Emerging Hybrid Ink Technology: Challenges in Jetting and Print Process

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Abstract

With a focus on aqueous ink technology we describe the jetting and print testing of different ink formulations across selected inkjet print head platforms applicable to high speed industrial print applications. Specific challenges relating to the necessary compromise between head performance and application/ substrate performance are discussed with respect to the observations made on newly developed hybrid inks. The available methods for optimizing the ink performance are contrasted and compared and future routes for improvement discussed.

Introduction

Aqueous (AQ) inkjet ink technologies for thermal (TIJ) piezo inkjet (PIJ) print heads for home-office applications have been prevalent for decades. However, in industrial print applications involving multiple print head arrays the first implementations in single pass mostly utilized UV inks. Early examples of this are the Dotrix and FastJet presses shown at Drupa 2004. Soon after then AQ inkjet has steadily proved itself an alternative to electrophotography in production print, driven initially by HP (TIJ), Kodak (CIJ), and Epson / Kyocera piezo print heads (PIJ). This was exemplified at Drupa 2008 by machines such as HP WebPress, Kodak Versamark VT300, Screen Truepress 520, and Oce Jetstream, respectively. As the print quality expectation has increased, the head technology itself continues to progress; usually presenting an even greater challenge to nozzle maintenance and the closely-related control of print quality. Also expanding is the application area of AQ technology, first to less porous coated papers and paper-based packaging, as seen at Drupa 2012 and most recently to non-porous substrates [1]. As a key supplier to the industry Sun Chemical is developing AQ inkjet inks for these emerging packaging markets as well as other industrial applications such as wide-format graphics and décor.

Sun Chemical has chosen to build on proven patented technology for traditional print [2] and adapt the AQ-hybrid ink approach to inkjet application. In doing so there are multiple challenges to be addressed in understanding how to optimize the product performance for each given application. As an independent ink supplier Sun Chemical develops inks for all available print heads chosen by Original Equipment Manufacturers (OEMs) and therefore we also have to consider the potential variation between the print heads as well as the applications requirements between segments. Here we describe some of those challenges encapsulated in ink and print head comparisons undertaken with a cross section of commercially available jetting equipment.

ImageXpert have positioned themselves as the premier supplier of vision based tools for inkjet R&D. Their JetXpert system has become the industry standard for drop watching and drop-in-flight analysis, and they also provide tools for analysis of print samples. Several ImageXpert tools, including a new "latency" testing option for JetXpert, and a scanner-based tool for analyzing printed targets, were used for this study.

Experimental Equipment & Methods

Heads Utilized in this Investigation

We have undertaken jetting of fluids using a number of print heads sourced from manufacturing partners. The print heads from Kyocera Fineceramics Ltd (Surrey, UK), Fujifilm Dimatix (HN, USA) and Ricoh (Telford, UK) were chosen for their contrasting design but relatively comparable drop volumes and potentially common usage in in the applications discussed above. Two of the heads have been demonstrated already in 1200DPI single-pass printing machinery running on AQ inks for paper. For simplicity of description the outline specification and hardware arrangement for each system is summarized in Table 1. The Dimatix prints heads are both recirculating, using RediJet technology [3], whereas the Kyocera and the Ricoh model used here can be recirculated but the flow paths are not adjacent to the nozzle openings [4,5].

Table 1: Print heads used in the current experiments

Print Head Supplier	Print Head Model	Nominal Native drop volume (pL)	Print Resolution (DPI)	Driving Hardware Supplier
Dimatix	Samba	2.5	1200x1200	Eval Kit
	QSR	10	100x400	Mercury Dev Kit
Kyocera	KJ4B-QA	5	600x600	GIS
	KJ4B-1200	1.5	1200x1200	TTP Meteor
Ricoh	proprietary		150x600	

Ancillary Equipment

Where ink recirculation was required then a commercially available ink system was used (Megnajet CIMS, Swavesey, UK). Otherwise meniscus pressure was controlled by height of a syringe relative to the print head nozzle plane. Print testing was performed using various a manual print stages (Griffin IJ Technology, Hungary) each using a Renishaw RLS10 encoder to communicate the position to the relevant print head electronics. Printing patterns are discussed below.

