Effect of Additive Induced Discharge on Tribocharging Process between Toner and Carrier

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To clarify the tribocharging characteristics of toner and carrier, the mixing time dependence of the toner charge at various toner concentrations was investigated. A new blow-off tribo-charge measurement apparatus was used to obtain more precise data. As a result, the decay of the toner charge was observed in most cases. A new model is proposed based on the assumption that recombination of the charges between the external additive and carrier caused the decay, and the model was evaluated by numerical analysis. Because the fitting curves derived from this model were in good agreement with the experimental values, it was concluded that this assumption is appropriate.

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Introduction

Electrophotographic processes can be divided roughly into mono-component development and two-component development. The two-component development process is applied widely for high-speed copiers and printers and is still the mainstream technology in this field. Therefore, understanding the tribocharging phenomenon[1–8] between toner and carrier is important, and the charge should be measured more accurately.

Although blow-off tribocharge measurement apparatus is generally used for measuring toner charge, recharge between the toner and carrier in a Faraday cage is a source of error. We used a new blow-off apparatus[3] which eliminates this error, and the relationship between the toner charge and the mixing time was investigated. In order to clarify the tribocharging phenomenon, mixing was carried out under mild conditions causing no wear of the toner or carrier. We also investigated the toner concentration dependence of the toner charge. Charging curves obtained from our experiment showed the decay of the tribocharge. It has been suggested in some previous reports that external additives greatly affect the tribocharging behavior of two-component developers.[4–6] Considering these results, we propose a new model. Because our model includes the charge recombination between the external additive and carrier, the obtained fitting curves agree well with experimental values.

In this study, two kinds of negative charge control agents (CCA) were used for the toner, and the content was fixed. Negative fumed silica (SiO_2) was used as an external additive, and the amount of additive relative to toner was fixed.

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Experimental

Material. A standard polyester resin with a low acid value (AV, approx. 5.0 mg KOH/g polymer) and branched chains was selected for use in this study. Two kinds of negative CCA (CCA 1, CCA 2) were employed, and both of them were the colorless salt type. Negative fumed silica (SiO_2) with a primary diameter of 16 nm was selected as the external additive. All toners were composed of polyester, CCA, and pigment (phthalocyanine). All of these components were compounded in a kneader and crushed to a powder with a particle diameter of 8 μm. The fumed silica was added to the powder at 1 wt%. A polymer-coated ferrite carrier 50 μm in diameter was used.

Measurement. We used the new blow-off apparatus. Figure 1 shows a schematic diagram of the new blow-off cage. We prepared the developers at toner concentrations of 1 wt%, 3 wt%, 5 wt%, 10 wt%, and 15 wt%. Then, 50 g of the developer was placed in a 20 mL polyethylene vessel, and the vessel was rolled on a roll mill. 100 mg of the developer was placed in a Faraday cage. When charged toner was removed by blowing and aspirating air, a charge with polarity opposite to the toner was left on the carrier in the cage. The net charge on the cage was measured with an electrometer. All measurements were carried out at 18 to 20°C and 50 to 60% RH.

Results and Analysis

Tribocharging Characteristic between Toner and Carrier. Hereafter let us call the total charge exchanged in 100 mg of the developer the toner charge. Figures 2 and 3 show the typical relationship between the toner charge

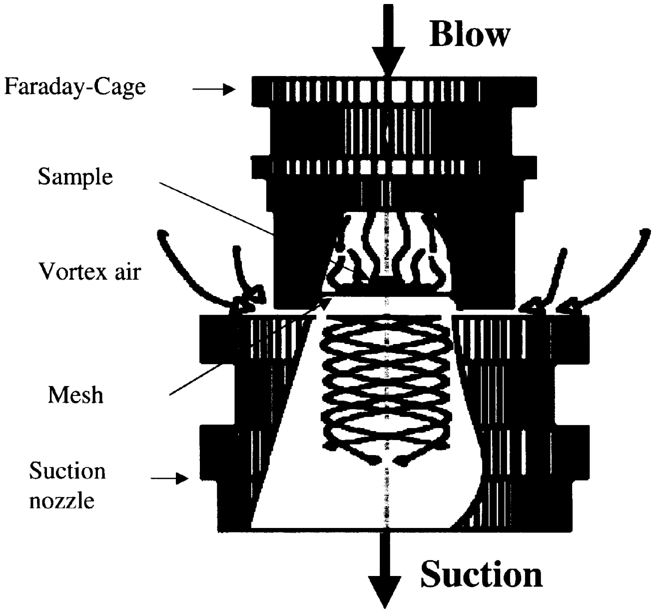

Figure 1. Schematic diagram of the new blow-off cage.

