Size Dependence on Toner Charge in Two-Component Developer

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Abstract

In the electrophotographic process, two-component developers are widely used for commercial machines. Quantity of tribo-electric charge on toner is one of the factors to affect image quality for copies. Effects of toner components and size on tribo-charging are important to evaluate electrophotographic developers. In this study, size dependence on toner charge is examined by a modified E-SPART (Electrical Single Particle Aerodynamic Relaxation Time) analyzer based on a laser Doppler velocimetric method for toner particles of styrene-acrylic copolymer in the size region from 6μm to 10μm. As a carrier, a polymer coated ferrite type or a non-coated type is used. From the experimental results, charge to mass ratio q/m decreases from 10 μC at 6.4μm to 4.6 μC at 9.5μm for toner without silica coating and CCA additives and the reverse m/q shows approximately a linear increase with diameter of toner in a two-component developer combined with a coated carrier. In case of a non-coated carrier, the n-th power size dependence on toner charge is shown to be about 2.7 for the toner with silica coating and CCA additives and about 2.2 for the toner without CCA additives. The results are explained to be consistent with prediction from 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 because toner particles have a main role to transfer latent images to visual images in developing process. 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. Tribo-electric 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 evaluate tribo-electric charging behavior in terms of q/m and 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].

In two-component electrophotographic developer, tribo-charging of toner particles is generated by contacting with magnetic carrier beads. It is important to understand the mechanism governing tribo-charging on toner particles by theoretical approach. The surface state theory of Lee [3] describes behavior of toner charging and it has been advanced by the researchers [4], [5]. In this study, the experimental results on toner charge in two-component developer are examined in terms of q/m with the surface state theory by focusing particle size dependence.

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. Calibration of particle diameter was carried out by using uniform Latex Microspheres of polystyrene of 3.15 μm. 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.

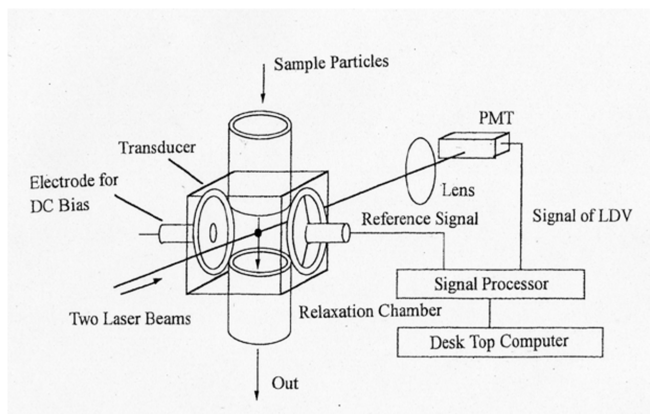

***Figure 1**. Schematic diagram of E-SPART analyzer*

Two kinds of negative toner based on styrene-acrylic copolymer with and without silica coating on the surface are prepared to analyze the relationship between charge to mass ratio q/m and diameter d. Each toner has four specimens classified by their particle size in the region from 6μm to 10μm. As carriers two kinds of carrier are also prepared. One is the polymer coated ferrite beads supplied by the ISJ (Imaging Science of Japan) and the other is non-coated ferrite beads. Toner concentration was maintained at 5 *wt%* for each sample in the two-component developer. For tribo-charging, manual shaking over 15 times was performed and it was followed by mixing mechanically for 10 minutes at 2.5 Hz of shaking frequency. *In Figure 2* a mixing shaker with an arm of 130mm length is shown and it is based on the recommended design by the ISJ. Relative humidity for measurement was also maintained at less than 70%.

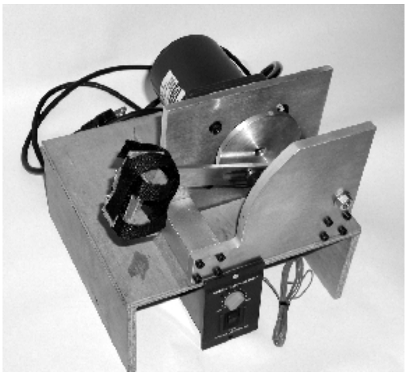

Figure 2. *Photograph of Toner Mixing Shaker with an arm of 130mm length*

Results and Discussions

The experimental results on size dependence of toner tribo-electric charge in terms of charge-to-mass ratio *q/m* are shown in *Figure* 3 for the negative toner specimens with silica coating and without CCA additives, in *Figure* 4 for the specimens without silica coating and CCA additives, and in *Figure* 5 for the specimens without silica coating but with CCA additives, respectively.

From the result in *Figure* 3 the absolute value of *q/m* decreased from 23μC/g at 6.5μm to 13μC/g at 8.9μm with increase of toner size *d*. From the result in *Figure* 4 the *q/m* decreased similarly from 10μC/g at 6.4μm to 5μC/g at 9.5μm but the level of *q/m* in the toner size region shifted towards a lower level. These suggest that treatment of silica coating on the surface of toner particles has an effect on increase of *q/m*.