Drop-Watching and Measurement of Latency

One of the key tools in developing inkjet inks is the ability to visualize drop formation in order to correlate this to drop placement and image quality. In the current investigation the SunJet Lab used a JetXpert system as developed, supplied and supported by the authors from ImageXpert. The latency functionality of the software allows for computer control of the jetting through the use of a programmable pulse generator. A variable time gap is introduced between successive burst of jetting and the jet velocity is measured for a specified drop in the burst. The method repeats itself until either all delay times are covered ("latency sweep") or until each successive drop is imaged at a fixed delay ("latency multi-drop"). Unless otherwise stated, the multip-drop latency measurements in this work were performed at 1kHz print frequency with a two second (2000 drop) activation prior to each test.

Printing and Measurement of Test Patterns

Specific test images were tested and developed in order to compare print head performance and achieve correlation to the above-described Latency method. The most useful version is shown in Figure 1. For any given drop size the print head state is set to an initial condition by the use of a solid strip prior to printing various bar widths. In the middle of the pattern the print may be paused for a desired length of time, prior to completion of the right-hand-side of the print. The performance of the ink on the print head can be qualitatively assessed (by visual grading based on visible pattern remaining) or, preferably, quantitatively assessed by measurement of the bar widths themselves thus determining the number of pixels missing. The potential measurement areas are highlighted.

ImageXpert software was used to automatically capture and evaluate the printed features. The algorithm first measures the width of the segments marked "1"-"3" in Figure 1. The first measurement is only for reference, since the time that the head is idle at the start of the print is not controlled. The latency is then quantified by comparing the second and third measurements.

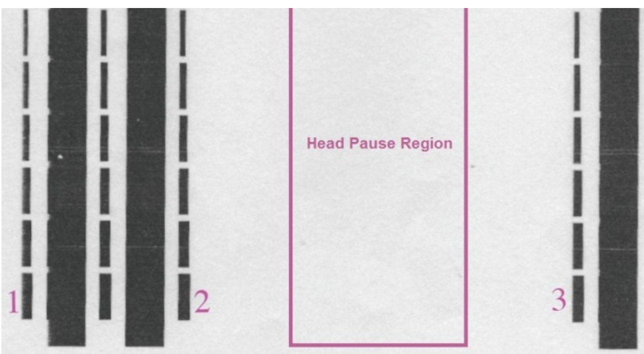

Figure 1: *Typical print head test pattern for latency testing.*

RESULTS AND DISCUSSION

Ink Comparisons in a Single Print Head

The Ricoh print head can take a full range of ink chemistries and thus was used to make an initial comparison of the print and jetting effect between different formulation approaches. In this experiment a 100% UV ink formulation used in labelling applications was compared to a non-functional AQ ink intended for uncoated papers and two functional inks for non-absorbing media: one based on binder resin and the other a prototype hybrid UV system. The ink properties are summarized in Table 2. The UV ink is specifically developed for the print head but the majority of AQ inks have been borrowed from applications developed on other print heads and so are lower viscosity than recommended for the Ricoh print head. The exception is UV-AQ-R, which will be described in more detail later. Due to the viscosity differences the print head drive voltage was adjusted along with temperature in order to set a target drop velocity of 7m/s.

Some images in Figure 2 are used to compare the drop formation as a function of the ejection event number after relatively short delays of 3-100 seconds for the first 3 inks considered. Double pulsing is used so that drop velocity may be measured simultaneously but this has the effect of reducing drop contrast a little. As expected the UV ink shows the most controlled behavior with the uncoated paper ink next-best. With reference to Table 2 the observations can easily be surmised as the relative content of volatile materials since the uncoated ink contains a significant fraction of glycerol, which has a boiling point of 290°C and holds onto the water very effectively. Similar dependence on material choice has been studied before [6].

