# High Speed Liquid Development Using Highly Concentrated Liquid Toner

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## Abstract

A new mechanism—incorporating a nip stabilizer—to increase the speed of liquid development was developed. The nip stabilizer stabilizes the contact of the liquid toner with the latent image during high-speed printing. It was experimentally shown that the new mechanism can improve the developing speed by over four times the original limit speed.

## 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. A liquid toner consists of an insulating liquid carrier in which charged submicrometer toner particles are suspended. The liquid toner contacts the electrostatic medium on which a 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. To solve these problems, the authors developed a liquid-developing unit that uses a highly concentrated liquid toner with a density of over 10 wt%. We previously reported 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[1)]. We also proposed a mechanism to explain liquid development using a highly concentrated liquid toner[2)].

In the present study, to increase the speed of liquid development, a simple developing mechanism using a nip stabilizer was developed. A nip stabilizer can stabilize the contact of liquid toner with a latent image during high-speed printing. It was experimentally shown that the new system can improve the developing speed over four times the original limit speed.

## Model of Liquid Development

Figure 1 shows a conventional 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.

The model assumes that toner particles are subjected to a Coulomb force and Stokes drag during electrophoresis; optical density D at time t and the time constant of development τ are therefore given as

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

and

$$\tau = (C_s + C_l)L_l/(avQ_p + \sigma), \qquad (2)$$

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

Equation (1) was derived by assuming a linear relationship between the weight of the adhered toner and its optical density. The optical density can be described with Equation (1) by using the proportional coefficient obtained from Figure 2, which shows the relationship between the weight of deposited toner and optical density.

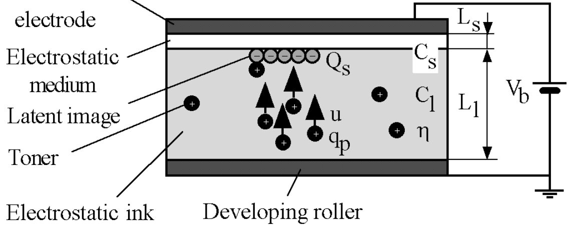


*Figure 1. Model of liquid development*

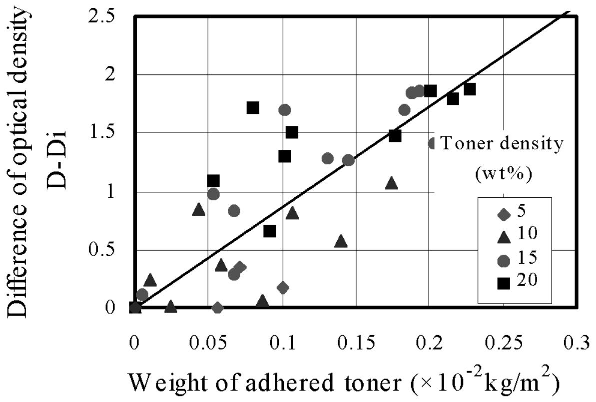


*Figure 2. Relationship between weight of deposited toner and optical density of toned image*

In this figure, the difference between the optical density of the toned image, D, and background density $D_i$ is shown as optical density. It is clear that optical density D increases linearly with increasing weight of adhered toner.

## Estimation of Development Characteristics

To achieve good printing quality without fog in a developing system using highly concentrated liquid toner, a developing bias must be applied. 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 toner particles deposited in developing time t can be calculated from Equation (1). And the amount of supplied toner particles can be calculated from the thickness of the liquid-toner lamina around the developing roller and the peripheral velocity of the developing roller (Figure 3). The developing bias is assumed to be large enough to deposit all supplied toner particles on the developing roller.

Under the above assumptions, the minimum developing bias to avoid fog can be estimated from the following equation.

$$q_{Id} \cdot a \cdot t = V_d \cdot t_d \cdot a \cdot t \tag{3}$$

$$V_b > (t_d \cdot d_d)/[v \cdot t \cdot \{1\text{-exp}(-t/t)\}] \tag{4}$$

Figure 4 shows the relationship between toner density and minimum developing bias potential. To estimate the bias potential, measured mobility and the ratio of the weight of deposited toner to optical density were used.[2] The estimated bias potential agrees well with the measured one by considering counter ions.

With the aim of achieving high-speed liquid development, we determined the relationship between process speed and weight of deposited toner by using equation (1) (Figure 5). This estimation is held under the condition of toner density of 15wt% and a developing gap of 0.5 mm. This result shows that when the mobility of the toner is 2 x 10$^{-9}$ m$^2$/Vs, liquid development at high speed, i.e., 1 m/s, is possible, and higher toner mobility can improve the potential.

## Experimental Apparatus

Figure 6 shows a schematic view of our previously reported 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 $V_b$ 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 $v_p$ while the developing roller rotates, opposite to the direction the medium is carried, at speed $v_d$. The development gap between the developing roller and the electrostatic medium is given as δd.

