Effect of Print Resolution in Single-Pass Inkjet Printer Design

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Abstract

The paper presents the results of some comparison testing of print quality achieved in single pass inkjet print. In particular a comparison of grayscale versus asymetric resolution binary print.

It includes an explanation of the effects of ink surface tension, material surface energy and delay before UV cure.

Finally it develops a set of guidelines to apply to the design of single-pass inkjet print engines.

Introduction

In recent years a large number of new applications for the use of inkjet have appeared. Our experience is that approximately 80% of these require the inkjet to print in a single-pass mode rather than a scanning or multi-pass mode. Examples would be label printing, product decoration (such as CDs or plastic parts), or packaging (such as pharmaceutical packets). Within each application area there are a number of different materials that must be printed. Overall we may be required to print onto paper (plain or coated), card (usually varnished), glass or ceramics and a wide range of flexible or rigid plastics – some with properties optimised to prevent contamination (and therefore to repel printing inks).

Perhaps because the use of inkjet in these areas is relatively new, there seems little published information as to how to optimise the inkjet printing process onto this wide range of materials. Marketing promotion by equipment suppliers has also served to confuse the issues.

This document explains some results of in-house testing by Konica Minolta Inkjet technologies and Industrial Inkjet Ltd using UV-cured inks.

Surface Energy versus Surface Tension Effects

Early attempts by ourselves to make single-pass print samples for customers often resulted in bad ink reticulation on the surface (Figure 1 – Ink reticulation). In other words the ink drops will not merge to form a contiguous ink film but instead flow and join together in a random manner to form large drops with corresponding "gaps" where the underlying substrate is visible.

Fig 1 – Typical Ink Reticulation

Requests for advice from Konica Minolta produced the comparative photographs shown in Figure 2.

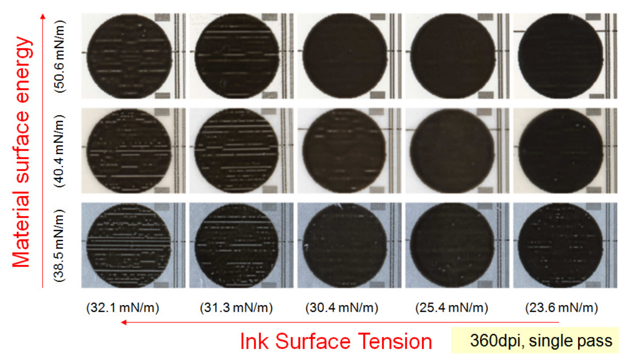

Figure 2 – Effect of Ink Surface tension and Material Surface Energy

Figure 2 clearly shows that in single-pass print the surface energy of the printed material, and the surface energy of the ink must be in a fixed relationship. Typically we find that for acceptable print :-

Material surface energy – ink surface tension => 20

Note that with some materials, particularly coated papers originally designed for offset print, there is no consistent surface energy of the material. Attempts to measure the surface energy (using Dyne pens) give variable results and similarly attempts to print using single-pass inkjet also give variable results. Print quality can vary from good to bad over distances of a few millimetres.

Cure Delay

Early attempts to optimise print quality also showed that the time delay between printing and UV cure of the ink is critical [1] .

Figure 3 shows typical results of the problems caused by too little or too late cure delay. In this example the ink is a relatively low surface tension (24mNm) and the substrate has relatively high energy (52mNm). As predicted by the large difference in the energy figures, the print quality at 360x360 dpi (3 greyscale levels, 14pl drops) is good. This is with a cure delay of about 1.8 second. However at a cure delay of 1 second the ink has not yet formed a film. The "light" coloured area of the printed image is still formed of individual ink drops that have not yet merged.

