Characteristic Analysis For Color Development Process Using Liquid Toner

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Abstract

The color development process using liquid toner in a color laser beam printer experiences very complicate parametric behaviors that determine the dynamic characteristic of the liquid toner into the development nip. In this research, the dynamics of the liquid toner are investigated to predict development current characteristics that effect to the development performances. To understand the development current behavior, the electric field analysis is generally characterized by the electric distribution with respect to the geometrical shape analysis (plate-to-plate); however, the proposed system to investigate the electric field characteristics takes the plate-to-cylinder analysis for Samsung's color printing system. The governing equations are obtained to understand variation effects of system parameters, and the final version of the system parameter is obtained through simulation runs. The results from the analytical approaches are compared with the experimental investigation.

Introduction

Various applications for printing systems such as ink-jet, mono laser dry toner based, and color laser for both dry toner and liquid toner have been proposed in previous. The particular interests in this research are in terms of using liquid toner and in terms of process speed with single pass. Compared with multi pass process that requires a photoconductor, belt or drum, to rotate as many as applied colors, the single pass process in the proposed system uses a belt as a photoconductor and generates images with a consequent order of colors while the photoconductor is operated with a period of rotation only. Therefore, it produces the advantages for process speed in high and for size of system in compact. A similar system has been reported in previous,[1,2] and the main interests of this research are to investigate the electrical behaviors of the photoconductor relative to the liquid toner, the geometrical parameters at the area of the image formation, and the characteristics of the developed toner mass dependent upon the potential and current variations of the developing roller and the photoconductor surface. The surface potential and the developing current are modeled using the geometrical shape analysis, and this developed model is performed by experiments and well-developed print samples are attained.

The system configuration for the single pass color printing system using the liquid toner is described in Fig. 1. As shown in Fig. 1, the photoconductive belt is electrically initialized by the eraser, then the photoconductive belt is charged by the primary charging device to generate the uniform charging distribution on the surface of the photoconductive belt. The secondary charging devices are placed before the developing unit, and they are functioned as the similar fashion of the primary charging device. The liquid toners to obtain colors are formed with exposing process subsequently, and the carrier is squeezed out from the formed image passing the squeegee station. Most of remaining carrier is removed through the drying station, and the almost dried image is delivered and transferred to the transfer roller. Then, the image on the transfer roller is ready to print on the paper. This process is done with the one periodic revolution of the photoconductive belt, 3.2 $in/\sec$. of the process speed, and it yields the process speed 4 times higher than that of the serial type 4-pass color development process. The overall process contains several sub-processes involving electrical and mechanical dynamics, and this paper is focused on the developing process only.

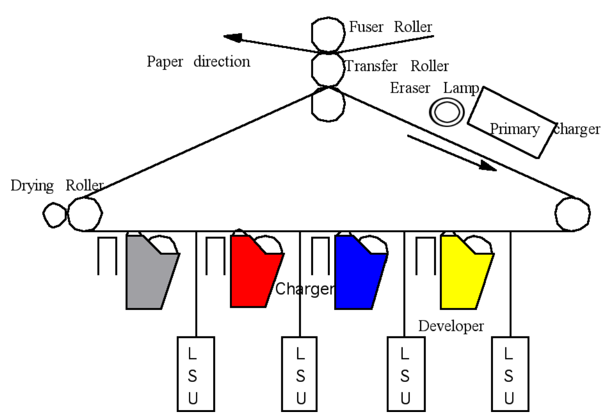

Figure 1. System Configuration

Characteristics of Developing Process

As shown in Fig.1, the developing units are aligned along the photoconductive belt, and a certain gap between the developing unit and the photoconductive belt is maintained systematically and is referred as the developing nip in this research. The supplied liquid toner through a delivery system is filled in the nip when the system is initiated, and the electrical biasing on the developing roller is applied to build up the electrical field at the nip. Since different surface potentials between the image area and non-image area are existent on the photoconductive belt through the exposing process, the developing roller is biased to the middle level of the voltage difference.

This biased voltage vector creates the dynamic activities of the charged toner in the direction of the electrical field applied. The migration of the charged toner particles caused by the columb force generates the toner formation on the photoconductive belt. The quality of the formed images is dependent upon the characteristic of the developed toner mass. Therefore, the characteristic of the developed toner mass is very important to predict the behavior of the developing process. Since the amount of the developed toner mass is controlled by the electrical field in the nip, the modeling for the potential distribution and the electrical intensity in the nip may be extended to investigate the developing current.

