Conductive Toner Cloud Confinement Using the Cone Shape of Dented Electrode

Suda Kiatkamjornwong, Witchanikul Sripho, and Yasushi Hoshino[1]
Department of Imaging and Printing Technology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand
[1]Department of Systems Engineering, Faculty of Engineering, Nippon Institute of Technology, Saitama, Japan

Abstract

Control of toner movement is an important parameter in the development of digital printing, which uses toner. The conductive toner has possibilities of new, simple printing mechanism. The conductive toner particles were sprayed onto the lower electrode. An electric field was applied between the two electrodes. The toner moved up and down between the two electrodes by electrostatic force. When the cone shape of the dented electrode replaced the lower plate, conductive toner particles were confined in the dented electrode. This research studied the toner confinement conditions required to form a toner cloud state using the cone shaped dented electrode. We found that the depth of cone-shaped, dented lower electrode, the resistivity of conductive toner and applied voltage between the electrodes are the influencing factors that determine the optimum size of toner cloud confinement and the toner jumping current. The deeper cone shaped, dented electrode reduces the size of the toner cloud confinement and the required toner jumping current. A high resistivity toner produces a larger size toner cloud and decreases the toner jumping current. When a greater amount of toner is placed into the electrode, a larger size toner cloud and greater toner jumping current are obtained. A higher applied voltage reduces the size of the toner cloud and increases the toner jumping current.

Introduction

Toner cloud beam (TCB) printing is one of the printing methods that are expected as being usable as a substitute for electrophotography. In TCB printing method, a direct toner recording method involves a toner jet system, whereas the toner can be controlled by a simple mechanism. Therefore, in order to simultaneously develop the printing speed and simplicity of the printing mechanism, which has been purposed to be faster than ink jet and lower in manufacturing cost than electrophotography, toner jet can be simplified using the TCB method. The control of toner motion can be used for property evaluation of the non-impact printing. Main evaluation items of the printing process are print quality, printing speed and simplicity of printing mechanism. The print quality is controlled by the precision of position where a toner particle is attached to a paper and the controlled amount of attaching toner particles.

The conductive toners start to move up and down between the electrodes because the conductive toners are charged by conduction from the electrodes under the electric field applied and electric force (toner charge × electric field) on the toners. The conductive toners can be confined between electrodes using the dented electrode. This confinement is realized by electric field toward the central axis of the dented electrode. Kiatkamjornwong et al,[1] applied the toner jumping method to estimate toner adhesion force by electric field activated toner jumping, by which various substrates and toner particle size were used. The voltage was applied to the electrode at a constant rate and toner jumping started at the voltage where the electric force overcomes adhesion and gravitation forces. From the toner jumping voltage or the threshold voltage, the adhesion force and toner jump were estimated. The control of conductive powder cloud by applying the toner jumping method, using the dented electrode was proposed and developed by Hoshino et al[2] and the TCB method was also invented by Hoshino et al.[3] The experimental setup for this method includes the dented electrode, lower control electrode, upper control electrode and pulling electrode being placed parallel. They can confine the toner cloud between the electrodes by the applied voltage and confining as a dot formed on a substrate. The toner beam is extracted from the toner cloud and projected to the substrate.

Experimental

Materials

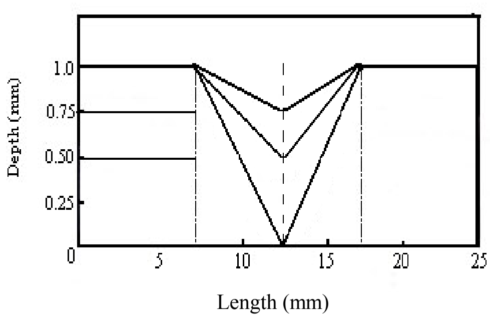
Three types of conductive toner from Hitachi Metal, Tokyo, Japan were used as follows: HMT 2059-1 with 4.4 x 10^8 Ω cm, diameter of 11.8 μm; HMT 2059-2 with 5.7 x 10^7 Ω cm, diameter of 11.8 μm; and HMT 2059-3 with 7.4 x 10^6 Ω cm, diameter of 11.7 μm. Pulling electrode: ITO glass 100 mm × 100 mm × 1 mm, dented electrode as follows: stainless steel plate 100 mm × 100 mm × 2 mm, Teflon sheet plate: 100 mm × 100 mm × 0.5 mm were used for the setup of TCB.

