A Study on the Tribocharging Behavior for the Two-Component Developers

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Abstract

We have studied the tribocharging behavior for two-component developers, which predicts the relationship between the toner triboelectric charge and the mixing time.

The triboelectric charge rate was considered to be the sum of the rates of charge gain and charge loss. In the conventional model, the rate of charge gain was assumed to be independent of the mixing time and to be constant.[1] There were some cases that disagreed with the experimental data.

We proposed a new model for the tribocharging behavior, where the rate of the charge gain was assumed to be dependent on the mixing time. The data derived from our model agrees closely with the experimental data. We further applied this model to the cases with different external toner additives, and found that our model is useful for understanding the triboelectric charging behavior of toner.

Introduction

The triboelectric charging characteristics of toner is one of the important factors of the two-component developers.[2,3] Charge control agents (CCA) are materials that can offer the suitable charging characteristics to the toner.[4] As with the negative CCA, which correspond to the negative toner, zinc or chromium complex compounds are generally used.[5] For the environmental and ecological preservation, however, non heavy metal CCA are considered to be desirable. We have therefore studied clean materials that do not contain heavy metal for the negative CCA, we found that the calixarenes with optimized molecular structure provide appropriate and sufficient triboelectric charge to the toner as well as a conventional CCA with heavy metal.

We also investigated the relationship between the triboelectric charge and mixing time. We found that the amount of external additives greatly affected the behavior of the triboelectric charge. Therefore, we proposed a new model that can explain the complexity of the various triboelectric charge behaviors. Using this model, the calculated data derived from the model were found to be in good agreement with the experimental data.

We investigated the triboelectric charging behavior of the toner with two kinds of the external additives, SiO_2 and TiO_2 powder, for various cases of the relative humidity in the environment. We found that the dependency of the charging behavior on the relative humidity of TiO_2 toner was relatively smaller than that of SiO_2 toner. By applying the proposed model to the above cases, the detailed mechanisms for the behavior of the toner triboelectric charge with different external additives can be well understood from the parameters used in the model.

Experiment

Materials

CCA: Calixarenes (see Figure 1).
External toner additive: Surface-treated TiO_2 powder, surface-treated SiO_2 powder.
Toner: The toner consisted of polyester resin, pigment, wax, CCA, and external additive. The mean particle size of the toner was 8 μm.
Carrier: Coated with resin ferrite powder with a nominal size of 60 μm.
Developer: A carrier/toner mixture at 5 wt% toner concentration was blended.

Measurement

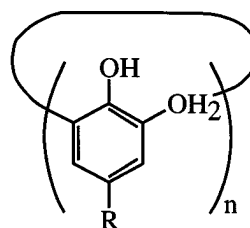The triboelectric charge of the toner against the mixing time was measured by the blow-off method.

Figure 1. Structure of calixarenes

Results and Discussion

Charge Control Agent Effects

Calixarenes were adopted as the materials which contain no heavy metal, in order to study the relationship between the molecular structure and the triboelectric charging characteristics. The molecular structure of the calixarenes is shown in Figure 1, where R represents the alkyl group and n the number of units in the ring.

Table 1 shows the amount of the triboelectric charge vs. R and n. It can be seen in the table that there is the tendency for the minus charge to increase as the molecular weight of R or the number of units n increases. This is because the larger molecular weight of R or the number of n is, the more acceptors calixarenes have. In order to get

the materials which provide sufficient triboelectric charge to the toner, we used the calixarenes whose structure had t-butyl for R and 8 for n.

Table 1. Triboelectric Charge for Calixarenes

n	R	Triboelectric charge (μC/g)
4	t-butyl	-3.4
6	t-butyl	-19.7
8	t-butyl	-54.0
8	-methyl	-34.2
8	-ethyl	-39.1
8	t-butyl	-54.0

External Additive Effects

Quantity of external additive effect. The calixarenes with optimized molecular structure could provide a sufficient triboelectric charge to the toner as explained above, but their sole addition could not provide enough initial rate of the triboelectric charge, which is also desired for the charge behavior. Therefore, we examined external toner additives to increase the initial rate of the triboelectric charge and investigated the triboelectric charge behavior against the mixing time for the amount of the external additives, we used TiO_2 powder.

