

Imaging and Evaluation of Droplet Generation Technologies for Pigment Based Inks

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Abstract

In this paper, we present the results of our work on the jetting characteristics for both drop on demand (DOD) and continuous ink jet technologies for a variety of ink formulations. Dye and pigmented solvent and water based inks have been evaluated and conclusions are drawn based on critical ink parameters and printer configurations. We use the soluble dye based inks which have been widely used as our starting fluids and use this results as a basis to compare pigment dispersions in different vehicles. We compare the jetting characteristics and the effect of pigment dispersions on jetting characteristics and show how the jetting characteristics for pigment dispersions compare with those of solutions under "similar" conditions. Differences between the various formulations are illustrated and used to establish empirical methods for "tuning" ink and printer operating parameters to achieve desired jetting characteristics and print quality. It will be shown that by controlling these parameters, we can formulate appropriate pigment based inks to effectively work with ink jet printheads. We also study the effect of parameters like ink temperature on drop formation and printability.

Introduction

Drop on demand (DOD) Piezo ink jet printheads are widely used in a variety of digital printing applications. At present, most of these printers use water based dye inks and the print quality is governed mostly by ink penetration into the substrate. Moreover, dye based inks are generally not water resistant and do not give the quality of printing that could be achieved by pigmented inks. Recently, there has been significant progress in developing pigment based inks for ink jet applications and there are some pigment based inks which are commercially available.

In this study, we examine the jetting characteristics of pigmented inks using droplet generators of the DOD and continuous ink jet (CIJ) types. The droplet formation process and the parameters of droplet ejection are observed and measured using high resolution imaging systems. We compare the jetting characteristics of the pigmented inks with those of dye inks as well as pure solvents with different physical parameters.

Three different pigmented inks were used in this study, a black ink using carbon black as the pigment, a blue ink, and a red ink both based on commercially available dry pigments. Along with these pigmented inks, we have used a dye based ink and water glycerin mixtures of different concentration. The jetting behavior of these fluids in both the continuous droplet generator and the DOD droplet generator are imaged with a high resolution strobed imaging system. The strobe used is a high intensity solid state strobe where the duration of the light pulse could be as small as a microsecond.

Our goal is to use DOD and CIJ experimental setups to determine drop break up and then use this information to design robust ink formulations which can be validated following print trials on commercial ink jet systems.

Experimental

The physical parameters of the inks used in this study are given in Table 1. The continuous droplet generator nozzle is of 50 micron diameter with a precisely adjustable flow rate through the nozzle. The excitation was sinusoidal where the voltage and the frequency are variable. The DOD test unit is composed of a conical shape glass orifice piezo activated via a "square" driving pulse. The voltage and the duration of the pulse can be adjusted, while the system can run in single or fixed repetition rates. We used nozzles of 40 micron and 60 micron diameter for the DOD jetting systems. We observed that in high frequency repetition rate mode wetting of the glass orifice can affect the quality and reproducibility of drop formation. In this work, the system was first run in single mode and then in continuous at a frequency that matched the drop formation of the single mode.

Results

The drop break up of a continuous jet is a classical problem in physicochemical hydrodynamics. Capillary forces, under low jet velocities, cause a liquid jet to break up into small spherical drops. The situation is different under high jet velocities as the dynamic effect of the surrounding medium and the effect of viscosity on the surface become important. If the disturbance on the jet is small compared with the jet radius, a simple linear approach to the hydrodynamic stability problem is usually very successful. On the other hand, if the disturbance is large, nonlinear effects, such as those responsible for the formation of satellites, complicate the analysis.

Table 1. Physical Properties

	Viscosity (cp)	Particle Size (nm)	Surface tension (mN/m)	Conductivity (mS)	pH
Water	1		71.6		~7
I-D1	1.35		43.3	11300	9.1
20% gly	2		71.5		~7
I-P1	2.8	155.5	39.8	750	7.85
40% gly	3.2		70		~7
I-P2	4.3	675		2300	7.45
I-P3	5.75	412		1450	7.45
60% gly	8.6		68		~7

The viscosities and surface tensions of inks used in inkjet applications vary widely and to substitute one ink for another in a particular ink jet engine (even if we bypass ink media interaction concerns) is not as straight forward as one might expect.

