Ink Concentration Control System for Continuous Ink Jet Printers

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Abstract

Continuous ink jet printers have been widely used for industrial marking such things as bar codes and product dates. An electronically controlled drop to ensure accurate printing positioning carries out the printing. An ink concentration control system has been developed to improve stability of the drop formation and printing quality. The key features are a unique in-line viscometer and an ink concentration control system. The ink concentration is constantly monitored by measuring ink viscosity and temperature, and the ink concentration control system can always maintain the concentration accurately by adjusting the ratio of solvent in the ink. The viscometer consists of a plunger moving vertically in a cylinder, a solenoid to raise the plunger by electromagnetic force and a proximity sensor to detect the position of the plunger. The ink viscosity can be calculated by the fall time of the plunger from the top to the bottom in the cylinder. The viscometer can measure it rapidly (in a few seconds), precisely, and automatically. Also, the reliability of the viscometer can be improved by measuring the fall time of the plunger repeatedly in a short period.

Introduction

In continuous ink jet printers (CIJs),[1,2] the drops ejected continuously from the nozzle are charged and deflected by an electrostatic field. Characters are printed by deflecting charged drops vertically relative to the moving target.

The characteristics of ink may contribute greatly to the printing quality. The ink viscosity is an especially important characteristic for drop formation and charging.

CIJs generally use fast-drying inks so the ink vaporizes in a nozzle as the jet is stopped. Therefore, pure solvent is poured into the nozzle in a shutdown sequence to prevent it from clogging up. Because the pure solvent is mixed with the ink in the nozzle, the ratio of the solvent in the ink always changes. The characteristics of the ink are very important to ensure proper drop formation and print quality. Therefore, a control system for the ink characteristics is necessary.

Several ink control systems were introduced, and they control most of the characteristics of the ink by measuring the viscosity. The previous viscometer, however, cannot examine the accuracy of the measurement by itself. So, if a viscometer is defective, the ink control system cannot be controlled to an accurate concentration.

Therefore, we developed a new ink control system to improve the reliability of ink control. The system has a unique viscometer and an ink concentration controller. The ink viscosity is measured quickly by the viscometer, and the desired ink concentration can be obtained by controlling the ratio of solvent in the ink based on a measurement of the viscosity.

Ink System

Figure 1 shows a schematic diagram of the ink system for CIJ. This system has an ink circulation system and an ink concentration control system. The circulation system consists of a supply line from the main tank to the nozzle and a return line from the gutter to the main tank. Ink in the main tank is moved by a pump and flows to the nozzle. The nozzle uses an ultrasonic vibration to break a pressurized ink stream into small drops. The drops are generated continuously from the nozzle at high speed. Each drop is selectively charged at an electrode that is applied to a signal based on the character data. When drops pass through the deflection electrode, their course is changed in proportion to their charge. After the drops leave the region of the deflection electrode, they continue to travel to the target. Drops that are not used for printing are caught by the gutter and subsequently recycled back to the main tank.

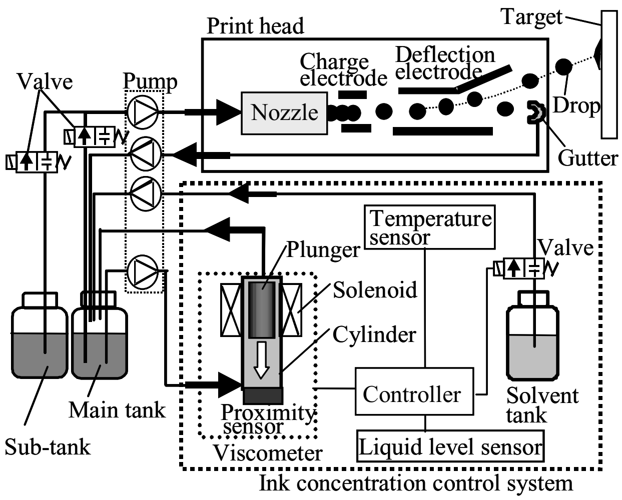

Figure 1. Schematic diagram of ink system for CIJ.

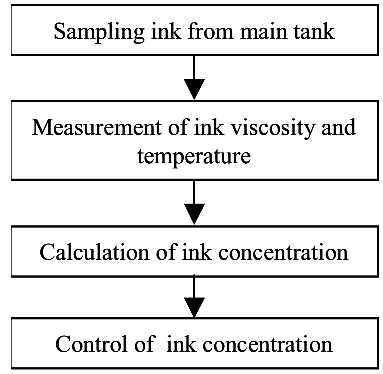

Figure 2. Flowchart of ink concentration control.