Figure 2 shows the relationship between the triboelectric charge and the mixing time. For the toner with external additives, the triboelectric charge suddenly reaches the maximum then decreases little by little, while the one with no external additives grows gradually and comes to a plateau.
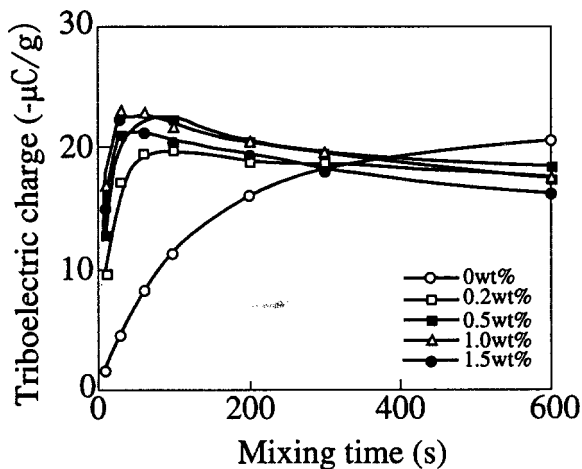

Figure 2. The relationship between triboelectric charge and mixing time.

This indicates that the triboelectric charging behavior strongly depends on the amount of external additives.

Model for triboelectric charging. The following differential equation is the conventional model for the triboelectric charging behavior with the mixing time.

$$q'(t) = k(\Phi_T - \Phi_C) - q(t)/\tau \qquad (1)$$

where $q'(t)$ is the charging rate, $(\Phi_T - \Phi_C)$ the difference between the work function of the toner and that of the car-

rier, k the constant which depends on the toner and the carrier, and τ the time constant for charging.

In this model, the triboelectric charging rate was expressed as the sum of the rates of the charge gain and loss and the rate of the triboelectric charge gain was assumed to be constant and independent of the mixing time.

The triboelectric charge $q(t)$ is easily derived from the Equation (1).

$$q(t) = k\tau(\Phi_T - \Phi_C) - d\,exp(-t/\tau) \qquad (2)$$

where d is the integration constant.

We first carried out the curve fitting of data listed in Figure 2 using Equation 2 with the least square method. As shown in Figure 3, the triboelectric charging behavior of the toner which has no external additive can be explained properly by Equation 1. Also, the other toners which have external additives do not agree with this model at all.
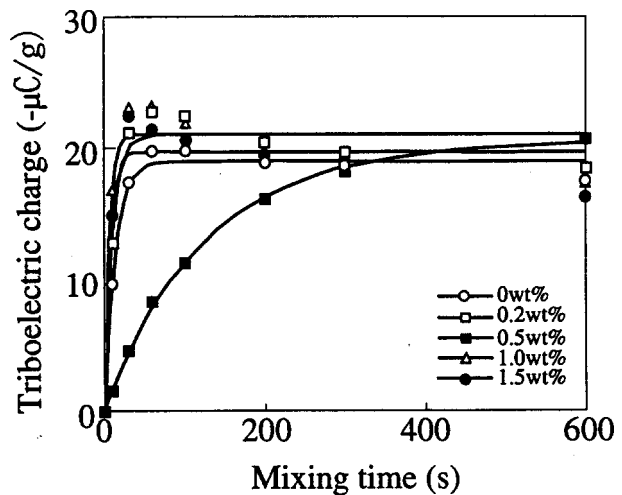

Figure 3. Curve fitting by conventional model.

We therefore constructed a new model that could explain the complexity of the triboelectric charging behavior for the various amounts of external additives. For a two-component developer, the rate of the triboelectric charge gain is considered to vary against the mixing time because the conditions of the toner surface and the carrier surface gradually change as the mixing time passes. We therefore gained the following equation replacing $k(\Phi_T - \Phi_C)$ under the above assumption.
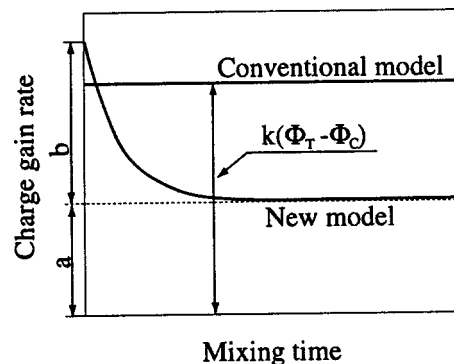

Figure 4. The relationship between charge gain rate and mixing time.

$$\phi\,(t) = a + b\,exp(-ct/\tau) \qquad (3)$$

where a is the rate of the charge gain at the steady condition, b the differences between $\phi(\infty)$ and $\phi\,(o)$, and c the rate of the gain equilibrium. Figure 4 shows the difference of the charge gain rate between of the conventional model and of the new model.

