Image-on-Image Color Process Using Liquid Toner

Hitoshi Yagi, Yasushi Shinjo, Haruhi Oh-oka, Mitsunaga Saito, Kouichi Ishii, Isao Takasu, and Masahiro Hosoya
Corporate Research & Development center, Toshiba Corporation
Kawasaki, Japan

Abstract

The image-on-image (IOI) color process, in which color images are superimposed on a single photoreceptor drum and then transferred to the paper at once, possesses capabilities for realizing a high speed, high quality, and compact color printer. However, in the IOI processes using dry toners, there are unavoidable problems that make it difficult to obtain high quality color images. The authors found that, using liquid toners, these issues are completely resolved and an excellent color process is realized. Development characteristics and color image qualities are compared between IOI processes using dry and liquid toners. The results of theoretical analyses agree with these experimental data.

Introduction

In the context of current demand for higher quality color printing, it has been suggested that dry electrophotography is reaching its technical limits. For the innovation of electrophotography it is crucially important to bring the capabilities of the liquid toner process into full play and to overcome disadvantages of the conventional technique.

The IOI process is an excellent color printing technique offering many advantages. For example, a simple and compact color printer can be realized, because only a single photoreceptor is necessary and a large-scale transfer drum can be omitted. Improvement of color registration, simplicity of paper feeding, and applicability for high speed printing are also significant merits in the IOI process. The IOI process has been researched extensively since the 1980s,[1-3] and some products using dry toners were commercialized.[4] However, these products were subject to several essential problems and it was difficult to realize high quality color image using dry toner. On the other hand, IOI color process using liquid toners have also been investigated.[5,6]

The authors have found that the essential problems in the dry toner IOI process can be resolved by applying liquid toners.[7] In this paper, it is confirmed that liquid toner IOI is a highly attractive color process by comparing between IOI processes using dry and liquid toners experimentally. Furthermore, theoretical analyses of the liquid toner process are performed, and it is revealed that the results of calculations agree with those of experiments.

Essential Problems of Dry Toner IOI Process

The dry toner IOI process is subject to the following problems, making it difficult to improve the image quality. 1) As the dry toner layer on the photoreceptor is bulky and scatters or absorbs the exposure beam, fluctuation of photoreceptor surface potential, reduction of photo-induced discharge, and destruction of the previously developed image occur in the subsequent charging, exposure, and development processes. 2) Specific development conditions are required in the dry toner IOI process. For example, non-contact development method must be applied, because the previously developed dry toner layer is easily destroyed and is removed in the subsequent development process. 3) It is extremely difficult to transfer multi-deposited and corona charged toner layers on the photoreceptor at once by the electrostatic method.

Configuration and Features of Liquid Toner IOI Process

Configuration of the liquid toner IOI process is shown in Figure 1. Four sets of image forming devices, which are composed of corona charger, exposing laser, and development and squeezing unit, are arranged around a single photoreceptor drum. Full color images are developed on the photoreceptor by the sequential YMCK color process, and the images are transferred to the paper at once. In addition to the advantages of the IOI process mentioned above, further merits can be obtained by using liquid toners as follows. 1) A high quality image can be obtained using superfine toner particles (< 1 μm in diameter). 2) High speed color printing can be realized by combining one pass full-color process and high speed liquid toner development. 3) As the thickness of developed toner layer is about one tenth that of dry toner layer, the influence of the previously developed liquid toner on the subsequent charging and exposure processes is extremely small. 4) Since the developed liquid toner is reformed into film-like layer by squeezing, the previously developed toner layer is not easily removed in the subsequent development process as shown in Figure 2. 5) Non-electrostatic transfer (offset transfer) using viscosity of liquid toner realizes high efficiency transfer to various types of paper. Furthermore, since the offset transfer is conducted after drying and collecting the solvent of liquid toner on the photoreceptor, the solvent is prevented from diffusing out of the printer and environmental problems are resolved.