Table 2: Properties of inks compared in the Ricoh print head

Type	Application	Viscosity (cP)	Humectant Material	Humectant Content
UV	Label	9 (45°C)	N/A	N/A
AQ	Uncoated paper	6 (32°C)	Blend with Glycerol	30-40%
AQ-resin	Coated paper	5.5 (32°C)	Blend with Glycerol	10-20%
AQ-UV	Non-absorbents	6.5 (32°C)	Propylene Glycol	25-35%
AQ-UV-R		9.0 (32°C)		10-15%

Unfortunately, although ubiquitous in current AQ inks because of their effectiveness in avoiding nozzle latency issues, glycerol and similar high-boiling polyhydric alcohols offer significant drying challenges when less absorbent media are printed. The use of co-solvents, or penetrants, become helpful to improve the "drying" process [7], but truly removing the humectant requires higher temperature than desired for polymeric substrates. The hybrid ink requires full drying to permit effective curing so propylene glycol (PG) was tested as the humectant since it has a significantly lower boiling point 188°C and so had an improved chance of being removed in a drying process. Unfortunately the effect of the PG was that drop velocity equilibrium was only reached after 30+ drop ejections on the Ricoh head, which is significantly longer than the other ink types.

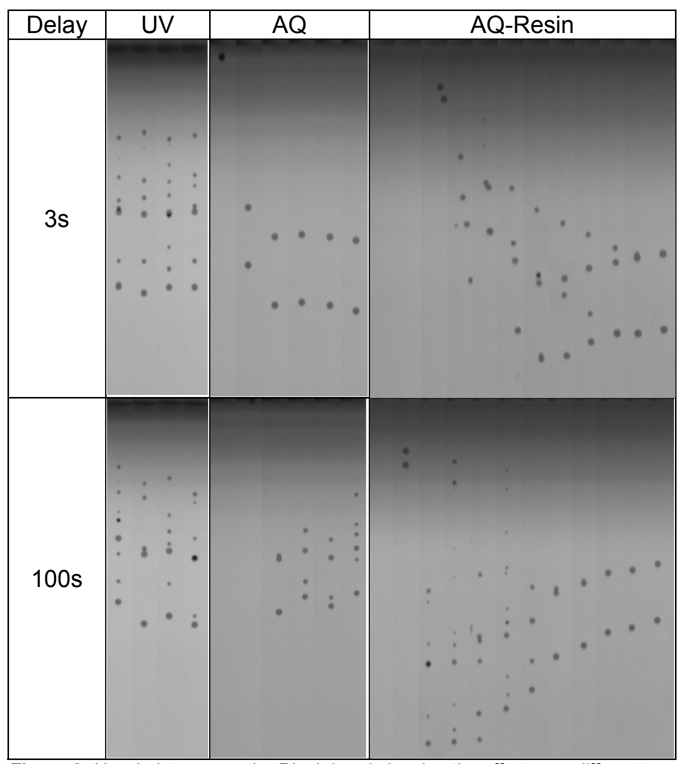

Figure 2: *Nozzle latency on the Ricoh head showing the effect over different time periods. After the first slow drops the AQ-resin ink ejection then settles to equilibrium velocity.*

When comparing the prints themselves as in Figure 3 the latency findings of Figure 2 are not altogether well corroborated and start-up issues appeared worse. It is found the nozzle re-start effect is highly dependent on the preceding test's quality (head memory effect) as well as the precise drop velocity, varied according to pulse amplitude. Latency measurements prove more consistent due the repeatable pre-pulsing prior to each measurement delay and the precise control of frequency and so look to be a more reliable gauge on which to develop chemistry.

