Dependence of Toner Tribocharge on Toner Concentration

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Abstract

We have had many papers describing that the toner charge-to-mass ratio of a two-component developer decreases with increasing toner concentration. This means that the toner charge distributed to one toner on a carrier surface decreases with increasing toner concentration. We have some questions about this result. We have very carefully investigated the dependence of charge-to-mass ratio of two component developers on toner concentration. It has been found that the toner charge-to-mass ratio, q/m, is constant value to about 50% of toner coverage on carrier surface under some conditions, that is, mixing method or toner and carrier properties, and is gradually decreasing over 50% coverage. To interpret the results, a new physical charging model will be proposed.

Introduction

The triboelectric properties of two-component developers are important in electrographic systems because toner charge governs the developed mass on latent images. However, the tribocharging phenomena of the toner has not been cleared in physical modeling. Previous work[1~5] has investigated the dependence of toner charge-to-mass ratio, q/m, on toner concentration, q/m is decreased with increasing toner concentration, Ct and m/q - Ct relation is linear. This suggests that the charge apportioned to one toner particle on a carrier decreases with increasing toner concentration. This dependence is explained by surface state theory[1,2] and macroscopic Gaussian model.[3,4,5] However, the different result was investigated by T. Oguchi et al.[6] His data by blow-off method shows q/m is constant with increasing toner concentration. This means the charge of one toner particle on a carrier is not changed with increasing toner concentration. Two different results for the toner concentration dependence of q/m have been reported and these phenomena can not be explained by previously proposed charging model. We had very carefully investigated the dependence of charge-to-mass ratio of two-component developers on toner concentration. To interpret the experiments, a new physical charging model will be proposed.

Experimental

Two types of toners were used in this experiment. One was commercially available pulverized toner (Ricoh 4000 type) with a mean diameter of 10µm. The other was polymerized spherical toner with a mean diameter of 7.25 µm. Two types of carriers were used. One was silicone coated ferrite spherical carrier with a mean diameter of 80µm, which was sintered at 150°C (type C), and at 320°C (type E). The other was untreated spherical iron carrier with a mean diameter of 100µm. Two-component developer materials were mixtures of toner and carrier particles, with a toner concentration from 0.3 to 8 wt%. Toner charge was measured with a specially constructed blow-off type Faraday cage. The known weight of developer was poured into a 10 ml glass tube. The glass tube was tumbled during 20 min on a roll mill. The known weight of tribocharged developer was poured into Faraday cage. When charged toner was blown out of the cage, the cage becomes oppositely charged. The net charge on the cage was measured with an electrometer (Keithley 614). The toner mass was obtained by weighting the developer before and after the toner particles were removed. The toner charge-to-mass ratio or carrier charge-to-mass ratio was calculated to normalize the measurements. At the same time, the one toner particle charge of tribocharged developer was measured by laser light scattering method,[7] which was specially developed by our laboratory.

Results and Discussion

The carrier charge-to-mass ratio, Q/M, for pulverized toner (Ricoh 4000 type) and two types of ferrite spherical carriers (type C and type E), respectively, is plotted as a function of toner concentration, Ct, in Figure 1. The values of Q/M of carrier types C and E increases linearly with Ct in the range from 0 to 4 wt% in Figure 1, while Q/M over 4 wt% Ct is apart from linear. Figure 2 shows the dependence of the toner charge-to-mass ratio, q/m, on toner concentration, Ct. The values of q/m is constant in the range from 0 to 4 wt% of Ct for carrier C and E, respectively. Over 4 wt%, q/m gradually decreases with increasing Ct and shows the constant value lower than the q/m value of low Ct. It is similar to the result by T. Oguchi et al.[6] that q/m is constant in lower Ct than 4 wt%. This means the charge of one toner particle is independent of the toner concentration. Laser light scattering method[7] can measured one toner particle charge of developer. Figure 3 shows the average value of one toner charge as a function of toner diameter for three toner concentration. The two columns in Figure 3 shows the toner polarity characteristics. Carrier C has higher negative tribocharging ability than carrier E. As shown in Figure 3, the average charge of one toner particle increases with increasing toner diameter. It is shown in Figure 3 that the average charge of one toner particle is not affected by the variation of toner concentration as indicated by the solid line or the dot line. It is thought that this result is similar to the blow-off measurement result.

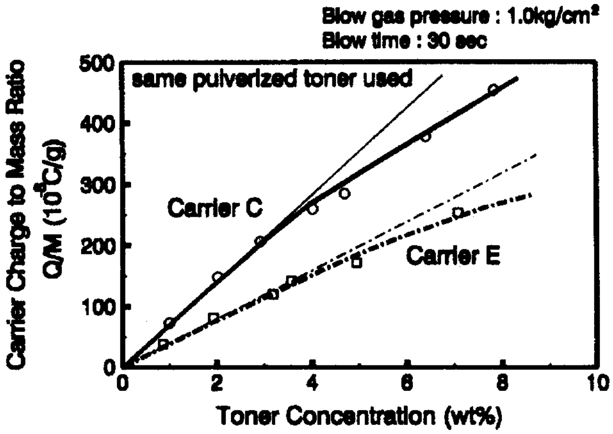

Figure 1. Relationship between carrier charge-to-mass ratio and toner concentration.