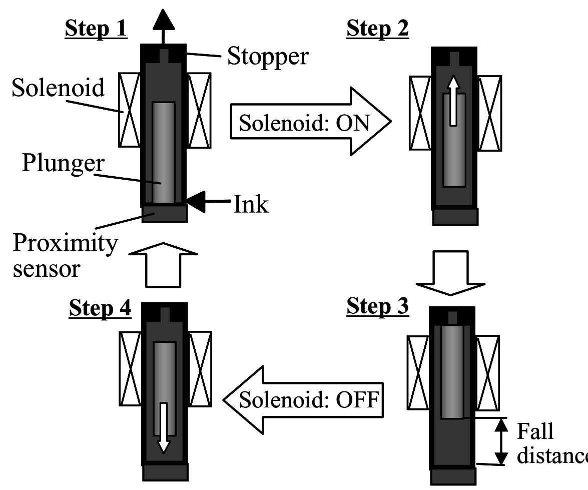

Figure 3. Schematic diagram of viscometer.

The ink concentration control system was developed to adjust the ink concentration in the main tank. This system consists of a viscometer, a controller of valves, and a liquid level sensor to supply fresh ink and solvent in the main tank. Figure 2 shows a flowchart of the ink concentration control. First, the ink in the main tank is introduced to the cylinder of the viscometer. The ink viscosity is measured. The ink concentration in the main tank is calculated from the ink viscosity and temperature. Finally, the ink in the main tank is adjusted to the optimal concentration by supplying fresh ink and/or solvent. They are supplied to make up for the decrease in the main tank due to printing and solvent volatilization. The amount of fresh ink and/or solvent to be supplied is restricted by the liquid level sensor so as not to exceed an initial liquid level in the main tank.

The measurement of the ink viscosity and the control methods of the ink concentration are discussed next.

Measurement of Ink Viscosity

Figure 3 shows the components and the measuring process of the viscometer. It consists of a plunger moving vertically in a cylinder, a solenoid to raise the plunger by electromagnetic force and a proximity sensor to detect the position of the plunger. The measurement process of the viscometer is as follows:

Step1: The ink in the main tank is poured into the cylinder by using the pump.

Step2: The solenoid is turned on, and the plunger is lifted by the magnetic force from the bottom to the stopper in the cylinder.

Step3: The solenoid is turned off, and the plunger free-falls to a fall distance.

Step4: The plunger is detected at the bottom of the cylinder by the proximity sensor.

The ink viscosity is led from the fall time. The fall time is the time needed for the proximity sensor to detect the plunger from the point the solenoid was turned off.

Figure 4 shows the relationship between the fall time and viscosity. The fall time was measured five times repeatedly. The liquid is the standard one for calibrating viscometers of Japanese Industrial Standards. Table 1 shows its characteristics. The relationship between the fall time, T_f, and viscosity of the liquid, η, is linear. This relation can be described as

$$T_f = \alpha \eta, \tag{1}$$

where α is a constant. In figure 4, α is estimated to be 0.5 from a least mean square approximation. The variation in fall time, which is a standard variation of fall times divided by the average, is less than 2%. We found that this viscometer is precise in its measurements. The fall time is influenced by foreign substances and air bubbles in the cylinder, especially in the gap between the cylinder and plunger. If the measurement of the fall time has great error, the ink concentration may be misread. Therefore, it is very important to examine the accuracy. In this viscometer, the foreign substances and air bubbles in the cylinder make the variation in the fall time increase substantially. Thus, the accuracy of measurement could be examined by the variation. Because the viscometer can measure ink viscosity repeatedly, the variation can be found easily by calculating it.

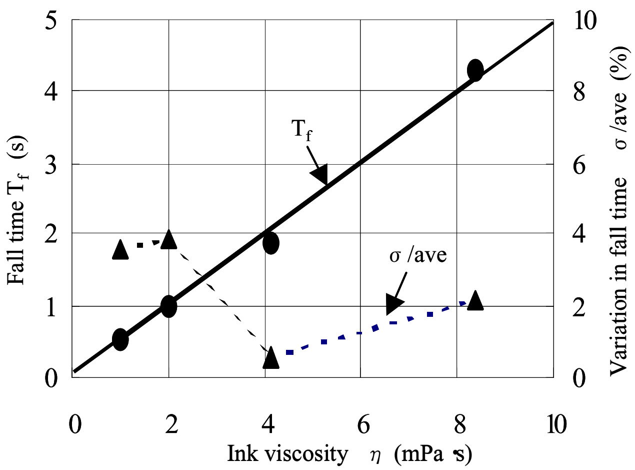

Figure 4. Relationship between ink viscosity and fall time.