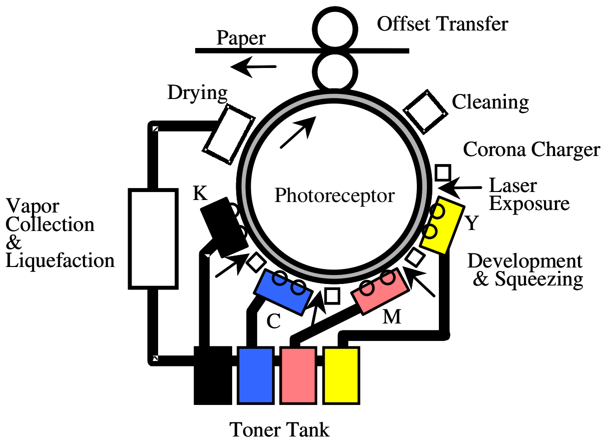

Figure 1. Configuration of liquid toner IOI process

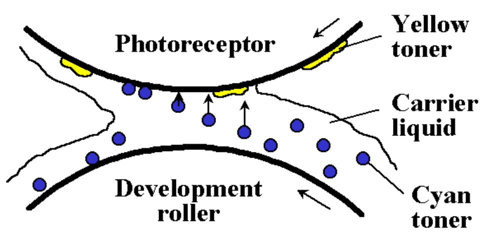

Figure 2. Liquid toner IOI development

Experimental and Result Superiority of the Liquid Toner IOI Process

Experiments were conducted to compare the characteristics of IOI processes using dry and liquid toners. As a result, superiority of the liquid toner IOI process is confirmed.

1. Light Transmittance Spectra of Toner Layer

The structural drawings and the light transmittance spectra of three kinds of toner layer (YMC) deposited respectively on the photoreceptor are shown in Figure 3. Though the liquid toners are not fused by heat, the light transmittance spectra are nearly equal to the bare pigments. In the case of yellow and magenta liquid toners, the transmittance of the light beam in the range from 680 to 780 nm in wavelength is extremely high. Cyan toner scatters or absorbs the light beam in the same wavelength range, whereas the light exposure process through cyan toner layer is available by image data processing, considering the sequence of the YMCK color process.

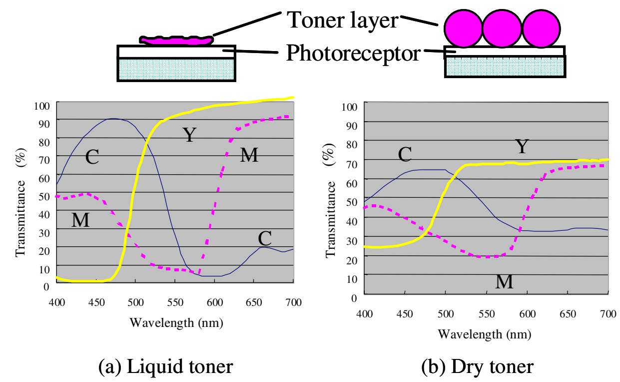

Figure 3. Light transmittance spectra of toner layer

2. Charging and Photo-induced Discharge Characteristics of Photoreceptor Covered with Toner

Charging and photo-induced discharge characteristics of photoreceptor covered with and without magenta toner are shown in Figure 4. In the case of dry toner, insufficient surface potential decay occurs due to scattering or absorbing of the light beam by the toner layer, and the potential difference between with and without the toner layer is about 150 V at maximum. On the other hand, in the case of liquid toner, the potential difference is small and is 30 V at most.