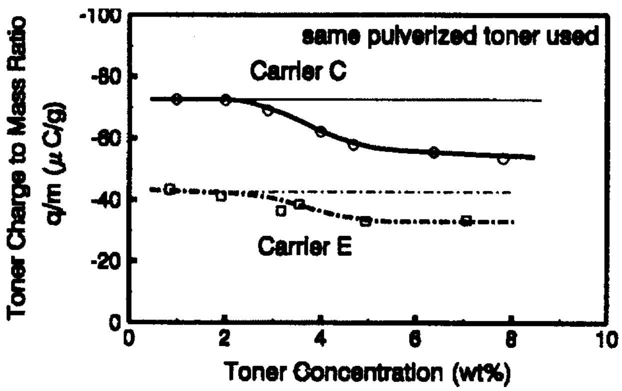

Figure 2. Relationship between toner charge-to-mass ratio and toner concentration.

Carrier C

Ct	Plus	Minus
○ 1.4	21%	78%
□ 3.2	24%	76%
△ 6.0	20%	77%

Carrier E

Ct	Plus	Minus
● 0.6	35%	61%
■ 2.2	31%	66%
▲ 5.2	38%	58%

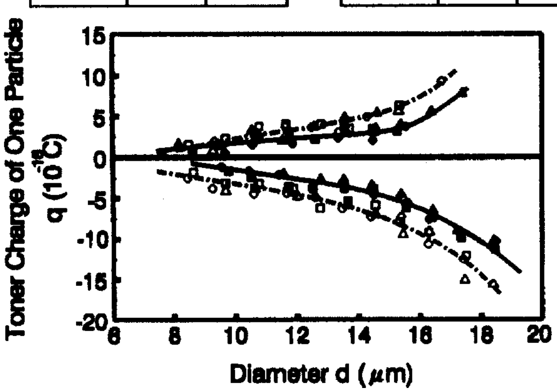

Figure 3. Measurements of the toner charge as a function of particle diameter for three toner concentration.

In Figure 4, Q/M for the polymerized spherical toner and two types of spherical carriers (ferrite carrier and iron carrier), respectively, is plotted as a function of Ct. Figure 5 shows the dependence of q/m on toner concentration, Ct. The value of q/m decreases with increasing Ct, but rapidly decreases under 4 wt% Ct. A similar dependence of q/m on toner concentration has been noted previously in analyses of data by Lee,[2] by T. Yamazaki et al.[3] and by Anderson.[8] Figure 6 shows the average value of one toner charge as a function of toner diameter for three toner concentration of spherical iron carrier-polymerized spherical toner mixtures. The average value of charge of one toner particle for the toner concentration of 1.8 wt% (surface coverage θ = 0.23) is indicated by the solid line in Figure 6. The average value of toner charge for higher toner concentration of 4 and 7 wt% (θ = 0.51,0.89) is smaller than the solid line as indicated by the dot line. This means one toner charge depends on toner concentration, and it indicate same phenomenon shown in Figure 5.

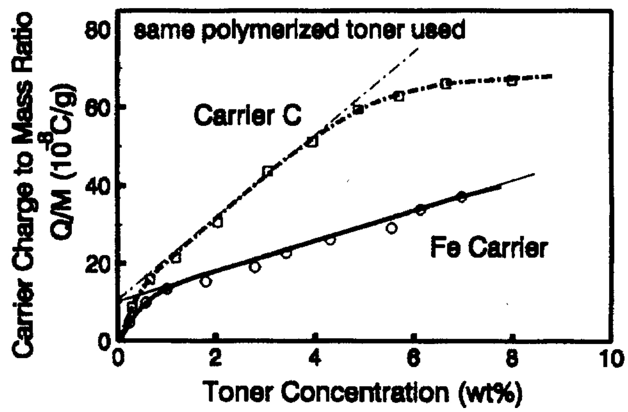

Figure 4. Relationship between carrier charge-to-mass ratio and toner concentration.