As shown in Figure 1, in general, in the continuous ink jet type experiments, for the same frequency and driver voltage, the breakoff distance of the droplet and the distance between successive droplets increased as flow rate increased. At the same flow rate and frequency, the distance between successive droplets and droplet size slightly increased as the activation voltage increased.

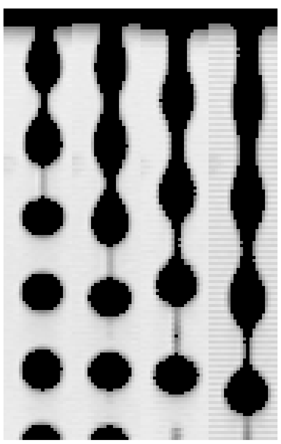

Figure 1. Drop formation for ink I-P3 at a driver voltage of 15 Volts and 4.0, 4.1, 4.8, and 5.0 ml/min from left to right.

The water and 20% glycerin in water solutions formed tadpoles with long tails. In these two cases the instability of the droplet increased as flow rate increased resulting in satellite drop formation. As shown in Figure 2, in general, the tadpole tail decreased and drop stability improved as viscosity increased.

The aqueous dye based ink (I-D1) has a viscosity between that of 100% water and 20% glycerin in water, but significantly lower surface tension than both. Its break off characteristics seem to be in between the break off results obtained for 100% water and 20% glycerin in water, respectively.

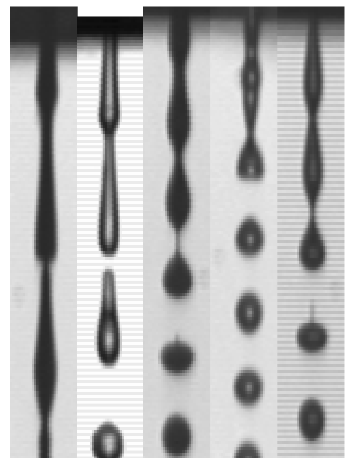

Figure 2. Drop formation at 10 Volts and a flow rate of 2.0 ml/min for I-D1, 20% Glycerin, I-P1, 40% Glycerin, and I-P2 from left to right.

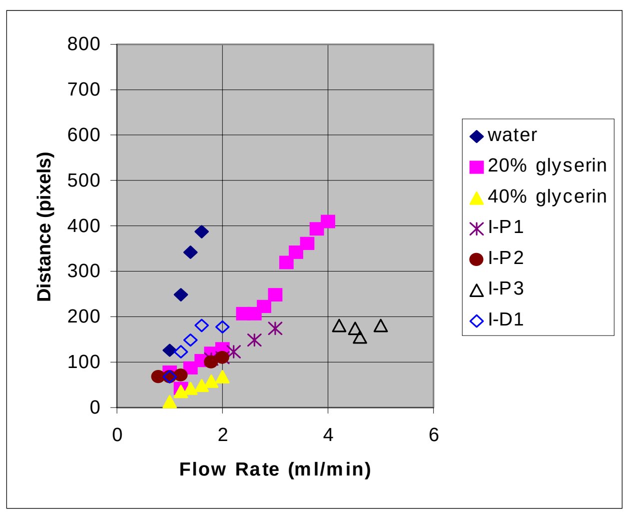

Figure 3. Distance of first drop from nozzle versus flow rare at a driver voltage of 10 Volts.

The pigment based inks had high viscosities and low surface tensions. They all exhibited short tails and stable drops. Again, as viscosity increased the drops became smaller and more frequent.

Figure 3 shows the distance of the first drop formed with the continuous ink jet system at 10 Volts versus the jet flow rate.

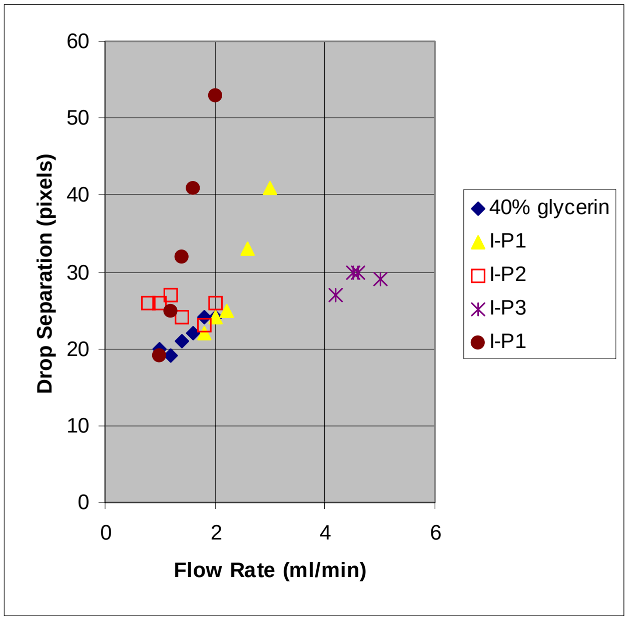

Figure 4. Separation between first and second drop at a driver voltage of 10 Volts.

