A Method to Confirm the Accuracy of the Blow-Off Tribo and Charge Spectrograph Measurement Techniques

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Abstract

A difficulty in assessing the accuracy of both the blow-off tribo and charge spectrograph measurement techniques is that there are no standard developer samples that have calibrated charge values. The precision of both toner charge measurement techniques can be assessed by plotting the average q/d value from the charge spectrograph measurement versus the q/m value obtained from the blow-off tribo measurement of a common developer sample. Julien and Gutman have both published results showing the q/d value is proportional to the q/m value. From the slope of the line drawn through the data, the average particle radius of the toner in the developer can be calculated. We have found that this calculated value for the toner radius is nearly equal to the measured median toner radius obtained from a volume displacement particle size measurement. This independent measurement of the toner radius serves as a confirmation of the accuracy of the toner charge measurement techniques.

Introduction

For the xerographic development process, an important developer material parameter is the charge distribution of the toner particles. The solid area and line development are functions of the amount of right sign toner while background is a function of the amount of wrong sign toner. Solid area development has been shown to be proportional to the blow-off tribo value. The amount of wrong sign toner in the charge distribution can be measured by a toner charge spectrograph.

These two toner charge characterization techniques have been the subject of some discussion. In one of the earliest studies of the comparison between the two techniques, we showed that the average charge per particle obtained from the charge spectrograph measurement was nearly equal to the average charge per particle obtained from the blow-off tribo measurement.[1] The small discrepancy could be attributed to 1) inaccuracies in the measurement of the toner size by the image analysis system used in the analysis of the charge distribution; 2) not completely removing all the toner by the low velocity air stream used in the charge spectrograph measurement; and, 3) the effect of the tribo cage used in the blow-off on the measured charge of the toner.

Gutman and Laing[2] showed that the measured width of the charge distribution is a function of the electric field strength used to disperse the toner particles in the charge spectrograph and the finite width of the inlet tube aperture, which admits a fine stream of toner particles into the analyzing field. The mean of the charge distribution is not affected by the finite size of the inlet tube. Their work reiterated the early finding that the average charge per particle obtained from the charge spectrograph was proportional to the average charge per particle obtained from a blow-off tribo measurement and a measurement of the toner size by fluid displacement.

Julien[3] reported that the charge-to-diameter ratio, q/d, measured at the average size of the toner particle was proportional to the blow-off tribo value. He examined a large database of tribo and charge spectrograph measurements made with three sizes of toner particles. The outcome of all these studies indicates that the measurement of charge by the two techniques is well correlated. Thus we can have confidence in the precision of the measurements. But, are the measurements accurate? In this paper we will examine a method to assess the accuracy of the combined measurements by comparing the toner particle size calculated from the slope of the line on a q/d versus q/m plot with an independent measurement of the toner size obtained by fluid displacement.

Experiment

Schein and Cranch[4] have discussed the blow-off tribo measurement. A sample of known weight of developer is placed into a metal cage formed by a cylinder fitted with screens at both ends. The mesh of the screens is selected to be large enough to permit the toner particles to freely pass through, but small enough to hold back the carrier beads. In addition, the screens must be rigid enough to withstand a high velocity air stream. The metal cage is attached to an electrometer. An air stream is used to dislodge the toner particles from the carrier beads and carry the toner particles out of the cage. The electrometer measures the charge on the carrier beads left behind in the cage. The mass of toner removed from the carrier beads is the difference between the initial weight of the developer sample and the weight of the carrier beads after the blow-off. The tribo value is the total charge divide by the total mass of toner removed. This can be shown to be equal to the average charge of a toner particle divided by the average mass of a toner particle.

Lewis, Connors, and Koehler[5] have described the charge spectrograph used in Xerox. To obtain the charge distribution of a xerographic developer, a small sample is placed in a magnetic chuck. A fine air stream is used to dislodge the toner particles from the carrier beads thus forming a powder cloud of charged toner particles above the inlet tube of the instrument. Toner particles from this cloud are entrained in the air stream entering the inlet tube and are carried into the analyzing chamber. The velocity of the air stream in the inlet tube is carefully matched to the velocity of air flowing through the analyzing chamber to prevent turbulence. In the analyzing chamber, the toner particles are dispersed by a uniform electric field perpendicular to the air stream. The toner particles are eventually trapped by a filter at the base of the chamber. The displacement of a toner particle is dependent on the strength of the electric field and the particle's charge to radius, q/r, or, equivalently, the charge to diameter ratio, q/d.

