Thermal Inkjet – Can the Ink Formulation Impact Throw Distance

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Abstract

Thermal Inkjet (TIJ) is becoming increasing important in the industrial coding market and the question of how to increase the throw distance with this technology is often discussed. Much of the previous work carried out has concentrated on the effects that the waveform used to fire the ink from the cartridge can have with little focus on the inks.

In this paper we examine the throw distances achieved with some of the TIJ inks available from Domino Printing Sciences. Using image quality measurements taken from printed 2D datamatrix codes the effect that ink formulations can have on throw distance has been studied, including the drop velocity and physical properties. The effect of using different TIJ cartridge technologies has also been investigated.

Introduction

Thermal inkjet (TIJ) technology offers significant customer benefits in the industrial coding market due to its simplicity, low maintenance, cleanliness and low cost of ownership. When combined with new legislation in key market sectors such as in the pharmaceutical sector where higher quality 2D datamatrix codes are required to be printed on the products, the need to embrace this technology is growing.

Compared to traditional coding and marking techniques such as continuous inkjet (CIJ), TIJ can provide the higher quality codes required, but has limitations when the packing can not be presented to the printhead in a flat orientation resulting in the need for a longer throw distance to be achieved.

Much of the previous work reported in the patent literature has investigated the effect that the waveform used to fire the ink from the cartridge has on droplet velocity [1] but little work has focused on the effect that the ink formulation can have on throw distance.

We report here results of an investigation into how the physical properties of a TIJ ink can be modified to achieve acceptable image quality at longer throw distances.

Experimental

Assessment of image quality

To assess the image quality that was achieved with our experimental TIJ inks, 2D-datamatrix codes (see Figure 1) were printed at different throw distances between the nozzle plate of the printer and the substrate.

The quality of the 2D codes was then assessed using an LVS Integra 9505 bar code verifier. This piece of equipment is able to measure many attributes of the 2D code, but for this study, the % grid non-uniformity (% GNU) was the chosen parameter.

Figure 1. 2D-datamatrix code printed to assess image quality

Grid non-uniformity is a measure of the symbols deviation from the ideal grid of a theoretical perfect symbol. The data matrix reference decode algorithm is applied to a binary image of the symbol, comparing its actual grid intersections to ideal grid intersections. The greatest distance from an actual to a theoretical grid intersection determines the grid non-uniformity grade.

A grid non-uniformity of greater than 15% is observable as a loss of image quality with the naked eye.

Assessment of drop velocity and volume

To measure the droplet characteristics as they were ejected from the TIJ head, a JetXpert system was used (Figure 2).

Figure 2. JetXpert system used to measure droplet velocity and volume

JetXpert is a drop watcher and drop-in-flight analysis solution from ImageXpert and using strobing technology combined with customized optics and software, enables drop velocity and volume to be quantified.

Ink formulations

Experimental ink samples were prepared using two standard formulations and the viscosity was varied by increasing the level of glycerol used in each (Tables 1 and 2).

Table 1. Ink formulations of various viscosities at 'high' surface tension

	Ink 1	Ink 2	Ink 3	Ink 4	Ink 5
% Glycerol	-	16%	30%	35%	40%
Viscosity / cP	1.89	3.15	5.06	6.14	7.92
Surface Tension mN/m	39.8	41.3	42.0	41.9	42.3

Table 2. Ink formulations of various viscosities at 'low' surface tension

	Ink 6	Ink 7	Ink 8	Ink 9	Ink 10
% Glycerol	-	5%	10%	20%	30%
Viscosity / cP	2.40	2.79	3.33	4.70	7.50
Surface Tension mN/m	22.4	23.2	22.2	22.6	23.0

Results

Data collected using commercially available inks using the Domino G-200 printer

The effect of increasing throw distance on the image quality of 2D-datamatrix codes was assessed for two commercially available Domino TIJ inks using the Domino G-200 printer (Figure 3).

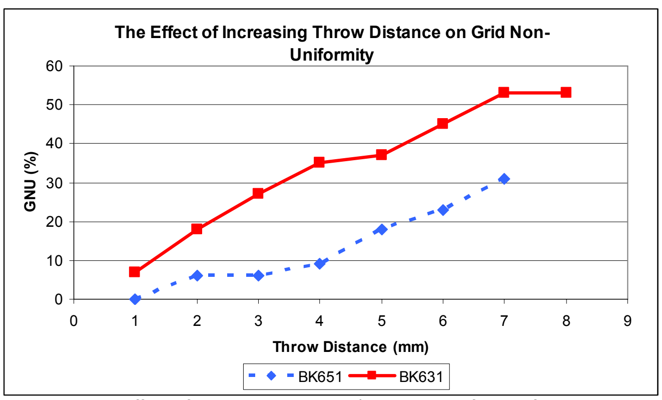

Figure 3. *The effect of throw distance on % grid-non-uniformity for two commercially available Domino TIJ inks*

The data in Figure 3 show that significantly lower grid non-uniformity results were achieved with the BK651 ink compared to BK631 indicating that longer throw distances are possible with BK651.

