Mechanism of Liquid Development Using Highly Concentrated Liquid Toner

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Abstract

A liquid development system using highly concentrated liquid toner was developed. This system can develop a latent image in a small development area, and it does not increase the complexity of the printer equipment. The mechanism of liquid development using a highly concentrated liquid toner is examined with simple developing model based on electrophoretic theory. The mobility of toner particles that was measured by using the electrophoretic deposition method and used to evaluate the properties of the liquid toner. The method could successfully determined the minimum developing bias potential needed for a good quality image without fog. It is concluded that a highly concentrated liquid toner has shorter development time.

Introduction

In recent years, demand for high-quality short-run printing has increased, and a liquid development process using liquid toner can meet this demand because it can achieve good image quality and high resolution. The liquid toner consists of an insulating liquid carrier and charged submicrometer toner particles suspended in the carrier. The liquid toner contacts the electrostatic medium where the latent image is formed and develops it faithfully by electrophoresis.

The conventional liquid development process uses a low toner density, typically less than 1 wt%. To obtain enough toner particles to develop the latent image, it is necessary to supply a large quantity of fresh liquid toner to the development area. And the conventional process requires a toner circulation system and a toner-density control unit, which make the printer equipment complex. Moreover, consumption of such a large quantity of liquid toner causes dispersion of the liquid carrier.

To reduce these problems, the authors developed a liquid developing unit using a highly concentrated liquid toner with a density of over 10 wt%. We reported in an earlier paper that the new developing system could eliminate fog by applying an optimal developing bias potential, between the electrostatic medium and the developing roller, and other optimal developing conditions.

In this study, to understand the mechanism of liquid development using highly concentrated liquid toner, a simple developing model based on the electrophoretic theory was applied. The mobility of toner particles was measured by the electrophoretic deposition method and used to evaluate the properties of the liquid toner. Time constant of development and minimum development bias potential to avoid fog were estimated by the method.

Model of Liquid Development

Figure 1 shows a model of liquid development. A latent image is formed on the electrostatic medium and charged toner particles move toward the image and electrically deposit on the medium.

It is assumed that toner particles are subjected to Coulomb force and Stokes drag during electrophoresis, optical density D at time t and time constant of development τ are therefore given

$$D = D_f\{1-\exp(-t/\tau)\} + D_i \tag{1}$$

and

$$\tau = (C_s + C_l)L_l/(avQ_p + \sigma), \tag{2}$$

where D_f is saturated optical density, D_i is initial optical density, C_s is capacity of electrostatic medium, C_l is capacity of electrostatic ink, a is initial toner density of electrostatic ink, v is mobility of toner particles, Q_p is charge density, and σ is leak current.

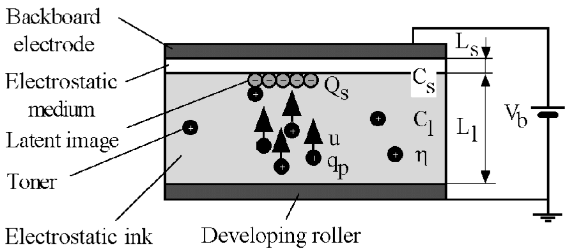

Figure 1. Model of Liquid Development

Experimental Apparatus

Figure 2 shows a schematic view of the experimental apparatus. The ink tank is filled with highly concentrated liquid toner in which the developing roller is partially immersed. A lamina of liquid toner forms on the rotating roller, and the thickness of the lamina is kept within the allowed range by the filming blade held against the roller. The backboard electrode is grounded, and a developing bias potential Vb is applied between the roller and the electrode. The electrostatic medium on which the latent image is formed passes between the roller and the electrode at speed vp while the developing roller rotates, opposite to the direction the medium is carried, at speed vd. There is a development gap δd between the developing roller and the electrostatic medium.

