# Size Dependence on Toner Charge in Two-Component Developer

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# Abstract

In the electrophotographic process, two-component developer is widely used for commercial machines. Quantity of tribo-electric charge on toner in the two-component developer is one of the factors to affect the image quality. The effects of toner components and size on charge are important to evaluate electrophotographic developers. In this study, a modified E-SPART (Electrical Single Particle Aerodynamic Relaxation Time) analyzer based on a laser Doppler velocimeter is adopted for measuring toner charge and size simultaneously. Two-component developer in combination with toner based on styrene acrylic copolymer and non-coated ferrite carrier is used for evaluation. From the experimental results the n-th power dependence of diameter on tribo-electric charge of toner is shown to be about 2.7 for the negative toner with CCA additives and about 2.2 for the negative toner without CCA additives. The difference of n value is examined theoretically by the surface state theory.

#### Key words: toner, tribo-electric charge, surface state theory

#### Introduction

In the electophotographic industry, two-component developers have been widely adopted for color copy machines as well as black and white. Toner used in two-component developer is a key factor for reproducing original images in a copy machine. For high quality on copy image, there is a general trend towards the smaller size of toner. This trend brings about a strong demand in control of size and charge distribution for toner particles. Triboelectric charge on toner is, however, affected by various factors such as material components, additives, and shape. From this point of view, it is important to examine size dependence on toner charge by measuring size and charge on toner particles.

An instrument based on laser Doppler velocimeter, the Electrical Single Particle Aerodynamic Relaxation Time (E-SPART) analyzer[1], enables us to obtain distribution of diameter d and electric charge to diameter ratio q/d on toner particles. We have developed a data processing system on the data set of d and q and we have also reported the relation between particle size and charge on toner in two-component developer [2].

## Experimental

The E-SPART analyzer was modified for data processing and measurement of aerodynamic diameter d and electric charge q on toner particles. There are the three basic parts in the modified analyzer: (a) a dual-beam, frequency-biased laser Doppler velocimeter (LDV), (b) a relaxation cell and (c) a data processing system in a desk top computer for obtaining the relation between q and d. A schematic diagram of the analyzer is shown in Figure 1. The LDV measures drift velocity due to DC electric field at the sensing volume in the chamber.

The LDV also measures vibrating velocity in acoustic field superimposed to the DC field and aerodynamic diameter of toner is deduced from phase shift due to the acoustic frequency at 1 kHz. Calibration of particle diameter was carried out by using uniform Latex Microspheres of polystyrene of 3.15  $\mu$ m. The processing system had been developed by an analytical program on C++ and it was used for statistical treatment on experimental data in terms of *q* and *d*.



Figure 1. Schematic diagram of E-SPART analyzer

Toner particles based on styrene-acrylic copolymer with silica coating on the surface were prepared to analyze the relationship between charge q and diameter d. The negative toner has each of four specimens classified by their particle size with or without CCA additives, whereas the positive toner has only four specimens with CCA additives. On the other hand, non-coated ferrite beads were used as carrier and the toner concentration was 5 wt% for each sample in the two-component developer. Relative humidity for measurement was maintained at less than 70%.

### **Results and Discussions**

Size dependence on toner charge for a negative toner specimen with silica coating and with CCA additives is shown in Figure 2 and that with silica coating but without CCA additives is shown in Figure 3.

From the result for Figure 2 the mean value of toner charge was -4.3fC for about three thousand particles with the mean diameter of 8.6 $\mu$ m and the absolute value of *q* increased with increase of toner diameter *d*. On the other hand, the mean value of *q* was -2.9fC with the mean diameter of 9.2 $\mu$ m in Figure 3, where the absolute *q* was much smaller than 4.3fC and the variation level of distribution *q* on *d* in Figure 3 was lower than that in Figure 2. This means that treatment with CCA additives is effective for charging negatively and strongly.



Figure 2. Size dependence on charge for negatively charged toner particles with silica coating and with CCA additives. (mean diameter:8.6µm)



**Figure 3.** Size dependence on charge for negatively charged toner particles with silica coating and without CCA additives. (mean diameter:9.2µm)

As the result in Figure 2 or in Figure 3 was that for one specimen, it was rather difficult for obtaining clearly size

dependence on toner charge, such as  $q \sim d^n$ . In order to get further information about the dependence, it was investigated by using the four specimens with different mean diameter as the analytical samples with CCA additives or without CCA additives. The result is shown in Figures 4, 5 and 6.



**Figure 4**. Size dependence on charge for negatively charged toner particles in the four specimens with silica coating and CCA additives. (mean diameter: 6.1µm, 7.1µm, 8.1µm, 9.2µm)

In Figure 4 the absolute q increased exponentially with diameter d in the particle size region from  $4\mu m$  up to  $10\mu m$  and the *n*-th power of d was obtained as about 2.7 for the negative toner with silica coating and with CCA additives. In Figure 5 the absolute q also increased similarly with d and the n-th value for the negative toner with silica coating and without CCA additives was obtained as about 2.2 smaller than 2.7. The variation level of q on d in Figure 5 was also lower than that in Figure 4. These above results suggest the decrease due to the non-treatment of CCA additives. For the positively charged toner with silica coating and with CCA additives in Figure 6, the polarity of charge q was eventually positive and the mean value of q in a specimen with its mean diameter 9.2µm was about +3.4fC. The n-th power value of d was about 2.8. The charged level of distribution q on d in Figure 6 was lower than that for the negative toner with silica coating and with CCA additives in Figure 4.