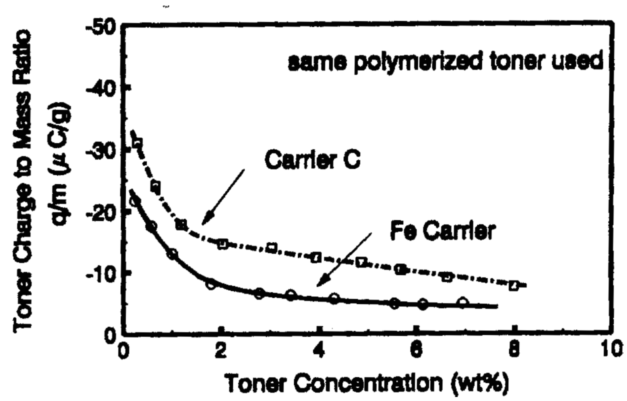

Figure 5. Relationship between toner charge-to-mass ratio and toner concentration.

It is suggested from these results that there are two types of tribocharging phenomena in toner-carrier mixtures. The two types of toner concentration dependence can not be described with previously proposed physical model. We propose a tribocharging equation by a new physical model. Tribocharging rate of developer is rapid in mixing and reaches to saturated value in a few minutes. The equilibrium value of tribocharge during mixing will be determined by the balance of charging and discharging rate. Tribocharging rate equation is represented as follow:

$$\frac{dn^+}{dt} = \alpha(Nc - n^-)(Nt - n^+) - \beta n^+, \tag{1}$$

where n^+ is the number of tribocharged site on toner, n^- is the number of tribocharged site on carrier and $n^+ = n^-$, Nc and Nt are the maximum number of site of carrier and toner, respectively, α is the tribocharging rate constant and β is the discharging rate constant. A positive charging site and a negative charging site coexist on a toner surface. In present case, we consider the number of negative charging sites negligible small, because the effect of CCA on a toner surface is very large. We give boundary conditions to Eq. (1), and can obtain Eq. (2).

$$n^+ = \frac{2NcNt}{(Nc+Nt)+\sqrt{(Nc+Nt)^2}} \tag{2}$$

In this case of $Nc \geq Nt$, Eq. (3) is obtained from Eq. (2).

$$n^+ = Nt \tag{3}$$

This means the number of tribocharged sites is equal to the maximum number of toner charging sites. Toner charge, q, is expressed by Eq. (4) and q/m by Eq. (5), respectively.

$$q = eNt = entSt \tag{4}$$

and

$$\frac{q}{m} = \frac{q}{m_t n_t} = \frac{en_t St}{m_t n_t} = \frac{eSt}{m_t}, \tag{5}$$

where: n_t is the number of toners, St is the number of charging site of one toner particle, and m_t is mass of one particle. Eq. (5) shows that q/m can not have the dependence of toner concentration under the condition of $Nc > Nt$, and corresponds to Figure 2.

Other hand, in the case of $Nc < Nt$, we can obtain Eq. (6) from Eq. (2).

$$n^+ = Nc \tag{6}$$

This means the number of tribocharged sites is determined by the maximum number of carrier charging sites. Toner charge, q, and q/m are expressed by Eq. (7) and (8), respectively.

$$q = eNc = encSc \tag{7}$$

and

$$\frac{q}{m} = \frac{q}{m_t n_t} = \frac{en_c Sc}{m_t n_t} = \frac{eSc}{m_t}\frac{1}{\left[\frac{n_t}{n_c}\right]} = \frac{eSc}{m_t}\frac{1}{C_t}, \tag{8}$$

where: n_c is the number of carrier and Sc is the number of charging site of one carrier particle. Eq. (8) shows that q/m has the dependence of toner concentration under the condition of $Nc < Nt$ and q/m decreases with increasing toner concentration, Ct, and corresponds to Figure 5. Our proposed tribocharging rate equation in the case of $Nc < Nt$ is similar to the previously charging model.[1–5]

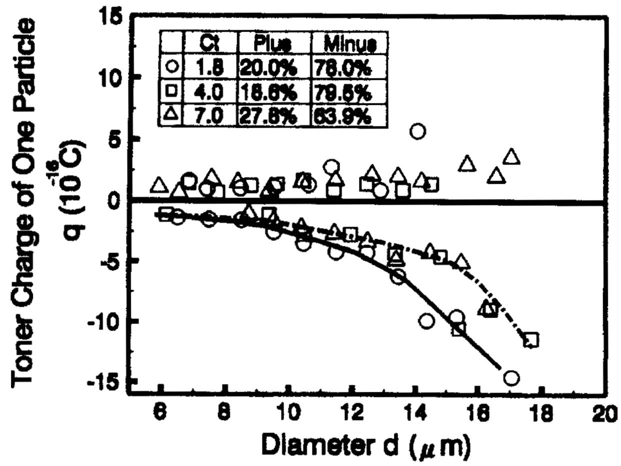

Figure 6. Measurements of the toner charge as a function of particle diameter for three toner concentration.

Conclusion

We have presented the experimental data that there are two types of tribocharging phenomena in two-component developers. Two types of tribocharging phenomena of two component developers can be explained by charging rate equation. It is thought that the tribocharging phenomenon is governed by the difference number of effective charging sites between toner and carrier.

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