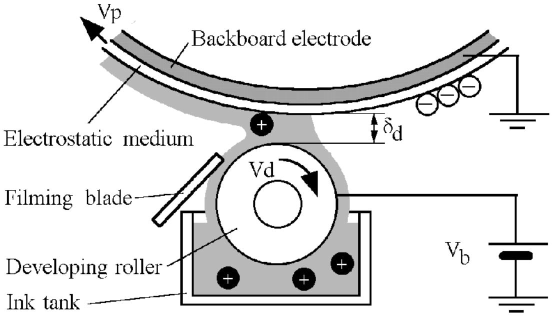

Figure 2. Schematic view of experimental apparatus

Using this experimental apparatus, we developed latent images on the electrostatic medium and measured their optical density in order to investigate developing characteristics under various developing conditions.

Development test were performed on liquid toner with several toner density. (5-20 wt%) The contents of the toner particles were the same.

Developing Conditions and Their Developing Characteristics

Figure 3 shows the relationship between the surface potential and the optical density of a toned image. Optical density increases with increasing surface potential when the toner density is over 15 wt%. This tendency indicates that development is saturated. But when the toner density is lower, the optical density does not increase enough because of lack of toner particles under this developing condition.

To investigate the relationship between weight of adhered toner and optical density, the weight and the optical density of the toned image of developed samples were measured. Figure 4 shows the relationship between weight of adhered toner and optical density. In this figure, the difference of optical density of the toned image, D, and background density D_i is shown as optical density. It is clear that the optical density D increases linearly with increasing weight of adhered toner. Equation (1) was derived by assuming a linear relationship between weight of adhered toner and optical density. We can describe the optical density with Equation (1) by using the proportional coefficient obtained from Figure 4.

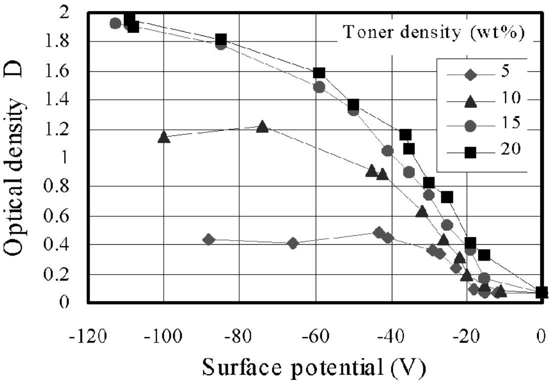

Figure 3. Relationship between surface potential and optical density of toned image

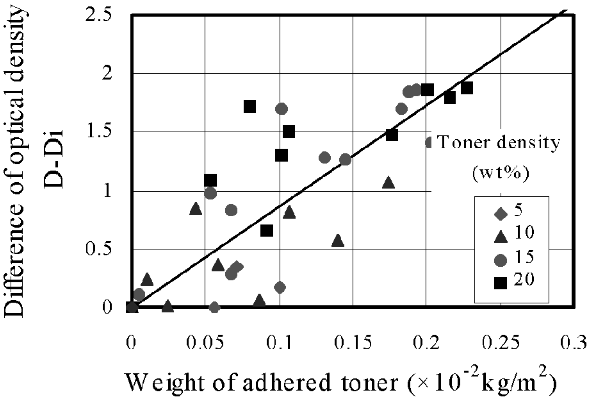

Figure 4. Relationship between weight of adhered toner and optical density of toned image

To investigate the relationship between developing time and optical density, the optical density of a toned image at several electrostatic medium feeding velocity vp (10 to 100 mm/s) was measured.

Figure 5 shows the relationship between developing time and optical density of the toned image. The developing time was calculated by dividing developing nip width by electrostatic medium feeding velocity vp. This figure shows that the optical density of the toned image is saturated faster when the toner density is higher. Equation (1) gives the relationship between development time and optical density of a toned image. Time constant τ was experimentally determined by applying Equation (1) and calculating the regression function from the density/time relationship. The obtained regression functions are plotted in Figure 5.