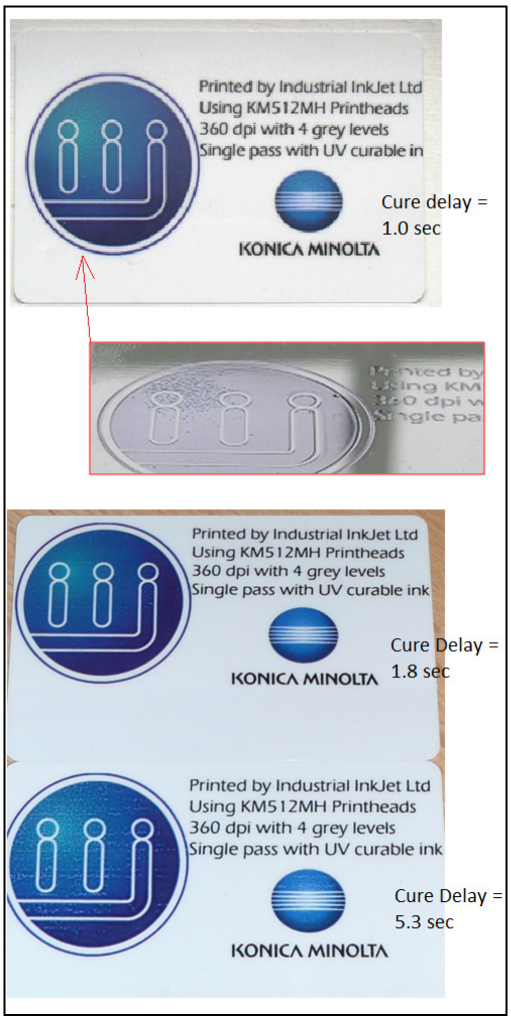

Figure 3 Cure Delay "Window"

And again at a long cure delay (in this case 5.3 seconds) the ink film has broken up again or reticulated. Print quality is no longer acceptable.

We are now able to talk about a "cure delay window" or the range of time over which the ink will form a contiguous film and print quality will be acceptable. With the ink and media in Figure 3 this range is approximately 1.5<t<3.5 seconds.

Other UV inks have been found to have larger or smaller "cure delay windows" but generally ink reticulation occurs within about 10 seconds after cure.

The optimum time for cure delay has also been found to alter with material surface energy. Logically a low surface energy material, one in which the ink has difficulty wetting onto the material, will also have a longer optimum cure delay. Testing of various materials has borne this out (See Figure 4)

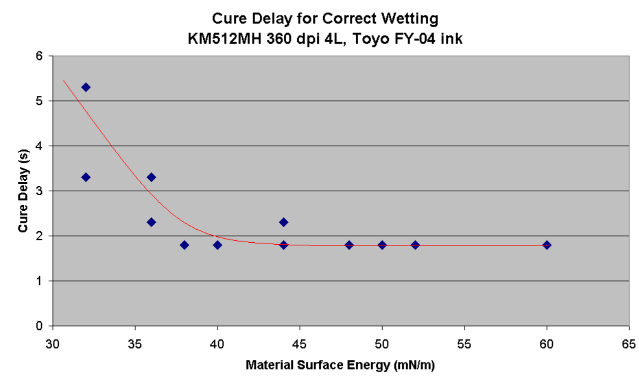

Figure 4 – Optimal Cure Delay for Different Surface Energy

A key point to note from this graph is that we now always expect cure optimum cure delays to be of the order of seconds. However we are aware that many UV wide-format printers cure the ink after only perhaps 100 or 200ms. Our conclusion is that this is too short and is resulting in reduced print quality and the need to make multiple passes (and use more ink) to achieve acceptable coverage of the media. The same is true of single-pass inkjet systems that attempt to "pin" with UV light each different colour of ink before the next colour.

Effect of Resolution

All of the above testing was carried out at 360x360dpi resolution using greyscale printing (variable drop sizes). In projects where the material surface energy was low we investigated the use of pre-treatment such as corona or heating of the substrate with some success. On other materials with varying surface energy a high-surface energy primer coating was often the only solution. However more recently we have experimented with changing the print resolution.

The majority of Konica Minolta printheads currently have inkjet nozzles on a 360npi ("nozzle per inch") pitch. Higher resolution single-pass printing is possible by interleaving of multiple printheads (see Fig 5), but this adds cost and complexity to the inkjet system.

We therefore investigated the effect of asymmetrical resolution printing, remaining with 360dpi print across the media being printed (as available from 1 inkjet printhead) but changing the resolution in the direction of motion of the substrate. Konica Minolta gives full access to the printhead drive waveform so we are able to simply change the printing method between binary and greyscale (variable drop size) print modes. We are also able to easily choose the maximum number of greyscale levels we will use (ie the maximum number of drops per pixel).

In the experiments we used KM1024SH printheads which fire a drop of 6pl volume. This printhead accepts 3 bits of data per pixel so the image data can be used to fire between 0 and 7 drops of ink per pixel. The print modes we compared were:-

360x360dpi, max 7drops x 6pl

360x720dpi, max 3 drops x 6pl

360x1440dpi, max 1 drop x 6pl

See Figure 6.

Changing between print modes is purely a software function and takes only a few seconds.

For clarification, greyscale printing means use of the print image data to determine the size of the printed drop to be used in each pixel. So in a light colour area the image data calls for a small number of ink drops per pixel. In a dark colour area more drops of ink will be fired into each pixel. The system software interprets the image data and chooses the appropriate number of drops to fire for that pixel, and feeds that data to the inkjet printhead.

Since the system has to cope with any image, normally the maximum number of drops is chosen so as to ensure 100% coverage of the printed media can be achieved (ie a continuous ink film with no gaps through which the underlying media is visible).