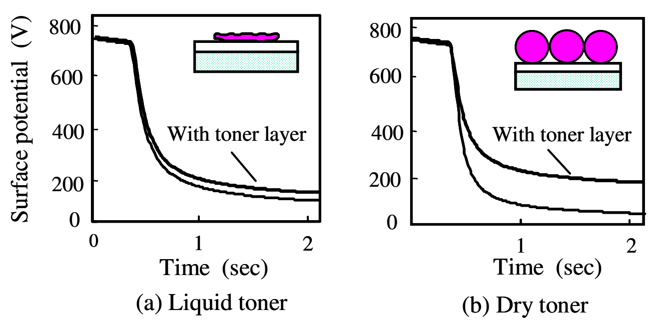

Figure 4. Photo-induced discharge of photoreceptor covered with and without toner layer

3. Sustaining of High Image Quality after Subsequent Exposure Process

The changes of the character images formed with magenta toner before and after the subsequent exposure process are shown in Figure 5. High quality image is sustained in the liquid toner after the subsequent exposure process. On the other hand, image destruction occurs in the dry toner. The reason for this image destruction in dry toner is explained as follows. At the moment that the previously developed toner layer is exposed in the subsequent exposure process, the potential difference of more than 150 V exists between the previously developed toner and the neighboring undeveloped region. Accordingly, some parts of the previously developed toner layer are scattered by the electric field due to the potential difference, and image destruction occurs as a result.

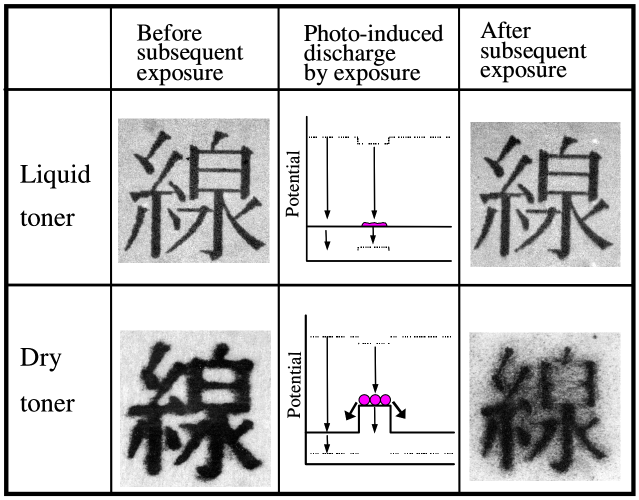

Figure 5. Image comparison between liquid and dry toners before and after subsequent exposure

4. Sustaining of High Image Quality in Subsequent Development and Squeezing Processes

In the subsequent development and squeezing processes, the previously developed toner layer is removed from the photoreceptor and contaminates the development units under a certain process condition. In particular, under reversal development, the previously developed toner on the unexposed background area suffers the electrostatic removal force in the subsequent development and squeezing processes.

Experimental results for toner removal in liquid toner IOI development are illustrated in Figure 6, which shows the image density of previously developed toner layer after the subsequent development and squeezing processes. Here, the optical density shows the degree of toner removal and ΔV shows the potential difference between surface voltage of previously developed toner layer on the unexposed background area (V_{ot}) and that of development roller (V_b). It is revealed that toner removal occurs when ΔV exceeds 300 V. However, in the normal range of development conditions, for example, when ΔV is smaller than 200 V, reduction of optical density by toner removal does not occur. Thus, non-specific development conditions are required in the liquid toner IOI process. By squeezing the solvent sufficiently and passing the subsequent charging process, the liquid toner with low glass transition temperature, which can be fused at room temperature, is reformed into film-like layer. Accordingly, the adhesion force of the toner layer increases and removal of the previously developed toners is prevented.

