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Methods for Optimizing Ink and Coatings for Packaging

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Abstract

We present experimental methods for the systematic study of material effects in developing water-based formulations for the optimization of print quality on non-absorbing polymeric substrates. We apply these to demonstrate the importance of materials selection, with particular focus on the competition between drop coalescence control and print head latency.

Introduction

Packaging continues to be area of active development for water-based inkjet ink technology. With some products already available into labels and corrugated board applications and many more emerging from R&D labs, there is a clear need for efficient and cost-effective methods for materials selection and optimization prior to scale-up to the full printer test phase. This is especially true for independent ink manufacturers seeking to supply into equipment manufacturers.

Drop watching systems [1] have formed the backbone of inkjet development procedures for many years, but for single-pass applications that depend on a combination of print process variables, the need to print cannot be avoided. This leads to a challenge for ink makers to develop understanding of ink-head and ink-substrate interactions in parallel.

Building on previous related jetting work focusing on latency effect in water-based inks [2,3], we look to extend the prototyping treatment to consider in more detail the contrasting requirements for each step of the print process when it comes to the contribution to print quality. Specifically, we are concerned with how to simulate and assess the influence of coverage on ink-to-ink bleed and the role of substrate temperature on ink drying.

With most high-throughput single-pass inkjet print processes relying on hybrid printing approaches of analog and digital technologies, the key target is the optimization of the interaction between primers and inks.

Equipment and Methods

There are several commercially available solutions for combining drop watching and printing functionality. As well as the Jetxpert Print Station from Imagexpert Inc (Nashua, NH) which we will soon describe in more detail, systems developed for materials deposition such as the ubiquitous Dimatix DMP, or Pixdro LP50 are also often used. The challenge in most "off-the-shelf" implementations is that the flexibility for integrating the necessary multiple colors is often limited by the design of the ink handling or the type of IJP heads supported.

Test Concept

Our approach has been to take the commercial drop watching systems and equip / adapt them with low-cost print heads that enable quick testing of new chemistries. Choosing end-shooter print heads also means each can be filled with a minimal amount of ink and time, thus reducing the overhead in resource commitment to undertake fluid development.

Jetxpert System Description

The Jetxpert Print Station (from Imagexpert, NH) is shown in Fig. 1. Our version uses a conveyor rather than a linear stage, which has the advantage of having better suitability for a range of tests, including sustained printing. For the current experiments a customized head mount is used to enable printing with two print GH2220 heads (Ricoh Products Ltd, UK), which is the maximum that can be fitted between the optical components. The mount has optional temperature control, but this was not used for the water- based chemistry we discuss here. Each head can be visualized by changing the position of the focal plane using a thumbscrew to move the whole optical system.

On the printing side, the conveyor can be used up to speeds in excess of 100 meters/minute. Temperature control of the substrate comes from a custom-built platen derived from parts from a 3D printer. It is insulated on the reverse to avoid damage to the belt and can be used up to a surface temperature of 80°C.

The print is visualized using a USB camera (Amazon, UK) connected to a PC, capable of recording videos at VGA resolution. The camera is mounted approximately 7cm from the center of the two heads. An optical sensor stops the belt at a predetermined position upon detecting the substrate. At a typical belt speed of 30 meters/minute the delay before the camera auto-adjust to the intensity within about 200ms allowing visualization of the interaction between drops.

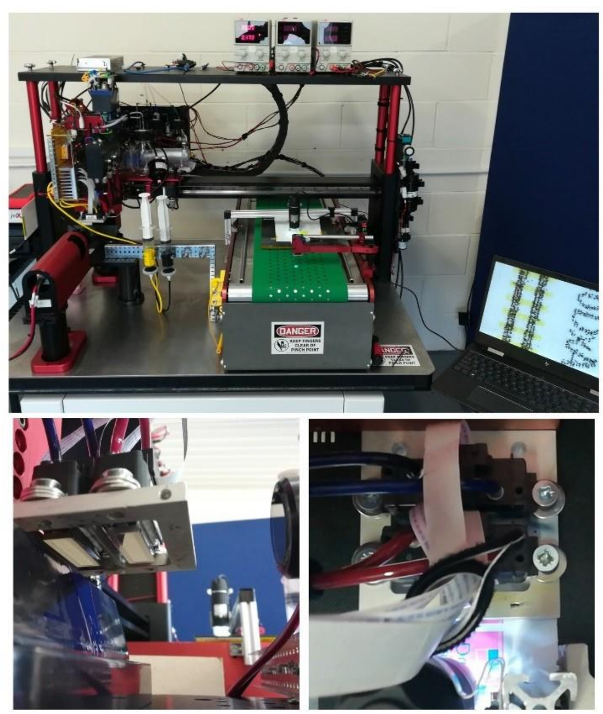

Figure 1. *Imagexpert print station for two-color ink-primer testing*

The limitation in the Imagexpert system used in this way is the number of colors that can be tested at any one time and still be characterized for jetting. There is also a restriction in the height of the parts that can be printed, without re-positioning the entire head mount. It is also rather complicated, although not impossible, to mount and test with more than one head type at once, thus making comparative testing less efficient.