Apparatus

The TCB Control unit (home made) is composed of five important units. First: a DC high voltage power supply (Bellnix Co., Ltd. Saitama, Japan, Model MHV 12 – 2.0 k, 1000 p. Input: + 10.8 ~ + 16.5 V. Output: 0 ~ + 2000 V, 1000 μA). Second: regulated DC power supply (PA 250 – 0.25 A/AL KENWOOD TMI Corporation, Japan); regulated DC power supply (532 C, Metronix Co., Ltd. Tokyo, Japan). Third: pulling electrode and Cone-shaped dented electrode. Fourth: a digital Camera (caplio. RR 30, Ricoh Co. Ltd.), and electrometer (R 8240 Digital Electrometer, Advantest Corporation, Tokyo, Japan). Fifth: an electronic balance (AX 20S, Mettler Toledo Corporation, Osaka, Japan).

Experiment Setup

The electrodes used in the experiments are of a stainless steel and an ITO (Indium Tin Oxide) sputtered transparent glass. The ITO glass is used for observing the toner motion. The ITO glass is flat and the stainless steel electrode is dented into three cone shapes. Configuration of the dented cone shaped electrode used in this study is 10 mm diameter with three depths of 0.2, 0.5 and 1.0 mm. Figure 1 shows the shape of the dented cone shape electrode both the cross- sectional and the top views.



a) Cross section of the dented shape electrode

b) top view of the dented cone-shaped electrode

Figure 1. Cone shape of the dented electrode

Toner Cloud Beam Control Unit (TCB)

A TCB control unit is constructed as shown in Figure 2 in which two electrodes are arranged in parallel. The upper electrode is an ITO glass and the lower electrode is dented called "the dented electrode". The spacing of the two parallel electrodes was set 0.5 mm apart by a Teflon sheet to keep the space constant.

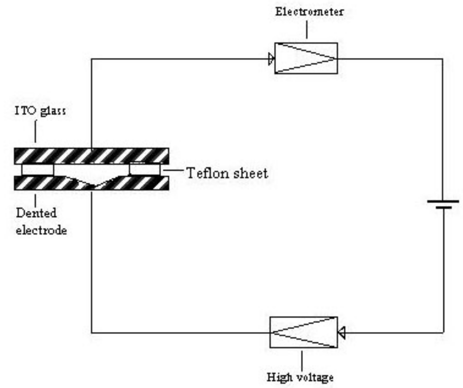


Figure 2. Schematic diagram of the experiment

Estimation of Toner Cloud Extent

The sample toner of HMT2059-1 weighed 0.30 mg (or 0.5, 0.8, 1.0 mg) was applied on the thin cone shape of the stainless steel electrode. The diameter and depth of the dented electrode are 10 mm and 0.20 mm, respectively. The voltages applied to the electrode were 500, 750 and 1000V for one second each. The cloud-state toner was photographed by a digital camera, and the toner could be viewed though ITO glass. Likewise the toners HMT2059-2 and HMT2059-3 were each used in the place of toner HMT2059-1 and the similar experiments were then repeated.

After taking the photographs, the size of the toner cloud diameter was measured by the software Image called *Proplus*. Then the average value of the toner cloud diameter was taken and plotted in a graph to indicate the relation between the toner cloud diameter and the toner amount. This method gives dependency of the toner cloud extent on the toner amount. Again, the averaged value of the toner cloud diameter and its applied voltage was plotted to get the relationship between the toner cloud diameter and applied voltage.

Evaluation of Toner Jumping Current

The toner jumping experiment was set up by following the configuration shown in Figure 1. The toner was then applied to the lower electrode. The voltage was thereafter applied. The threshold voltage and toner jumping current at the initial jumping were determined.

Dependence of Toner Jumping Current on
The Toner Amount

The experimental mentioned above was repeated to observe the toner jumping current detected by the electrometer.

