Dynamics of Droplet Forming in Ink Jet Printer

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Abstract

The process of ink droplet formation in ink jet printing was observed by a micro image monitoring system synchronized with a printer head driver. Two types of jet ink, dye solution type and pigment suspension type were investigated.

The jet forming process is associated with viscoelastic properties of jet ink. Therefore, rheological properties of jet inks have been discussed. The printed dot pattern was observed using a specially designed dynamic simulation system. The effect of scanning velocity of printer head on dot pattern was investigated in connection with satellite formation. In order to evaluate the print quality on a paper, we used three parameters; 1. fractal dimension for dot outline, 2. optical density, 3. ratio of dot and droplet diameter.

The useful information for printability of ink jet printing was obtained.

Introduction

Ink jet printer is a widely used non-impact printer and their print quality depends on characteristics of ink and paper. At present, a water-based dye ink is widely used in ink jet printing and the quality of printed image is governed by ink penetration behavior. In order to obtain a good quality of print image, we have to use special coated paper. Recently, pigment type of jet inks are investigating from a viewpoint of printability.

In this study, we intend to examine rheological and physicochemical properties of various types of jet inks and discuss about ink droplet formation process in connection with the basic properties of jet inks.

The process of ink droplet formation in ink jet printing is observed by the micro image monitoring system synchronized with a printer head driver.

Experimental

1 Jet Formation Monitoring System

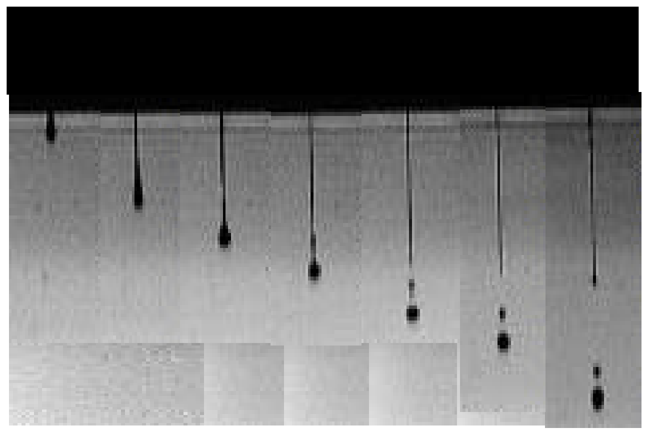

Figure 1. Image of ink jetting (for pigment type ink1)

The jetting of ink was observed as a still image by synchronizing the timing of ink jetting and stroboscope flashing. It was investigated just from nozzle to ink droplet forming. The image monitored by this system was showed in Figure 1.

2 Specially Designed Dynamic Simulation System

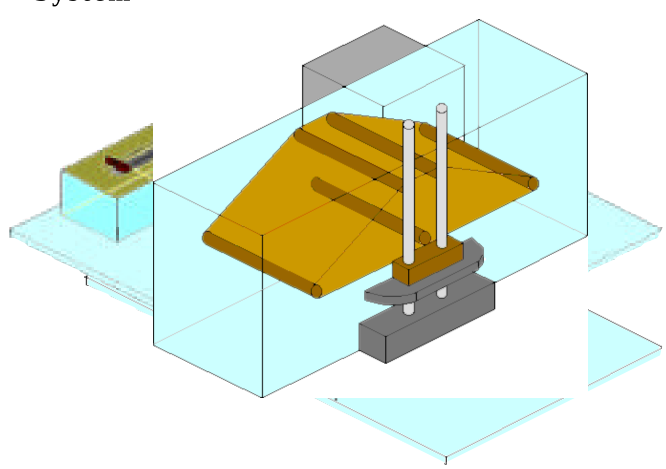

Figure 2. Schematic diagram of Specially Designed Dynamic Simulation System

In order to obtain the dot image on paper, we constructed to Special Designed Dynamic Simulation System, which consists of driving unit, printer head and precisely distance adjustment unit. The paper under the printer head is fed and driven at constant velocity ranging from 0.31(m/s) to 0.68(m/s). By using this apparatus, the effect of scanning velocity to print quality (the shear in printing, effect of satellite) was measured.

