Analysis of 2540 dpi Dot Reproduction by Liquid Development

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Abstract

High-resolution liquid development process was examined theoretically and experimentally. Recently, we have realized extremely high-resolution (2540 dpi) images on a liquid toner developing system. The mechanisms of reproducing such extremely high resolution are investigated from the viewpoint of the developing process. An electric potential distribution in a single-dot latent image on a photoreceptor is calculated from the exposure energy of high-resolution Laser Scanning Unit (LSU) and surface properties of a photoreceptor. The development characteristics of single-dot images are investigated using numerical simulations of two-dimensional continuity equations based on the electrostatic forces in the development, taking account of the motion of both toner particles and counter ions. The simulation shows that, at an early stage of the development, the toner particles are developed around the edge of the latent image on the photoreceptor, and then the particles are accumulated to form a single dot with horizontal migration toward the center of the latent image. Such developing behavior is characteristic of liquid toner, and the result suggests the mechanism of the high reproducibility of liquid development.

Introduction

Liquid toner electrographic imaging systems have attracted interest due to their potential to provide high-resolution images equal in quality to those produced by offset printing.[1-4] Recently, we have realized such extremely high-resolution images on a liquid toner developing system using fine toner particles, a high-resolution Laser Scanning Unit (LSU) with a 2540 dpi resolution, and an image transfer system that does not use any electrical means.[5,6] The mechanisms, which make it possible to reproduce the extremely high resolution, are examined by theoretical and experimental analyses. We have reported a numerical simulation of liquid development using a one-dimensional model, taking into consideration the motion of both toner particles and counter ions.[7,8] The present study examines the development characteristics of single-dot images using numerical simulations of two-dimensional continuity equations based on the electrostatic forces in the development, taking into consideration both toner particles and counter ions.

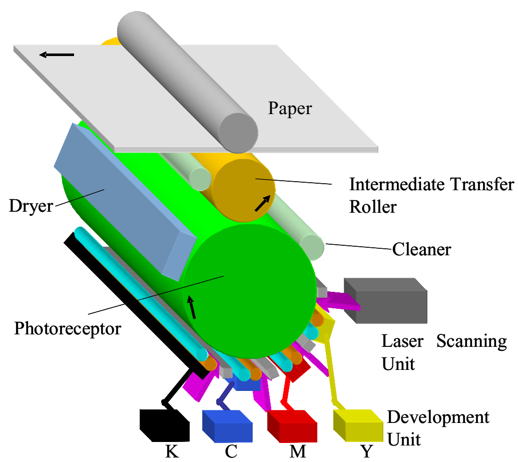

Figure 1. Configuration of the image-on-image (IOI) liquid electrophotography system.

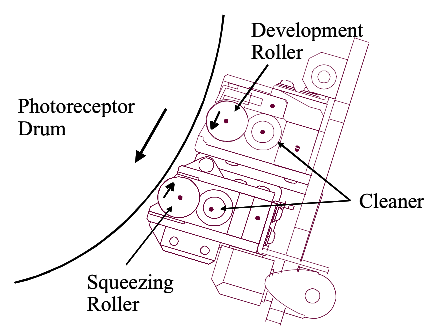

Figure 2. Composition of the development unit.

Composition and Process of Liquid Toner Electrophotographic System

The configuration of our liquid toner electrophotographic system is shown in Fig. 1 and the composition of its development unit is shown in Fig. 2. The system includes a photoconductive drum, a scorotron charger, LSU with a resolution of 2540 dpi, a development unit, a dryer, and a transfer unit at the periphery of the photoconductive drum. The development unit accommodates four developing devices containing liquid developers of different colors, namely yellow, magenta, cyan, black, respectively. This system employs the Image-on-Image (IOI) color process. A full color image on the photoreceptor is formed by superimposing the following color during one rotation of the photoreceptor drum. The full color image is dried on the photoreceptor,[9] and then, using "non-electrostatic" intermediate transfer roller,[10] transferred to and fixed on a paper.