The Applied Voltage

The dependence of the toner jumping current on the applied voltage was studied using the cone shape of dented electrode with the depths of 0.2, 0.5 and 1.0 mm. The cone shape of the dented electrode was sprayed with the conductive toners: HMT2059-1, HMT2059-2, and HMT2059-3 with the toner resistivity of 4.4×10^8, 7×10^7 and 7.4×10^6 Ω cm, respectively. The amounts of toner of 0.3, 0.5, 0.8 and 1.0 mg were used. The applied voltages used were 0 to 1000 V with an increment of 100 V and the spacing between the electrodes is 0.5 mm. When the applied voltages had been set at 0 to 1000 V, the experimental procedures mentioned above were repeated. The toner jumping current was then measured by the electrometer.

Results and Discussion

Toner Cloud Confinement

The control of the conductive toner motion is important in applications such as the non-impact printing. The conductive toner was sprayed freely on the electrode. When more than a certain value of electric field had been applied between the electrodes, the conductive toner started to move up and down between the electrodes by electrostatic force. Using an electrode dented to a cone shape, the conductive toner was confined between the electrodes in the dented area. As stated earlier, the electrodes used in the experiments are made of a stainless steel plate and the second one, the ITO sputtered transparent glass. The ITO glass was used for observing the toner motion. The stainless steel plate was dented to a cone shape.

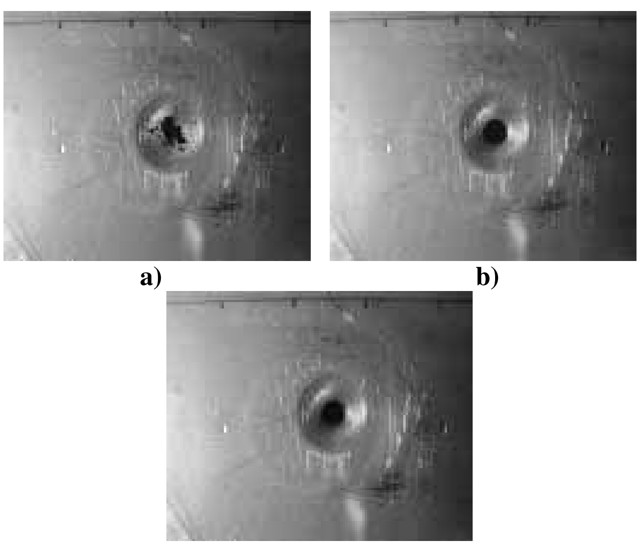


Figure 3. The photographs of the conductive toner observed by the ITO glass, a) toner before the cloud state, b) toner at the cloud state and c) toner after the cloud state.

Figure 3 displays the photographs of the toner before the cloud state (Figure 3a), the toner at the cloud state (Figure 3b), and the toner after the cloud state (Figure 3c). Dispersion or scattering of the conductive toner on the dented electrode was found before the cloud state. After the voltage had been applied to the electrode, the conductive toner started to move up and down between the electrodes by the electric force. The conductive toner on the electrode was out of sight and became like a black cloud as shown in Figure 3 b). When the applied voltage was stopped, the conductive toner still moved down to the dented electrode, which could be observed from the ITO glass. It was confined on the dented electrode as shown in Figure 3c). The diameters of the toner cloud, photographed and shown in Figure 3, were measured by Image Proplus software. The results of the toner cloud diameter are shown in Table 1. As stated previously, the toner at the cloud state is confined in the dented electrode. This can be postulated that some component in the electric force traveled toward the central axis as shown in Figure 4.[2]

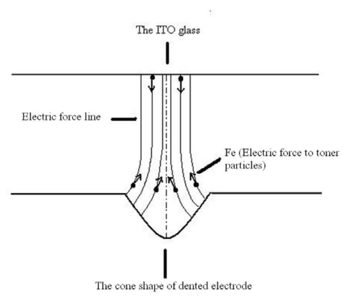


Figure 4. Schematic illustration of the toner motion in the dented cone-shaped electrode (------- central axis)

Figure 4 demonstrates that the toner motion and direction as shown by the electric force lines, moves towards the central axis. The electrostatic field external to the body of a conductor must always be perpendicular to the surface.[4] Therefore, the electric force lines between the electrodes from the cone area of the dented electrode must always be perpendicular to the electrode surface and the ITO glass.

