Optimisation of Ink Jet Droplet Formation Through Polymer Selection

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Abstract

Drop on demand ink jet printing involves the generation of ink droplets and their projection onto a substrate in response to electrical signals generated from a microprocessor. A major factor in controlling the quality of the resultant printed image is the way in which the ink droplet is formed and the consistency of this process.

This paper describes the optimisation of the droplet formation process for a piezoelectric ink jet printhead. Taking typical ink as the starting point, a range of polymers with different molecular weights and viscoelastic properties were investigated as potential modifiers of the droplet formation process. The formation and ejection of ink droplets were recorded using visualisation techniques and a structure/property correlation made between the polymer and droplet formation process. An analysis of correlation allows recommendations to be made concerning the selection of suitable polymers for incorporation into an ink formulation, either as binder or as an additive. The efficiency and reproducibility of the droplet formation process is correlated with the print quality of the final image.

Introduction

Commercially, ink jet printing is a relatively young industry. Major advances in new printhead technologies have been observed and the number of applications where ink jet shows advantages over current printing/fluid delivery systems is growing at a phenomenal rate. As this application set increases then the complexity of the demands on the ink system grows concurrently.

Typically an ink would contain a liquid carrier (oil, water or solvent), a polymeric binder, colorants (dyes or pigments) and various additives such as surfactants, pH controllers and conductivity salts.

While a significant amount of R&D effort has been put into developing colorants suitable for ink jet applications, and the range of additives available is expanding rapidly, the development of binders and polymers for the ink jet market has been much slower, and few have been tailor-made for ink jet use. As the number of these increases there is expected to be more interest from the polymer manufacturers, but as of yet little work has been published on the influence of the binder on jet formation characteristics. Worthy of mention however are some publications from Hewlett-Packard, one of which investigates the effect of polymeric additives on aqueous thermal ink jet inks.[1] Small amounts of polymer (ppm levels) were added to an aqueous ink to suppress the disintegration of the ink jet in flight and consequently reduce splatter. Relatively high molecular weight polyacrylamide was incorporated into a model ink at low concentrations. At the lowest molecular weight (500K) suppression of ligament fragmentation was observed, increasing the molecular weight to 2000K caused the ligament to be drawn into the primary drop and at higher molecular weights or concentrations the elastic stresses caused drop return. As the concentrations of these polymeric additives were of the order ppm it was concluded that the elasticity must come from the single chains i.e. intramolecular in nature. In the same way polyvinylpyrrolidone has also been investigated for aqueous inks.[2]

For solvent based industrial ink jet inks, the use of higher polymer concentrations will allow the development of many new applications. Hence it is of interest to investigate molecular weight ranges and other polymer properties to understand how they influence drop formation and print quality for these solvent-based systems.

Experimental

Experimental inks were formulated, by dissolving the polymer and, if required, colorant (Orasol RLI, available from Ciba Speciality Chemicals) in the carrier solvent with the aid of high speed shear mixing. The polymers used were Joncryl 680, 678, 67, HPD 671 and 586, which are styrene/acrylic polymers available from S.C. Johnson Polymer Ltd. These were dissolved in methoxy propanol.

Drops were characterised using the OPTICA System (supplied by VisionJet Ltd., UK). In this system the drops are recorded using a stroboscopic system to freeze the motion, images are then stored using a video camera/PC. A delay mechanism allows visualisation of the drop at different times after emerging from the faceplate. A constant delay was used unless otherwise stated.

The print head used for the experiments was a 64-channel piezo head available from MIT/Xaar Ltd., typically running at a negative ink head pressure of 2cm. This head uses the shared wall shear mode technology to produce droplets. The drops were examined at a fixed frequency of 2000 Hertz.

Image quality was quantified using the ImageXpertTM equipment available from KDY Inc. Nashua USA, or from VisionJet Ltd., UK.

Images were printed using a custom made print rig which fired the MIT shared wall printhead. The carriage speed was 14 inches per second and a print head angle of 30.9 degrees was used, to give 360-dpi resolution.

Results

The Optica images were analysed by comparing droplet characteristics. Figure 1 shows some representative images, showing the three ranks of droplets in different stages of flight. In this study the lengths of the ligaments of the two phases of droplets furthest away from the faceplate have been measured and the nature of their break up analysed. Thus ligament 1 is a later measure of the ligament length of a droplet than ligament 2.