In this study we examine the reproducibility of a fine single dot in liquid development, and therefore, one development unit was used for the experiment and numerical analysis also deals with a single development process, without considering the squeezing process depicted in Fig. 2.

Potential Profile of a Latent Image of a Single Dot in 2540 dpi Resolution

In this experiment, a high-resolution laser scanning unit (LSU, developed by OPCell Co., Ltd.) was employed. The beam spot is about 17 micrometers ($1/e^2$) and it enables the formation of dots at intervals of 10 micrometers (2540 dpi). Since the shape of a beam spot on the photoreceptor can be formulated by Gauss's distribution, the exposure energy distribution was determined using the scanning speed and the exposure time of the LSU.[11,12] The surface potential distribution which corresponds to the single dot of 2540 dpi was obtained from the exposure energy distribution in the main scanning direction and the Photoinduced Discharge Curve (PIDC) of the positive-charge photoreceptor used in the experiment (Fig. 3).

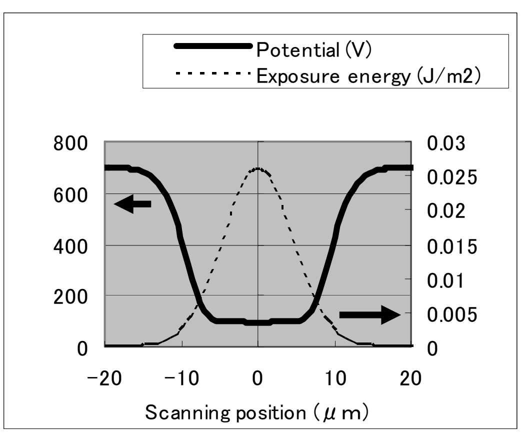

Figure 3. Exposure energy and potential distributions in the main scanning direction.

Two-Dimensional Theoretical Analysis of Liquid Development

In the present study, we examined the time evolution of two-dimensional distribution of the toner particles and the counter ions in the development. The numerical analysis was based on the two-dimensional continuity equations and Poisson's equation taking into account the charges of the toner particles and the counter ions, which are positively and negatively charged, respectively. The calculation was performed using differential equations.

Two-Dimensional Liquid Development Model

A model for the simulation of the liquid development in the gap between the developing roller and the photoreceptor is illustrated in Fig. 4. The development area is defined as the rectangle of 40 μm on the x-axis and 150 μm on the y-axis. The surface potential distribution Vp is as shown in Fig. 3. The charge density of the toner particles ρ_p is positive and the charge density of the counter ions ρ_n is negative. In the initial state of the development, both the charge densities are homogeneous in area and their absolute values are the same, $\rho_p = -\rho_n$. The toner particles migrate toward the latent image with a mobility μ_p due to the effect of the electric field E originated from the surface potential on the photoreceptor Vp and the development bias Vd. The space and time distribution of the charge density are brought about by the continuity equations (1, 2) and Poisson's equation (3).

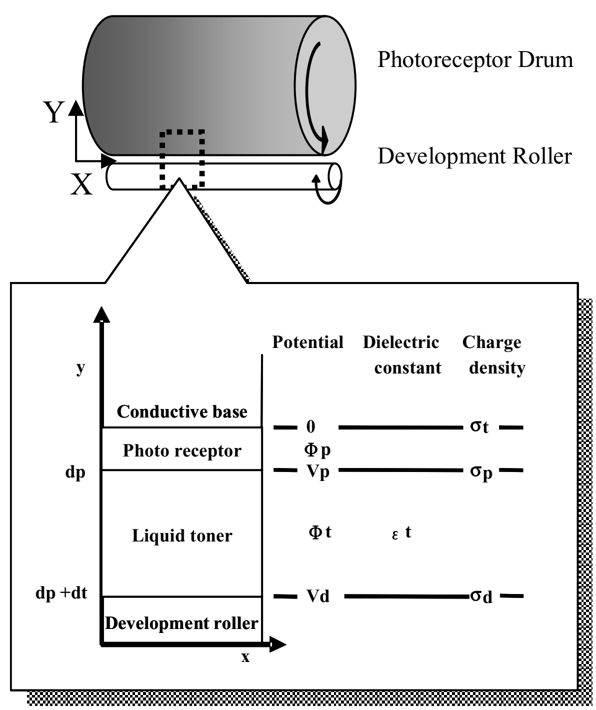

Figure 4. Model for the liquid toner development process.