From the surface state theory [3] for the low density limit in  $N_c$  and  $N_t$ , charge to mass ratio q/m on a single toner or Q/M on some amount of toner is expressed in Eq.(1), as

$$q/m = Q/M = 3e\Delta\phi/[RC_t\rho_c/N_c + r\rho_t/N_t].$$
 (1)

Here,

- $N_c$ : number of charge states on carrier per unit energy per unit area
- $N_t$ : number of charge states on toner per unit energy per unit area
- *e* : absolute magnitude of electronic charge
- $\Delta \phi$ : energy difference between the charge state on toner and the state on carrier
- R: radius of carrier
- r: radius of toner
- $\rho_c$ : mass density of carrier
- $\rho_t$ : mass density of toner
- $C_t$ : toner concentration in weight
- m: mass of toner particle
- q: charge of toner particle



Particle size(µm)

**Figure 5**. Size dependence on charge for negatively charged toner particles in the four specimens with silica coating and without CCA additives. (mean diameter: 6.1µm, 7.1µm, 8.1µm, 9.2µm)

When *m* is replaced by  $(4/3)\pi \rho_t r^3$ , charge quantity *q* on a single toner particle can be expressed in Eq.(2), as

$$q = 4\pi e \Delta \phi r^{3} / [RC_{t}(\rho_{c}/\rho_{t})/N_{c} + r/N_{t}].$$
(2)

From Eq.(2), it is shown that electric charge q has a tendency to be approximately proportional to  $r^2$  as shown in Eq.(3) for such a condition of  $N_t \le N_c$  and/or in relatively large radius r region of toner particle as the second term becomes dominant in denominator:

$$q \approx 4\pi e \Delta \phi \, N_t \, r^2 \tag{3}$$

On the other hand, electric charge q tends to be proportional to  $r^3$  for such a reverse condition of  $N_t \ge N_c$  and/or in relatively small r region as shown in Eq.(4).

$$q \approx [4\pi e \Delta \phi \rho_t N_c / (\rho_c R C_t)] r^3$$
(4)

Therefore, it is suggested that *q* has generally the *n*-th power dependence of radius *r* where  $2 \le n \le 3$ .



**Figure 6**. Size dependence on charge for positively charged toner particles in the four specimens with silica coating and CCA additives. (mean diameter: 6.3µm, 7.1µm, 8.2µm, 9.2µm)

The experimental results of size dependence on toner charge can be examined by the above surface state theory. Considering that  $R \sim 45 \mu m$ ,  $\rho_c / \rho_t \sim 5$ ,  $C_t \sim 0.05$  and  $N_c \sim$  a constant value, the first term in denominator in Eq.(2) would be comparable with the second term and it would be variable with  $N_t$  and r. In case of the result in Figure 4, the first term can be dominant and the n value tends to about 3 because  $N_t$  is probably higher than the constant value of  $N_c$  due to the effect of CCA additives. The higher value 2.7 of n is consistent with the above expectation. On the other hand, the lower value 2.2 of n with the lower absolute value of charge q is also consistent with the expectation from the theory in case of  $N_t \leq N_c$  due to the non-treatment of CCA additives. For the case of the positive toner with silica coating and CCA additives, it is also consistent with the theory in expectation of  $N_t \ge N_c$  due to the effect of CCA additives that the n value of 2.8 is also nearly equal to 3 in Figure 6.

#### Conclusion

Toner size dependence on charge in two-component developer was examined experimentally for the toner based on styrene-acrylic copolymer in combination with non-coated ferrite carrier and theoretically by the surface state theory.

Conclusion is as follows:

(1) The dependence on q was obtained by using the modified E-SPART analyzer. The *n*-th power value of d was 2.7 for the toner with CCA additives and that for the toner without CCA additives was smaller as 2.2.

(2) From the theory it is deduced that q has generally the *n*-th power dependence of d where  $2 \le n \le 3$ . The difference of n between 2.7 and 2.2 can be explained from variation of  $N_t$  due to the effect of CCA additives.

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## Author Biography

Youichi Nakamura received his B.S. degree in Applied Physics from Waseda University in Tokyo in 1966, and his M.S. and Doctor of Science from Tokyo Metropolitan University in 1968 and 1973, respectively. He joined in R&D Div. of Semiconductor LSI Works of Hitachi Co., Ltd. in 1971. Since 1987 he carried out on electrical and physical evaluation for electrophotographic materials at Nippon Institute of Technology. He is a member of the IS&T, the ISJ and the Japanese Society of Applied Physics.