Table 1. Viscosity of standard liquid for calibrating viscometers of Japanese Industrial Standards (Unit: mPa · s)

Name	20°C	30°C	40°C
JS2.5	1.966	1.614	1.352
JS5	4.109	3.177	2.532
JS10	8.361	6.070	4.588

When the variation exceeds 2%, we know that there is a problem in the measurement. In that event, the ink in the cylinder may be replaced, and the measurement may be retried until the variation falls to 2% or below. Our viscometer in this way has the advantage of higher reliability.

Calculation of Ink Concentration

Ink viscosity depends heavily on the temperature and ink concentration. The optimal ink concentration should be determined based on the stability of the drop formation and printing quality. The concentration should be controlled within a deviation of ±5 wt% of the initial ink concentration. Figure 5 shows the relationship between the temperature and viscosity in ink concentrations of 95 wt%, 100 wt%, and 105 wt%. Here, ink concentration, D, is defined as

$$D = (1 + \Delta Wd/Wd)/(1 + \Delta Ws/Ws) \times 100, \quad (2)$$

where Wd is the initial weight of the dye in the ink, ΔWd is the deviation of Wd, Ws is the initial weight of the solvent in the ink, and ΔWs is the deviation of Ws. D = 100 wt% indicates the initial ink concentration. D > 100 wt% indicates that the ink is more concentrated than the initial ink, while D < 100 wt% indicates that the ink is less concentrated.

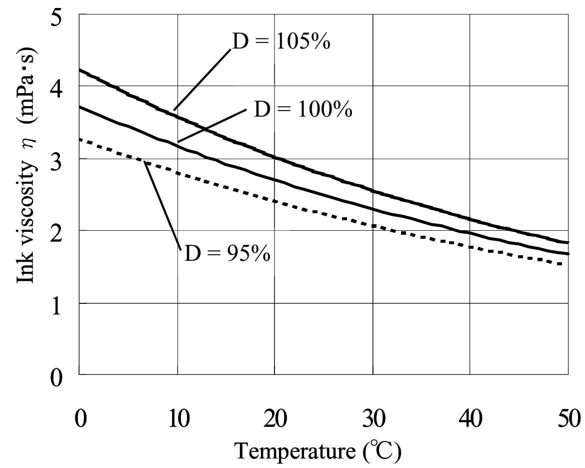

Figure 5. Relationship between temperature and viscosity of ink.

The viscosity, η, of the ink may be expressed by the equation

$$\eta = \alpha \exp(\beta T), \quad (3)$$

where α, β is constant, depending on the ink concentration, and T represents the temperature of the ink. In this study, we made a reference table for every 0.25% in the ink concentration so that we could get the ink concentration from the viscosity and temperature.

Control Methods of Ink Concentration

Ink concentration control has three methods: decreased control, maintained control and increased control. One of the three methods can be executed selectively based on the measurement of the ink concentration. The ink concentration, D, in the main tank should be maintained between the lower limit, D_{min}, and the upper limit, D_{max}.

When D > D_{max}, decreased control is executed to make the concentration less than D_{max}. Only the solvent in the solvent tank is pumped into the main tank up to the initial liquid level of the main tank. Ink in the main tank is diluted, and the ink viscosity is decreased. This control can be continued until D becomes less than or equal to 100 wt%, and then it is maintained between D_{max} and D_{min}.

In maintained control, both fresh ink and solvent are supplied to the main tank. The controller counts the drops used for printing since the last compensation and opens the valve to supply fresh ink to the nozzle until the drops ejected from it correspond to the counted drops. After that, the solvent is supplied up to the initial level of the main tank. In this way, as fresh ink equivalent to the ink used for printing and as solvent equivalent to the solvent loss due to the volatilization are supplied, it can be set in an ink concentration that is the same as the last compensation.

When $D < D_{min}$, increased control is executed to be more than D_{min}. Only fresh ink in the sub-tank is supplied up to the initial level of the main tank. Thus, the ink in the main tank can be concentrated and can have increased viscosity. Also, this control can be continued until D becomes more than or equal to 100 wt%, and then D is maintained within the range of $D_{max} \geqq D \geqq D_{min}$.