3 Samples

Table 1 Sample properties

Carbon black	Mean diameter	Surface functionality
CAB-O-JET™ 200	0.118μm	Sulfonated
CAB-O-JET™ 300	0.163μm	Carboxylated

Two types of jet inks were used. One is water based black ink with dye as a coloring material (FIT). The others are water based pigment inks with carbon black ; CAB-O-JET (CABOT Co.). Two types of carbon black shows in Table 1 are used.

These pigments are easy to incorporate into aqueous systems and pigment stability is achieved through ionic stabilization.

Concentration of carbon black in aqueous suspension of CAB-O-JET 200 is 19.6% and that of CAB-O-JET 300 is 15.2%.

Figure 3 shows the ζ potential in aqueous suspensions of these carbon blacks.

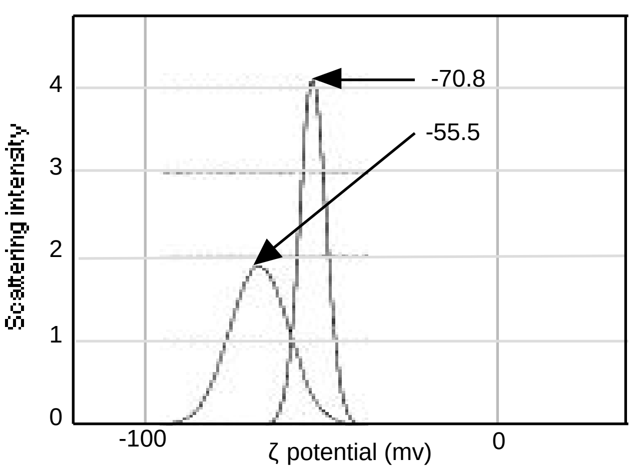

Figure 3. The relation between ζ potential and scattering intensity

Results

1 Steady State Viscosity

Figure 4 shows logarithmic plots of apparent viscosity against rate of shear for CAB-O-JET 200 and 300. Generally, the surface characteristics of carbon black are very

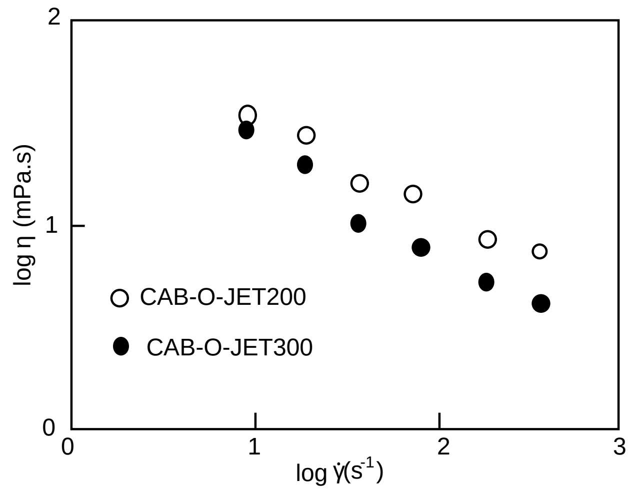

Figure 3. Logarithmic plot of viscosity against rateof shear measured at 298K

active, then the carbon black particles form flocculated structures in concentrated suspensions. The concentrated suspensions show peculiar rheological behavior such as pseudo plastic flow, thixotropy, rheopexy, remarkably shear-thinning behavior due to breaking down and reformation of the flocculated structure and the viscosity of the system is comparatively high. However, the value of viscosity of this disperse system is rather small, considering the weight fraction of carbon black. Furthermore, it is interesting the small value of viscosity to show a shear thinning behavior. The values of viscosity of CAB-O-JET 200 are larger than those of CAB-O-JET 300 in the experimental shear rate region.