The physical property data in Table 3 show that there is a significant difference in both the viscosity and the surface tension of these inks which led us to investigate whether either of these factors was the key parameter to understanding how the ink formulation can affect throw distance.

Table 3. Physical properties of inks BK631 and BK651

Ink	Viscosity (cP)	Surface Tension (mN/M)
BK631	1.68	30
BK651	2.60	23

In addition, higher drop velocity was achieved for BK651 at each throw distance (Figure 4).

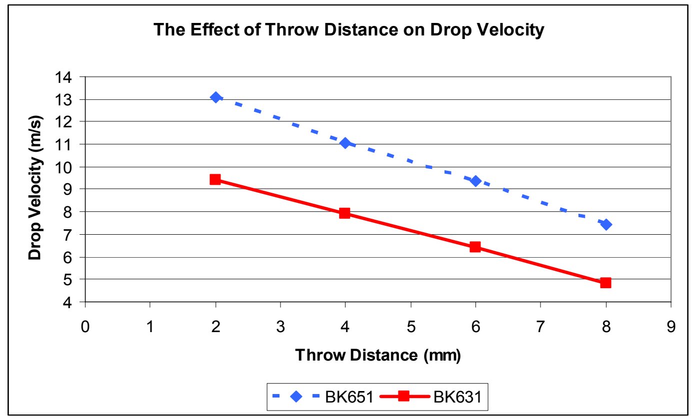

Figure 4. *The effect of throw distance on drop velocity for two commercially available Domino TIJ inks*

Investigating the effect of ink viscosity on throw distance using the Domino G-200 printer

To understand the effect of the ink viscosity on throw distance, ink formulations 1-5 were prepared where the viscosity ranged from 1.9 to 7.9cP (see Table 1) and the surface tension was maintained at 40-42 mN/m.

The data in Figure 5 show that as the ink viscosity was increased, the drop velocity decreased and at longer throw distances, lower drop velocities were achieved. This was to be expected for a given firing energy as a higher viscosity fluid will produce greater friction loss as it travels through the nozzles. At longer throw distances, the drop velocity would be expected to decrease as the drops are subjected to aerodynamic drag. Such a result might lead to the conclusion that a major factor in gaining good printing performance at distance is to increase the jet velocity.

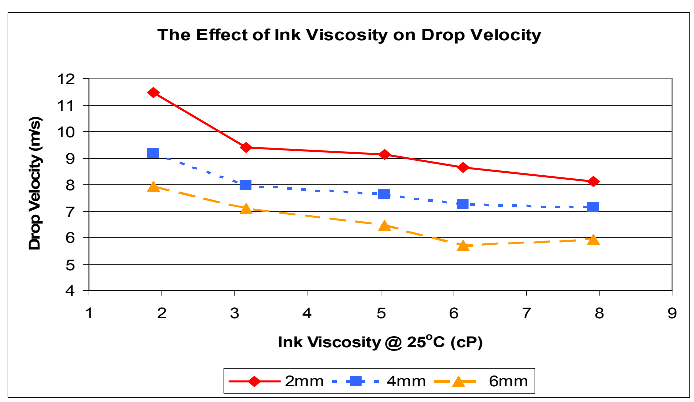

Figure 5. *The effect of ink viscosity on drop velocity at a range of throw distances*

When the effect of ink viscosity on throw distance was investigated using the Domino G-200 printer, an unexpected result was obtained; there appeared to be an optimum ink viscosity where a larger throw distance could be achieved whilst still maintaining good image quality (Figure 6).

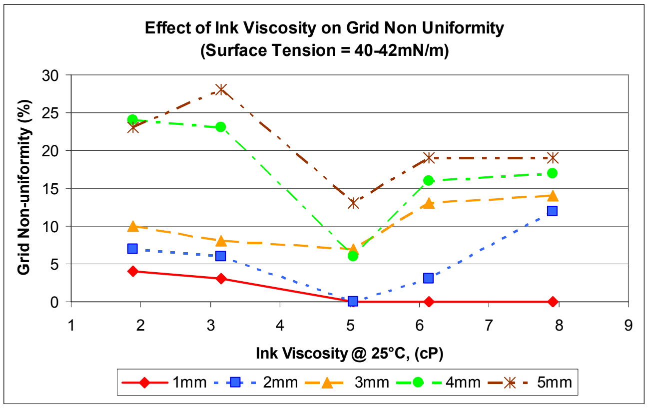

Figure 6. The effect of ink viscosity on grid non-uniformity at a range of throw distances for inks with a surface tension of 40-42mN/m using the Domino G-200 printer

When printing using ink formulations 1-5 with the G-200 printer, the optimum ink viscosity was approximately 5cP where a throw distance of 5mm could be used whilst maintaining a grid non-uniformity of less than 15% and therefore good image quality.

