Digital Printing White Paper
In collaboration with

SunChemical

Enhancing label print quality with UV pinning

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Contents

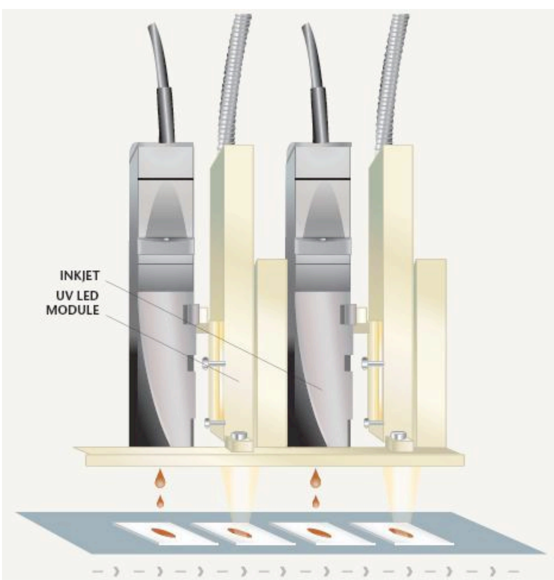

Figure 1 *– LEDs are used for pinning immediately after jetting UV inks on Sun Chemical's new Solarjet™ machine*

Introduction

The potential benefits of digital printing narrow web labels are well understood and desirable:-

- Economically viable "short runs", (when compared to analogue, traditional printing methods)
- Comparable quality to flexo
- Minimal set-up time and low material loss
- Comparable production throughput to flexo

A good proportion of label stock is either of low, or very low absorbance and often UV curable acrylate-based inks are used to overcome this basic problem on a variety of substrates, with excellent results.

It has only relatively recently been possible to obtain UV inks of sufficiently low viscosities, along with the other necessary physical properties, to allow them to be jetted by modern drop on demand (DoD) piezo inkjet heads. A number of manufacturers have been working on this problem, including Sun Chemical who has completed developing such inks, suitable for jetting onto a range of standard label stock.

"The interaction between the Drop on Demand jetted UV inks and the label stock material is crucial after jetting."

The interaction between the DoD jetted UV inks and the label stock or plastic film, such as those used in "no-label" look applications, is crucial after jetting. In this white paper we discuss experimental results which have clearly established the benefit of a short, high 'shock' of UV radiation immediately after jetting with good benefits in finished colour print quality for lines, dots and solids. This is known as 'UV pinning'.

Problem Statement

UV curing inks do not dry by absorption into the substrate or by evaporation. Rather, the action of UV light of sufficient intensity and of the right range of wavelengths causes a polymerizing cross-linking reaction within the ink, in effect forming a plastic. Due to this drying mechanism some standard industrial label stock materials, including and more especially plastic films, have wetting problems when printing monochrome, or CMYK colour.

However, this is not the whole story. Modern label stock materials designed for UV flexo printing may have a surface coating to promote wetting. When tiny droplets of UV jettable ink from a DoD head land on such a label substrate, the droplets will tend to spread out, even up until the point at which the ink is passed under the full curing UV lamp. Depending on the speed of the line, the distance (time) from the inkjet head to the UV lamp and on the actual image being printed, this effect will manifest itself in a number of ways, including, but not limited to:

- Dot gain
- Line spread
- Solids mottling
- Colours mixing incorrectly

All of which can result in sub-optimal label print quality, which may also be dependant on line speed.

Previous Options

The conventional approach of modifying the rheology of the ink is relatively constrained since inkjet inks must, in general, have a low viscosity in the range of 10-14cps to be able to be jetted from commercially available DoD ink jet heads.

To overcome these types of effects, that result in the sub-optimal print results mentioned, different types of surface coating may be used to modify the dot gain behavior.

However it has been shown that modifying the viscosity of the UV material itself **after jetting** turns out to be another potential ally in gaining the best possible print quality on a variety of substrates.