The triboelectric charging behavior in the new model is expressed as follows.

$$q'(t) = \phi\,(t) - q(t)/\tau$$
$$= a + b\,exp(-ct/\tau) - q(t)/\tau \qquad (4)$$

And the triboelectric charge against the mixing time is derived as

$$q(t) = a\tau - b\tau\,exp(-ct)/(c\tau - 1) - d\,exp(-t/\tau) \qquad (5)$$

The curve fitting using Equation 5 was also carried out with the least square method. As shown in Figure 5, the calculated data derived by the new model agrees well with the experimental data in all cases.
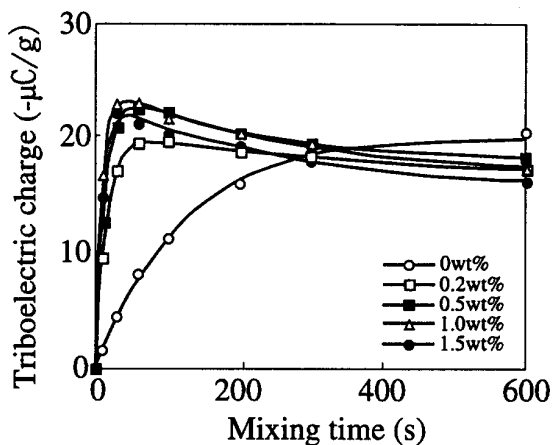

Figure 5. Curve fitting by new model.

Triboelectric charge behavior in various relative humidity. For the two-component developers, a tribocharging behavior that does not depend on the relative humidity in the environment is the most desired characteristic. We investigated the effect of the external additives against the tribocharging behavior in order to obtain the preferable external additives.

For external additives samples, we adopted the surface-treated SiO_2 powder, which is generally used as the external additive, and surface-treated TiO_2 powder. In each case, we measured the triboelectric charge against the mixing time, while varying the condition of the relative humidity. We then curve fitted with the new model using the obtained data.

As shown in Figure 6 and 7, it is found that the tribocharging behavior of the TiO_2 toner is not as dependent on the relative humidity as the SiO_2 toner.

For further investigation of the different behavior of the above external additives, we also compared the TiO_2 toner with the SiO_2 toner in terms of the tribocharging rate. Figure 8 and 9 show that the tribocharging rate of the SiO_2 toner dramatically varies under the different condition of the relative humidity. There is the tendency for the

tribocharging rate of the SiO_2 toner to be quite large initially, but the higher the relative humidity, the earlier the rate falls off. On the other hand, the tribocharging rate for the TiO_2 toner has very little dependency on the relative humidity.
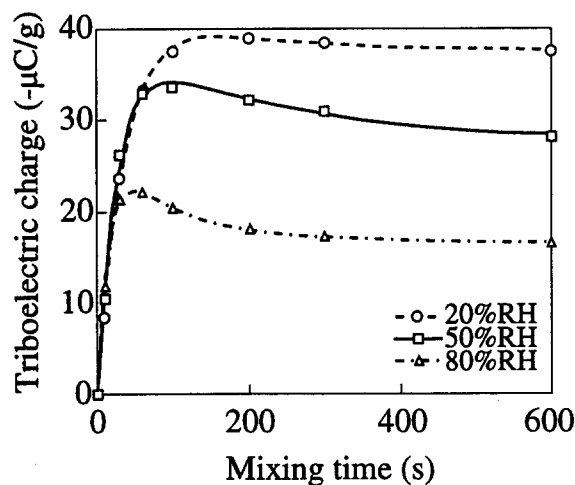

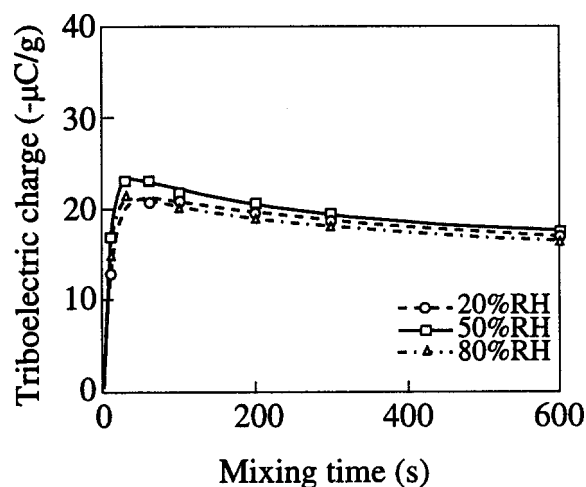*Figure 6. Dependence of toner triboelectric charges with SiO_2 on relative humidity.*

Figure 7. Dependence of toner triboelectric charge with TiO_2 on relative humidity.
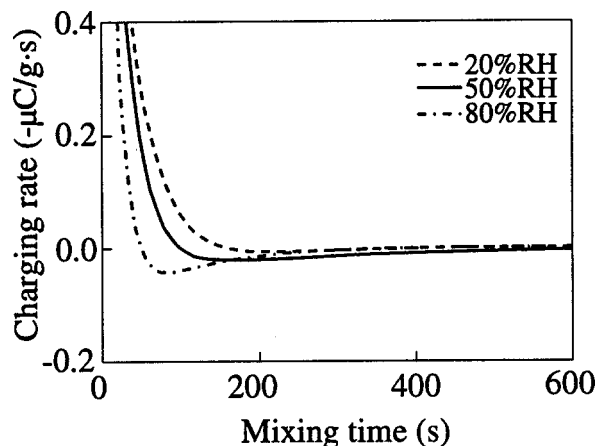