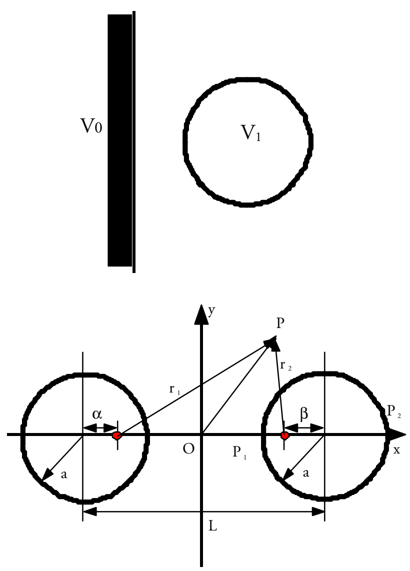

Figure 2. Schematic of Development Model

Figure 2 shows the schematic of development. In general, the analysis is conducted using the plate-to-plate model.[3] This research adapts the plate-to-cylinder model because the geometrical shape in the proposed system consists of the photoconductive belt assuming a plate and the developing roller assuming a cylinder.

Assuming that the cylinder is mirrored symmetrically behind the boundary plane of the photoconductor, the potential, V, acting on the point, P, shown in Fig. 2 may be described in terms of the electrical conditions and the geometrical dimensions between the cylinder and the conducting plane, and it is given by

$$V = \frac{\rho_L}{2\pi\varepsilon}\ln\frac{r_1}{r_2} + C \quad , \tag{1}$$

where ρ_L is the line charge density of the cylinder and ε is the permittivity within the nip.

As well known, the boundary plane of the photoconductor may be replaced by the equivalent negative polarity cylinder. Since the charge is distributed along the cylinder and assumed to be a point charge at a position, the parameters, α and β are the dimensions where the point charge is accomplished. Two boundary conditions may be applied in this consideration. First, the potentials acting on the circumference of the cylinder are identical while the locations of the applied potential, r_1 and r_2, are varied from the location of the point charge. The other one is that the potential, V_o, acting on the photoconducting plane in the direction of the y-axis is same through the plane. Therefore, the potential, V, acting on the point, P, is given by

$$V = -\frac{(V_o - V_1)}{\ln\left(\dfrac{a-\alpha}{L-a-\alpha}\right)}\ln\left(\frac{r_1}{r_2}\right) + V_o \, , \tag{2}$$

where a is the radius of the cylinder and V_1 is the developing bias. Hence, the potentials acting on the cylinder and its mirrored cylinder are identically same, the parameters, α and β, may be given by

$$\alpha = \beta = \frac{L - \sqrt{L^2 - 4a^2}}{2} \, . \tag{3}$$

Therefore, the line charge density, ρ_L, can be obtained using Eqns.(2) and (3), and it is given by

$$\rho_L = -\frac{2\pi\varepsilon(V_o - V_1)}{\ln\left(\dfrac{a-\alpha}{L-a-\alpha}\right)} \, . \tag{4}$$

Since the toner is developed by the electric field acting on the nip, it is considered that the x component of the electric field is dominant. Therefore, the electric field in the x-direction can be calculated by taking a derivative of Eqn.(2) with the constants shown in Eqn.(3), and it is given by

$$E_x = -\frac{\partial V}{\partial x} = \left(\frac{(V_o - V_1)}{\ln\left(\dfrac{a-\alpha}{L-a-\alpha}\right)}\right)\left(\frac{x + L/2 - \alpha}{r_1^2} - \frac{x - L/2 + \alpha}{r_2^2}\right) \quad , \tag{5}$$

The motion of the charged toners within the developing nip is governed proportionally by the electric field; thus, toners are led to develop the image electrically on the discharged areas of the photoconducting plate surface. The developed toner mass can be predicted by investigating the characteristics of the developing current that is measured from the migration of the charged toner within the developing nip. Since the developing current is the function of the liquid toner conductivity and the electric field within the developing nip, the conductivity is the property of the liquid toner and is assumed as a constant, and the electric field is discussed in previous. However, the electric field is varied within the developing nip due to the geometrical dimensions of the developing nip and the variation of the voltage on the surface of the photoconductor. Based on the concept, plate-to-cylinder model, it is noticed that the electric field distribution is not uniform between the cylinder and the photoconductor. Therefore, the current density associated with the toner migration may be considered, and it is given by the usual formulation as follows:

$$\boldsymbol{J} = \sigma \boldsymbol{E} \,, \tag{6}$$

where σ is the conductivity. The developing current per unit length of the developing roller within the nip can be calculated by taking the integral of the electric field term shown in Eqn.(5) and substituting this into Eqn.(6), and it may be given by

$$I = \sigma \int_{-d}^{d} E_x(x=0)\,dy$$

$$= 4\sigma \frac{(V_o - V_1)}{\ln\left(\dfrac{a-\alpha}{L-a-\alpha}\right)} \tan^{-1}\left(\frac{d}{L/2-\alpha}\right), \tag{7}$$

where d is a half-length of the developing nip, and the unit length of the nip, dy, contains the information of the process speed given by $dy = vdt$.

