

The Physics of Toner Concentration Dependence of Toner Charge at Two Component Developer

Yasusuke Takahashi[*], *Teruki Kishimoto*[**] *and Won-Sup Lee*[***]
[*] *Tokai University, Hiratsuka, Japan*
[**] *Fujitsu LTD., Inagi-shi, Japan*
[***] *LG Chemistry Lab., Tejon, Korea*

Abstract

It is clarified by the experimental procedure and theoretical models that there exist two types in toner concentration dependence of toner charge at two-component developer. One is independent (*Type 1*) and other is dependent (*Type 2*) on toner concentration. The reason of these phenomena is responsible to the relative difference in each charging site number of toner and carrier of given developer, and is not the contamination of carrier surfaces by the toner. New model and also conventional models will explain these phenomena by introduction of the relative difference of the charging site number of toner and carrier. The characteristics of the two-component developer can be classified as *Type 1* and *Type 2* for the developer design.

Introduction

The triboelectric properties of two-component developers are important in practical machines because toner charge is an important parameter that controls the developed toner mass. By this reason, the toner concentration dependence of toner charge, ***q/m***, in two-component developer is very important factor for the developer design in commercial copier and printer. In practical use, it will be desirable for machine designer and user to be able to have the developer that the toner ***q/m*** is independent on toner concentration.

Recently, we have reported that there are two types in the toner concentration dependence of toner charge of two-component developer, e.g. independent and dependent types.[1)-5)] In this paper, we restudy more deeply the toner concentration dependence of toner charge on approaching by experimental procedure equations, experimental results and model equations. The results will indicate that the consideration of the difference of the state density on the carriers and toners is very important for understanding the toner concentration dependence of two-component developers and will suggest not to be the carrier surface contamination for the toner concentration independence of the ***q/m***.

Procedure of Measurement of q/m

Toner charge is measured with specially constructed blow-off equipment. The toner charge-to-mass ratio ***(q/m)*** or carrier charge-to-mass ratio (Q_c/M_c) is calculated to normalize the measurements. The toner concentration (C_t) is defined as the ratio of toner to carrier mass,

$$C_t = \frac{M_t}{M_c} \quad . \tag{1}$$

The carrier charge-to-mass ratio is given by

$$\frac{Q_c}{M_c} = \frac{q_c}{m_c} \quad . \tag{2}$$

The toner charge-to-mass ratio is given by

$$\frac{q}{m} = \frac{Q_t}{M_t} = \frac{q_t}{m_t} \quad , \tag{3}$$

where, "***t***", "***c***" : refer to toner and carrier.

Thus, "***Q***" and "***M***" are denoted total charge and mass, and "***q***" and "***m***" are denoted one particle charge and mass of toner and carrier, respectively. From (1), (2) and (3) equations, the relationship between carrier charge-to-mass ratio and toner charge-to-mass ratio is defined as

$$\frac{q}{m} = \frac{q_t}{m_t} = \frac{(Q_c / M_c)}{C_t} = \frac{(q_c / m_c)}{C_t} \quad . \tag{4}$$

This equation shows the measurement procedure to obtain the toner charge-to-mass ratio from carrier charge-to-mass ratio divided by toner concentration and was already shown by E. J. Gutman etal.[6)]

However, it is important to be the ***q/m*** value under the condition that all toner particles adhere on the carrier particle and free toners do not exist in the developer.

First in the blow off method, the carrier charge (q_c/m_c) is measured by changing toner concentration, C_t. The q_c/m_c values are plotted for C_t. As shown in Figure 1, if q_c/m_c-C_t curve is linear, toner charge ***q/m*** will be constant for C_t as follows,

$$\frac{q}{m} = \frac{q_t}{m_t} \quad . \tag{5}$$

In this case, the ***q/m*** is independent of toner concentration change.