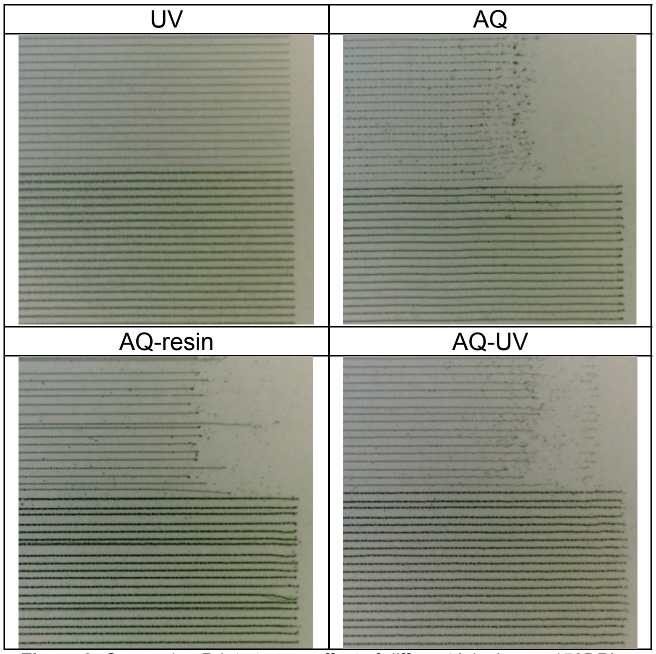

Figure 3: *Comparing Print start-up effect of different inks in one 150DPI row of the Ricoh head. One-pulse and two-pulse recovery is compared after a 5 second pause.*

Non-Linear Drop Size Effect in Kyocera Head

It is seen from Figure 3 that the drop size can be a critical variable in the recovery of a given nozzle with any ink. The Kyocera 1200DPI head was used to explore this characteristic further. In this head the waveform design is proprietary so the pulse shape is not known, but it is seen from Figure 3 that the drop velocity recovery after a short 5 second delay is clearly dependent on the grey level. In contrast to the previous print head result, the drop size from the KJ4 1200DPI head that was best was the middle-sized one.

These results were obtained with the AQ ink, for which the first drop ejection with any reasonable velocity occurs between 2-5 pixels, The AQ-resin ink showed behavior that was similar to the AQ ink but with 9-15 pixels to recover, although there is also a discernable dependence on the length of delay, reminiscent of the "v-shaped" recovery described previously [7]. We observed that initial drop ejections at longer idle periods tend to emerge with higher velocity, whilst over shorter periods the velocity increases until the equilibrium is reached.

The AQ-UV inks were quite challenging with respect to latency in the Kyocera head since the velocity recovery of the small drop took >40 pixels at a comparable pause of 5 seconds and was preceded by almost spray-like ejection. This is presumed due to the very small nozzle size.

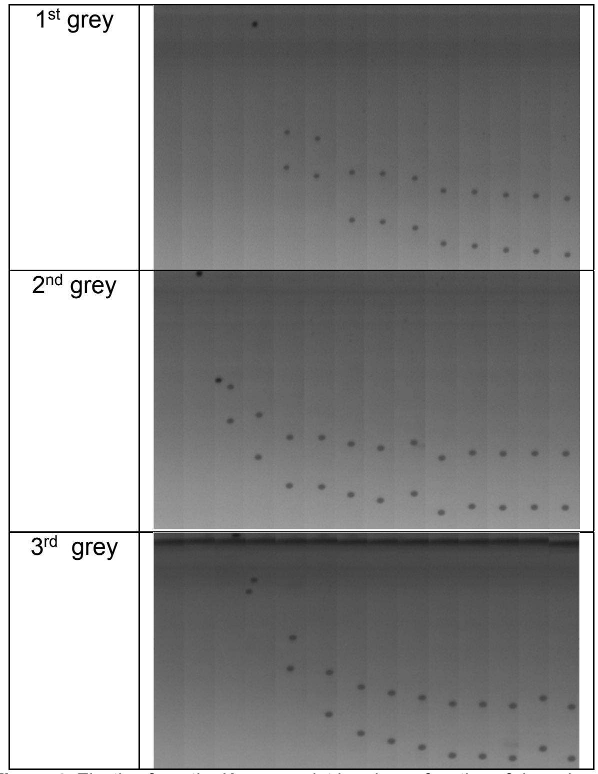

Figure 4: *Ejection from the Kyocera print head as a function of drop size on AQ ink showing asymptotic velocity recovery with successive pulsing.*