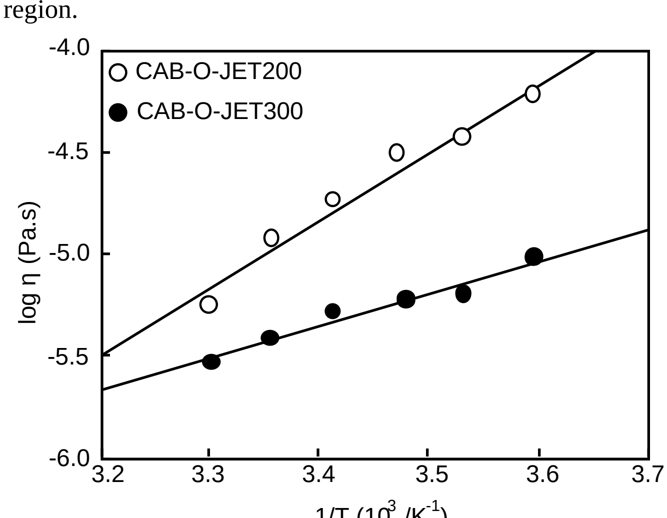

Figure 5. Arrhenius plots of viscosity for CAB-O-JET 200 and 300

Flow characteristics can also be investigated by a flow activation energy which is calculated from temperature dependence of viscosity applying the Andrade equation.

Figure 5 shows the plots of log η against reciprocal absolute temperature for the CAB-O-JET inks. From these results, the activation flow energy for CAB-O-JET 300 was determined as 12 kJ and that for CAB-O-JET 200 was determined as 27 kJ. For the CAB-O-JET ink, though the value of viscosity is smaller, the value of the activation flow energy is extremely large. It is thought that the flow mechanism for these disperse systems is special. Since higher ζ potential brings about repulsion among particles, pigment dispersibility and stabilization are improved but the flow mechanism becomes to depend on rate of shear and temperature. On the other hand, the dependence of viscosity on concentration is remarkable in CAB-O-JET system, especially in CAB-O-JET 200.

2 Several parameters in droplet formation

For dye solution type ink, we pointed out previously that the jetting velocity decreased and the ink extension increased with increasing viscosity.

In this study, we examined the relation between the concentration and the velocity of ink droplet for the pigment type inks. The velocity of ink droplet decreased with increasing concentration irrespective of the type of carbon black as indicated in Figure 6. This tendency seems to depend on the ink viscosity. Furthermore, with increase concentration, the printer nozzle becomes to clog up with pigments. This is very serious problem for pigment type of jet inks.

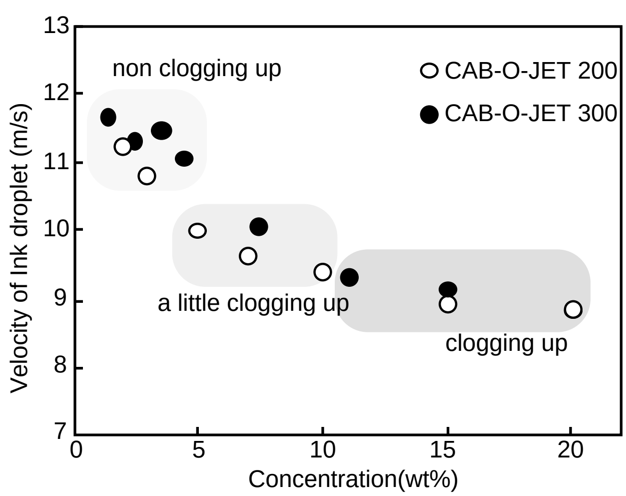

Figure 6. Concentration dependence of droplet velocity and clogging up at printer nozzle

3 Evaluation of printability

We propose to use the triangle form the vertex of which is three parameters to do the general evaluation of the print quality.

3.1 Fractal dimension

Fractal dimension is convenience to evaluate complexity of the shape. Fractal dimension is applied to describe the

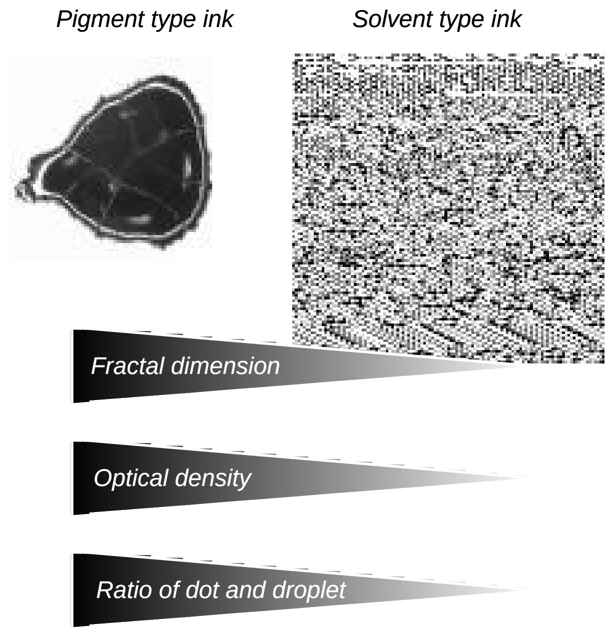

Figure 7. The difference of printed dot form on PPC paper

irregularity of printed dot pattern.