Toner Cloud Extent Dependence on *The Toner Concentration*

The dependence of the toner cloud extent on the toner concentration was studied using the dented cone-shaped electrode. The relationship between the conductive toner cloud diameter and the toner amount can be seen in Table 1. The higher amount of the toner produces the larger diameter of the toner cloud during toner jumping, resulting from the greater quantity of toner particles on the dented electrode. Furthermore, the extent of toner cloud also depends on the toner characteristic resistivity, the applied voltage and the cone depth of the dented electrode as follows:

Table 1. Averaged diameter of toner cloud for the three toners

Voltage (V)	Toner amount (mg)	The toner cloud diameter (mm) at Cone depth of dented electrode (mm)								
		HMT2059-1			HMT2059-2			HMT2059-3		
		0.2	0.5	1.0	0.2	0.5	1.0	0.2	0.5	1.0
500	0.3	3.82	3.47	3.14	3.88	3.85	3.55	3.15	2.98	2.83
	0.5	4.33	4.13	3.85	4.32	4.02	3.93	4.16	3.99	3.94
	0.8	5.21	4.89	4.24	5.08	4.65	4.16	5.04	4.71	4.1
	1	5.73	5.4	5.27	5.48	5.23	5.19	5.5	5.17	5.12
750	0.3	3.54	3.47	2.99	3.54	3.48	3.15	2.92	2.8	2.75
	0.5	4.26	4.02	3.77	4.02	3.93	3.7	3.85	3.84	3.78
	0.8	5.12	4.81	4.48	5.04	4.38	4.32	4.86	4.63	3.78
	1	5.66	5.2	4. 9	5.81	5.12	4.96	4.93	4.73	4.71
1000	0.3	3.35	3.15	2.75	3.46	3.25	3.07	2.84	2.74	2.36
	0.5	4.18	3.94	3.14	3.98	3.78	3.62	3.92	3.62	3.46
	0.8	5.89	4.57	4.47	4.32	4.32	4.26	4.78	3.7	3.61
	1	5.94	5.16	4.83	5.66	5.23	4.96	4.89	4.41	4.32

HMT2059-1, HMT2059-2, and HMT2059-3 have the resistivity of 4.4×10^8, 7×10^7 and 7.4×10^6 Ω cm, respectively

The Cone Depth of the Dented Electrode

The results in Table 1 show that the toner cloud diameter increases when the toners amount increases. For the effect of the cone depth of the dented electrode on the toner cloud diameter, the cone depth of the dented electrode of 0.2 mm gives the biggest diameter while that of 1.0 mm produces the smallest diameter. In the same manner regardless of the magnitude of applied voltage, the smaller depth of the dented electrode produces the largest toner cloud diameter at any toner amount. The largest depth (1.0 mm) of the dented electrode gives the smallest diameter of toner cloud while the 0.5 mm depth of the dented electrode yields the intermediate diameter.