The captured toner particles form a "smear" on the filter paper that is representative of the charge distribution of the toner particles in the air stream, and by inference, of the toner particles in the developer. The position of the toner particles on the filter paper is determined by using an automatic image analysis system that has been programmed to measure the displacement of the particle from a zero line as well as to measure the size of the particle. The displacement of the toner particle is converted to the q/d value using the parameters of the spectrograph and the equation,

$$\frac{q}{d} = \frac{3\pi\eta v_a}{h}\frac{x}{E}, \qquad (1)$$

where η is the viscosity of air; v_a is the air speed; h is the distance from the inlet tube to the filter paper; x is the displacement of the particle on the filter paper in the direction of the electric field; and E is the strength of the electric field. It is convenient to represent the output of the image analysis as the number fraction of toner particles with a given q/d and d or n(q/d,d).

The size of the toner particles was measured with a Coulter Counter Multisizer 2. This instrument measures the volume of a particle by fluid displacement.

Results and Discussion

Figure 1 shows a plot of q/d versus q/m for two different developers with nearly the same size toners. The data are from Ref. 6. The charge on the toner particles was varied by changing the toner concentration of the developers. The lines are the proportional fits to the data for each toner. From the slope of the lines the size of the toner particles in microns can be calculated by the equation,

$$r_t = \left(\frac{3*10^{-5}\, slope}{2\pi\rho}\right)^{\frac{1}{2}} *10^4, \qquad (2)$$

where *slope* is the slope of the line on a q/d versus q/m plot with units of 10^{-5} g/cm when q/d is measured in femto-Coulombs per micron and q/m is measured in micro-Coulombs per gram; and, ρ is the density of the toner particles.

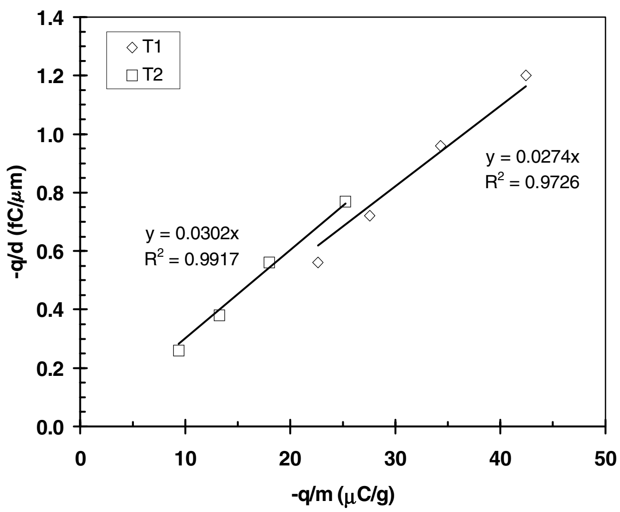

Figure 1. A plot of q/d from the charge spectrograph measurement versus q/m from the blow-off tribo measurement for two toners. For both toners, q/d is proportional to q/m.

Table I lists the slopes, R^2, the coefficient of determination, the calculated toner radius, the measured toner median number radius and median volume radius for the data in Figure 1 and data from Julien (Figure 3 in Ref. 3). We noticed that the calculated toner radius is nearly equal to the number median toner radius. Figure 2 is a plot of the calculated toner radius versus the toner median radius for the data in Table I as well as data for other experimental toners. The 1:1 line of correspondence is shown. The regression line for all the data in Figure 2 has a slope of 0.98±0.02 with an R^2 of 0.74, consistent with a correspondence of 1:1.

We are not aware of any definitive theoretical reason to use any particular particle size statistic. We propose the reason that the toner size calculated from the slope of a q/d versus q/m plot is nearly equal to the measured toner number median size is because both measured triboelectric quantities depend on a first power of the toner radius, namely, q/d ~ r and $q/m \sim r^{-1}$. The number or arithmetic mean statistic is the sum of the values divided by the number of values; the median value is the middle (or interpreted middle) value of a set of values. These statistics are nearly equal if the distribution is not badly skewed. For the charge spectrograph measurement, we expect the q/d-value for each toner particle to be proportional to its radius. The mean q/d-value would then be proportional to the mean radius.

$$\left(\frac{q}{d}\right)_i \sim r_i \quad \text{and} \quad \overline{\left(\frac{q}{d}\right)} \sim \bar{r} \qquad (3)$$

Likewise, we expect the median q/d-value to be proportional to the median radius.