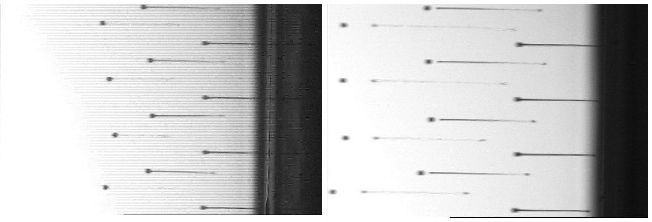

Figure 1. Jet Pictures of Inks Containing High and Low Molecular Weight Polymers

From the pictures taken the relative speed was measured from the distance between the three phases of drops (there is a constant time interval between each phase, at a given firing frequency). The features will be described in more detail in the discussion section. Speed and distance are in relative units.

Discussion

The pictures in Figure 1 illustrate the combined effects of viscosity and molecular weight on the appearance of the droplets for a given percentage solids. The left hand picture is of an ink that contains a high molecular weight polymer (viscosity 14.8 cps) whilst the right hand picture is of an ink which contains a low molecular weight polymer (viscosity 6.1 cps). Note the three phases of droplets, the shorter ligaments of the high molecular weight (high viscosity) sample and the separation of the ligaments from the drops in the low molecular weight (low viscosity) sample.

Dye Free Inks

As a model system the Joncryl polymers were dissolved in methoxy propanol at constant percentage solids. As expected the viscosity increases with increasing molecular weight. The solutions were then examined using the Optica system and parameters such as relative speed, ligament length, satellite formation were measured.

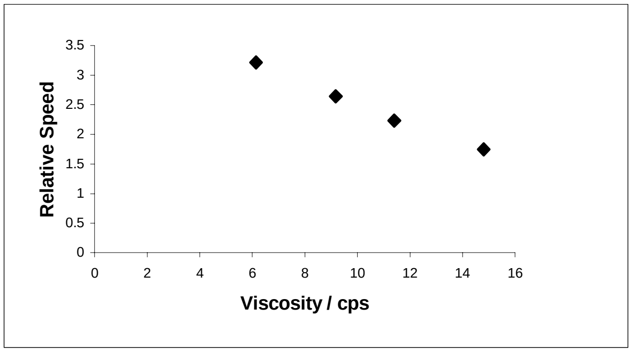

Figure 2. Drop speed vs. viscosity for constant percentage solid (by weight)

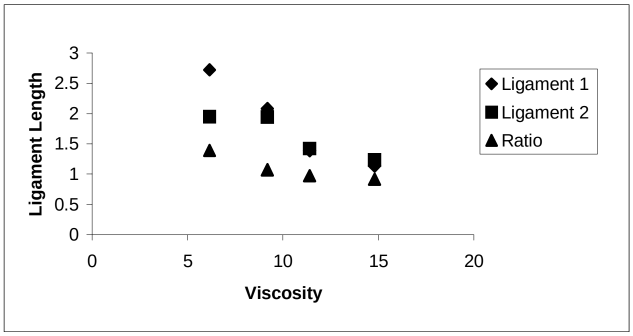

Figure 3. Ligament length vs. viscosity for a constant percentage of solids (by weight)

From the speed versus viscosity curve (Figure 2) it can be seen that the velocity of the drops decreases with increasing viscosity. More interestingly, the relative length of the ligaments changes as a function of viscosity so that at low viscosity the ligaments of the drops furthest from the printhead are longer than those closer. Whereas at higher viscosity the ligaments are much more similar in length or decreasing i.e. are not growing with increasing distance from the printhead. This could be a function of molecular weight or viscosity. At low molecular weights and for different acid number polymers, ligaments increase in length further from the faceplate at lower viscosity.

To study this further an experiment was performed on inks with high and low viscosity, and high and low molecular weight polymers, whereby the delay was varied and the ligament length measured as a function of the delay time. It was observed that at low viscosity (5 cps) for both high and low molecular weights the ligaments increased in length with increasing delay. At the higher viscosity the ligaments lengthened then contracted with increasing delay (see Figure 4). The effect was more pronounced with the higher molecular weight polymer.