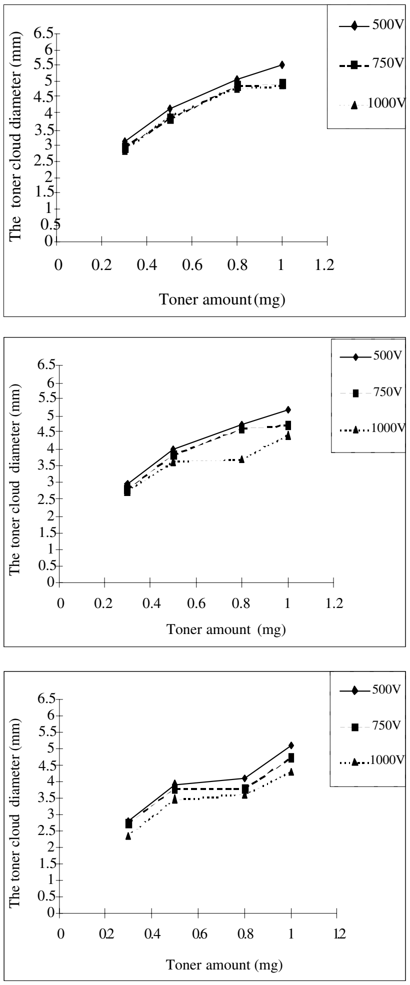
Toner Characteristic Resistivity

Toners HMT2059-1, HMT2059-2, HMT2059-3 with the resistivity of 4.4×10^8, 5.7×10^7 and 7.4×10^6 Ω cm, respectively, are used for toner cloud study. Figure 5 shows the dependence of the toner cloud diameter on the toner amount in their corresponding resistivity at the fixed cone depth of 0.2 mm of the dented electrode with different applied voltages of a) 500, b) 750 and c) 1000. The resulting lines show the similar trend, of straight lines with increasing slopes. That is, increasing toner amount increases the diameter of toner cloud. Comparing the level of toner resistivity, the higher the resistivity of the toner, the greater the toner cloud diameters could be realized. Therefore, one can observe the longest toner cloud diameter of HMT2059-1 (4.4×10^8 Ω cm) and the shortest toner cloud diameter of HMT2059-3 (7.4×10^6 Ω cm), while the HMT2059-2 (5.7×10^7 Ω cm) gives the intermediate diameter.

The Applied Voltage

Dependence of the toner cloud extent on the toner amount at three applied voltages of 500, 750, and 1000 V is shown in Figure 6 at the toner resistivity of 4.4×10^8 Ω cm with different cone depths of the dented electrode of 0.2, 0.5 and 1.0 mm. The toner cloud diameter increases, when the toner amount increases. Considering influencing factors of the applied voltage on the diameter of toner cloud, the lowest applied voltage (500 V) produces the longest diameter whereas the 1000 V gives the smallest diameter size of the toner cloud. Similarly, the dependence of toner cloud diameter on the toner amount at the applied voltages and the toner resistivity of 5.7×10^7 and 7.4×10^6 Ω cm, at the cone depths of the dented electrode of 0.2, 0.5 and 1.0 mm could be observed. The toner cloud diameter increases with increasing toner amount in the same manner. The lower applied voltage (500V) is found to give the larger toner cloud diameter than that at 1000 V, which produces the smaller diameter. When the voltage was applied to the electrodes, the toner particles were charged and then moved between the electrodes due to the electrostatic force. The electric force acting on the toner particle can be calculated by the following equation:

$$F_e = qE \tag{1}$$



(a)

(b)

(c)

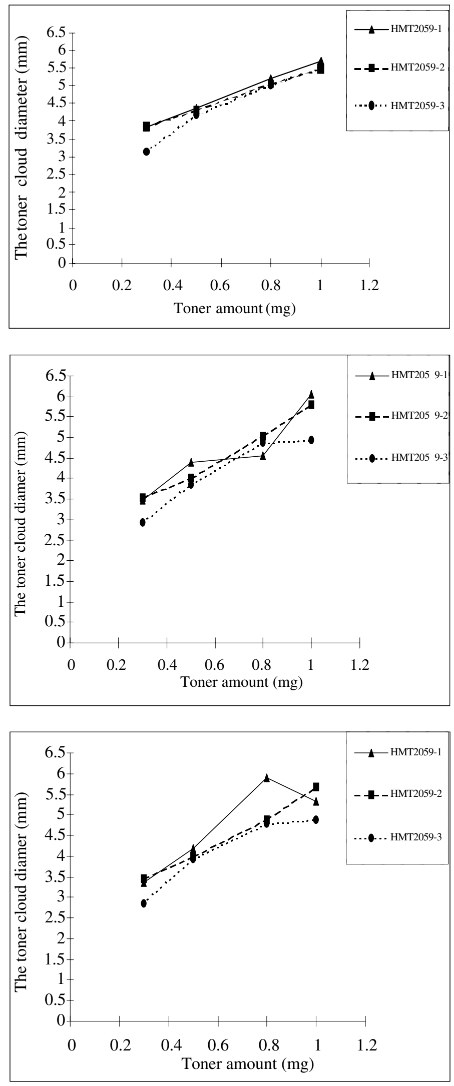
Figure 5. Dependence of the toner cloud diameter on the toner amount at three applied voltages for toner HMT2059-1 at the cone depths of dented electrode of a) 0.2, b) 0.5 and c) 1.0 mm