Before comparing the different print modes, the colour calibration of the system was carried out, and an IIC profile generated for each print mode. This was to reduce or eliminate any observed differences that were simply due to incorrect mapping between the original image data and the final print. In this way we are able to compare the performance of the print modes.

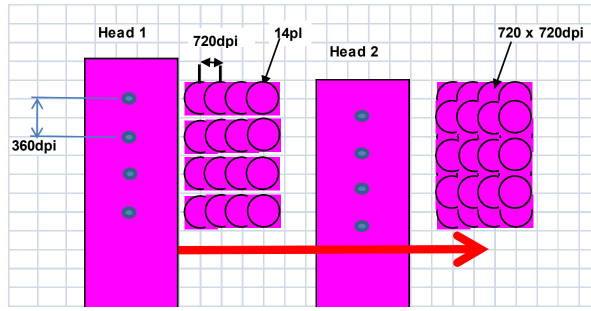

Figure 5. Interleaving of Printheads for Higher Resolution

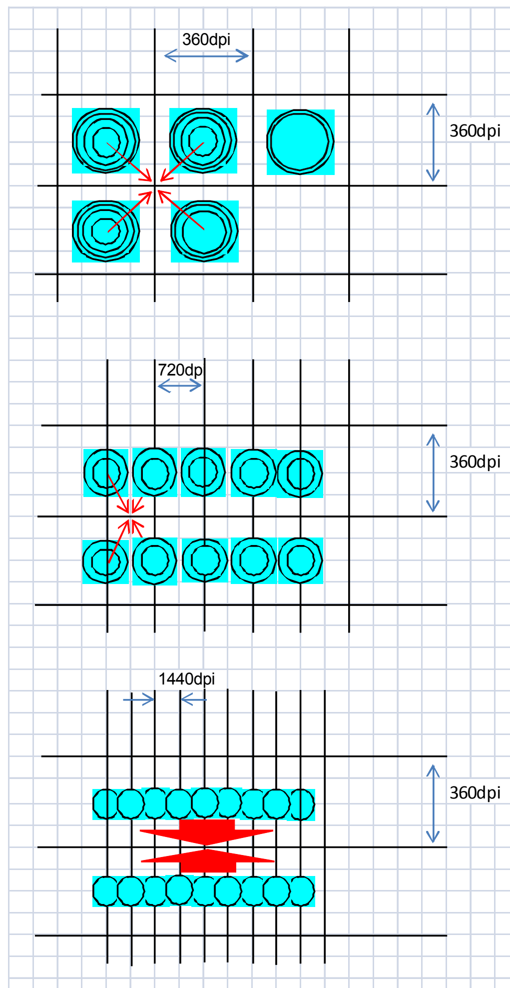

Figure 6 – Diagram of Print Resolutions

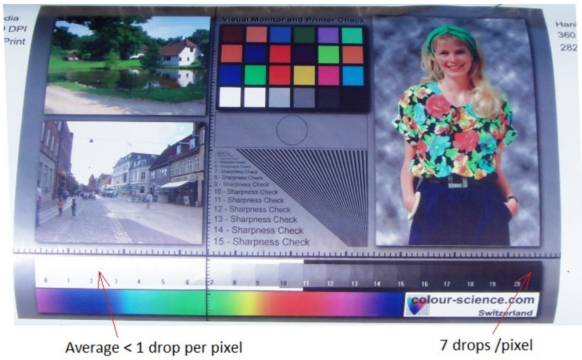

Figure 7. Greyscale Printing

Results

The printed results from the 3 print modes show only small differences. Edge definition of fine text and "grainyness" of lighter coloured areas were considered little different.

Figure 8. Printed samples at Different Resolution

Figure 9. Close-up views of Figure 8

Note that the 360x1440dpi print mode is using less ink than the other print modes. On a like-per-like basis, the maximum amount of ink used per colour per pixel is:-

Resolution X dpi	Resolution Y dpi	Max No Drops per pixel	Max Ink vol (pL)/pixel	Total per 360x360 dpi area	Reduction in ink use
360	360	7	42	42	/
360	720	3	18	36	14%
360	1440	1	6	24	43%

While these figures hold true for printing of solid colours (where close to 100% ink is used in each pixel) an analysis of the ICC profile generated for each print mode shows that the average reduction in ink use in typical colour image reproduction is not nearly so large. The colour calibration process is reducing the ink used in mid-density colours in the 360x360dpi print mode to a level closer to that required in the 360x1440dpi mode. In summary 360x1440dpi achieves 100% coverage of the media with significantly less ink (useful in text or barcode printing), but the saving is less in typical colour printing.