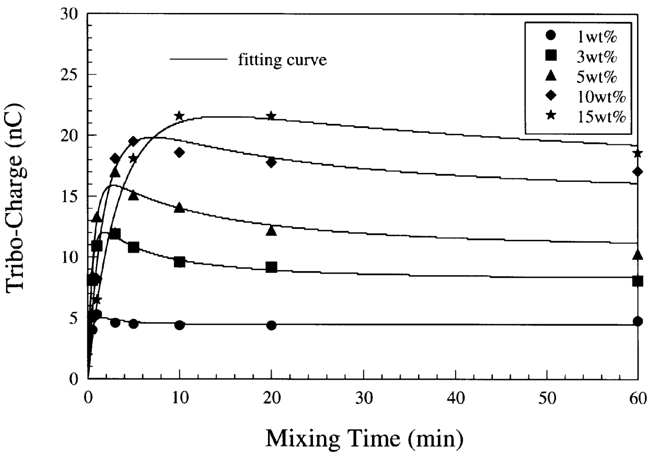

Figure 2. Relationship between the total charge exchanged in 100 mg of the developer with toner A (using CCA 1) and the mixing time at various toner concentrations. (Solid circles: 1 wt%, solid squares: 3 wt%, solid triangles: 5 wt%, solid diamonds: 10 wt%, solid stars: 15 wt%)

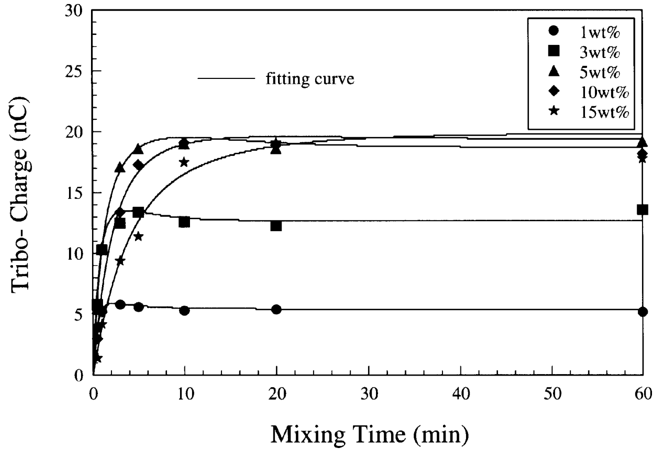

Figure 3. Relationship between the total charge exchanged in 100 mg of the developer with toner B (using CCA 2) and the mixing time at various toner concentrations. (Solid circles: 1 wt%, solid squares: 3 wt%, solid triangles: 5 wt%, solid diamonds: 10 wt%, solid stars: 15 wt%)

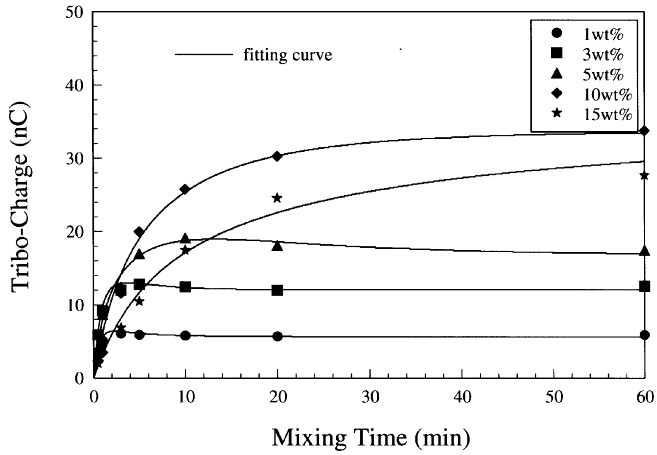

Figure 4. Relationship between the total charge exchanged in 100 mg of the developer with toner C (CCA free) and the mixing time at various toner concentrations. (Solid circles: 1 wt%, solid squares: 3 wt%, solid triangles: 5 wt%, solid diamonds: 10 wt%, solid stars: 15 wt%)

and the mixing time with toners A and B, respectively. As shown in Figs. 2 and 3, the toner concentration dependence of the toner charge is different for toner A (using CCA 1) and toner B (using CCA 2). However, in both cases, the toner charge falls gradually after reaching a maximum, and it takes longer to reach the maximum charge with increasing toner concentration.