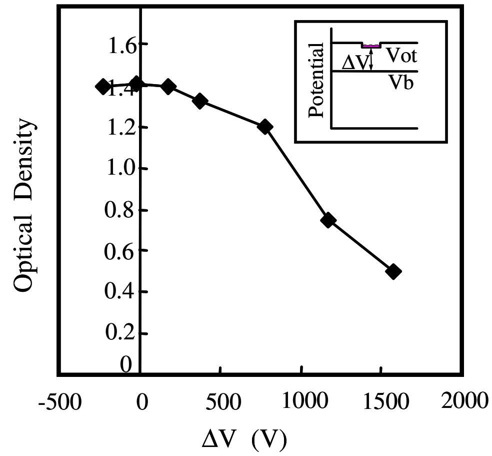

Figure 6. Toner removal in liquid toner IOI development

5. High Efficiency Transfer and High Image Quality Using the Offset Transfer Method

The non-electrostatic transfer (offset transfer) method is applied for the purposes of avoiding the deterioration of the high quality color images and transferring the images to various types of paper. Transfer efficiency is nearly equal to 100% and high image quality comparable to that of offset prints can be realized. Since the transfer process is carried out after drying out the liquid toner solvent on the photoreceptor, the paper is prevented from wetting and the solvent vapor does not diffuse out of the printer.

Theoretical Analysis Simulation of Liquid Toner IOI Development

Theory of Liquid Toner Development

When the theory of liquid toner development was in its infancy[8,9], electric field by electrostatic latent images was assumed to be uniform and only the effect of viscous resistance of the liquid toner solvent was taken into consideration. Furthermore, it was assumed that liquid toners are supplied in the development zone infinitely. In this paper, an advanced theory of liquid toner development is discussed, including considering of the time dependent distributions of toners and counter ions and the decrease of toner particles during the development process.[10] The model for liquid toner development is illustrated in Figure 7. The time and space distributions of charge densities of toner particles and counter ions are given by the continuity equations and Poisson's equation.

$$\frac{\partial \rho_p(x,t)}{\partial t} = -\frac{\partial \{\mu_p \cdot \rho_p(x,t) \cdot E(x,t)\}}{\partial x} \tag{1}$$

$$\frac{\partial \rho_n(x,t)}{\partial t} = -\frac{\partial \{\mu_n \cdot \rho_n(x,t) \cdot E(x,t)\}}{\partial x} \tag{2}$$

$$\frac{\partial E(x,t)}{\partial x} = -\frac{\rho_p(x,t) + \rho_n(x,t)}{\varepsilon_t} \tag{3}$$

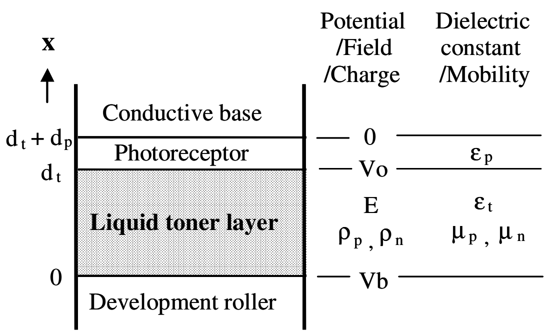

Figure 7. Model for liquid toner development

Surface potential of photoreceptor V_O and toner charge are positive, and counter ions charge is negative. Toner particles move toward photoreceptor side by electric field with drift mobility μ_p. Initial conditions are as follows. 1) The absolute values of the toner charge density (P_O) and the counter ion charge density ($-P_O$) are equal, and both of them are distributed uniformly in the development zone. 2) Electric field is the analytical solution of Poisson's equation and is expressed as equation (4).

$$E(x,0) = \frac{Vb - Vo}{\varepsilon_t (d_p / \varepsilon_p + d_t / \varepsilon_t)} \tag{4}$$