> ***"The conventional approach of modifying the rheology of the ink is relatively constrained since inkjet inks must have a low viscosity."***

LED Pinning as a solution

UV curable inks require a ultra-violet lamp source of sufficient intensity and duration of exposure to affect a full cure through to the desired finished and stable cured state. This process is often called 'UV drying' within the print industry. As mentioned, the photo-polymerization reaction actually creates an acrylic based plastic. The final properties of the UV cured ink are determined by the ink formulator and are somewhat dependant on the type of substrate to be printed upon e.g. rigid or flexible, absorbent or non-absorbent.

The ink will not be cured at all until it reaches the UV lamp, which often is necessarily quite some distance from the inkjet heads. Most reasons for this separation of jetting and curing are lamp related:

- The UV lamp is physically large and does not fit well within the compact frame of the inkjet head array
- It may require a large cooling airflow, which could interfere with the jetting of tiny ink droplets
- It creates significant heat load which may effect the inkjet heads
- It generates a lot of UV light, some of which could shine directly, or be reflected onto the print heads, causing the ink to be cured there, then requiring the head to be serviced or replaced
- The lamp takes many seconds or even minutes to reach stable operation so must be often be left in a 'standby' mode when the web is not running which still generates heat and air flow.

When the jetted ink pattern on the moving web reaches the high intensity 'final cure' UV lamp, the ink will change from a thin liquid of low enough viscosity to be jetted (10-14cps is typical) to a solid plastic material of the desired flexibility or hardness for the substrate.

All the while, on its way to the final UV cure lamp, there is the potential for the ink droplet pattern to change as the droplets either spread out on a non-adsorbent substrate, or conversely absorb too much into a substrate, or undesirably merge with each other. These effects, if not controlled, may adversely affect print quality, which may also be speed dependant.

However, by applying an interim dose of lower intensity UV light, correctly matched to the ink's photochemical properties, the ink drop pattern can be moved to an interim higher viscosity state, but stop short of full cure. This thickening or gelling of the ink can be effectively done by using an array of high power UV light emitting diodes (LEDs), strategically placed right next to the inkjet head for immediate effect after the ink droplets have been jetted onto the substrate. This interim gelling is now more usually known as pinning.

"The ink drop pattern can be moved to an interim higher viscosity state."

Implementation

UV LEDs have been known for some time to have desirable properties as follows:

- Long life, measured in many thousands of hours
- No warm up or cool down – i.e. instant on/off
- Narrow UV wavelength emission for maximum electrical efficiency when matched to the photochemistry of the process

It is only recently that UV LEDs of significantly high output have become commercially available to be useful to industrial UV processes in the presence of atmospheric levels of oxygen.

Using such LEDs, Lumen Dynamics have made both 365nm and 400nm LED pinning head units designed to mount right alongside standard drop on demand piezo inkjet heads and have developed a 12-head system version specifically with the 6.3" (12 print head) version of the Sun Chemical Solarjet™ four colour label press in mind.

Alongside, Sun Chemical has been developing a primer to also improve print quality across a range of substrates.

Print Trials

These two approaches were combined to explore the potential for achieving the best print quality possible for full colour graphic images.

To gather quantitative data the primary aim was to test the effect of 365nm and 400nm pinning LEDs on line width for each process colour at a number of speed settings. In addition to this, a number of images were also printed, including some charts that aimed to test reproduction of text.

A prototype Solarjet™ label press installed at Sun Chemical's R&D site in Midsomer Norton (nr. Bath, UK) was used for these trials running with standard Sun Chemical inks on Xaar Omnidot 760 GS8 print heads, with an ink jet head to Lumen Dynamics LED pinning head spacing of approximately 2". The speed of web was varied between 25, 50 and 75 feet per minute (fpm), with the final curing lamp set at 65%, 75% and 85% intensity level respectively.

The Lumen Dynamics' 400nm and 365nm LED heads were able to have their percentage intensity controlled to examine the effect on print quality.

In order to limit the number of required measurements only two substrates were used, namely Fasson Matte Litho and a #60 Elite Semi Gloss pre-coated with an aqueous primer developed by Sun Chemical.

A full set of measurements was taken with only 1 LED unit used per colour so that behaviour between colours could be compared.