On the other hand, the *q/m* for the specimens with silica coating and CCA additives as shown in *Figure* 5 was in a medium level and it decreased from 15μC/g at 6.6μm to 9μC/g at 10μm. This means that treatment with CCA additives is effective for adjusting and controlling the charging level.

As the results in *Figures* 3-5 do not vary linearly with toner diameter, it is rather difficult for obtaining clearly size dependence on toner charge. In order to get analytical information about the dependence, relationship between toner size and the inverse of charge-to-mass ratio, *m/q* is displayed also for the specimens with or without silica coating as shown in *Figure* 6.

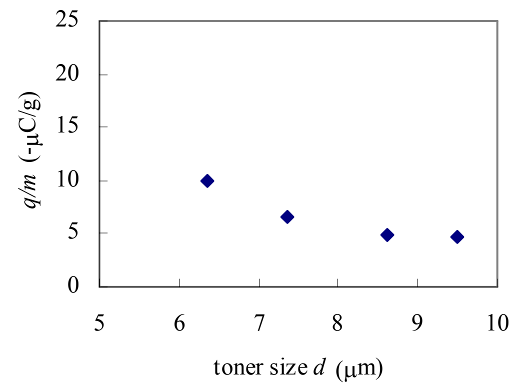

Figure 4. *Size dependence on q/m for negatively charged toner particles without silica coating and CCA additives. (carrier: polymer coated ferrite beads)*

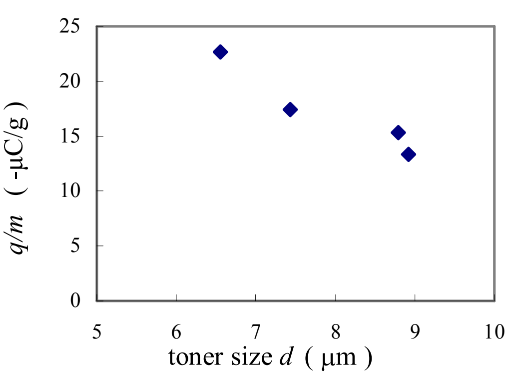

Figure 3. *Size dependence on q/m for negatively charged toner particles with silica coating and without CCA additives. (carrier: polymer coated ferrite beads)*

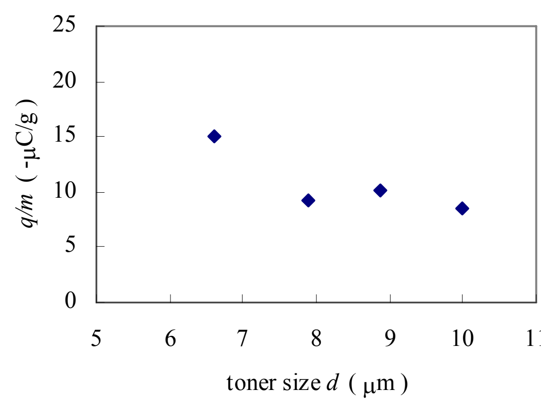

Figure 5. *Size dependence on q/m for negatively charged toner particles with silica coating and CCA additives. (carrier: polymer coated ferrite beads)*

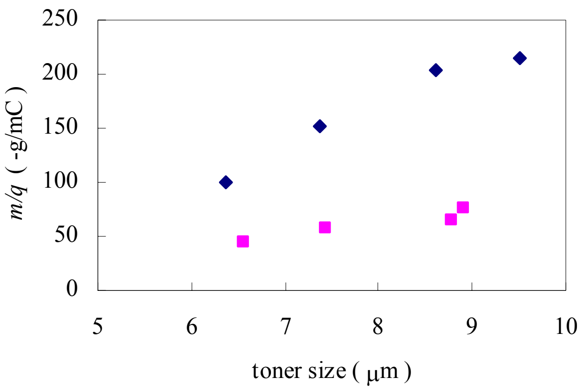

***Figure 6**. Size dependence on charge in terms of m/q for negatively charged toner particles with and without silica coating. (carrier: polymer coated ferrite beads), (diamond: toner specimen with silica coating and without CCA additives, square: toner specimen without silica coating and CCA additive)*

The *m/q* showed mostly a linear relationship with toner size in the region from 6µm to 10µm for each of the toner specimen with or without silica coating as shown *Figure* 6. This tendency is consistent with prediction from the surface state theory as shown later.

In order to know an effect on carrier for tribo-charging, the carrier specimen was exchanged from the polymer coated ferrite bead to the polymer non-coated one in two-component developer. The experimental results for the toner with silica coating and CCA additives in *Figure* 7 and for the toner with silica coating but without CCA additives in *Figure* 8 are shown respectively.

In *Figure* 7 the absolute q increased exponentially with diameter d in the particle size region from 4µm up to 10µm and the n-th power of d on q was obtained as about 2.7 for the negative toner with silica coating and with CCA additives. In *Figure* 8 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* 7 was higher than that in *Figure* 8 and the CCA additives were effective for increase of tribo-charge on toner particles in the two-component developer combined with the non-coated ferrite carrier beads: the effect of CCA additives on toner varies from one carrier to the other.