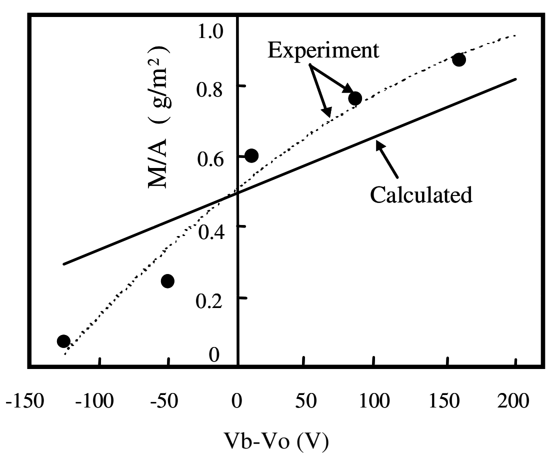

Figure 8. Calculated development characteristics

Photoreceptor surface potential is modified by toner deposition on the photoreceptor in the development process and this phenomenon is introduced to the numerical analyses as a boundary condition. Under the above-mentioned conditions, the equations (1)-(3) are numerically analyzed by the finite difference method. The values used for calculations are as follows: P_O=1.54 C/m^3, ε_t=2.03ε_O, ε_p=12ε_O, d_t=150 μm, d_p=30 μm, μ_p=4×10^{-10} m^2/Vs, μ_n=4×10^{-11} m^2/Vs, and development time t_d=48 ms. The calculated development characteristic is shown in Figure 8. The calculated values are comparable with the experimental ones.

Model for Liquid Toner IOI Development

Our model for liquid toner IOI development is illustrated in Figure 9. The figure shows the instantaneous state in which the previously developed toner layer on the unexposed background area comes into the subsequent development zone. Solving Poisson's equations analytically, electric potentials can be obtained.[11] As a result, electric field in the previously developed toner layer is expressed as equation (5).

$$E_r = -\frac{d\phi_r}{dx} = \frac{q_r m_r}{\varepsilon_r d_r}\left[x - \frac{1}{A}\cdot\frac{d_r}{m_r}\left\{-\frac{V_o - V_b}{q_r} + \left(\frac{d_r}{2\varepsilon_r} + \frac{d_t}{\varepsilon_t}\right)m_r\right\} - d_p\right],$$

$$\left(A = \frac{d_p}{\varepsilon_p} + \frac{d_r}{\varepsilon_r} + \frac{d_t}{\varepsilon_t}\right) \tag{5}$$

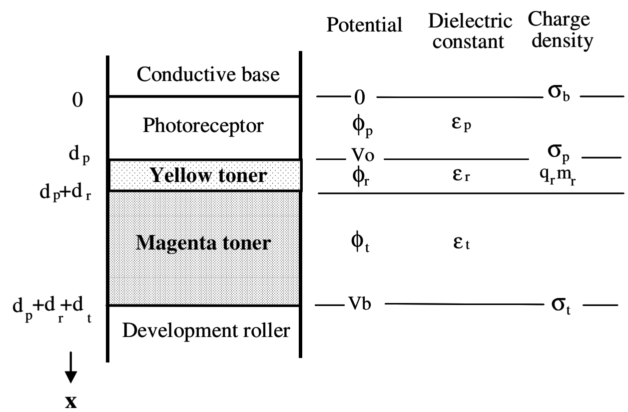

Figure 9. Model for liquid toner IOI development

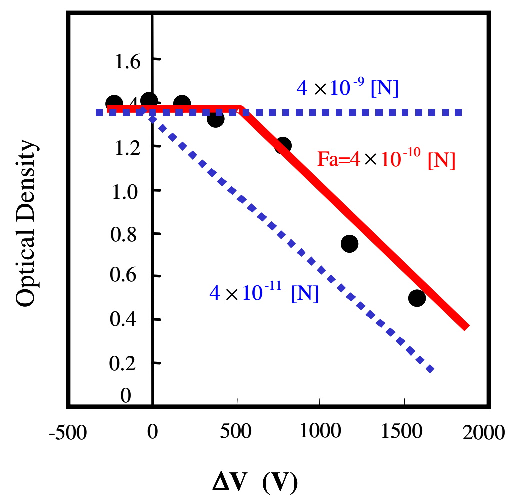

Figure 10. Calculated toner removal characteristics in liquid toner IOI development

Whether the previously developed toner layer is removed or not is determined by the competition between toner adhesive force and electrostatic force. Calculated toner removal characteristics in liquid toner IOI development are illustrated in Figure 10, in which toner adhesion force F_a is applied as a calculation parameter. The values used for calculations are as follows: $m_r=1\times10^{-3}$ kg/m^2, $q_r=0.23$ C/kg, $d_p=30$ µm, $d_r=2$ µm, $d_t=148$ µm, $\varepsilon_p=12\varepsilon_o$, $\varepsilon_r=1.2\varepsilon_o$, $\varepsilon_t=2.03\varepsilon_o$. As shown in Figure 10, it is confirmed that removal of previously developed toner does not occur under the normal development condition ($\Delta V <$ 200 V) if the adhesion force is larger than 4×10^{-10} N.