Note that the print speed of the higher resolution modes is greater than the original mode. The linear speed of print is 43% higher in 360x1440dpi mode compared to 360x360dpi mode.

From these results we conclude that the 360x1440dpi print mode has clear benefits for the customer in terms of ink usage and linear speed of print.

An Additional Benefit

An unexpected benefit however was in the way the different resolutions print modes coped with defects in the media being printed.

In Figure 10 we can see a close up of the same image printed on the same roll of media (and in the same position on the roll). The media was from a reject batch. The surface energy of the media is variable and there are scratches along the media – probably defects from the media manufacture.

The lower image clearly shows the defects in the media including ink reticulation due to low surface energy. The upper image (at 360x1440dpi) shows few problems.

Discussion

The mechanism by which higher resolution print produces better results than lower resolution greyscale print are not strictly understood. Referring again to figure 6, our opinion is that in 360x360dpi mode the ink drops are large and well separated. The gaps between ink drops immediately after striking the substrate is of the order of 30 micron in both X and Y directions. In order for the separate ink drops to achieve a contiguous layer of ink they must spread out evenly in 2 axes at once. Any small error in the placement of an ink drop will mean it reaches one neighbour before another with the result that no contiguous ink film is achieved and ink reticulation occurs.

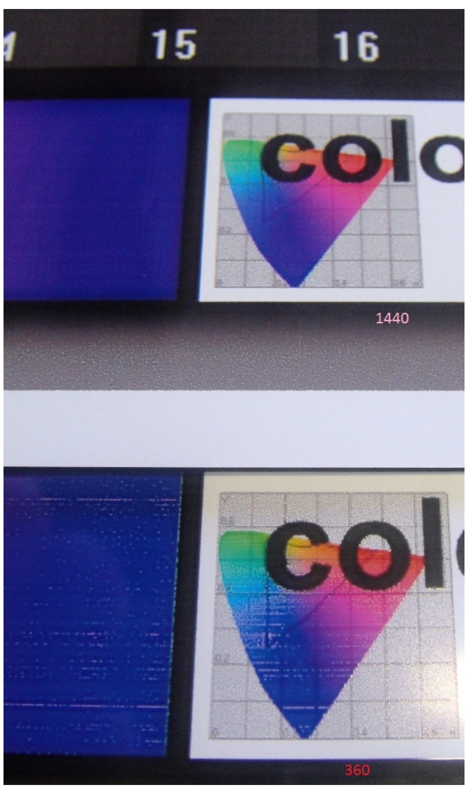

Figure 10 – Effect on Defective Media

With the 360x1440dpi mode the ink drops are much closer together along the substrate than across it. We suggest that the ink drops quickly join together along the substrate to form parallel rows of ink. The rows then “zip” together to form a smooth ink film. Because this process is more regimented it is also less susceptible to small errors in the initial drop placement, or to local changes in the ink flow rate due to media defects or surface energy variations.

Conclusion

From earlier work we know that ink surface tension and media surface energy are critical to achieving good print quality. On many media we can predict print quality from a measurement of the material surface energy.

The cure delay between the inkjet printheads and the UV lamp is also critical. There is usually a reasonable period of time (2 or more seconds) between the ink drops forming a contiguous film and the ink film breaking up or reticulating.

The optimum cure delay has been shown to increase as the surface energy of the media decreases. We presume this is because the ink flow rate is less.

We have compared print quality from three particular modes of printing using asymetric resolutions. We conclude that there is little difference in print quality on good media. However the higher resolution mode :-

- May use less ink
- Prints faster
- Copes with defects in the media

These conclusions have been found to hold true over a wide range of customer applications that use UV inks on non-porous materials.

Guidelines for Single-Pass Printer Development

The following are general guidelines drawn up as a result of the above work:-

Ink surface energy should be as low as possible (provided the printhead can still jet the ink in a stable manner)

Media surface energy needs to be high (>52mNm for most common UV inks)

Where the media surface energy cannot be guaranteed then corona pre-treatment or similar is likely to be required

All UV single-pass printers should allow for quick and easy movement of the UV lamp to or from the inkjet printheads so as to ensure optimum cure delay. A range of cure delays from <1 to >3 seconds is required.

As well as "standard" 360x360dpi greyscale print, all single-pass printers should provide the option of higher resolution print in the direction of movement.

References

[1] J. Corrall. High Quality In-Line UV Printing. 15th IMI Europe. Nov 2007.

Author Biography

John Corrall is Managing Director of Industrial Inkjet Ltd who provide technical support for Konica Minolta Inkjet customers. IIJ Ltd also develops single-pass inkjet print systems.

John has 24 years experience in R&D for inkjet printing in Industrial applications for Domino, Videojet, Xaar and others.