Print Effect of Tickle Pulse on Printing

The positive effects of "tickle" pulses or "shaking" pulses on the head stability are well studied and commonly utilized [7,8]. Due to limitations in the current commercially available functionality we have not been able to implement the extra testing on the drop watcher. Instead we have tested the effect on actual printing, albeit at low frequency. The contrasting print result of the different inks in the Ricoh print head has already been presented in Figure 3. In that head the application of a non-ejecting pulse in the white areas did not show a great effect (results not shown).It may be possible this was due to the limited optimization of pulse amplitude used and is a clear area for improvement through further investigation. To prove that low-humectant AQ-UV ink approach is viable the Kyocera 600DPI head was driven with GIS hardware to enable a meniscus activation pulse segment in non-printed pixels.

Figure 4 shows the benefit seen with the smallest 5pL drop. The print quality is assessed on the right-hand-side segment "3" of the test pattern depicted in Figure 1 as a function of different print delays. Since the print is paused between the two halves of the pattern then the benefit comes from the tickle pulse acting as pre-pulse to the second half of the print. To prove the use of tickle pulse for head maintenance in the idle times between prints the hardware can supply a non-printing meniscus activation function. This can serve as a cleaner alternative to ink spitting.

In contrast, when the same approach was implemented on the 1200DPI print head driven with the TTP hardware the benefit was detectable but much less effective. As in the case of the Ricoh head some optimization of the non-ejecting pulse should improve this and is an area for further study.

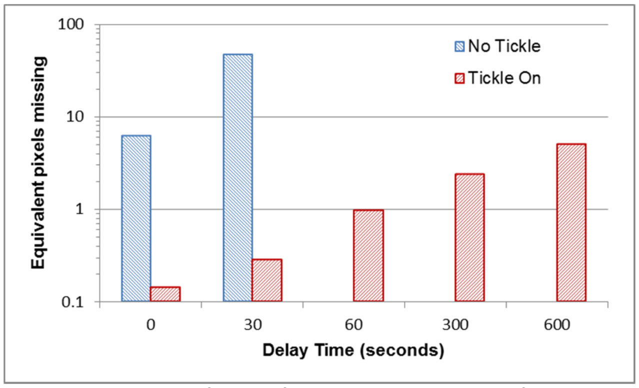

Figure 4: The positive influence of tickle pulse in white areas of test print patterns of Figure 1 with a variable pause between.

Effect of Viscosity Adjusting Materials

In order to maximize the jetting efficacy of a given ink-head combination it is normal to adjust the viscosity of the ink to match the head guideline. This becomes more important if the overall humectant content is lowered or indeed, if more volatile co-solvents are used. As discussed above, the more viscous humectants are commonly applied for this purpose – in textile ink formulations for example - so an alternative route to achieving higher viscosity is needed when designing AQ-UV inks for single pass applications where faster drying is important. Soluble polymeric materials such as polyvinylpyrrolidone (PVP) or thickeners like carboxymethylcellulose (CMC) are considered. The authors have found that, generally, the impact of such materials is strongly negative on the jet-ability of the ink in one head or another, sometimes leading to no jetting at all. This is thought to be molecular weight influence. There is also potential effect on the final film properties of an AQ-hybrid ink, dependent on how the cured film structure is influenced: water soluble materials such as PVP make the film less water resistant, whilst the jetting/substrate effect of CMC is very source supplier.