In addition, a more limited set of measurements was obtained at the two extremes of web speeds using multiple LED exposures to simulate real printing conditions. Due to the print head arrangement this leads to multiple LED exposures for certain colours, with each successive dose spaced by approximately 6", with time between each clearly dependent on web speed.

A QEA portable image analysis system was used to record images and to measure the line widths of single nozzle test patterns. The same system was used to measure the width of the letter "r" in the text part of a test print as well as the optical density & mottle of the specific sky region of the same full colour image. In fact, several images were used to gauge print quality and these graphics were chosen for their challenging mix of tone and block colour.

"The 400nm and 365nm LED heads were able to have their percentage intensity controlled to examine the effect on print quality."

Results

The full set of results is too lengthy to present here but the following observations have been made:

- On coated paper, LED pinning can be successfully used to lessen ink spreading
  - 400nm and 365nm wavelengths are both effective for achieving this
  - There is still a small dependence on web speed
- Use of pinning on uncoated paper does not appear to affect (increase) line width by minimizing absorption into substrate

- 400nm has little or no effect – no difference MIN-MAX
- 365nm has only a small effect on average

The extent of spreading after pinning would be reasonably expected to depend on the dose applied. Similarly, it may also be expected that inks would show a marked difference between singly-exposed and multiply-exposed lines. However, when comparing the line width results for 1x and 4x pinning application for cyan ink printed at two different LED powers and up to three different web speeds, it was found that the measurements are indistinguishable, i.e. repeated doses have no effect on line width relative to increased single doses.

One can infer therefore that the observed small dependence on web speed depends most significantly on the time between print and pin. If this is true then the ink that receives the lower dose must continue to spread for a period after the first LED exposure and must have either (i) finished spreading by the time it reaches the second LED, or (ii) receive no further benefit from further UV exposure from the LED. This behaviour was similar for all process colours.

A full analysis of the results for 400nm exposure of all colours is presented in the graph of figure 2 below.

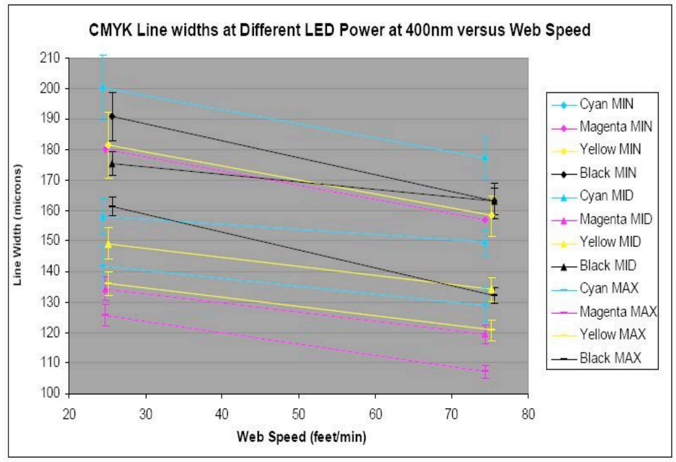

***Figure 2** – line width results using Lumen Dynamics' 400nm LED pinning system*

Although there are a few exceptions, there appears to be comparable speed dependence across all colours with a small but clear sensitivity to colour in the relationship to LED power. Not surprisingly, the minimum LED setting gives results that are very close to that obtained with no pinning at all.

"400nm & 365nm wavelengths are both effective"

Discussion of Line Width Results and overall print quality

From the above presented line data, by using 400nm pinning units with variable intensity control on each colour it will be possible to mitigate the speed dependence by setting the LED intensity to keep the line width constant and therefore maintain a consistent print quality and colour. The setting parameters would be substrate dependent, so variable and reliable intensity setting is vital and can be achieved with the pining system.

Although less quantitative, it was possible to observe definite differences in print quality with and without pinning on the both substrates tested. The best images were obtained using maximum power pinning on the primed substrate at speeds of about 50fpm, though Lumen Dynamics now has a higher power LED pinning system available for full speed operation.

In these cases the ink spread on paper was controlled so that 4pt text was clearly readable and that the chance of ink bleed between solid and tone areas was minimized. The appearance was smooth and glossy but with very fine lines visible in the print direction. These artifacts have been shown to be mitigated by careful optimization of LED power.

