary. Currently, the organisers are planning for all scenarios and working on robust measures being in place to stay safe if a face-to-face event will be permitted. The programme includes the Introduction to Rights conference, The Research & Scholarly Publishing Forum, What Works? Education Conference, and The Writers' Summit.

From the three touchpoint stages, over 20 sessions are dedicated to packaging, such as a panel discussion on the new opportunities in alternative channels and e-commerce for food brands and another one providing a design perspective on packaging sustainability. The latter topic is also covered in the lectures presenting some of the available solutions for reducing waste. The other packaging topics explore the development and growth of printing for smart packaging, applications of augmented reality, means to achieve the right colours, and more. Among over ten sessions at the touchpoint textile, one of the panel discussions deals with a future outlook for the Digital Textile Microfactory, a concept for the virtual development and digitally networked production of personalised textiles and clothes, which is discussed also in a number of other sessions. The touchpoint 3D fab+print includes about ten sessions dealing with 3D metal printing, material innovations, the monitoring system for the additive manufacturing process that employs artificial intelligence, and other topics.

Several sessions included in the programme of virtual.drupa are provided by VDMA, the German Engineering Federation. Their content mostly reflects the four main topics, presenting the networked production systems and connecting directly to the customer, the solutions enabled by artificial intelligence, the technology and approaches helping to increase sustainability, and more. The conference area of virtual.drupa also features the symposium, which is jointly organized by IC, the International Circle of Educational Institutes of Graphic-Media Technology and Management, iarigai, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries, Hochschule der Medien, the University of Media Stuttgart, and HELGRAMED, the Hellenic Union of Graphic Arts and Media Technology Engineers, and presented in the following section.

Bridging Industry, Education and Research in Graphic Communication, Print and Media

The event is held on 21 April 2021 later in the afternoon and comprises five lectures highlighting the importance of the interaction among the print media industry, education and research. After the opening of the conference, the programme features Frank Romano with the lecture addressing the future of printing. The focus of the following presentations is on the next generations and education, with Beatrice Klose describing the need for a younger workforce and summarising the efforts to attract skilled people to work in the European printing industry, John R. Craft reviewing the innovative initiatives at university graphic communications degree programmes in the United States, Jan De Roeck providing the real-life examples of beneficial cooperation initiatives between industry technology supplier and educational institutions and their potential to drive overall innovation in the industry, and Jörg Hunsche presenting the topic of digital printing evolution and its opportunities to create added value when linked to the digital world being a living experience of young generations. The event concludes after the presentation of the iarigai and IC annual scientific conferences to be jointly held in September 2021 in Athens, Greece.

This virtual.drupa event is supported by Intergraf, the European federation for print and digital communication, GCEA, the Graphic Communications Educators Association, EGIN, the European Graphic-Media Industry Network, TAGA, the Technical Association of the Graphic Arts, and the WAN-IFRA's World Printers Forum.

Journal of Print and Media Technology Research
A PEER-REVIEWED QUARTERLY

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UDC 665

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