Figure 4 shows the relationship between the toner charge and the mixing time with toner C, which is CCA free. In the case of toner C, the time required to reach the maximum charge is longer than that for toner A or B. The amount of the saturated charge of toner C is larger than that of toner A or B at each toner concentration. In addition, the time to reach the maximum charge also lengthens with increasing toner concentration. These results indicate that one of the functions of the CCA is to activate the toner charge quickly.

Model and Theory

In order to clarify the tribocharging process of the toner and the carrier, we developed a new model and fitted the experimental data. Because decay of the toner charge was observed in the CCA-free toner (toner C) in the low toner concentration range, the decay tendency is independent of the CCA. Moreover, according to some reported experimental results,[4–6] this tendency was not observed with external additive-free toner. Hence, we assume that the external additive mainly influences this phenomenon, and recombination of the charge between the additive and the carrier occurs during mixing.

Figure 5 illustrates the charging process of our model. We divided charging sites of the toner into additive sites and other sites. Further, we assumed that the exchange of charge between the two sites depends on the energy level of each site. Therefore, we divided the charging sites of the carrier into two groups. One group includes the carrier sites that selectively exchange charge with the additive sites, and the other group includes the car-

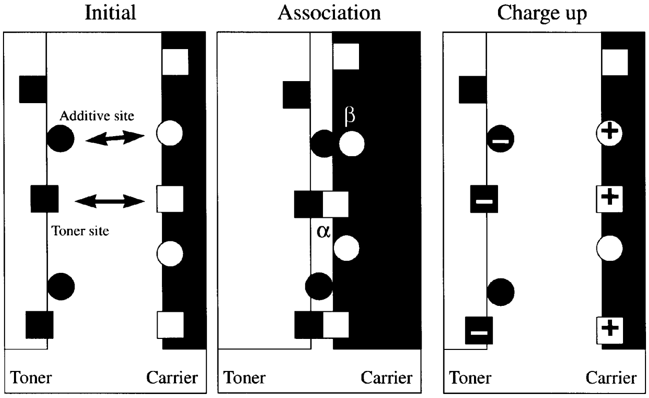

Figure 5. Charging process of the model.

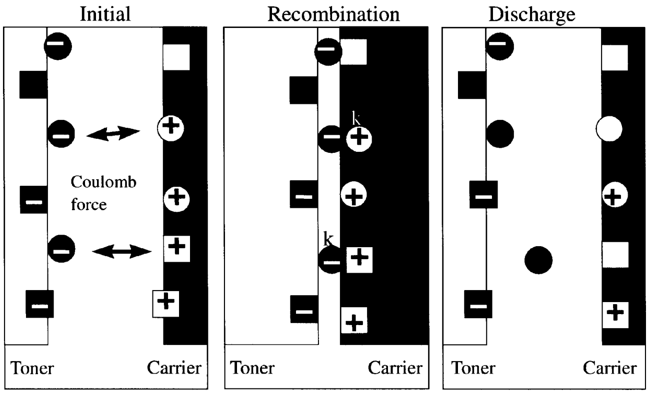

Figure 6. Discharging process of the model.

rier sites that selectively exchange charge with the toner sites without the additive. The additive sites associate with the carrier sites and exchange charge with a rate constant β. Similarly, the toner sites without the additive exchange charge with the carrier sites with a rate constant α.