$$\frac{\partial \rho_p}{\partial t} = -\frac{\partial(\mu_p \rho_p E_x)}{\partial x} - \frac{\partial(\mu_p \rho_p E_y)}{\partial y} \tag{1}$$

$$\frac{\partial \rho_n}{\partial t} = +\frac{\partial(\mu_n \rho_n E_x)}{\partial x} + \frac{\partial(\mu_n \rho_n E_y)}{\partial y} \tag{2}$$

$$\frac{\partial^2 \phi_t}{\partial x^2} + \frac{\partial^2 \phi_t}{\partial y^2} = -\left(\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y}\right) = -\frac{(\rho_p + \rho_n)}{\varepsilon_t} \tag{3}$$

Parameters and Initial Condition for the Simulation

The initial conditions of the simulation are as follows:

1. The charge densities of the toner particles and the counter ions, which are homogeneous in the system, are defined as Po and –Po, respectively.
2. Potential V is given as a solution of the Poisson equation. The values used in the analysis are listed in Table 1.

Table 1. Parameters for the Numerical Simulation.

Prameters	Symbol	Value	Unit
Development time	T_d	48	msec
Development nip	W_d	5	mm
Initial charge density of liquid toner	P_0	1.54	C/m3
Relative dielectric constant of liquid toner	ε_t	2.03	-
Development gap	d_t	150	µm
Mobility of liquid toner	μ_p	4.00E-10	m2/V*sec
Mobility of counter ion	μ_n	2.00E-10	m2/V*sec

The Potential and Charge Density Distribution in the Developing Gap

The calculated potential distribution at the early stage of the development (t = 0.4 msec, Vd = 500 V) is shown in Fig. 5.

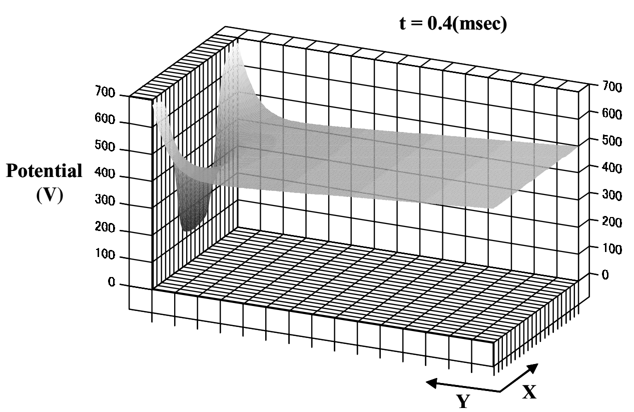

Figure 5. Potential distribution in the developing gap at t=0.4 msec, where the direction of the surfaces of photoreceptor drum and the developing roller is shown by the x-axis, and the direction of the developing gap is shown by the y-axis.

The result indicates that the potential gradient in the positive direction of y-axis is low except in the vicinity of the photoreceptor; electric field is rather small in the major part of the developing gap. The charge distribution of the toner particles at t = 48 msec is shown in Fig. 6, where the charge density is indicated by the mesh density. Clear contrast of the charge density was observed in the vicinity of the photoreceptor; the toner particles migrate toward the image area, whereas they migrate away from the non-image area. On the other hand, in the vicinity of the development roller, the density of the toner particles becomes low due to the effect of the low potential gradient mentioned above. In the middle of the developing gap, the charge density is almost unchanged.