Image quality on the matte paper was helped by controlling the behaviour of ink wet-on-wet which, without pinning, leads to a speed-dependent mottled appearance of the print in block composite-colour areas combined with a slight pitted appearance to the gloss. With pinning applied, the pitting is much reduced and the finish much more reproducible at different print speeds. As before, some very fine lines may be observed as with the primed paper. In single colour block areas the lack of drop spread exaggerated the voids between adjacent nozzles as may be seen in Figure 3.

By way of a summary, pinning on primed paper produces cleaner lines, improved fill on 100% area colour and smoother tone areas than on the coated matte substrate. Where tested, however, bar codes were readable on all substrates.

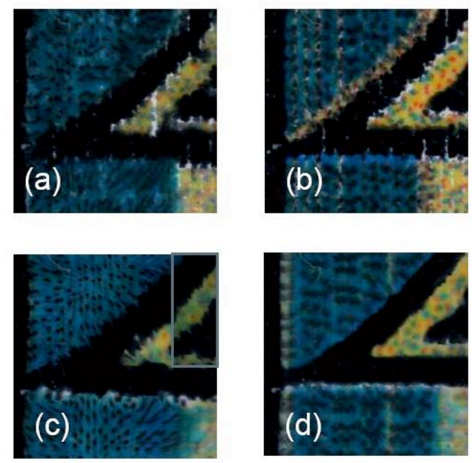

Figure 3: *QEA images showing the same zoom of bottom left of a letter "H" on a printed label (a) matte paper at 25fpm (b) matte paper at 25 fpm with pinning, (c) primed paper at 50fpm and (d) primed paper at 50 fpm with pinning.*

The Lumen Dynamics pinning solution

The Lumen Dynamics pinning system used in these experiments and fitted to the commercially available Sun Chemical web label press comprises a 12 head controller and 12 individual LED pinning heads. Each head can be selected from a choice of wavelengths, either 365nm or 400nm. The 12 pinning heads can be arranged flexibly in groups to suit the application, but in this case the label press is four colour (CMYK), 3 inkjet heads wide, so the LED pinning heads are arrayed as 4 groups of 3, one colour per group.

"Ink spread on paper was controlled so that 4pt text was readable and that the chance of ink bleed between solid and tone areas was minimized."

The 19" rack mounted controller provides independently adjustable levels for each group from 10% to 100%, the effects of which were observed during this study and have been optimized since, depending on the colour and speed. The intensity levels will be independently adjusted either locally or remotely via USB connection to a host computer.

The following are the most significant benefits of this system approach:

1. **The LED pinning head is physically very small** – so can be mounted directly next to the inkjet head to give a low level shock of UV light immediately after jetting
2. **Variable power** – each head can be independently varied in power level, from an instant on/off to any level in between 10 and 100%. The intensity of the pinning can then be optimized for the print results
3. **Variable wavelength –** the choice of 365nm or 400nm heads have each been shown to have better matching to certain inks and colours.

Summary

An extensive set of experiments was undertaken to explore the advantages of using LED pinning to improve image quality.

The mechanism of "pinning" involves retarding the fluid behaviour of the ink by creating a gel through partial initiation of the cross-linking reaction. This may be controlled to an extent by varying the intensity of the LED pinning head.

Two different wavelengths were studied in order to establish technical performance relative to cost. The results are focused on quantitative analysis of the line widths of test prints but with some qualitative analysis of print quality.

It has been shown that pinning offers added value in terms of control of drop spread on primer-coated paper, therefore increasing the flexibility of the press, but also as a tool to control the wet-on-wet ink behaviour that effect print quality on all substrates.

Pinning using LED units offers an increased degree of control over image quality in term of terms of ink wetting to the substrate but also the interaction between different process colours. The ability to vary the power of the unit is an important characteristic if looking to optimize the ink behaviour on a range of substrates (i.e. not just paper).

Acknowledgements

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The Lumen Dynamics LED pinning heads were first publicly shown on the Solarjet™ 6.3" digital web label press at LabelExpo, Brussels September 2007.