Figure 6 illustrates the discharging process of our model. We assume that recombination of the charge causes the discharge and that the recombination results from Coulomb attractive force. The additive particles are on the toner surface and are free to move around. On the other hand, the other charging sites on the toner surface (CCA for example) should be peeled off so that they can move around. It should be mentioned here that we investigated short-range charging phenomena between toner and carrier before wear or fatigue was observed. Therefore, the contribution of the toner sites without the additive particles to the discharging process was not considered. In addition, we did not identify the origin of the carrier charge, because recombination of the charge depends on Coulomb attractive force. As shown in Fig. 6, the charged sites recombine with each other and discharge with a rate constant k.

According to the charging and discharging process described above, the tribocharging rate equation for the toner side is as follows:

$$d(T)/dt = \alpha(T_0 - T)(C_{0T} - C_T), \quad (1)$$

where T and C_T are the number of tribocharged sites of the toner and the carrier, respectively, T_0 and C_{0T} are

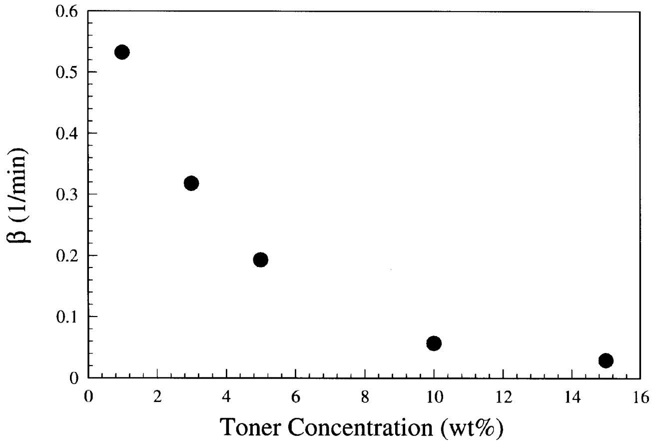

Figure 7. Relationship between toner concentration and the value of β.

the number of effective tribocharging sites of the toner and the carrier, respectively, and α is the charging rate constant for the toner and the carrier. T means the number of the tribocharged sites of the toner without the external additive.

$$d(E)/dt = \beta(E_0 - E)(C_{0E} - C_E) - kE(C_E + C_T), \quad (2)$$

where E and C_E are the number of tribocharged sites of the external additive and the carrier, respectively, E_0 and C_{0E} are the number of effective tribocharging sites of the external additive and the carrier, respectively, β is the charging rate constant for the external additive and the carrier, and k is the discharging rate constant for the external additive and the carrier.

Similarly, the tribocharging rate equations of the carrier side are given by

$$d(C_T)/dt = \alpha(T_0 - T)(C_{0T} - C_T) - kEC_T, \quad (3)$$

$$d(C_E)/dt = \beta(E_0 - \mathrm{E})(C_{0\varepsilon} - C_E) - \mathrm{kEC}_{\varepsilon}. \quad (4)$$

The only quantity that we can actually measure is the sum of C_T and C_E, because we cannot identify the origin of the carrier charge. We solved these equations numerically using the Runge-Kutta method.

Parameters

The parameter set of Eqs. 3 and 4 was obtained by Monte Carlo parameter fitting, and the fitting curves were obtained by numerical analysis (Runge-Kutta method). The fitting curves obtained from Eqs. 1 through 4 are in good agreement with the experimental data shown in Figs. 2, 3, and 4. The correspondence of the obtained parameters was investigated as follows.

Figures 7, 8, and 9 show the relationship between toner concentration and the values of β, E_0, and C_{0E}, respectively. The obtained values of β, E_0, and C_{0E} must be common to toner A, B, and C because our model is based on the assumption that there is no triboelectric interaction between the toner and the external additive. Therefore, the values were calculated from the fitting data of toner C as typical data. As shown in Fig. 8, the value of E_0 increases with increasing toner concentration. And the data, when extrapolated, almost coincide with the origin. Because the additive particles cannot exist without the toner, this result is very reasonable.