Results and Discussion

The models developed in the previous section can be compared with the plate-to-plate model for the variation effects of the surface potential on the photoconductor and the developing current. The main difference between the plate-to-plate model and the plate-to-cylinder model is based on the geometrical shape of the developing nip; therefore, it yields the different electric field distribution and the developing current density within the developing nip. Using the analytical approaches shown in Eqn.(1) through Eqn.(7), Fig. 3 shows the comparison of the surface potential within the developing nip between the plate-to-plate model and the plate-to-cylinder model. The current density can also be compared with them, and the results are shown in Fig. 4 respectively.

The results shown in Fig. 3 and Fig. 4 are generated by setting 200 $pmho/cm$ of the ink conductivity, σ, 200 μm of the developing gap, and 300 pF/cm^2 of the photoconductor capacitance. The developing bias is set to 450V and the discharged voltage is set to 130V then, the results show the deferent pattern of the surface potential and the current density within the developing nip given by 0.6 cm.

As shown in Fig. 3, the change of the surface potential for the plate-to-plate after passing through the beginning of the developing nip is relatively high compared with the plate-to-cylinder. In general, the change of the surface potential is effected by the developing gap, and the electric field is uniformly built up within the developing nip if the developing gap remains constant. Therefore, the rate of change in the surface potential is moderate through the developing nip.

If the geometrical shape of the developing nip is considered, the developing gap may not be constant. As shown in Fig. 2, it is shown that the developing gap is big at the ends of the both sides within the developing nip while the developing gap is small around the center point of the developing nip. With keeping this in mind, the migration of the toners is occurred rapidly around the center point of the developing nip compared with the points at the ends of the both sides. It results in the high rate of change of the surface potential around the center point of the developing nip. Fig. 3 shows the different phenomenon for both the plate-to-plate model and the plate-to-cylinder model.

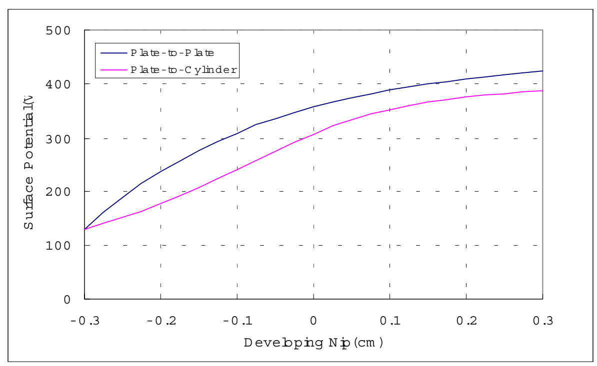

Figure 3. Comparison of Surface Potential between Plate-To-Plate and Plate-To-Cylinder Models

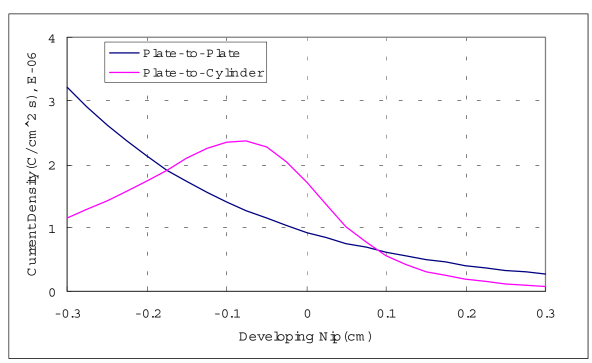

Figure 4. Comparison of Current Density between Plate-To-Plate and Plate-To-Cylinder Models

In case of the current density, Fig. 4 shows the more convenient results to understand the difference of the surface potential characteristics for the both models. The migration of the toners for the plate-to-cylinder model is mostly active at the center of the developing nip because the electric field is the strongest through the developing nip.

The variation effects of the surface potential with the constant gap are discussed. Another variation effects of the surface potential may be investigated dependent upon the conductivity. Since the proposed system takes 4-color based (Yellow, Cyan, Magenta, and Black), the ink conductivities may be different for each color. In addition, the superimposed developing system is adapted, thus, the primary surface potential affects the next following color development as a reference potential.