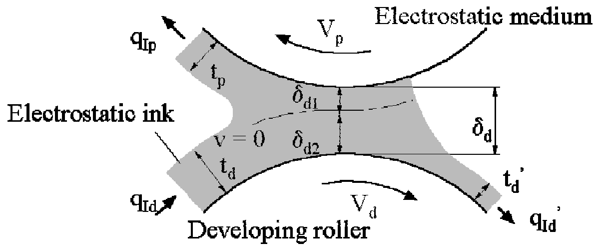


*Figure 3. Model of nip area*

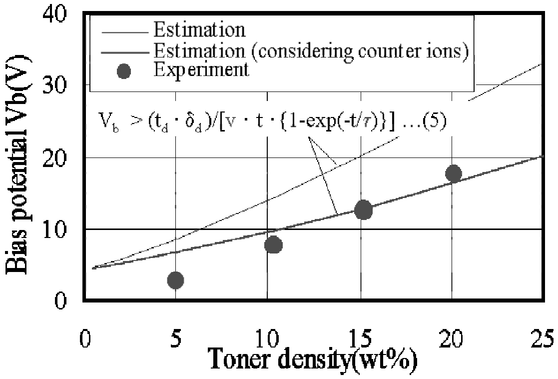


*Figure 4. Relationship between toner density and minimum developing bias potential to avoid fog*

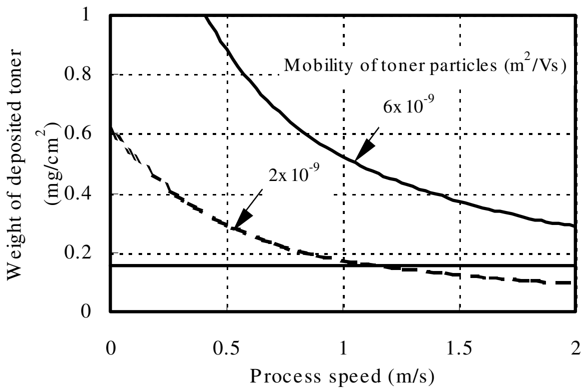


*Figure 5. Relationship between process speed and weight of deposited toner (calculated)*

This experimental apparatus was used for development tests on one kind of liquid toner with several toner densities. (5-20 wt%); accordingly, the optimal developing conditions for high-quality images without fog were identified.

This mechanism can realize a simple liquid-development system with good developing capability at a process speed of less 100 mm/s. The developing speed is limited by the stability of the nip area, and at over 100 mm/s, liquid toner is separated from the electrostatic media and development is not possible.

To stabilize the contact of liquid toner with the latent image during high-speed printing, we fitted a nip stabilizer on the developing roller. Figure 7 shows a schematic view of the experimental apparatus including the nip stabilizer. The nip stabilizer can widen the nip area by capillary-tube action. The nip stabilizer is settled on the upstream of the nip area. Because the nip area does not widen downstream of the nip blade, the developing condition is almost the same as that for the system without the nip blade.

This system also has an ink-supply roller. The gap between the developing roller and the ink-supply roller controls the thickness of liquid-toner lamina around the developing roller.

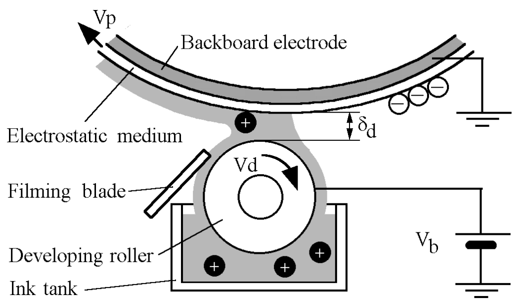


*Figure 6. Schematic view of experimental apparatus (Previous System)*

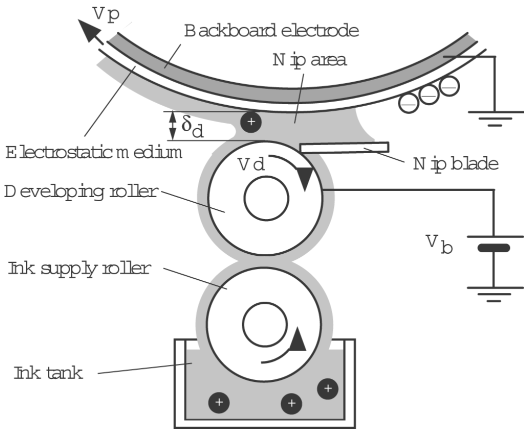


*Figure 7. Schematic view of experimental apparatus (Advanced System)*

## Developing Conditions and Characteristics

Figure 8 shows the relationship between developing bias and the optical density of the background area at a process speed of 1 m/s. It is clear that the optical density of the background area decreases with increasing developing bias. This result shows that when the developing bias is over –200 V, good printing quality—i.e., without fog—is achieved. And the estimated points from equation (4) agree well with the measured density.