And as shown in Figure 2, when the C_t-dependence of q_c/m_c is not linear, the toner charge q/m will be decreased with increasing the toner concentration. In addition, equation (6) is shown in the reciprocal of equation (4).

$$\frac{m}{q} = \frac{m_c}{q_c} C_t \tag{6}$$

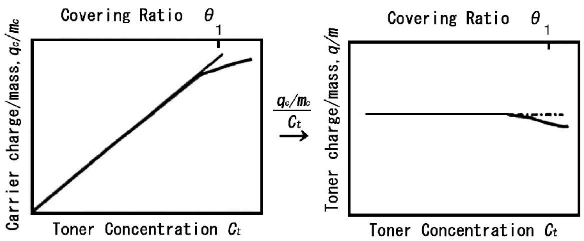


*Figure 1. Experimental procedure to obtain toner charge **q/m** from carrier charge q_c/m_c. in the case of $q_c/mc\text{-}C_t$ curve linear (Type 1).*

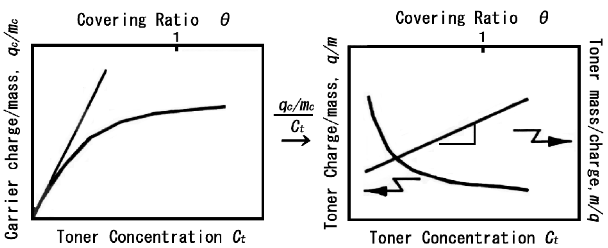


*Figure 2. Experimental procedure to obtain toner charge **q/m** from carrier charge q_c/m_c. in the case of $q_c/mc\text{-}C_t$ curve non-linear (Type 2).*

The $m/q\text{-}C_t$ curve becomes a straight line in equation (6) and the gradient m_c/q_c includes carrier particle size and charging site density that are the material information in the carrier side. The experimental procedure equation (4) will contain two kind of C_t dependence for the toner q/m. Theoretical models and equations will be required to explain the physics of the measured data shown in Figure 1 and Figure 2. Especially, the models have to explain why the q/m decreases with increasing toner concentration, C_t and does not depend on C_t.

Measurement Procedure Equation and Theoretical Model

Our model[1] is based on the dynamic process of charging and discharging and the toner charge-to-mass ratio, q/m is expressed as follows,

$$\frac{q}{m} = \frac{2eN_c N_t \Delta W}{m\left[N_c + N_t + \sqrt{(N_c - N_t)^2}\right]} \tag{7}$$

where N_c and Nt are the maximum number of the charging sites of carrier and toner, respectively, "e" is the electron charge and "ΔW" is the difference of effective work function of charging site between toner and carrier.

1. The case of $N_c > N_t$ (Type 1)

If the surface condition of the developer is $N_c > N_t$, then the q/m is given by equation (8),

$$\frac{q}{m} = \frac{e\Delta W n_t k_t}{m_t k_t} = \frac{\Delta W q_t}{m_t} = const. \tag{8}$$

where "k_t" is total number of toner particles and "n_t" is the number of charged sites on a toner particle. It can be seen that the expression of equation (8) is identical with equation (5) of the experimental procedure. The toner charge-to-mass ratio, q/m, is independent of increasing the toner concentration, C_t. We call this a *Type 1* as shown in Figure 1.

2. The case of $N_c < N_t$ (Type 2)

If the surface condition of the developer is $N_c < N_t$, the q/m is given by equation (9) derived from equation (7),

$$\frac{q}{m} = \frac{e\Delta W n_c k_c}{m_t k_t} = \frac{\Delta W q_c}{m_c C_t}, \tag{9}$$

where "k_c" is the total number of carrier particles, "n_c" is the number of charged sites on a carrier particle. And also, it can be seen that the expression of equation (9) is identical with equation (4) of the experimental procedure. The q/m decreases with increasing of C_t and $m/q\text{-}C_t$ curve becomes a strait line as shown in Figure 2 (*Type 2*).

These results suggest that the relative difference of charging site density on the toner and carrier surfaces of the developer should be considered when the toner concentration dependence of the q/m will be discussed and the two types exist in the toner concentration dependence of the q/m.