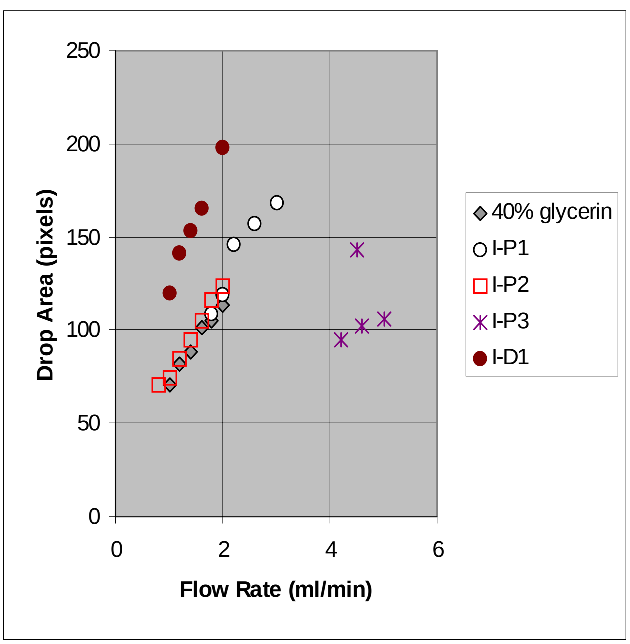

Figure 5. Drop size (average of four) versus flow rate in the continuous ink jet set up.

Distance increased almost linearly with flow rate. The increase in distance with increasing flow rate was steeper for the less viscous fluids. The separation between the first and second drop increased as flow rate increased as shown in Figure 4.

The relative increase in drop separation decreased as fluid viscosity increased. The drop separation for the high viscosity, pigmented inks seem to be indifferent to flow rate changes. As discussed at the beginning of the section, the increase in the number of drops was accompanied by a decrease in drop size. Figure 5 shows the average size of four drops for a number of fluids tested in the continuous ink jet set up.

The drop size decreased as the viscosity of the jetted fluid increased. By examining ink I-P1 and 40% glycerin in water, which have similar viscosities but significantly different surface tensions, it seems as the effect of viscosity on the drop size is more pronounced than that of surface tension.

Next we consider the results of our drop on demand experiments. In this set up we have the ability to change nozzle sizes and operate in single or continuous modes while controlling the duration and height of the driving pulse.

The following Table is a compilation of data collected for various fluids at different dwell times and dwell voltages for the driving pulse.

Table II. Drop size for drop on demand experiments through a glass nozzle of 40 microns in diameter.

Dwell Time	Dwell Voltage	Water	20% Glycerin
microsec	Volts	(microns)	(microns)
7	20	31.4	no drop
		10.0	
10	20	37.9	
		35.7	
		9.3	
20	20	32.1	31.4
5	30	17.9	no drop
		34.3	
10	30	42.9	25.7
		39.3	40.0
		30.0	47.1
		53.6	30.7
		40.0	35.0
		32.1	
40	30	40.0	37.1
40	40	52.1	47.1
40	50	25.7	23.6
		54.3	47.1

The results indicate that dwell time had to be increased in order for drop ejection to occur as the jetted fluid viscosity increased from 100% water to 20% glycerin in water. Also, as dwell voltage increased, drop ejection became unstable with multiple drops being ejected per event. Increasing the dwell time at a constant dwell voltage seems to improve drop formation.

Figure 6 shows how drop size changed with applied voltage for conditions which generated single drops. It also shows how drop size decreased as fluid viscosity increased. Table III shows similar data for a 60 micron nozzle.