Meteor System Description

As a comparison we have developed an alternative print system based on a larger conveyor that can accommodate a range of print heads at once. This system is combined with another commercially available drop watcher (Meteor Inkjet, UK). The system is depicted in Fig. 2.

Unlike the previously described equipment, the optical part is now relocatable to allow it to be used between different print heads without any re-arrangement to a given print head. This is particularly useful for conducting experiments to confirm that the prototyped ink formulation performs as predicted on the ultimate intended head. In bottom left of Fig 2 the Dimatix Starfire SG1024 head is shown in addition to the afore-mentioned Xaar 1201. For flexible packaging applications the Dimatix Samba or Xaar 5601 head would be expected to be likely alternatives.

Due to the size of the optical components the printed part needs to be raised up to the head height, as seen in the bottom right photo. The print encoder is also just visible at the bottom of the image. Although it is also possible to add a longer z-axis range to overcome this requirement this would have to be repeated for each print head position, so it is easier to adjust the substrate. The extra height of the heads relative to the belt can actually be quite useful since it allows for the printing of different form factors of packaging parts, such as bottles / boxes and even 3D printing (given an appropriate bed system [4].

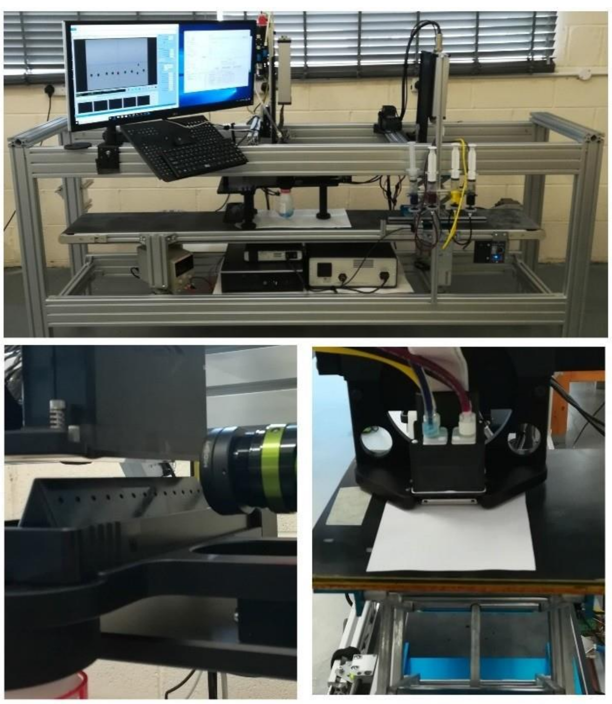

Figure 2. The Meteor-based system for four-color printing.

Materials & Processes

To demonstrate the prototyping potential, various primer coatings were deposited onto a polyethylene film. The primers were kindly supplied by a 3rd party (Kustom Coatings Group, Cincinnati, OH). The coatings were made by a hand flexo system (RK Coat, UK) using a #140 anilox giving approximately 3gsm wet.

Inks were obtained from two sources. Initial method development was undertaken on standard GH2220 ink kindly supplied by Ricoh. The yellow and black inks were chosen for the highest contrast. For the more detailed testing of material influences on different primers, several sets of inks were supplied by Mexar (Mexar Ltd, UK) as listed below in Table 1.

Table 1

Supplier	Ink Ref	Description	V_{Jet}
Ricoh	GH	GH2220 standard	N/A
Mexar	LL	Low viscosity, low binder	10V
	LH	Low viscosity High Binder	
	HL	High Viscosity, Low binder	12.5V
	LL2	Alternative pigment	10.5V

The inkjet printing is done at lower native resolution than the typical print head expected to be used for the application. This means that the drop laydown needs to be tuned to better simulate the coverage that is possible with the higher resolution head. The concept is shown in Figure 3. The number of drops in the print (x) direction is increased compare to the cross-process (y) direction and the drop size exaggerated by using multi-pulsing techniques.