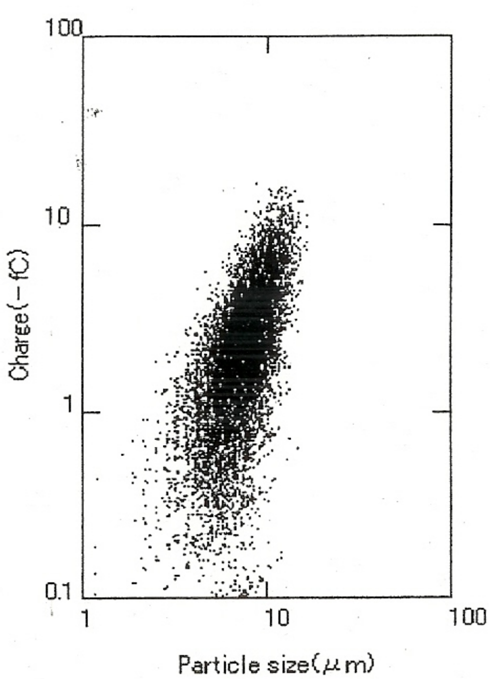

***Figure 7**. Size dependence on charge q for negatively charged toner particles in the four specimens with silica coating and CCA additives. (carrier: polymer non-coated ferrite beads), (mean diameter: 6.2µm, 7.1µm, 8.2µm, 8.6µm)*

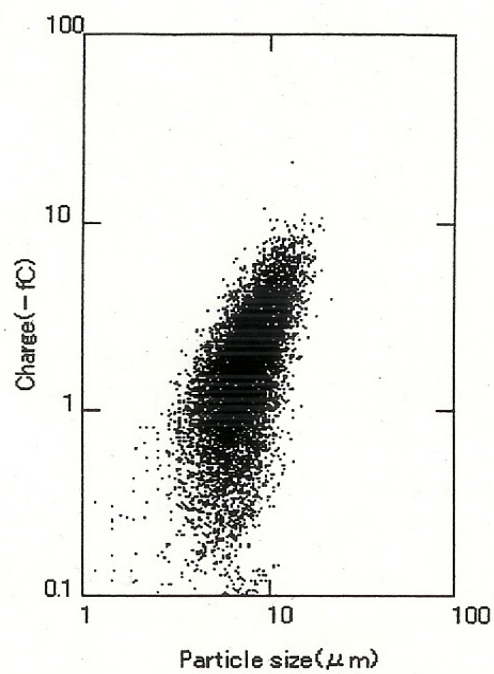

***Figure 8**. Size dependence on charge q for negatively charged toner particles in the four specimens with silica coating and without CCA additives. (carrier: polymer non-coated ferrite beads), (mean diameter: 6.1µm, 7.1µm, 8.1µm, 9.2µm)*

From the surface state theory [5] 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

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

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
ρ_c : mass density of carrier
ρ_t : mass density of toner
C_t : toner concentration in weight
m : mass of toner particle
q : charge of toner particle

From Eq.(1), the m/q, reciprocal quantity of q/m, has a linear relationship with toner radius r. The result in *Figure* 6 is effectively explained by this relationship in the diameter region from 6μm to 10μm but it might be suggested to differ from the theory in the lower toner diameter region below 5μm.

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

$$q = 4\pi e\Delta\phi\, r^3//[RC_t(\rho_c/\rho_t)/N_c + r/N_t]. \qquad (2)$$

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:

$$q \approx 4\pi e\Delta\phi\, N_t r^2 \qquad (3)$$

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

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

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

The experimental results of size dependence on toner charge can be examined by the above surface state theory. Considering that $R \sim 45$μm for the non-coated ferrite carrier beads, $\rho_c/\rho_t \sim 5$, $C_t \sim 0.05$ and $N_t \sim N_c \sim$ a constant value, the first term in denominator in Eq.(2) would be comparable with the second term and it could be variable with N_t and r. In case of the result in *Figure* 7, 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 prediction. On the other hand, the lower value 2.2 of n with the lower absolute value of charge q is also consistent with the prediction from the theory in case of $N_t \le N_c$ due to the non-treatment of CCA additives.

Conclusion

Toner size dependence on charge in two-component developer was examined experimentally for the toner based on styrene-acrylic copolymer in combination with a polymer coated ferrite carrier or a non-coated ferrite carrier by using the modified E-SPART analyzer and it was explained theoretically by the surface state theory.

Conclusion is as follows:

(1)The size dependence on m/q was shown to be a linear relationship with r of toner radius for both of the toner specimens with and without silica coating in the two-component developer combined with a polymer coated ferrite carrier. This is consistent with the theory.

(2) The size d dependence on q was also obtained by a data processing system. 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 in the two-component developer combined with a non-coated ferrite carrier.

(3) 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 and/or r.

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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.