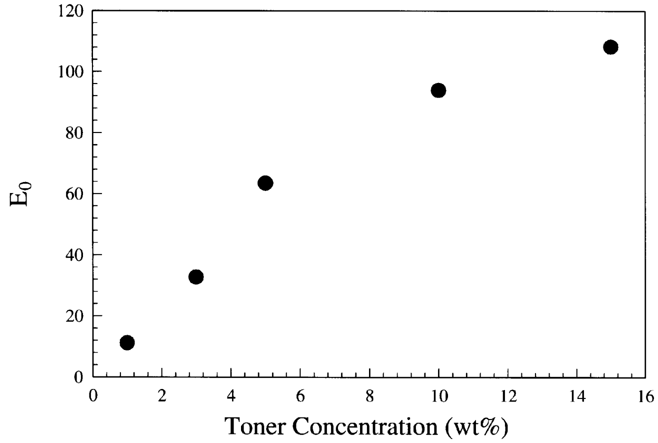

Figure 8. Relationship between toner concentration and the value of E_0.

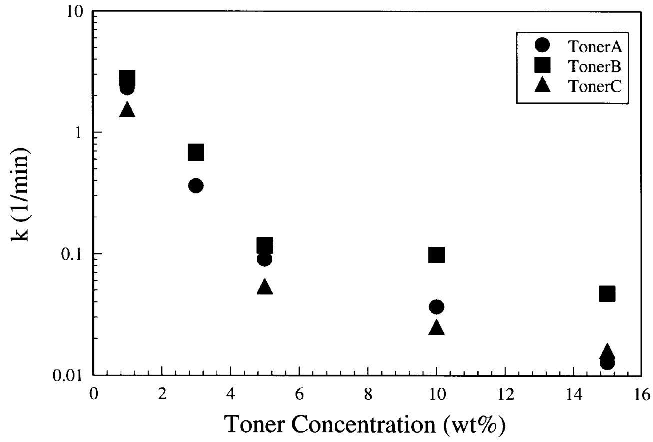

Figure 10. Relationship between toner concentration and the value of k. (Solid circles: toner A, solid squares: toner B, solid triangles: toner C)

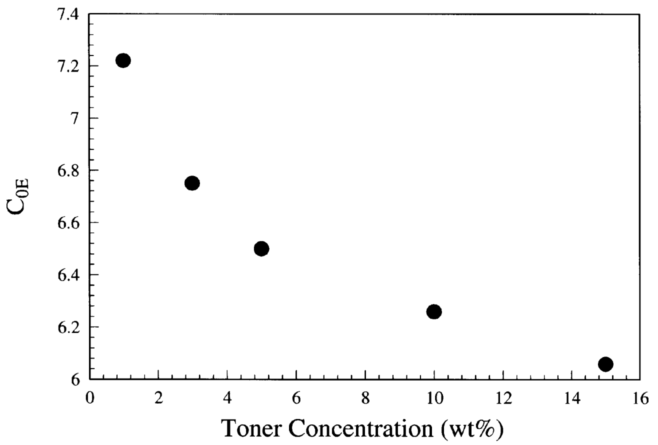

Figure 9. Relationship between toner concentration and the value of C_{0E}.

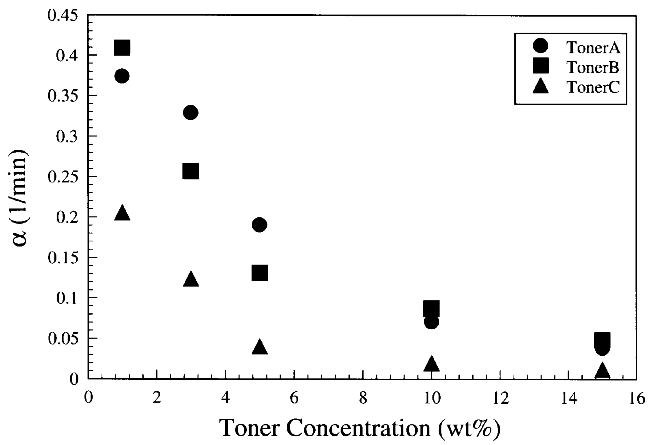

Figure 11. Relationship between toner concentration and the value of α.(Solid circles: toner A, solid squares: toner B, solid triangles: toner C)

As shown in Fig. 9, the value of C_{0E} decreases gradually with increasing toner concentration naturally because the carrier concentration decreases with increasing toner concentration.

Figure 10 shows the relationship between toner concentration and the value of the discharging rate constant k for the external additive and the carrier. As shown in Fig. 10, the value of k decreases by two orders of magnitude or more with increasing toner concentration, and this tendency does not depend on the toner species. This result indicates that the discharge depends only on the charge recombination resulting from Coulomb attractive force.