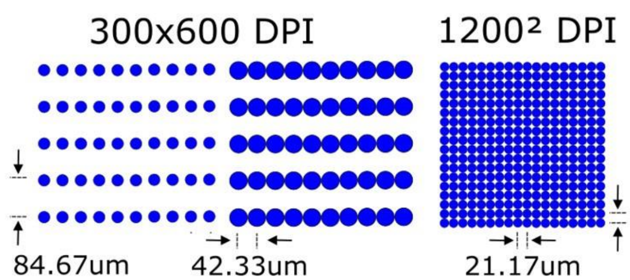

Figure 3. The print strategy to achieve comparable coverage

For the GH2220 head the print resolution was normally set to 600DPI and a 4- or 5-pulse waveform of head was adjusted to give a repeatable 16-18pL drop at 6 meters/second. This corresponds to a print frequency of 4kHz at a stage speed of 30 m/min. In one example we will show later the resolution in the print direction was increased to 1200dpi. The Xaar head could also be configure to either of these settings.

A simple test image was created consisting of a main ink bleed area and some of varied coverage. The USB camera was positioned so that the bleed pattern was imaged in the field of view when the belt drive came to rest.

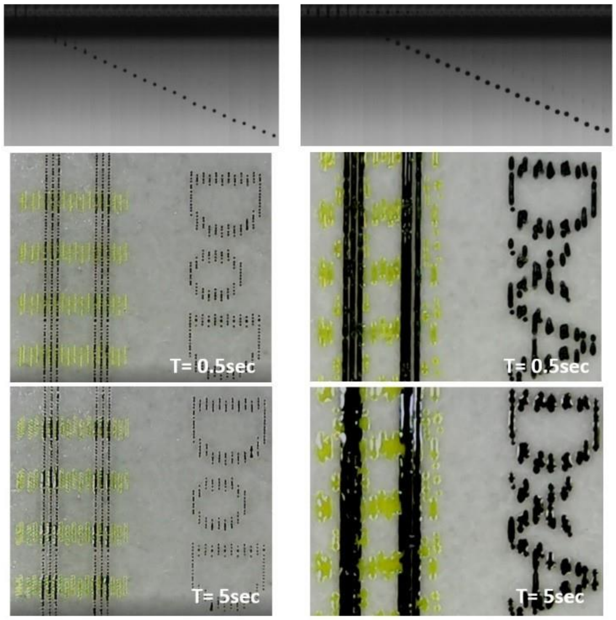

Figure 4. The effect of drop size on inducing ink bleed issues with GH ink.

Testing with the GH ink demonstrated the effect of the drop size on the ability to print meaningful patterns that can be used to make material comparisons, as shown in Figure 4. If the drop size is too low, then individual droplets do not merge.

Example Results & Discussion

We will describe two experiments to compare the effects that formulation difference can having on the evolution of ink bleed. In the first, we use simplified formulations made in our own laboratory. By reducing the number of ingredients, it is possible to pick apart formulation contributions. As a second stage we return to looking at the full set of Mexar inks listed in Table 1.

Simple Formulations

According to literature, the ink-surface interaction occurs in several phases [5]. The timing of the phases depends on the relative amount of ink absorption. The initial impact effects occur < 100ms, which is simply too quick for us to visualize them with the current configuration of belt speed and camera. Most published work on wetting effects, including crop coalescence relies on relatively simple systems, so that models can be developed in parallel [4]. To start to demonstrate the speed of drying we adopt a similar approach by creating simply ink analogs using a minority of ingredients.

As shown in Table 2, we have compared propylene glycol as a main co-solvent to glycerol. The reason for this choice is that the commonly used glycerin is simply too difficult to remove at temperatures that can be tolerated by typical packaging substrates. We have created color contrast by adding water soluble dyes, (Allura red & Brilliant blue), in addition to a standard surfactant (Surfynol 465, ex Evonik, Germany). As a third example, a soluble polymer is added to make an ink with comparable viscosity but with a lower glycerin level. The polyvinylpyrrolidone (PVP) was stated by the supplier (Aldrich, UK) to have an average molecular weight Mn of 40,000.

Table 2

Ink	Humectant	Polymer	Viscosity	V_{Jet}
GLY	45% Glycerin	N/A	4.8cP	11.3
PG	Propylene Glycol 45%		4.9cP	12.0
PVP	25% Glycerin	5% Polyvinyl-pyrrolidone	7.0cP	12.5

The micrographs of Figure 5 capture the drop coalescent effect of the three different test fluids at room temperature on one of the more wet-able primers we shall discuss in the next section. The images have been cropped from videos and have been edited for increased contrast to correct for the auto exposure of the unsophisticated camera.