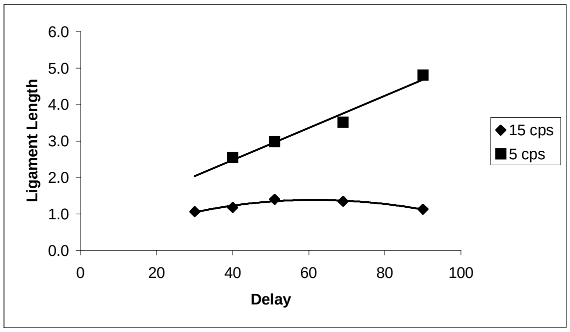

Figure 4. Ligament length vs. delay, for an ink containing low molecular weight polymer at high and low viscosity

These observations indicate that there are elastic forces present possibly due to polymer chains acting as springs and/or entanglement effects. These effects will be greater for the high molecular weight polymer, since molecular weight corresponds to chain length, for polymers of the same type, and also therefore to the degree of entanglement/coiling.

Dye Containing Inks

A black dye was added to the model ink systems to allow printing and analysis of print quality. It was decided to keep the ratio of dye to polymer constant and so ink was made at the highest required viscosity and then diluted as necessary.

Figure 5 shows a plot of speed vs. molecular weight for the three viscosities, and shows a downward trend in drop speed as molecular weight is increased. The effect is greatest for the 15 cps inks and smallest for the 5 cps inks. This can be rationalised by considering polymer concentrations in these inks – there is more polymer present in the high viscosity ink than the low one, so changes due to differences in polymer will be more pronounced.

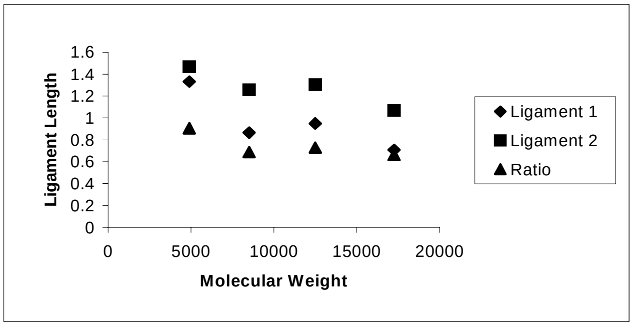

Figure 5. Drop Speed vs. Molecular Weight for 15, 10 and 5 cps inks

The downward trend itself can be understood by considering the energy required to form the droplet. For a higher molecular weight polymer, as explained above, there will be more entanglement/coiling, so it will be harder for the droplet to break away from the bulk liquid, and it will leave with less kinetic energy.

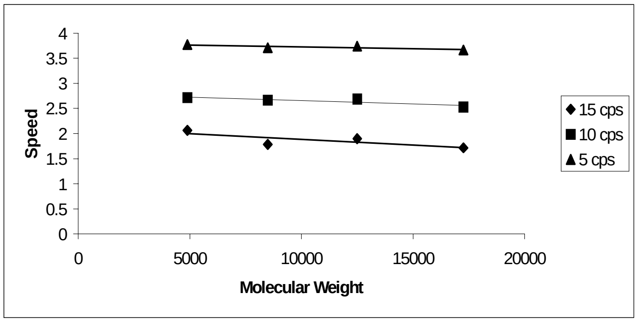

Figure 6. Ligament length vs. Molecular Weight at 15 cps

As for ligament length - at a viscosity of 15 cps it can be seen that there is a tendency for the ligaments to decrease in length with increasing molecular weight and that the ligaments furthest from the face plate are shorter than those nearer, (Figure 6). The higher molecular weight system shows a greater reduction in ligament length with distance.

At 10 cps the ligaments are similar in length with no discernible trend with molecular weight variations. (See Figure 7).

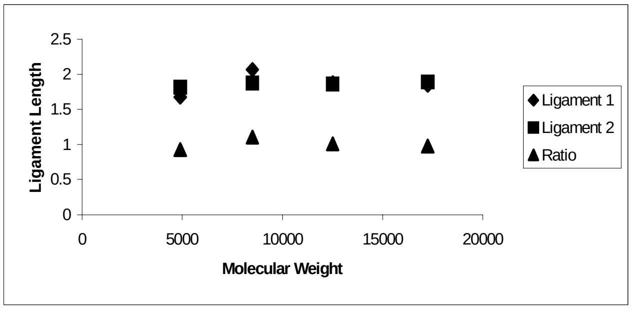

Figure 7. Ligament length vs. Molecular Weight at 10 cps.