Because of $F = ma = mdv/dt$, while v is the velocity of the toner particle and x is the displacement of the toner particle, Equation (1) can be derived in the second derivative equation along the x and z directions as shown in Figure 2:

$$\frac{d^2x}{dt^2} = \frac{q}{m}E_x \tag{2}$$

$$\frac{d^2z}{dt^2} = \frac{q}{m}E_z \tag{3}$$

Considering the displacement of the toner particle along the x and z directions, which indicate the toner cloud extent. Using the integrated Equations (2) and (3), here, the charge q and the mass m are assumed to be constants on the position A, and the displacement of the toner particles from the position A is then obtained. When the time is a constant, the displacements then depend on the electric field. From the following relation of voltage and electrode, $E = \nabla V$,[5] when the higher voltage was applied, the displacement of the toner particles is longer and move towards the central axis of the dented electrode. So, the higher applied voltage (1000 V) is found to give the shorter cloud diameter than that at 500 V.



(a)

(b)

(c)

Figure 6. Dependence of the toner cloud diameter on the toner amount in their corresponding resistivity at the fixed cone depths of dented electrode of 0.2 mm. Different applied voltages of a) 500, b) 750 and c) 1000V.

Dependence of the Toner Jumping Current on Toner Amount

Figure 7 shows the dependence of the toner jumping current on the applied voltage for three types of toner characteristic resistivity. For toner HMT2059-3 with 7.4×10^6 Ω cm, the threshold voltage is 400 to 500 V. We also found the higher threshold voltages for toner HMT2059-1 and HMT2059-2 with the higher resistivity of 4.4×10^8 and 5.7×10^7 Ω cm, respectively. As mentioned earlier, conductivity is inverse proportional to resistivity. The higher conductivity of the toner can move the toners up to the upper electrode. When the voltage exceeds a threshold value, the toner jumping starts to increase the current. The process of the toner jumping continues. The rates of induction changing of the conducting toner will depend upon the charging time constant or the relaxation time. The charging time constant can be expressed as:[2, 6]

$$\tau_c = C_{tc} R_t \tag{4}$$

where C_{tc} is the capacitance between the toner surface and the upper electrode and R_t is the resistance of the toner layer. Whether or not a material obeys Ohm's law, its resistance can be described in terms of its bulk resistivity. The charging time constant is a measure of how fast the conducting approaches electrostatic equilibrium.[4] The charging time constant for the toner HMT2059-1, HMT 2059-2, and HMT2059-3 depends on the resistivity of these toners. The relaxation time of the toner HMT2059-1 is the longest time, therefore the toner moves up to the upper electrode with the larger threshold voltage.

Conclusions

When a certain value of the electric field was applied between the electrodes, the conductive toner starts to move up and down between the electrodes by the electrostatic force. We can observe the conductive toner motion by the ITO glass. At the toner cloud state, the conductive toner on the dented electrode is out of sight and becomes like a black cloud that the electric force carries the toner component toward the central axis of the dented electrode. Investigation of the dependence of the toner cloud extent on the toner amount, at three values of the toner characteristic resistivity indicated that the increase in the toner amount leads to the larger toner cloud extent. The toner cloud extent decreases with increasing applied voltage. For the depth of the cone-shaped dented electrode, the smaller toner cloud extent, the larger the depth of the dented electrode. In addition, the effect of applied voltage was additionally studied for toner jumping current. It was found that the toner jumping current depends on the toner amount. When the toner amount increased, the toner jumping current also increased. Likewise, the applied voltage to the electrodes was higher; the toner jumping current was also increased. Moreover, the toner characteristic resistivity is another parameter in the toner jumping current. The lower resistivity toner gives the higher toner jumping current.