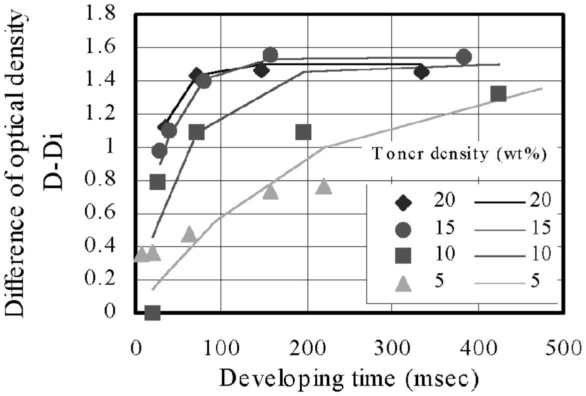

Figure 5. Relationship between developing time and optical density of toned image

Measurement of Mobility of Toner Particles

To describe the mechanism of liquid development, it is important to measure the mobility and charge density of toner particles. In this study, the electrophoretic deposition method was used to measure these toner characteristics.

The measurement setup consisted of a pair of parallel-plate electrodes whose gap was the same as the developing gap filled with highly concentrated electrostatic ink. Several magnitudes of electrostatic fields were applied to the gap and the current transition during electric deposition was measured.

Figure 6 shows the current transition during the electric deposition. This figure shows that electric deposition current decreases with time, and the curve becomes steeper when applied electrostatic field strength is increased.

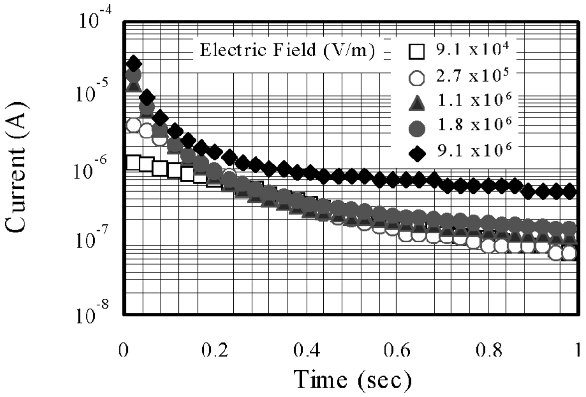

Figure 6. Current transients during electric deposition (Toner density: 15 wt%)

In this study, we adopted a simple electric deposition model in which deposition current I_p is given as

$$I_p = I_i + I_0 exp(-t/T_r), \qquad (3)$$

where I_i is leak current, I_0 is initial electric deposition current, and T_r is traveling time of toner particles from one plate to another.

Mobility of toner particles v can be calculated with T_r obtained by applying Equation (3) to the current transient property shown in Figure 6. The charge density is obtained by integrating the measured current.

Figure 7 shows the relationship between electric field strength applied to the cells and mobility of toner particles.

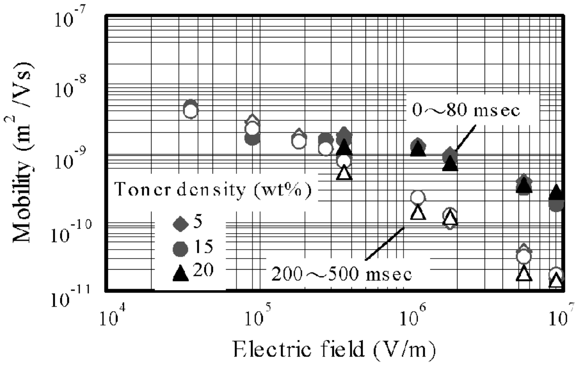

Figure 7. Relationship between electric field applied to the cells and mobility of toner particles

When the electric field strength is less than 2 x 10^5 V/m, the mobility of toner particles is almost constant and independent of toner density. This means that electrophoretic velocity increases according to increase of applied electric field.

But when the electric field strength was over 2 x 10^5 V/m, the mobility of toner particles decreased according to the increase of applied electric field, and the mobility at the first stage was larger than that at the second stage. In Figure 7, mobility at the first stage is calculated from the current between 0 - 80 msec (Figure 6) and mobility at the second stage is calculated from that between 200 – 500 msec. It is supposed that under the large electric field, counter ions around the toner particle are peeled off from the particle. This peeling-off causes a difference mobilities of the counter ions and toner particles.. The counter ions are thought to move faster than the toner particles and are colorless, so we adopted the mobility of the second stage in our estimation of development characteristics.