According to this suggestion, we have tried to apply the concept of the relative difference of charging site of the developer to the surface state model proposed firstly by L. H. Lee.[7] The equation (10) is the q/m of L. H. Lee's equation, but is modified in some parts.

$$\frac{q}{m} = \frac{eN_t(W_c - W_t)}{\left[1 + (N_t / N_c)C_t\right]}, \tag{10}$$

where "W" is the work function and the charge exchange motive force between toner and carrier. In the case of $N_c >> N_t$, equation (10) is modified to equation (11),

$$\frac{q}{m} = \Delta W\left(\frac{q_t}{m_t}\right)\left(1 - \frac{N_t C_t}{N_c}\right) \cong \Delta W \frac{q_t}{m_t}. \tag{11}$$

This is the same form as equation (8) in Dynamic model. In the case of $N_c << N_t$, equation (10) is modified to equation (12),

$$\frac{q}{m} = \frac{eN_c(W_c - W_t)}{C_t} = \frac{\Delta W q_c}{m_c C_t}. \tag{12}$$

This equation is identical with equation (9) in our model.

Table 1 Characterization of two component developer by developer type

Toner charge	*Developer type*	
	Type 1 ($N_c > N_t$)	*Type 2 ($N_c < N_t$)*
Charge up speed	*Fast*	*Slow*
Charge distribution	*Narrow*	*Wide*
Environmental dependence	*Small*	*Large*
Toner concentration depen	*Stable*	*Non*
Developing stability	*Stable*	*Non*

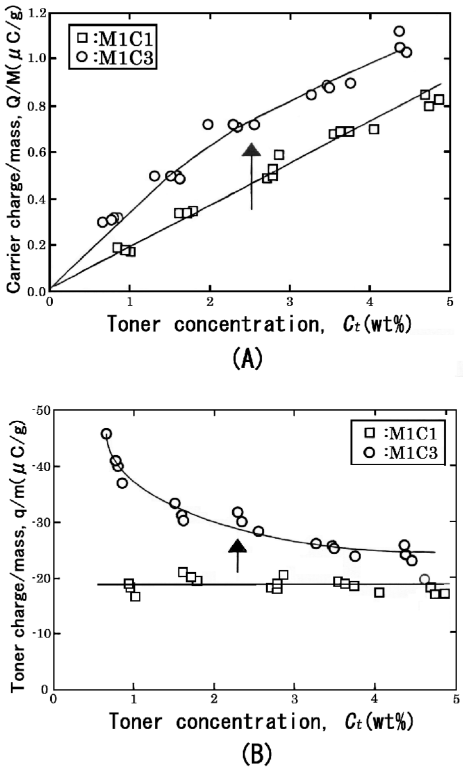


Figure 3. Examples of experimental data to be obtained from equation (4), M1: negative toner, C1: spherical ferrite carrier (100μm), C3: spherical silicone coated ferrite carrier (100μm), (A) carrier charge/mass vs. Ct, (B) toner charge/mass Vs. C_t

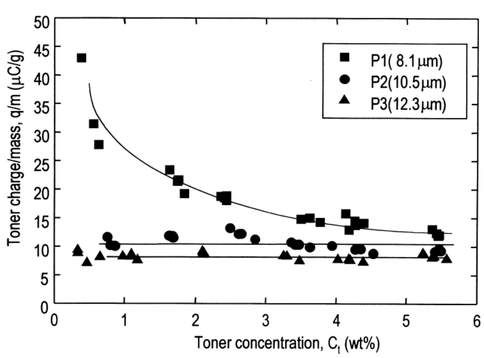


Figure 4 Dependence of toner charge-to-mass ratio, q/m, on toner concentration, C_t*, by combination of plus toner-P1, P2 and P3 and uncoated spherical ferrite carrier-C1 (100μm).*

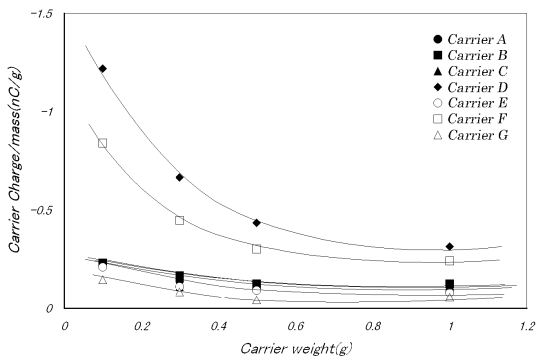
Experimental Data to Proposed Model and Discussion

We will show the experimental evidences[3), 5)] of two kinds of C_t dependence of the ***q/m***. The used toner (***M1***) was minus type with a mean diameter of ***10μm***. The used carrier (***C1***) was the spherical ferrite carrier with a mean diameter of ***100μm*** and the carrier ***C3*** was the silicone coated spherical ferrite carrier with a mean diameter of ***100μm***. Toner and carrier were fully mixed by shaking in ***200 cycles/2min***. The toner charge, ***q/m*** was measured by modified blow-off method.