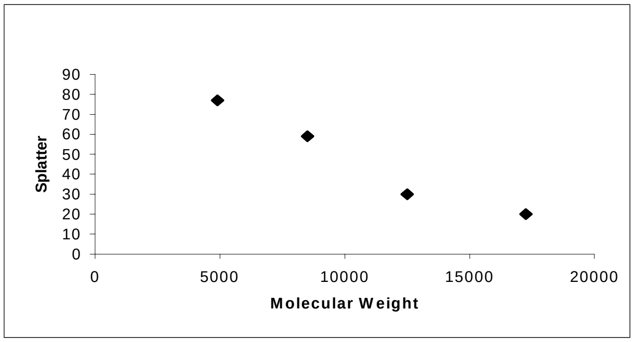

Figure 8. Ligament length vs. Molecular Weight at 5 cps.

At 5 cps ligament 1 is always greater than ligament 2 for the molecular weight range examined. (See Figure 8).

Again, this is understood in terms of an elastic effect caused by the polymer chains acting as individual springs and/or being entangled, which generates a force acting to shorten the ligament (at 15cps). This force is greatest for the higher molecular weight polymer for reasons that have already been discussed.

At 10 cps the forces for ligament extension/contraction are more closely balanced with no obvious growth or contraction of the ligament.

At 5 cps the polymer has less influence on the ligament and the ligament grows with increasing distance from the faceplate. It is also observed that the ligament splits from the main drop to form a satellite at this viscosity.

As there is a difference in behaviour at the different viscosities it is reasonable to assume that there is a polymer dependent threshold viscosity where no change in ligament length is observed.

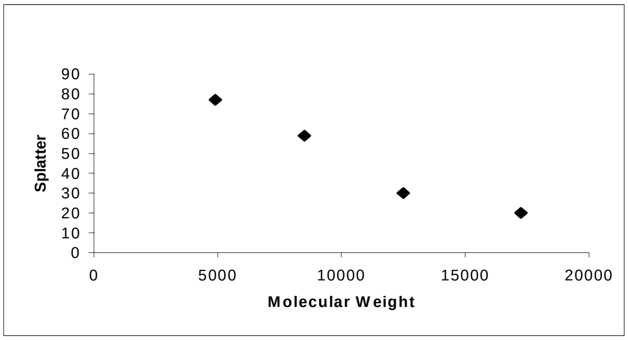

Figure 9. Splatter vs. molecular weight at a constant viscosity.

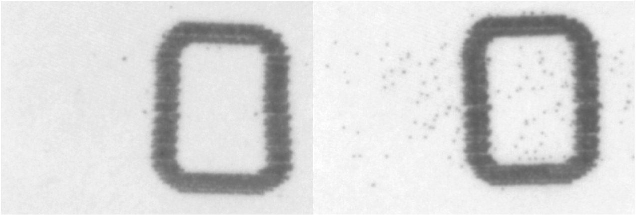

Figure 10. Image showing (a) low splatter (b) high splatter

Print Quality

To observe the effects that these changes had on print quality the inks were printed onto a coated ink jet paper via the MIT printhead, the orientation was such that 360-dpi resolution was obtained. The printed samples were then analysed using the ImageXpert image analysis equipment. This analytical tool is capable of measuring many parameters such as dot quality, roundness of dots, line quality, raggedness and splatter amongst many others. For the purposes of this work the amount of splatter was quantified by examining the number of small drops which lie off the printed image in a fixed area close to main image. For viscosities of 10 and 15 cps, understandably, very little splatter was observed, however at 5 cps considerable difference was noted between the different molecular weight polymers. Figure 9 quantifies the amount of overspray, or splatter for inks containing a molecular weight range of polymers, all adjusted to 5 cps.

It can be seen that the amount of splatter decreases with increasing molecular weight, which is consistent with the ligaments being less likely to fragment with the higher molecular weight polymer, the entanglement of the polymer chains reducing the fragmentation process.

Conclusion

The use of ink jet characterisation techniques has been shown to be a useful tool to probe the formation and development of structure within a drop. Differences in behaviour have been noted at different viscosities and by using different molecular weight polymers in inks at the same viscosity. The formation of ligaments that grow with time has been shown to produce splatter, which can be quantified by image analysis techniques. Study of the behaviour of ligament would suggest that increasing the viscosity, or the molecular weight of the polymer used, can control the elasticity of the ligament. Increased elasticity encourages the ligament to recoil back into the main drop and not fragment. Therefore, by using one polymer as the binder instead of another, the droplet forming properties of an ink can, to an extent, be varied independently of viscosity, and hence optimised for a particular application.

References

1. Meyer, Bazilevsky, Rozhkov, *Effects of polymeric additives on Thermal Ink Jet Inks*, IS&T NIP 13 1997 Proceedings page 675.
2. U.S. Patent number 5,814,683