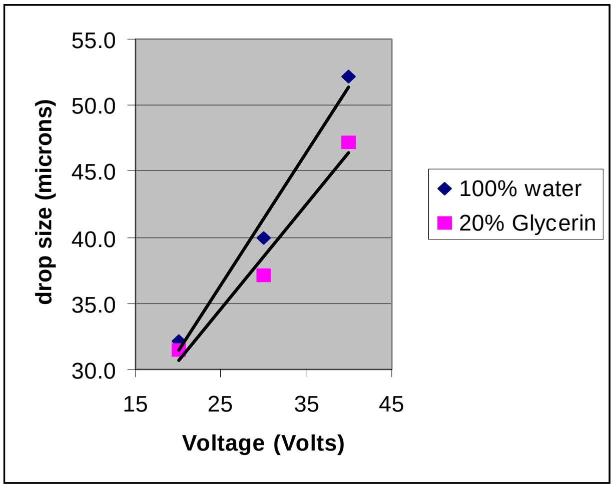

Figure 6. Drop size versus applied voltage for conditions in Table II which generated single drops.

Table III. Drop on demand data.

		Average feret size		
Dwell Time microsec	Dwell Voltage Volts	Water (microns)	20% Glycerin (microns)	I-P1 (microns)
30.0	40.0	27.1	22.7	
		43.9	43.2	
50.0	40.0	39.5	33.7	
30.0	50.0	33.7	22.7	44.6
		26.3	45.4	
		53.4		
50.0	50.0	39.5	55.6	26.3
			18.3	30.7
30.0	60.0	45.4	12.4	27.8
		35.1	39.5	41.0
		40.2	30.0	
			53.4	
50.0	60.0	66.6	46.1	20.5
			47.6	34.4
				44.6

We noticed that the drop break off characteristics changed as ink parameters changed. This is shown in Fig. 7.

For the high viscosity pigmented I-P1, and I-P2 inks the drop formation at a dwell time of 60 microseconds and a dwell voltage of 60 Volts shows long tails on one of drops forming. The same was not true for the 20% Glycerin in water solution. This may be due to the high extensional viscosity of I-P1 and I-P2.

Results on the effect of temperature on drop formation will be reported in subsequent publications.

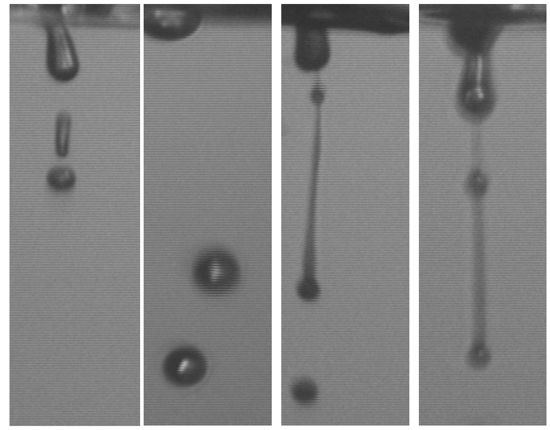

Figure 7. Drop formation for 20% Glycerin in water at initial and later stage of drop formation, and I-P1 and I-P2 at initial stage.

Conclusions

We have established techniques for measuring the drop formation characteristics of various ink formulations. From our continuous ink jet set up we have seen that viscosity is a major controlling parameter in drop formation. We have also noticed that our pigmented formulations exhibited more stable threads. We theorize this to be due to an increase in the viscosity of the outer phase of the drop. Similarly a thread could become more stable by decreasing the interfacial tension or by decreasing the radius of the thread. Differences were also noted in our drop on demand experiments. The number of drops being ejected and the tailing characteristics changed as ink parameters changed. The drop on demand set up in single or repetitive modes has a great potential to be used for ink quality and ink runnability testing.

Biography

Georgios D. Karles is a senior research staff with Philip Morris working on evaluating new packaging technologies and creating and validating packaging specifications. Prior to his employment with Philip Morris he worked for five years at the corporate R&D of International Paper.

Arup K. Basak is a research staff member with the Digital Printing Group at Philip Morris USA, R & D Center, Richmond, Virginia. His research interests include solution chemistry, reaction mechanisms, chemical synthesis, thermodynamics and physical chemistry.

Henry M. Dante is currently at Philip Morris research and development where he is working on implementing digital printing technologies. He has been with Philip Morris from 1989 where he has worked on developing vision systems, process control, modeling and simulation and implementing new technology.