Investigating the effect of ink surface tension on throw distance using the Domino G-200 printer

To investigate whether the surface tension of the ink also had an effect on throw distance, ink formulations 6-10 were prepared (see Table 2), where the viscosities fell within a similar range to ink formulations 1-5 but the surface tension was maintained at a lower level of 22-23 mN/m.

When the effect of ink viscosity on throw distance was investigated using these lower surface tension inks, a similar result was seen, where an optimum viscosity was found that enabled a longer throw distance to be used (Figure 7). With this set of inks, the optimum viscosity was found to be approximately 4.7cP.

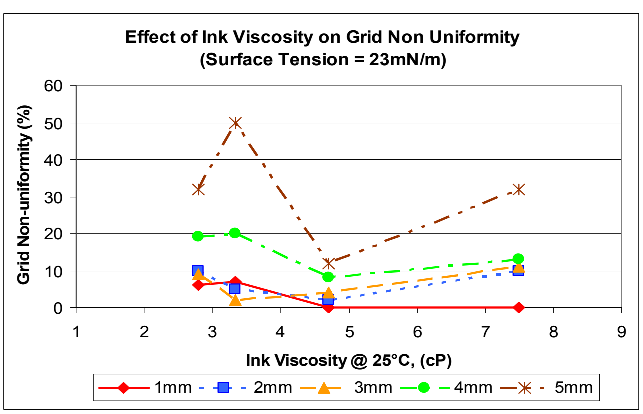

Figure 7. The effect of ink viscosity on grid non-uniformity at a range of throw distances for inks with a surface tension of 22-23mN/m using the Domino G-200 printer

Investigating the effect of the ink physical properties on throw distance using the Domino L-400 printer

To understand whether the effects of ink viscosity on throw distance were limited to a particular TIJ cartridge, the experiments were repeated using the same ink formulations with the Domino L-400 printer (Figures 8 and 9).

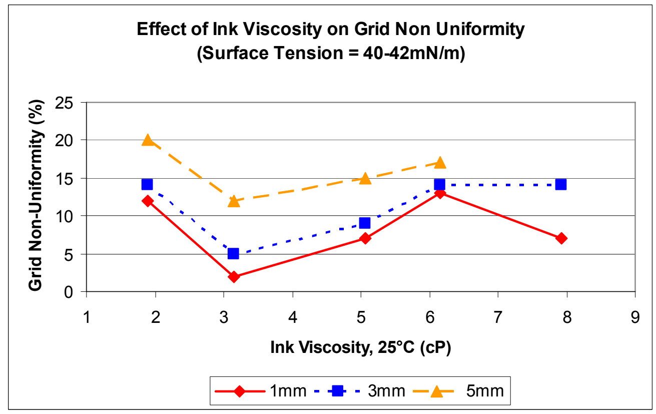

Figure 8. The effect of ink viscosity on grid non-uniformity at a range of throw distances for inks with a surface tension of 40-42mN/m using the Domino L-400 printer

Figures 8 and 9 show a similar effect of viscosity on throw distance was also seen when using the L-400 printer in that an optimum viscosity could be found to enable a longer throw distance to be used whist maintaining good image quality.

With the combination of these ink formulations in this printer, the optimum viscosity was between 3-3.5cP and therefore slightly lower compared to when the G-200 printer was used. Once again, there was no significant effect of surface tension.

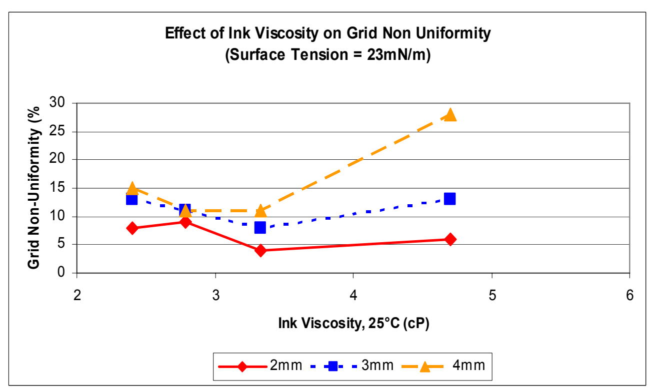

Figure 9. The effect of ink viscosity on grid non-uniformity for inks with a surface tension of 23mN/m using the Domino L-400 printer