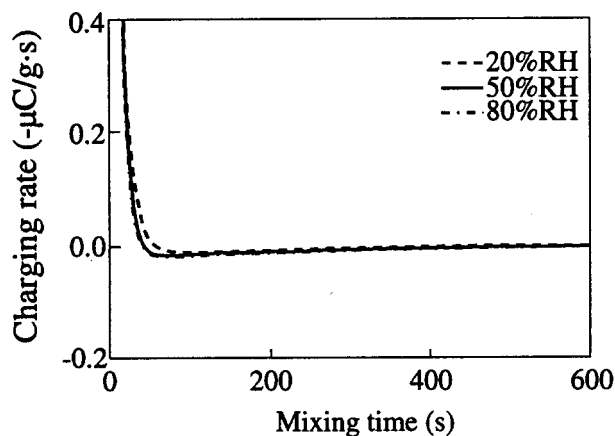*Figure 8. Dependence of toner charging rate with SiO_2 on relative humidity.*

Figure 9. Dependence of toner charging rate with TiO_2 on relative humidity.

Next we decomposed the tribocharging rate into two parts, the charge gain rate, $\phi(t)$, and the charge loss rate, $q'_{loss}(t)$, which is obtained from Equation 4 and 5 as follows.

$$q'_{loss}(t) = -q(t)/\tau$$
$$= -a + b\,exp(-ct)/(c\tau - 1) + d\,exp(-t/\tau)/\tau \qquad (6)$$

Figure 10 and 11 show that the charge loss rate of the TiO_2 toner counterbalances the gain rate under any relative humidity condition. On the other hand, the SiO_2 toner loss rate and gain rate are not counterbalanced and vary under the different relative humidity conditions.
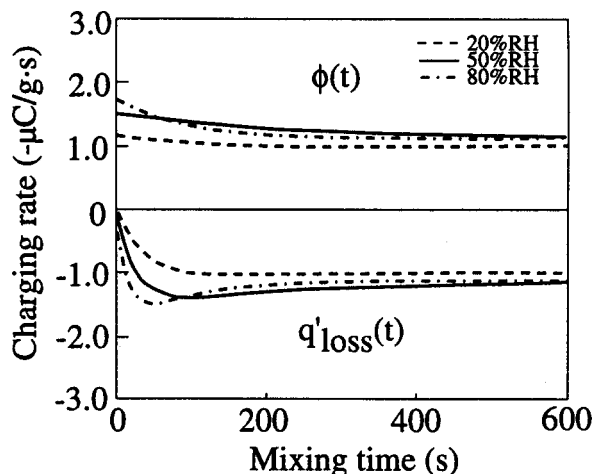

Figure 10. Dependence of the toner gain rate $\phi(t)$ and loss rate $q'_{loss}(t)$ with SiO_2 on relative humidity.
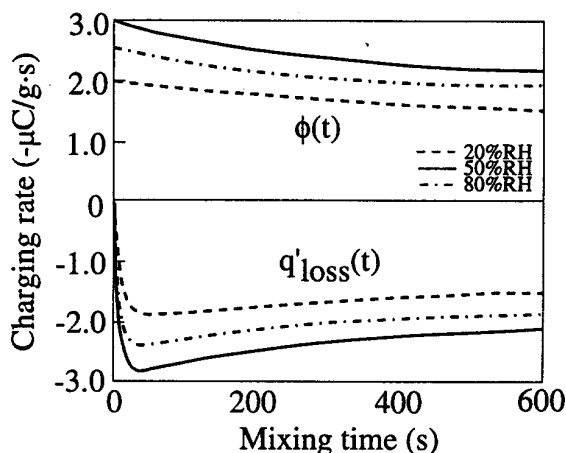

Figure 11. Dependence of the toner gain rate $\phi(t)$ and loss rate $q_{loss}(t)$ with TiO_2 on relative humidity.

Conclusion

In this study, we concluded that:

Calixarenes with an optimized molecular structure can provide sufficient triboelectric charge to toner.

External additive plays an important role to increase the initial rate of the triboelectric charge.

The new model proposed under the assumption where the rate of the charge gain is dependent on the mixing time can explain the complexity of the triboelectric charge behavior for various amounts of external additives.

The tribocharging behavior of the toner with TiO_2 external additives has little dependency on the relative humidity. This is because the charge loss rate of the TiO_2 toner counterbalances the charge gain rate under any relative humidity conditions.

Acknowledgments

References

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