Some of the lowest impact materials have been found to be poly(alkylene oxides) and co-polymers thereof. Again, the materials have to be chosen for the required viscosity effect, balanced with the film property requirement. Addition in the range of 2-10% is found to be the best compromise. We have measured the influence of viscosity-adjusted inks on the Ricoh and Kyocera 1200DPI systems starting with a single-pass targeted 3cP base ink with <20% propylene glycol. The material attributes and latency results are summarized briefly in Table 3. The strong effect seen in the Ricoh example in particular indicates that the modifiers can increase the latency issues significantly, possibly by exaggerating the partial dried ink viscosity effect. For the low-humectant type ink it is therefore preferable to have a print head that has a capability to jet in a viscosity range towards the 3-5cP naturally achieved by the ink without such the need for such additives.

Table 3: Effect of viscosity modified single-pass style inks on latency effect comparing two print heads and materials.

Head	Modifier	Mw	Viscosity benefit	Latency at 0.5 sec
Ricoh	PAO1	8k	+6cP	15 to 30
Kyocera 1200DPI	PAO2	2.6k	+2cP	12 to >50

Effect of Recirculating Print Heads

Previous authors have demonstrated that for particular print head structure the ink flowing past the nozzle can have a beneficial long term benefit on nozzle health by refreshing the meniscus region [7]. The Dimatix Samba print head runs with such recirculation and so was used to assess the influence using the AQ-UV ink at a nozzle size that can be compared to previously-described data herein. As may be seen in Figure 5, initial latency measurement on the AQ-UV ink has not shown a strong influence of the recirculation on the start-up effect, as compared over relatively short periods.

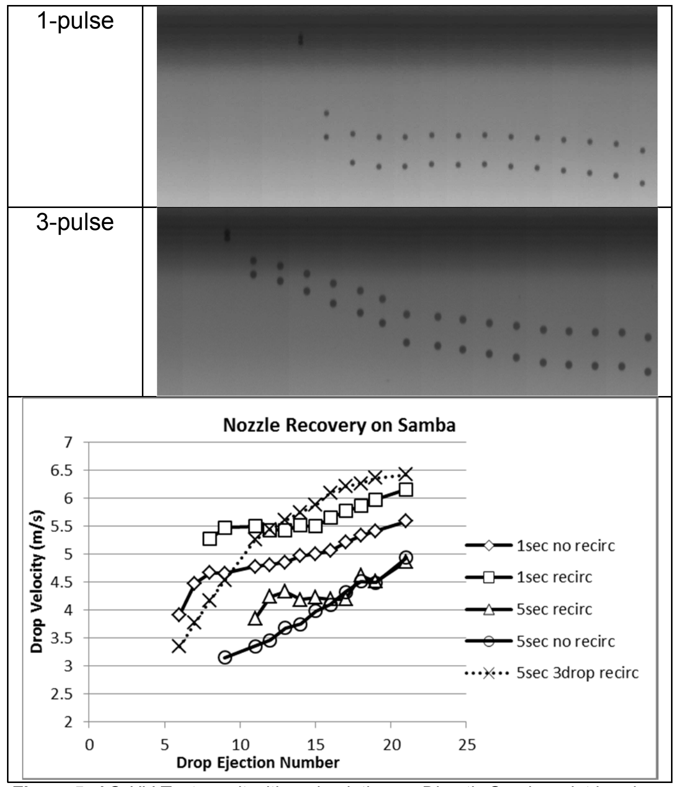

Figure 5: *AQ-UV Test result with recirculation on Dimatix Samba print head*

This relatively small impact has been confirmed in the Dimatix QSR10 head, which is used in wide format graphics printers. In contrast to all the previous heads, the first ejected drop was reliably obtained, allowing for the velocity of the first drop with increased latency time to be measured. This is presumably a function the larger drop native drop size of 10pL as well as the head architecture. The data is presented in Figure 6 as a composite image showing the ejection. In this experiment the double pulse was modified to capture the ligament formation as well as the drop in flight as a function of the latency delay from 1-50seconds. A more direct corroboration of the so-called “v-shaped” recovery described in [7] is now obtained, although it is notable that the effect occurs even without recirculation, which is interesting given the contribution of fresh ink in the Author’s proposed mechanism.