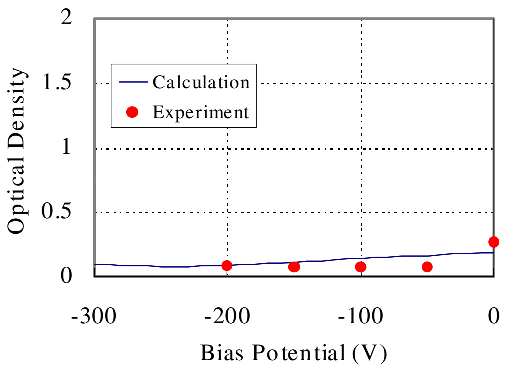


*Figure 8. Relationship between developing bias and optical density of background area (process speed: 1m/s)*

Figure 9 shows the relationship between the surface potential of the electrostatic medium and the optical density of the toned image at a process speed of 1m/s. In this experiment, developing bias was fixed at –200 V in order to avoid fog. It is clear from the figure that optical density increases with increasing surface potential. This result shows that when the surface potential is over –200 V, sufficient optical density (OD 1.4) is obtained. The estimated points from equation (1) agree fairly well with the measurements. From these results, high-speed developing conditions can be determined.

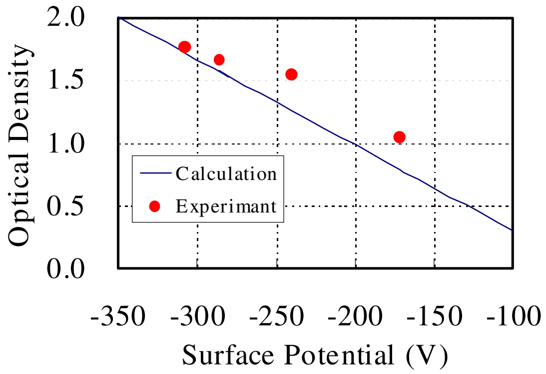


*Figure 9. Relationship between surface potential and optical density of toned image (process speed: 1m/s)*

Figure 10 shows a toned image produced by the experimental nip-blade-equipped apparatus under the optimized developing conditions.

To confirm the capability of the nip-blade modification for high-speed liquid development, a high-speed laser printer system was modified. Figure 11 shows the modified printing system, in which the developing unit for dry toner was removed and the developed liquid-developing unit (diameter of developing roller: 20 mm) was fitted. The process speed of this system is 0.4 m/s and its resolution is 240 dpi. Figure 12 shows a printed image produced by the system. It is clear that the laser-spot figure in the image printed by using a liquid toner can be discriminated more easily than one printed by using a dry toner.

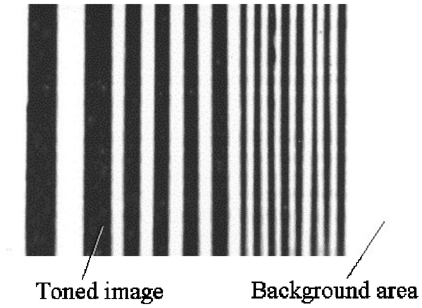


*Figure 10. Toned image (process speed: 1m/s)*

## Summary

To increase the speed of liquid development, a simple developing mechanism using a nip stabilizer was developed. It was experimentally shown that the nip stabilizer stabilizes the contact of the liquid toner with the latent image during high-speed printing. It is thus concluded that a highly concentrated liquid toner with the new mechanism can increase the developing speed by over four times the original limit speed.

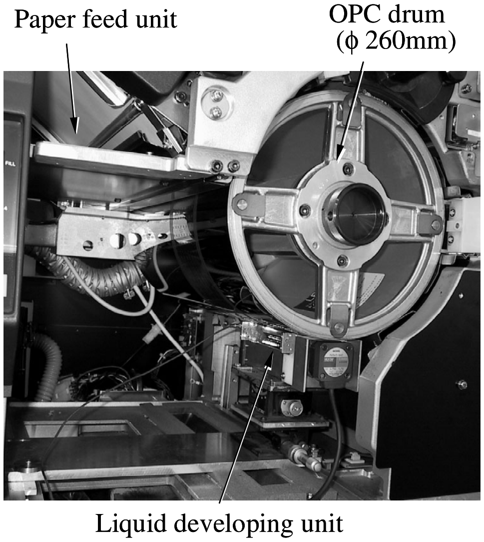
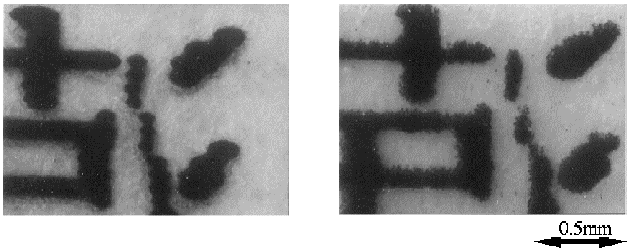


*Figure 11. Printing system modified for liquid development*



(1) Liquid Toner (2) Dry Toner

*Figure 12. Printing sample (process speed: 0.4 m/s, 240dpi)*

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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. in 1988. He has been engaged in the development of non-impact printing systems since 1988.