Comparison of experimental data with model data

If it is assumed that the droplet ejected from a thermal inkjet printhead can be considered to be a free jet that is ejected in response to a pressure inside the ink chamber, and that the nozzle is efficient then the pressure inside the head can be calculated as:

$$P_i = \frac{2\sigma_i}{d_{j0}} + \frac{\rho_i v_{j0}^2}{2} + \frac{32\mu_i d_{j0}^2 v_{j0} l}{\pi d_n^4}$$

Where P_i is the pressure on the ink in the chamber
v_{j0} is the free jet velocity
d_{j0} is the free jet diameter
d_n is the nozzle diameter
l is the nozzle length
μ_i is the ink viscosity
σ_i is the ink surface tension
ρ_i is the ink density

If we assume that the pressure created for ejection is independent of viscosity then we can calculate the expected jet velocity for the range viscosities achieved with ink formulations 1-5 when printed with the G-200 printer (Figure 10).

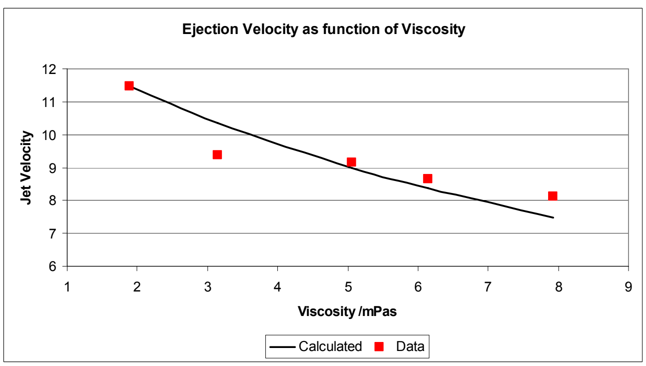

Figure 10. *Calculated vs. experimental data for ejection velocity as a function of viscosity for ink formulations 1-5 printed with the Domino G-200 printer*

Figure 10 shows a good fit to the model considering the experimental error in measurement and so we can be confident that the ejection velocity is consistent with theory.

If we assume that the volume of the ejected droplet is independent of the jet viscosity then we can calculate the drop momentum as a function of velocity for ink formulations 1-5 when printed with the G-200 printer (Figure 11).

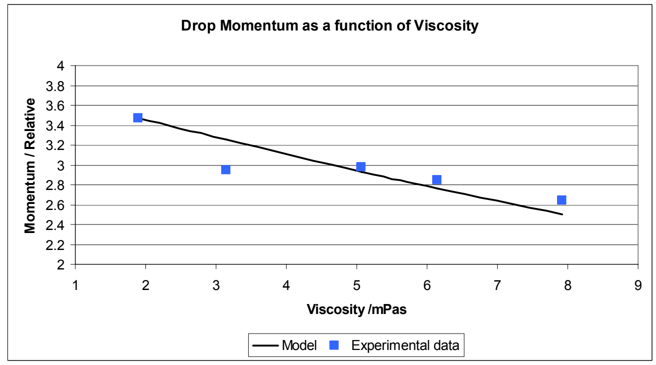

Figure 11. *Calculated vs. experimental data for drop momentum as a function of viscosity for ink formulations 1-5 printed with the Domino G-200 printer*

Drop momentum is reduced as viscosity increases, therefore we can deduce that the superior drop placement that we have observed is not a result of ejection velocity or momentum.

Conclusions

By analysing the grid non-uniformity of printed 2D-datamatrix codes using two sets of ink formulations of varying viscosity and surface tension, this study has indicated that the ink formulation can have an impact on the throw distance that is achievable with TIJ inks.

Much of the work reported by previous authors has focused on achieving a high drop velocity by modifying the waveform. However, this study has shown that lower grid non-uniformity data and therefore good image quality can be achieved when the drop velocity isn't at a maximum.

For a given ink formulation, an optimum viscosity may be found to enable a longer throw distance to be employed whilst maintaining the required image quality [2]. Surface tension has been shown to have little effect.

This effect has been shown with TIJ cartridges from two different manufacturers.

References

[1] C.Stango, N.Miller, R.Rogers, C.Tamarin, Trident International Inc, US patent US6126259, 3/10/2000

[2] J.Cross, S.Molloy, Domino Printing Science, GB Patent application June 2011

Author Biography

Julie Cross received a BSc in Chemistry from Thames Valley University in 1991.

She started her career as a formulation scientist for Kodak Limited where she worked on the development of products for a broad range of applications such as Graphic Arts Films and Inkjet media. She then moved into the Printed Electronics group and developed technology for flexible third generation solar cells before becoming a project leader working with a group to develop a proprietary vapour deposition process for applications such as TFTs.

She joined Domino Printing Sciences in 2009 where her current role is the Ink Development Manager for Drop on Demand (DOD) ink.