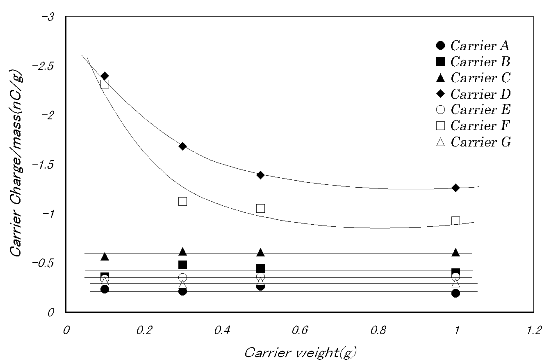
Figure 3 shows the examples of experimental data obtained by equation (4) and the change of toner concentration dependence of the ***q/m*** by carrier surface modification. Figure 3-A shows the dependence of the carrier charge on toner concentration and Figure 3-B shows the toner concentration dependence of the ***q/m***. The developer of ***M1-C1*** exhibits the characteristics of *Type 1* and the developer of ***M1-C3*** changes to the characteristics of *Type 2* by the modification of carrier surface from *Type 1*. It can therefore be assumed that the surface conditions of ***M1-C1*** developer would change from the condition of $N_c > N_t$ to that of $N_c < N_t$ by silicone modification of the carrier surface.

Figure 4 shows the toner size dependence of the ***q/m-***C_t curve. The used carrier was ***C1*** and the toners were positive type. The toner sizes are shown in Figure 4 and the toner composition is all the same. The developer of ***C1-P1*** combination shows the characteristics of *Type 2*, but others show *Type 1* characteristics for the toner concentration dependence of the ***q/m***. ***C2*** carrier is the small size ferrite carrier (***6μm***). ***C2-P1*** developer exhibited *Type 2* characteristics for the toner concentration dependence of the ***q/m***. These toner and carrier size effects for the toner concentration dependence of the ***q/m*** will suggest that the C_t-dependence of toner charge of two-component developer would be not responsible for material effect such as the carrier surface contamination by the toner, but for charging site number effect which is attributable to the limited surface area on toner and carrier.

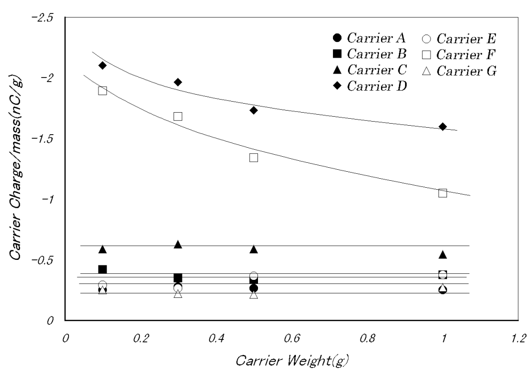
It will be possible to explain the reason for the C_t-dependence of the ***q/m*** under introducing the concept of the difference of the charging site number between toner and carrier. Figure 1 is independent of the toner concentration for the ***q/m*** and is in the case of $N_c > N_t$ (*Type 1*). The value of ***q/m*** is constant for increasing of toner content, that is, all toner particle charge is same and in the saturated state according to energetic requirement. For example, the number of toner particle (*10μm*) on one carrier (*100μm*) is about *250* particles at monolayer coverage. The carrier changing sites are rich in this case, and therefore, one carrier surface can give the same charge to each toner particle of *250* on the carrier. This is the reason for the C_t-independence of the q/m and *Type 1* developer.



(A) 5ml glass bottle



(B) 50ml glass bottle



(C) 100ml glass bottle

Figure 5 Glass bottle volume and carrier weight dependence of carrier tribo-charge with glass surface.