Figure 11 shows the relationship between toner concentration and the value of the charging rate constant α for the toner and the carrier. As shown in Fig. 11, the value of α decreases with increasing toner concentration. Toner C (CCA free) has a smaller α value than the others. This means that CCA increases the value of the charging rate.

Figure 12 shows the relationship between toner concentration and the number of effective tribocharging sites T_0 of the toner. As shown in Fig. 12, the value of T_0

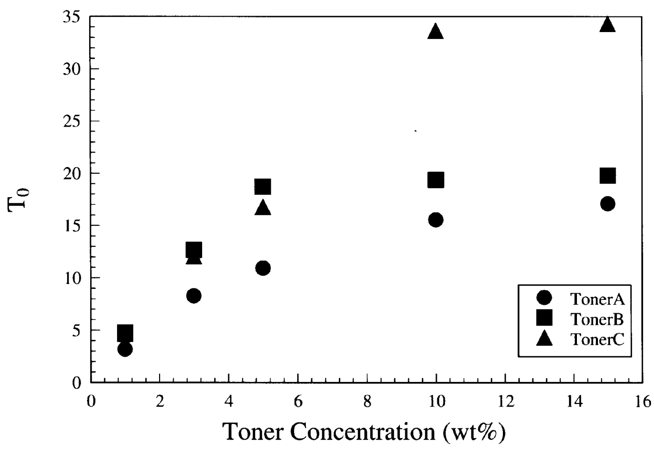

Figure 12. Relationship between toner concentration and the value of T_0. (Solid circles: toner A, solid squares: toner B, solid triangles: toner C)

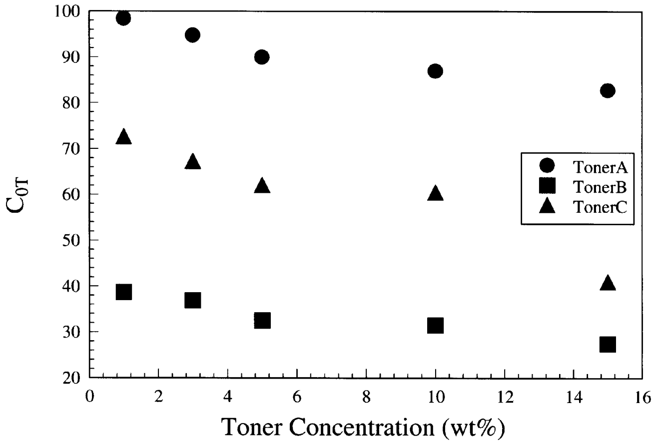

Figure 13. Relationship between toner concentration and the value of C_{0T}. (Solid circles: toner A, solid squares: toner B, solid triangles: toner C)

increases with increasing toner concentration. Toner C has a much larger T_0 value than the others in the high toner concentration range. In the calculation,[7] when the toner concentration is about 12 wt%, the carrier is completely covered by the toner. Therefore, the value of T_0 will include errors resulting from the excessive toner concentration. Toner A has a smaller T_0 value than toner C at each toner concentration. From this result, it was found that the number of the sites is not necessarily increased by adding CCA.

Figure 13 shows the relationship between toner concentration and the number of the effective tribocharging sites of the carrier relative to the toner. As shown in Fig. 13, the value of C_{0T} decreases with increasing toner concentration. In this case, the value of C_{0T} strongly depends on the kind of toner. This suggests that the combination of toner and carrier is important in controlling their tribocharging behavior. During the experiment, no parameter changed linearly in relation to the toner concentration, and both the charging rate constant and the discharging rate constant decreased with increasing toner concentration. Therefore, the average distance of the sites should increase with increasing toner concentration.

Conclusion

We have developed a new model based on the assumption that recombination of the charges between external additive and carrier causes the decay of the tribocharge. Because the fitting curves derived from this model agree well with the experimental values and the toner concentration dependence of the obtained parameters is quite natural, it is concluded that this assumption is appropriate. The guiding principle that it is essential to find a suitable combination of toner and carrier is demonstrated by our model.

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