The co-solvent choice is dominant in the relative drying of the inks and the expected gelling of the polymer-containing ink is retarded by the humectant effect of the glycerin. This is because the levels of humectant are typically higher than usual in order to obtain a viscosity suitable for the head to achieve multi-pulsing.

As a result of the high level of humectant the latency was very good for the inks without polymer. The glycerin ink jetted with a minority of nozzles missing with no maintenance after being left overnight. In contrast, adding just 5% PVP completely disrupted the stability and several sacrificial prints on paper were needed to recover the nozzles before making a test on film, even after a purge and wipe. This competition between the functional (polymer) content of packaging inks and the latency underlines the importance of combining printing and drop watcher.

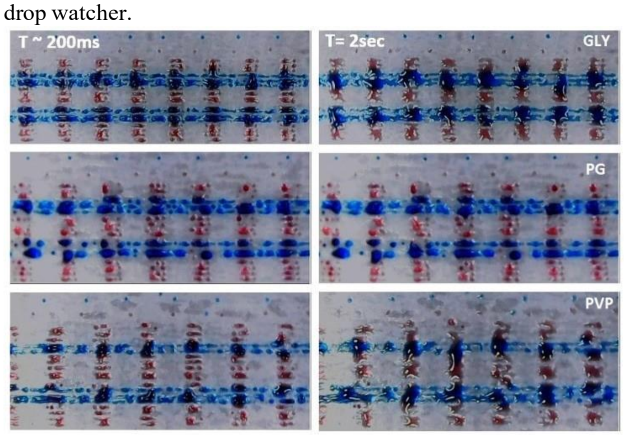

Figure 5. The bleed effects with different test fluids of table 2.

Commercial Inks

As well as using relatively low temperature drying, packaging inks will inevitably have to contain a binder resin to provide functionality. In this next section we have taken four commercially ink samples from Mexar and compared them for their print quality effect on the 6 different primers from Kustom Group.

It is important to keep in mind that none of the materials we shall describe here are specifically developed for the packaging market. They are used simply because they are commercially available as existing recipes, and the vendors were prepared to allow their use in this research. Their performance when combined is not the outcome any specific development and is certainly not meant to represent the capability of either supplier in providing materials suitable for flexible packaging applications.

For each combination printing was conducted at both room temperature and at a platen temperature of 60°C, which was enough to cause minor distortion of the coated films. This resulted in having to use adhesive tape to keep the substrate flat, although an obvious improvement would be to use a (microporous ceramic) vacuum chuck.

Primer Dependence

Primers are commonly used in industrial inkjet for two major reasons depending on the substrate. For paper applications it is important to reduce the penetration of the colorant to increase color density. The secondary role is to reduce or remove the variation between different printing media. For polymeric substrates, as more likely to be found in flexible packaging applications, the additional functional control of adhesion is also a critical consideration. Performing many design of experiments (DOEs) to balance these properties is one of the main reasons that an efficient predictor is required.

Our observations of the ink bleed behavior as function of primer and ink is presented as Figure 6, below. The primer clearly dominates the ink difference as the main determining factor in ink spread, although this is not that surprising unless the ink surface tension is being modified substantially. The main ink effect seems to be the viscosity, since the HL ink reticulates less than the lower viscosity versions.