On the other hand, Figure 2 shows the decrease of the ***q/m*** with increasing toner concentration and is in the case of $N_c<N_t$. In this case, the carrier donor sites are not rich. Therefore, at the assumption, the value of the ***q/m*** will be maximum value at $C_t=0$ and then, the toner charge uniformly distributed to individual toner particle should be decreasing from maximum value with increasing of toner particles. This is the reason for the C_t-dependence of the ***q/m*** and *Type 2* developer.

H. Okada et al.[8] have deeply examined about L. H. Lee model by same approach as the above-mentioned concept. They have proposed the practical characteristics of the commercial developer as shown in Table 1. This is the important concept and information for developer designs.

It is thought as the reason for these phenomena that the two-component developers utilizing the frictional tribo-charging between two fine particles are the limited area system and not the infinite area system. That is to say, the toner concentration dependence of toner charge can be regarded as the unique phenomena that take place at the two-component developer having the limitation at mutual tribo-charging site number.

Area Effect of Tribocharges in Fine Particles

The area effect of tribo-charging in fine particles was verified by the following measurement.[9] The tribo-charging between spherical carrier particles and glass bottle wall was measured with seven kinds of commercial carriers of 100μm diameter. The change of the friction area was done by the bottle size and carrier amount. The glass bottles were three kinds of 5ml, 50ml and 100ml. For example, the carrier of 0.1g put into 5ml glass bottle and was charged by machine agitation for about 1 min.. The tribo-charged carrier was poured into the Faraday cage and its tribocharge was measured. The carrier tribocharge was saturated within 1 min. By changing the carrier amounts, the same operations were carried out and also were done on other bottles. The inner wall of the glass bottle can play the role of the carrier of two-component developer and seven kinds of carriers are corresponding to the toner. The results are shown in Figure 4. The tribocharges, ***Q/M***, of all carriers at 5ml glass bottle obviously decrease with increasing of the carrier amounts. The carrier amount dependence of the ***Q/M*** becomes clearly small with increasing of the friction area, that is, of the bottle size, such as 50ml and 100ml. In some carriers, the area size dependence of the ***Q/M*** disappears at large bottles. The reason of these phenomena will be explained by considering the relative difference between glass wall charging site numbers and carrier charging site numbers. Therefore, it is suggested by these results that the friction area effects, that is, the mutual charging site number differences should be also considered in the tribocharging of two-component developers.

Summary

We have shown that there are two types in the toner concentration dependence of toner charge of two-component developer and the concept of the relative difference of charging site number between toner and carrier is useful for the analysis of microscopic behavior and the practical developer design. Also, we have explained the physics of the toner concentration dependence of the ***q/m*** based on new concept and have shown that new concept is possible to apply to conventional models and the analytical results would be same as that of Kisimoto-Takahashi model.

References

1. T. Kishimoto and Y. Takahashi, Electrophotography, **34** ,No.3,190 (1995).
2. Y.Takahashi and W-S. Lee, IS&T's 12th International Congress on Advances in Non-Impact Printing Technologies, p-526 (1996).
3. W-S. Lee and Y. Takahashi, Electrophotography, **37**, No.2, 167 (1998).
4. W-S. Lee and Y. Takahashi, Electrophotography, **37,** No.2, 175 (1998).
5. W-S. Lee and Y. Takahashi, J. of the Imaging Society of Japan, **38**, No.1, 2 (1999)
6. E. J. Gutman and G. C. Hartman, J. of Imaging Science and Technology, **36** No.4, 335 (1992).
7. L. H. Lee, J. of Photographic Science and Engineering, **22**, No.4, 228 (1978).
8. H. Okada et al, Japan patent Tokaihei-8-136504, -8-248672 (1996).
9. M. Aoike, W.S. Lee, M. Omodani and Y. Takahashi, IS&T's 14th International Congress on Advances in Non-Impact Printing Technologies, p-386 (1998).

Biography

Yasusuke TAKAHASHI received his B.S. degree from Chiba University in 1959 and his Doctor of Engineering from Tokyo Institute of Technology in 1978. He joined Chiba University in 1962 and moved to Tokai University in 1971 as professor. His interest is the field of Hardcopy Technology, Toner charging phenomena, Digital paper, Human interface in Imaging technology. His society activities are as following: President of Imaging Society of Japan (1998-1999) and Japanese Society of Printing Science and Technology (1994-1999).