From another point of view, the toner adhesion force is estimated to be 2.1×10^{-10} N based on the Lifshitz theory. This value agrees with the above calculation result.

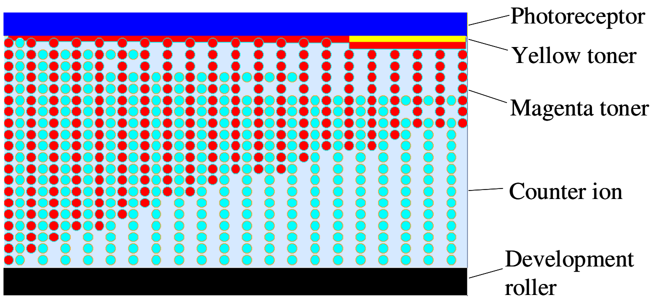

Figure 11. Toner motion in development zone

Motion of Toner Particles and Counter Ions

Motion of toner particles and counter ions in the development zone is plotted in Figure 11, using the values of charge densities obtained by the numerical analyses. At the initial stage, toner particles are distributed uniformly in the development zone. As the development proceeds, toner particles and counter ions interact with each other and move to the opposite directions respectively. Using these numerical analyses, motion of toner particles and counter ions in the liquid development can be shown visually.

Conclusion

High quality and high speed color prints can be obtained by image-on-image (IOI) color process using liquid toners. Image quality is comparable to that of offset prints. From the experimental results and theoretical analyses, it is confirmed that photo-transparency, electrical characteristics, and rheological features of liquid toners are suitable for the IOI development process. Furthermore, non-specific development condition is required for the liquid IOI development. Combining this liquid toner IOI process with the offset transfer method and solvent vapor collection technology, excellent color electrophotography can be achieved and various applications will be realized.

References

1. N. Hoshi, M. Anzai, S. Akimaru, and I. Komatsu, Japanese Patent Application, No.S55-95738 (1980)
2. C. Snelling, US Patent #4,4403,848 (1983)
3. M. Hosoya, S. Tomura, T. Uahara, M. Kohyama, T. Kasai, and M. Yamanashita, J. Electrophotography of Japan, 26(2), 107 (1987)
4. S. Haneda and M. Itaya, Japan Hardcopy ’89, 163 (1989)
5. R. S. Jones, US Patent #4,660,503 (1987)
6. V. D. Loewen, T. Camis, and K. A. Lindblom, US Patent #5,557,377 (1996)
7. M. Hosoya, H. Yagi, Y. Shinjo, H. Oh-oka, M. Saito, and K. Ishii, Japan Hardcopy 2000, 161 (2000)
8. T. Kurita, J. Electrophotography of Japan, 3(3), 26 (1961)
9. R. M. Schaffert: Electrophotograpy, Focal Press, London, p.562 (1975)
10. I. Chen: J. Imaging. Sci. and Technol., 39(6), 473 (1995)
11. M. Hosoya, M. Saito, T. Ueghara, Y. Ohtaka, and M. Endo, J. Imaging. Sci. and Technol., 36(4), 382 (1992)

Biography

Hitoshi Yagi received his B.E. degree in applied physics and M.E. degree in physics from Waseda University. Since 1989 he has been with the Corporate Research & Development Center, Toshiba Corp., where his main research themes have been the theoretical analysis of liquid toner processes and the improvement of photoreceptor performance.