We assessed the performance of the ink concentration control. In this test, we set D_{max}= 102 wt% and D_{min}= 98 wt%. The solvent and ink were consumed at about 1.3 wt%/hour and 2.9 wt%/hour of the ink in the main tank. Measurement and control were executed every 20 minutes. If the controller could not obtain an accurate viscosity, maintained control was executed to prevent an incorrect measuring viscosity from adjusting the ink concentration.

Figure 6 shows the results of decreased control and maintained control. The initial ink concentration was 105 wt%. In this experiment, the quantity of the solvent to the supply was 4.2 wt%/hour of the main tank. Decreased control was continued until the ink concentration was less than 100 wt%. After that, maintained control was executed as long as the ink concentration was within 100±2 wt%. The concentration reached below 100 wt% within 100 minutes and was maintained within 100±2 wt% for more than three hours. Decreased control adjusted 3 wt% an hour of the ink concentration.

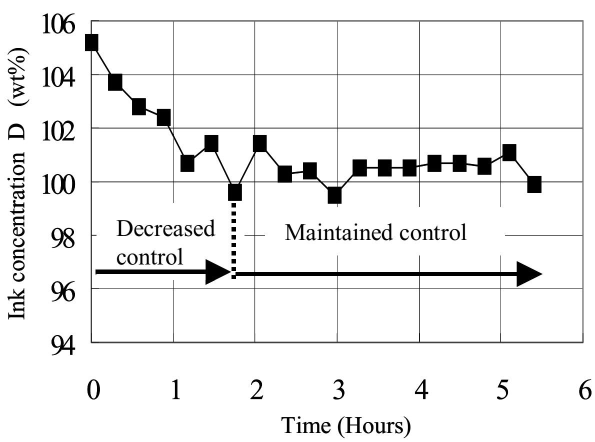

Figure 6. Results of decreased and maintained control.

Figure 7 shows the results of increased control and maintained control. In this experiment, the quantity of the ink to supply was 4.2 wt%/hour of the main tank. Increased control was continued until the ink concentration was more than 100 wt%. After that, maintained control worked, and the concentration could be controlled within 100±2 wt%. It was adjusted from 95.5 wt% to 100 wt% within 140 minutes. This control can adjust 1.9 wt% an hour of ink concentration.

As already described, this system is applicable not only for decreased and increased control but also for maintained control. Even if the viscometer does not work well, the ink concentration can be controlled within ±2 wt% by executing maintained control. As a result, we can say that this system can make the ink concentration stable under any conditions.

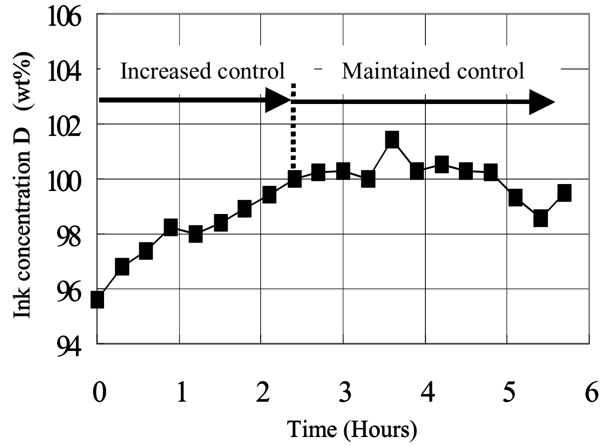

Figure 7. Results of increased and maintained control.

Conclusions

We developed an ink concentration control system to improve the stability of drop formation and printing quality. This system consists of a new in-line viscometer to find ink concentration and a controller to adjust ink concentration by supplying fresh ink and/or solvent.

1) This viscometer has the capability to examine the accuracy of the measurement because a variation in the measurements can be obtained easily by measuring repeatedly.
2) Ink concentration control, which is performed by adjusting the supply rate of the ink and the solvent, has not only decreased and increased control but also maintained control. This technique is effective when there are problems in the viscometer. These control methods can control ink concentration within ±5 wt% of initial ink concentration.

References

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2. T. Inoue, et al., J. Info. Storage Proc. Syst., 1, **203** (1999).

Biography

Tomohiro Inoue is a researcher in the Mechanical Engineering Research Laboratory of Hitachi, Ltd. He received his B.E. and M.E. in mechanical engineering from the Tokyo University of Science, Japan, in 1990 and 1992. He has been working on continuous ink jet printers for industrial marking. His work is focused on the stability of drop formation and on flying drops for improving printing quality.