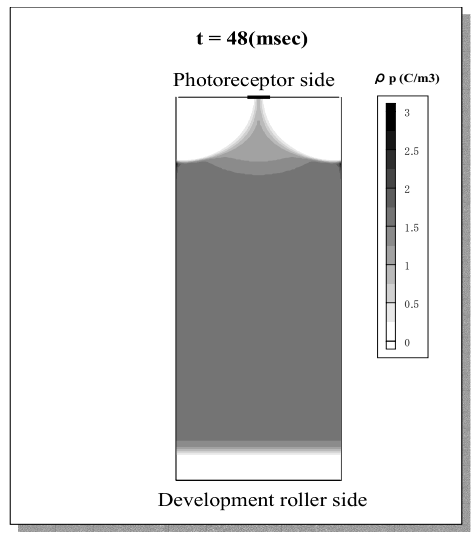

Figure 6. Charge density distribution of toner particles in the developing gap at t=48 msec.

Time Dependence of Dot Formation

In the previous section, the toner charge density in the whole of the development gap was examined. In this section, we focus on the process of forming a fine dot, which corresponds to a single dot at 2540 dpi, by analyzing the change of the charge density on the photoreceptor. The charge density of the toner particles at the surface of the photoreceptor is regarded as being proportional to the amount of the toner particles adhered on the photoreceptor.

A time evolution of the distribution of the mass of developed toner particles on the photoreceptor is shown in Fig. 7. The result indicates that at the early stage of the development, the toner particles are developed mainly not at the center of the latent image but around the edge of the latent image, forming a circle with radius of about 5 µm. Then the toner particles gradually gather toward the center, growing to form a single-dot image. Such horizontal migration of the developed toner particles on the photoreceptor can be regarded as being characteristic of liquid development.

The time evolution of the distribution of the counter ions is shown in Fig. 8. The result indicates that the counter ions form high-density area 10-15 µm from the center of the dot image, migrating toward the side of the image area. To our knowledge, there has not been such an investigation of the counter ion, and this study is the first to reveal such detailed dynamical behavior of the counter ion.

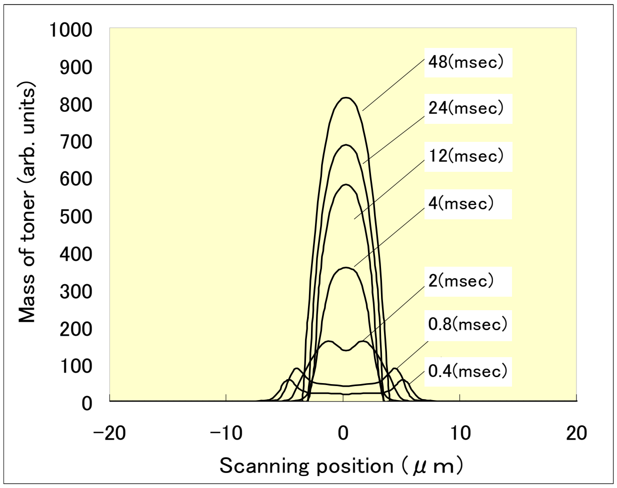

Figure 7. Time evolution of the mass of toner particles deposited in the image area.

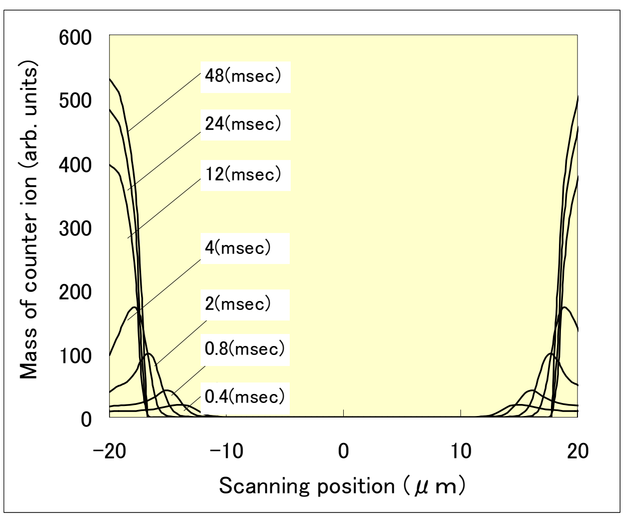

Figure 8. Time evolution of the mass of counter ions adhered in the non-image area.