We can determined the fractal dimension from the slope in the plot of the radius of circle, r against the number of circles that covered whole outline, $N_{(r)}$ as equation (1).

$$\log r / \log N_{(r)} \qquad (1)$$

If the outline shape of dot pattern was circle, the fractal dimension is 1 and the value of fractal dimension becomes larger with its complexity.

3.2 Optical density

In this study, the optical density was evaluated by 100 steps; the density of most black portion of printed dot was refined to 1, and that of the paper stock was refined to 0.

The optical density of the edge portion of printed dot pattern is rather small and this tendency seems to associated with ink penetration.

3.3 Ratio of dot and droplet diameter

The ratio of dot and droplet diameter was calculated as follows :

$$\text{Dot diameter / Droplet diameter} = \text{Ratio of dot and droplet} \quad (2)$$

According to "Imaging", the ratio yield to approximately 2 then we refer the ratio as the most probable ratio.

The value obtained by this equation against the value by the most probable ratio were used.

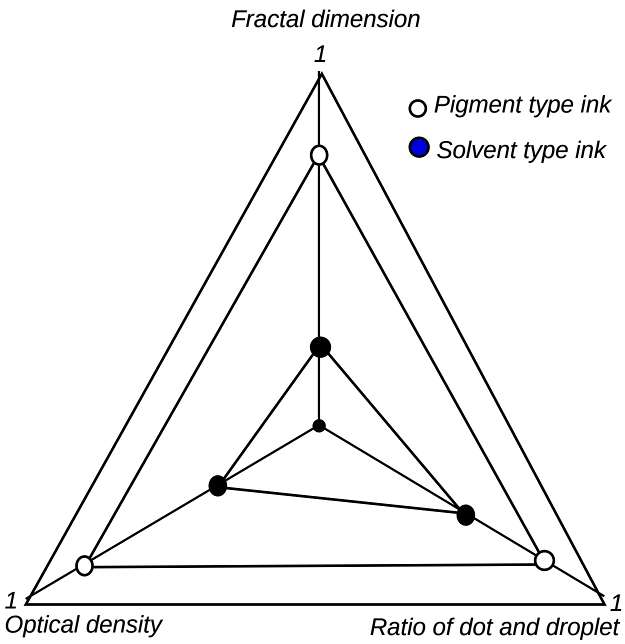

Figure 8. Evaluation triangle composed by 3 parameters for two type inks on PPC paper

3.4 Evaluation Triangle for printability

The printed image was evaluated by fractal dimension of the edge line of the dot pattern, optical density of the dot pattern and the ratio of the printed dot and ink droplet diameter.

The characteristics of pigment type inks used this study were similar. But the steady shear viscosity and surface tension of dye solution type ink were different compared with these of the pigment type inks.

Print quality of the printed dot pattern was investigated by using three parameters for the two types of ink on PPC paper. Up to now, the print quality was evaluated by several parameters independently. However, we intend to propose the generea evaluation method using the combination of three parameters. The evaluation triangle with the apex, corresponding to three parameters, describe the quality of dot pattern quantitatively.

We evaluated three parameters of printability by the position on the line from the center of triangle to each apex, namely the point on the center means poor and that on the apex is excellent.

Figure 8 shows the evaluation for the sample of dotted patterns on PPC paper. The area of triangle for pigment type ink is larger than that for dye solution type ink. We understand the print quality of each printed pattern using this triangle clearly. Further more, in this study, the difference of print quality becomes more pronouns considering the scattering of the data.

Conclusion

It is obvious that the rheological properties of jet ink effect the jetting formation process remarkably. The rheological properties of the pigment type of jet ink differ from that of the dye solution type jet ink, thus the jet forming behavior and the print quality seem to be different from there of dye type inks.

The evaluation that used the area of triangle is very useful for print quality quantitatively.

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Biography

I received my B.S. and M.S. in Image Engineering from Chiba University in 1994 and 1996, and now I have studied D.S. in Science and Technology department of Chiba University from 1996.

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