In the future, characterizing the behavior of recirculating head architectures as a function of the flow rate should reveal whether further improvements may be obtained in the small drop reliability. In combination with customized tickle pulse designs this should allow greater flexibility for ink formulation choices.

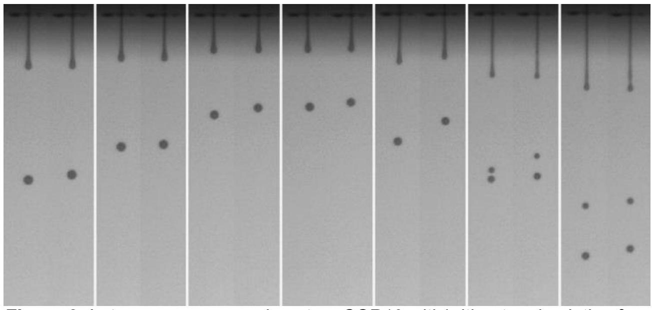

Figure 6: *Latency sweep experiment on QSR10 with/without recirculation for 0.5s, 1s, 2s, 5s, 10s, 20s & 50second delay times. The similarity is striking.*

Summary & Future Experiments

We have demonstrated that the emerging technology of aqueous hybrid UV-curing inks have many challenges in common with existing aqueous inks, such as those used extensively in plain paper and coated paper applications, when applied to the latest small drop piezo inkjet heads. We have shown how demands of the faster drying formulations exaggerate the potential negative effects related to nozzle stability and thus print quality. Although there are differences between different print head suppliers' technology there is a theme of increasing sensitivity is common among single-pass-targeted print heads that seems not-so-prevalent in heads used in a multiple-pass systems.

Advanced drop characterization has been proven invaluable in comparing the new chemistry approaches. Likewise, print quality evaluation can be used for qualitative and quantitative verification of the practical implication of the observed jetting effects.

The next steps are to continue to build a knowledge base of raw material influence on jetting properties, including latency, in more print head types whilst continuing to develop the test & measurement processes themselves to makes possible the study of influencing factors like tickle pulsing, which have been confirmed already to be important to obtain the best performance possible.

Moving forward with commercialization, co-operation with head manufacturers and OEMs alike will be necessary to achieve the best print results with the more challenging inks that will be required to meet the needs of tomorrow's digital packaging production processes. This includes waveform optimization as well as hardware provision for nozzle maintenance strategies.

References

[1] Patent Application US2015/050467, Ricoh Co Ltd.

[2] WO 03/093378, Sun Chemical.

[3] M. Schoeppler, 21st IMI European Ink Jet Conference, Lisbon, Portugal, 2013.

[4] K. Yoshimura, "Development of Ink Jet Printhead Equipped With a Large Monolithic Unimorph Actuator Unit," in Proc. NIP29, IS&T, p158-162 (2013)

[5] G. Kennedy, 22nd IMI European Ink Jet Conference, Barcelona, Spain, 2014.

[6] H. Nakao, "Development of water-based UV-curable inkjet inks for printing on plastic substrates," Radtech Europe Conference, Basel, Switzerland, 2011.

[7] Patent US8919948, Kyocera Document Solutions.

[8] S. Hirakata, J. Imaging Sci. and Technol., 58, 050503 (2014).

[9] Patent US8708441, Dimatix

Author Biography

Mark Bale received his MPhys in Physics from the University of Birmingham (1997) and his PhD in Nanoscale Physics also from University of Birmingham (2001). After starting originally in OLED device development and manufacturing technology he has worked in Sun Chemical's UK Ink Jet R&D Labs since 2007. His recent work has focused on the process development and jetting understanding of inkjet fluids in a range of applications including graphics, packaging and printed electronics.