Development Bias Dependence of the Dot Diameter

The effect of development bias dependence on the dot forming process was examined by comparing the analytical values and observed values of the real dots fused on papers at Vd = 300 V, 400 V, and 500 V. The analytically obtained mass distribution of developed toner on the photoreceptor and the photographs of the single dots on the papers at each developing bias are shown in Fig. 9. Although each of the diameters of the real dots is a little larger than that of the corresponding analytical result, the diameters almost agree with each other. The results indicate not only the precision of the theoretical analysis in this study, but also the high reproducibility of the liquid development of hyperfine latent images. An example of such a high-resolution image on paper by 2540 dpi liquid development is shown with a reference of an image by dry-toner development.

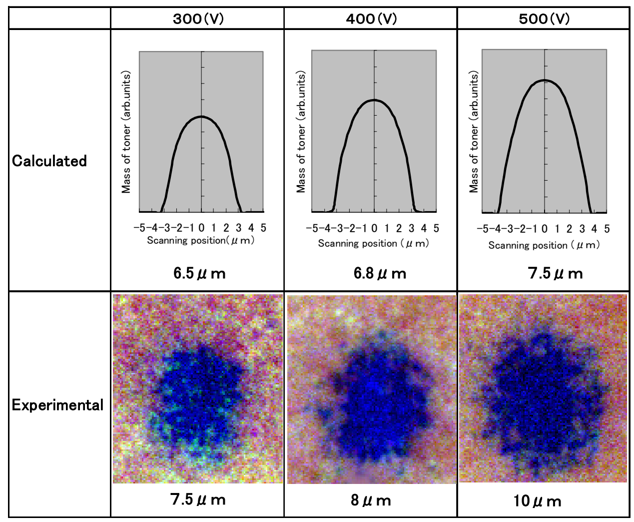

Figure 9. Development-bias dependence of dot diameters of calculated and experimental values.

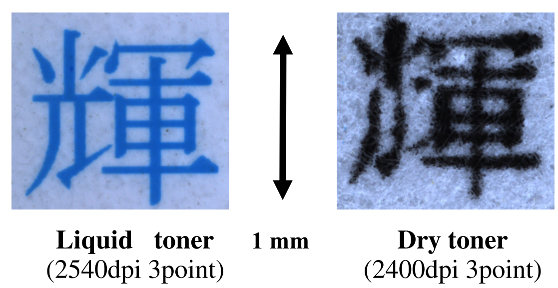

Figure 10. Image comparison between liquid toners and dry toners.

Conclusion

The liquid toner developing process for the very fine single dot of 2,540 dpi resolution has been theoretically analyzed. The resultant developing process shows that at the early stage, the toner particles are developed onto the area apart from the center of the latent image, and then the particles are gradually gathered toward the center and condensed to form a single dot. The developing-bias dependence of the dot diameter agrees well with that of the actual dot images experimentally obtained. The results confirm the accuracy of the theoretical analysis, and moreover, strongly support the high potential of the liquid development for even higher-resolution image.

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Biography

Isao Takasu received the B.E. degree in basic sciences, the M.E. degree, and the Ph.D. in physical organic chemistry from The University of Tokyo, Tokyo, Japan, in 1993, 1997 and 2000, respectively. Since 2000 he has been with the Corporate Research & Developing Center, Toshiba Corp., Kawasaki, Japan, where he is engaged in the development of electrophotographic imaging processes.