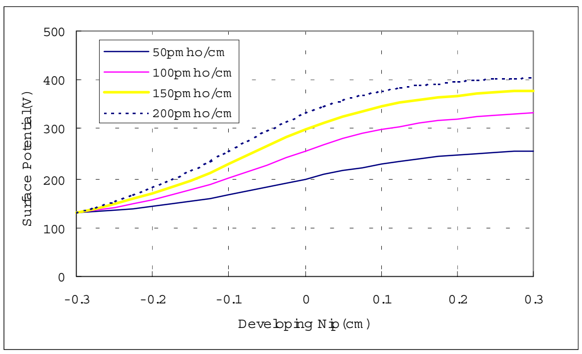

Figure 5. Variation Effects of Conductivity

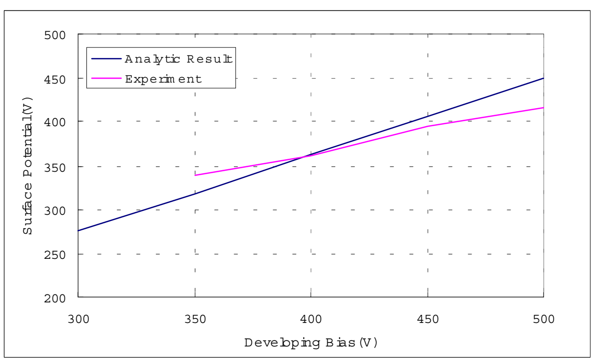

Figure 6. Comparison of Surface Potential between Analytical Result and Experiment

As mentioned previously, the conductivity is the property of the liquid toner and is influenced by the toner charge. If the toner charge is small, the rate of the change per unit time in the surface potential is decreased. It means that the surface potential may be characterized by the ink conductivity, and the lower ink conductivity generates the lower surface potential. Therefore, the process condition may be determined dependent upon the variation effects of the ink conductivity, accordingly. Figure 5 shows the variation effects of the conductivity, and 4 different cases are investigated. Each line may imply the ink conductivity for 4 different colors.

To perform the results shown in Fig. 3, Fig. 4, and Fig. 5, experiment can be accomplished, and the comparison for the surface potential is shown in Fig. 6. As shown in Fig. 6, the conductivity is chosen as 200 $pmho/cm$, and the experiment is carried out with the change of the developing bias. The discharged voltage is set to 130V, and the developing biased is used as 450V. The results are well matched for both the analytical approaches and the experiment. Therefore, it can be extended to determine the characteristics of the other colors.

Based on the previous investigations, the developed mass may be predicted by understanding the characteristic of the developing current shown in Eqn. (7). Fig. 7 shows the relationship between the developing current and the developing bias with the different value of the conductivity, and the developed toner mass can be calculated. Simulating the result of the developing current also leads to design the developing parameters.

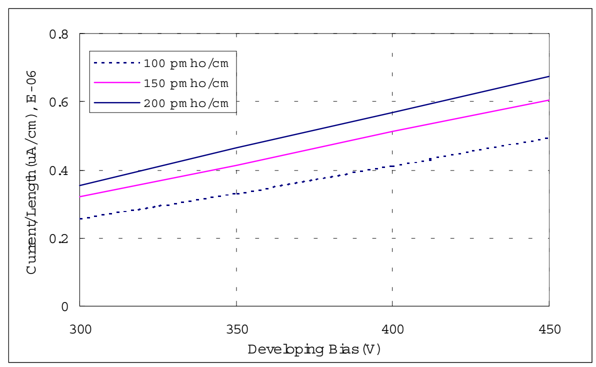

Figure 7. Relationship between Developing Current and Bias

Conclusion

The developing current model is developed using the plate-to-cylinder analysis for the color printing system based on the liquid toner and performed by the experiment. The variation effects of the geometrical shape of the developing nip and the ink conductivity are investigated by conducting the numerical simulation runs with the analytical model. The characteristics of the developing process can be predicted and the design parameters for developing process can be established. The results shown in this research may be extended to investigate the relationship between the developing current and the developed mass analytically for further research.

Acknowledgement

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Biography

Inyong Song received his MS degree in Mechanical Engineering from Korea Advanced Institute of Science and Technology, and he joined Samsung Advanced Institute and Technology in 1990. In 1994, He published the paper "Non-contact non-magnetic mono-component rubber roll color development" in IS&Ts Nip 10. Now, He has developed the process of color laser beam printing system using liquid toners at Samsung Electronics since 1997. His work is focused on the color development process.

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