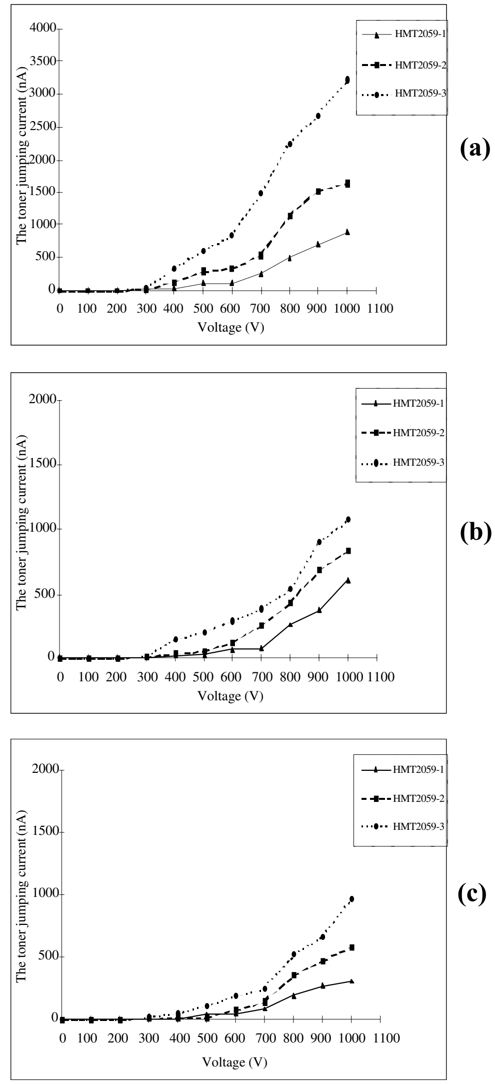


Figure 7. Dependence of the toner cloud diameter on the toner amount in their corresponding resistivity at the fixed cone depth of the dented electrode of 0.2 mm. different applied voltages of a) 500, b) 750, and c) 1000 V.

Acknowledgements

The authors expressed their gratitude to Thailand-Japan Technical Transfer Project under the research Profile (RP) 21 Imaging Technology, on the topic of Toner Technology, of Chulalongkorn University. Many thanks go to the suppliers mentioned in the articles for their contribution of materials for this research.

References

1. Kiatkamjornwong, S.: Noppakundilograt, S.; Ando, Y.; Hoshino, Y. Toner adhesion force estimation by electric field activated toner jumping, J. Imaging Science and Technology, 1997, 41(1), 54-58.
2. Hoshino, Y.; Muta, T.; Kamata, M. Confinement of conductive powder cloud by using an electrode dented to a thin lens shape. J. Imaging Society of Japan, 1997, 36(3), 156-162.
3. Hoshino, Y.; Hirayama, H. Dot formation by toner beam from toner cloud, IS&T's NIP 15, International Conference on Digital Printing Technologies, Springfield, VA, 1999, pp. 598-600.
4. Hecht, E. Physics Calculus, 2nd ed. California, Thompson Learning, 2000, p.634.
5. Corson, R.D.; Lorrain, P. Introduction to Electromagnetic Field and Waves. San Francisco, Freeman, W.H., 1962, pp. 40-41.
6. Hoshino, Y.; Kutsuwada, N.; Watanabe, Y.; and Izawa, H. Measurement of van der Waals force of toner adhesion employing a linearly increasing electric field and determining the toner jumping voltage. *Particulate Science and Technology* **14**: 267-277 (1996).

Biography

Suda Kiatkamjornwong received her B.Sc. degree in Chemistry and M.Sc. in Physical Chemistry from Chulalongkorn University, Thailand in 1970 and 1972, respectively; and Ph.D. in Polymer Science and Engineering from Lehigh University, U.S.A. in 1983. She is now the Head Department of Imaging and Printing Technology where she is a full professor for Polymer Science. She is the recipient of many awards such as the Outstanding Professor Award of Chulalongkorn University for teaching and research, Outstanding Science Faculty alumnus Award; Outstanding National Researcher Award in chemical and pharmaceutical sciences from the National Research Council of Thailand. Her research interests are hydrogel, imbiber beads and imaging polymer.