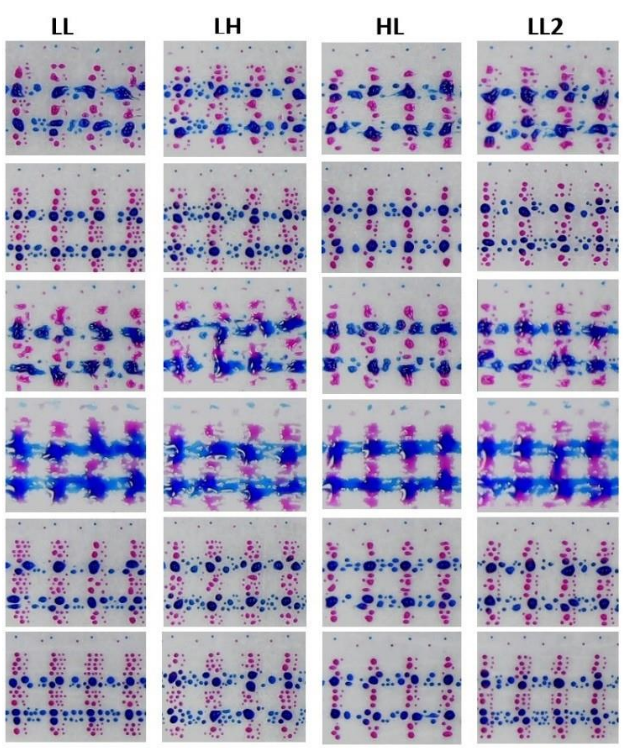

Figure 6. Cropped microscope images comparing ink-primer iterations at RT

Temperature Effects

The application of temperature to the substrate to accelerate drying is common in production printer design and can be expected to be helpful in packaging printers. The mechanism for droplet control is two potentially two-fold. Temperature induced viscosity changes can promote penetration and increases in the evaporation rate of the carrier liquid can pin the edges of the drop.

From a practical perspective we are interested to explore whether substrate heating can introduce some control to ink-ink interactions before the substrate has time to be provided with forced drying from and IR lamp or hot air system. At print speeds in the range of 50-200m/min (0.8 – 3m/s) the time to a final drier can be of the order of seconds.

Figure 7 depicts the influence of temperature and the wetting over time with two of the Mexar inks printed on the most wetting 4th Kustom primer. Both inks show increased initial wetting that has evolved before 0.5seconds, but the effect is most pronounced for the lower viscosity ink, despite the higher resin binder content.

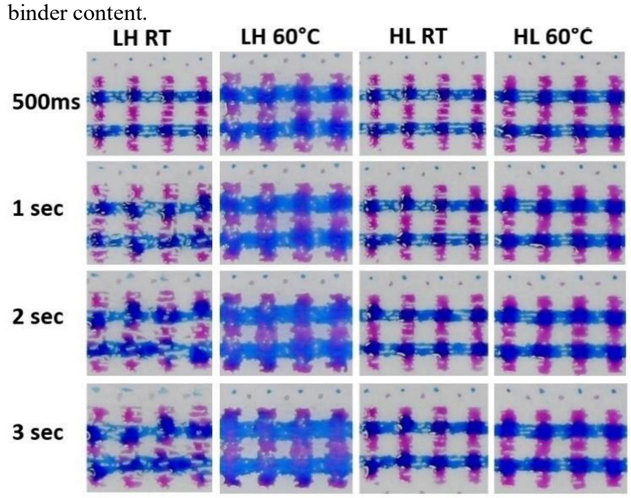

Figure 7. The evolution of ink bleed with time and temperature

Limitations & Further Work

There are some limitations to the techniques described. The most notable is latency, which as discussed earlier made the testing of the PVP test fluid difficult. Given that packaging inks will necessarily be fast-drying then if they are too fast, then maintaining jetting and printing at all in an "end-shooter" print head may become impractical, even with the use of tickle pulses.

It is also not likely to be possible to extrapolate an optimum formulation combination to another print process at 1200dpi without some modification, although investigating this is the next stage of the planned work.

It is possible to improve other areas of the testing with some relatively simple changes. For example, the current USB camera took some time to auto-expose, limiting the capture of the first image to about 400ms of the initial belt movement. Therefore, the time response of the printing by using a better camera that can be manually adjusted for exposure, thus imaging the print as soon as the belt comes to rest, and thus exploring times ≤ 200ms from print that are more relevant to higher speed processes.

A more precise head mounting and the afore-mentioned vacuum platen are both obvious areas for improvement.

Summary

We have described how relatively cost-effective prototyping methods can be used to identify key material interactions between primers and inks that are expected to be a key part of the print process development for flexible packaging.

The use of simple "end shooter" print heads means that multiple inks can be tested quickly in combination with different primers, with less ink volume required to be prepared.

Over and above the expected, strong primer dependence, the ink viscosity and drying speed of the ink co-solvents are the main ink variables seen to impact wetting at different temperatures. The former is slightly in disagreement with theoretical predictions - which suggest viscosity is less important in the spread phase - but the relatively complex surface morphology is probably the reason for this.

It has been demonstrated that optimizing primer and inks together is likely to be the most reliable route to achieving the required print quality results, just like has been proven in other industrial inkjet implementations.

Acknowledgements

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Author Biography

Mark Bale studied at the University of Birmingham, UK, gaining an MSci in Physics and a PhD in Nanoscale Physics/Microfabrication. Starting in OLED manufacture his inkjet experience includes wide-format graphics, labels & packaging, decorative surfaces, electronics manufacturing, product coding and 3D printing. He is the founder of DoDxAct Ltd, a UK- based consultancy advising on, and providing training in, all aspects of inkjet R&D from ink formulation and manufacture through jetting & process integration to final application optimization.