Estimation of Development Characteristics

Using the required toner, we can estimate the development characteristics of each development conditions.

At first, we calculate the time constant of development from Equation (2). Figure 8 shows the relationship between toner density and time constant of development. To estimate the time constant, the mobility of the second stage of the same electric field as used in the developing condition was used. In this figure, time constant that was obtained by a developing test (Figure 5) was also plotted. This figure shows that the time constant becomes smaller with increasing toner density; thus, a highly concentrated liquid toner is effective for increasing developing speed. The measured data (black dots) and the estimated line have a similar tendency. The cause of the difference between these results is thought to be the effect of counter ions. In this study, the current due to the counter ions was not estimated. The resulting overestimation of current is thought to make an underestimation of the time constant.

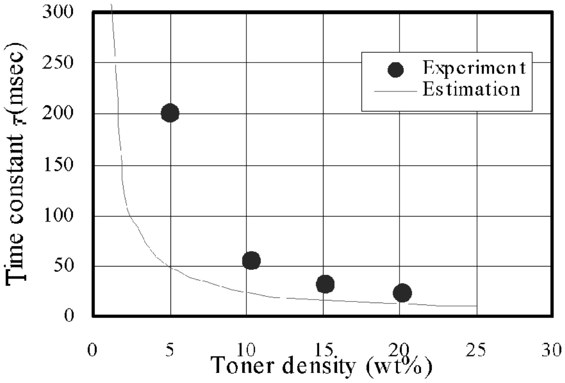

Figure 8. Relationship between toner density and time constant of development

To achieve good printing quality without fog, a developing bias must be applied in a developing system using highly concentrated liquid toner. The bias potential applied to the developing roller is assumed to be large enough to deposit all supplied toner particles on the developing roller. The amount of depositing toner particles in the developing time t can be calculated from Equation (1). And the amount of supplied toner particles can be calculated from the ink thickness around the developing roller and peripheral velocity of the developing roller. Under the assumption above, the minimum developing bias to avoid the fog can be estimated. Figure 9 shows the relationship between toner density and minimum developing bias potential. To estimate the bias potential, measured mobility (Figure 7) and the ratio of weight of toner and optical density (Figure 3) were used. The estimated line in Figure 9 is higher than the measured bias potential because of the overestimation of the time constant. But the estimated bias potential (from measured time constant τ) agrees well with the measuerd one.

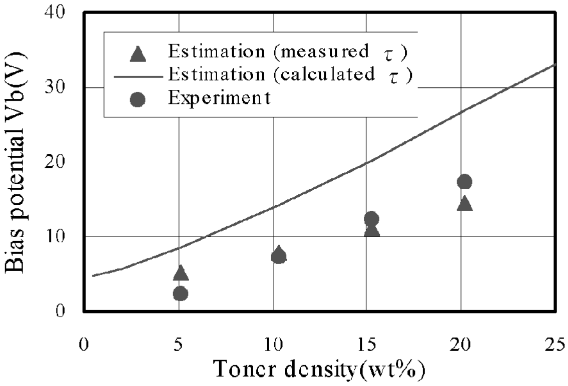

Figure 9. Relationship between toner density and minimum developing bias potential to avoid fog

Conclusion

To understand the mechanism of liquid development using a highly concentrated liquid toner, a simple developing model based on electrophoretic theory was applied. The mobility of toner particles measured by the electrophoretic deposition method was used to evaluate the property of the liquid toner. The time constant of development and the developing bias were estimated by using the developed model. It is thus concluded that a highly concentrated liquid toner has shorter developing time.

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Biography

Shogo Matsumoto received his master's degree in Mechanical Engineering from the Science University of Tokyo in 1988 and joined the Mechanical Engineering Research Laboratory of Hitachi, Ltd. He has been engaged in the development of non-impact printing systems.