Table I. Slope, R^2, Calculated and Measured Toner Sizes

Source	Slope (10^{-5} g/cm)	R_2	**Calculated r_t (μm)**	**Measured Toner radius (μm)**	**Calculated r_t (μm)**
				Number median	**Volume median**
Figure 1	0.0274	0.97	3.30	3.32	4.01
	0.0302	0.99	3.47	3.50	4.11
Ref.3, Fig. 3	0.0146	0.87	2.41	2.55	3.60
	0.0211	0.87	2.90	3.40	4.55
	0.0390	0.83	3.94	4.55	6.30

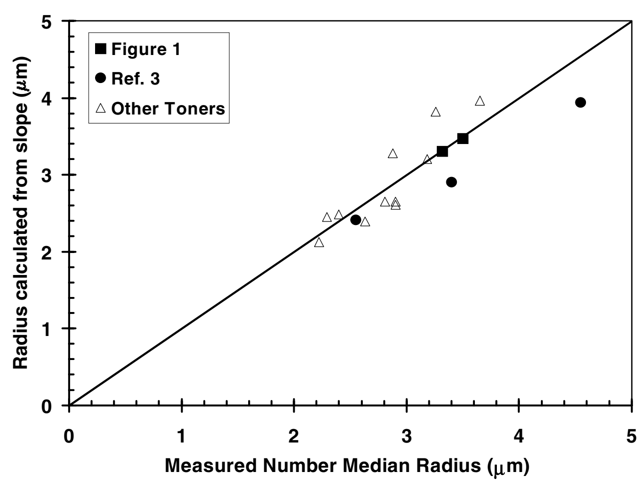

Figure 2. The calculated toner radius as a function of the measured number median toner radius for 16 toners.

It is more difficult to assign a radius metric to the tribo value. For each toner, we expect the charge-to-mass of the particle to be proportional to r^{-1}. However, unlike q/d, the charge-to-mass of each particle in the sample is not measured; but rather, the quantities total charge and total mass are measured separately. To the extent that the mean charge divided by the mean mass is equal to the mean of the charge-to-mass values, the arithmetic mean reciprocal radius might be expected to be the representative size metric. The arithmetic mean reciprocal radius is not a readily available metric from the particle size measurement.

$$\left(\frac{q}{m}\right)_i \sim r_i^{-1} \quad \text{and} \quad \overline{\left(\frac{q}{m}\right)} \sim \overline{r^{-1}}$$

$$\frac{q_{total}}{m_{total}} = \frac{\bar{q}}{\bar{m}} \approx \overline{\left(\frac{q}{m}\right)} \sim \overline{r^{-1}} \approx \bar{r}^{-1} \qquad (4)$$

For a few of the classified toners used in the experiments, we confirmed that the mean reciprocal radius and the reciprocal of the mean radius were nearly equal. We believe this is due to the fact that both metrics give more weight to the smaller particles in the distribution. In addition, we have observed that the number median size is approximately equal to the number mean size for the types of classified toners used in these measurements. Thus, it seems reasonable that the two triboelectric quantities, the median q/d and the tribo value, could depend on a first power of the median number radius

We expect a plot of q/d versus q/m to show a good correlation between these two measurements of the toner charge and without an intercept on either axis. Our experience indicates that an intercept indicates there is a problem with one of the measurements. This plot showing the measurements to be proportional indicates that the two measurements are precise. From The slope of the line in such a plot, one can calculate the toner radius. With the observation that the toner radius calculated from the slope of q/d versus q/m corresponds to the measured number median toner radius, one can use the fluid displacement measurement to calibrate the combined toner charge measurements. The good agreement with the independent fluid displacement measurement indicates the two charge measurements are most likely accurate.

Summary

We have reviewed the blow-off tribo and the charge spectrograph measurement techniques. The q/d value from the charge spectrograph measurement is proportional to the q/m value obtained from the blow-off tribo measurement. The proportionality of the data indicates the measurement techniques are precise. From the slope of the line in a plot of q/d versus q/m, one can calculate the toner radius. We found that this calculated toner radius is nearly equal to the measured number median toner radius obtained from a fluid displacement measurement. The good agreement between the calculated and measured toner size from two independent measurements indicates the two charge measurement techniques are most likely accurate.

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Biography

Edward Gutman holds B.S. and M.S. degrees from John Carroll University and a Ph.D. in solid state physics from Iowa State University. In January, 2001, he retired from Xerox Corporation where his research interests had focused on the physics of the xerographic development process and the science of xerographic developer materials. He holds patents on xerographic developer materials and devices. He is a member of the IS&T and American Physical Society.