The Relationship between Blowoff Tribo and Charge Spectrograph Measurements

Paul C. Julien
Wilson Center for Research and Technology
Xerox Corporation, Webster, New York

Abstract

The relation between the blowoff tribo and charge spectrograph output has been a matter of discussion throughout the history of spectrograph analysis. A large database including both spectrograph and blowoff data has been examined to look at the consistency between the measurements over a range of materials and test conditions. A subset of negatively charging toners from the database was selected where the charging data was linked to volumetric size information on the toners as well as the size information generated in the course of the charge spectrograph image analysis. The range of size in the toners went from about 6 to 14 µm. The relation between Q/D from the spectrograph and Q/M from blowoff tribo is expected to vary with toner size. To illustrate this the samples were divided into sets centered at 7, 9, and 12 µm. These lie along different trend lines when Q/D is plotted against tribo. When a "pseudotribo" of Q/D^3 derived from charge spectrograph measurements is plotted against blowoff tribo, the measurements fall on trend lines with similar slopes and correlation coefficients in the range of .85. However, the magnitude of the tribo predicted from charge spectrograph measurements was about 70% of the actual tribo. Using the average charge on the toner particles for comparison leads to similar results.

Introduction

This paper will focus on the relationship between two of the fundamental measures of the charge on a toner as its size changes. One is the blowoff tribo or charge to mass ratio of the toner, and the other is the output of the charge spectrograph, which measures the charge to diameter ratio of the individual toner particles. A recent paper found individual strong correlations but very different slopes between the two measurements for two developers of differing toner size.[1] This paper will look at the much noisier situation of samples from a wide variety of sources and with a broad range of sizes.

The blowoff tribo has been used to measure the state of xerographic developers for decades.[2] A sample of the developer is placed in a metal cylinder fitted with screens at the ends. The screen size is selected so that the toner particles can freely pass through, while the carrier beads are retained in the cage. A known weight of developer is placed in the cage, the cage is connected to an electrometer, and the toner is blown off by an air stream. The final weight after blowoff is now measured. The charge flowing through the electrometer during blowoff gives the charge on the toner, while the difference in mass gives the amount of toner. The ratio of the two is the blowoff tribo.

Several devices, called charge spectrographs, have been developed to go beyond the limitations of the blowoff tribo and look at the distribution of charges on individual toner particles.[3-6] In the spectrograph developed at Xerox,[3] toner particles are carried in a moving column of air through an electric field perpendicular to the direction of flow. A balance between the electric force on the particle and the Stokes drag force opposing motion leads to a drift velocity perpendicular to the air velocity. The particles are collected on a filter at the bottom of the spectrograph tube. The displacement of each toner particle on the filter paper is proportional to its charge to diameter ratio. Measurement of size and position through an optical microscope determines the size and charge of each particle in the developer. The units for the charge to diameter ratio are femtocoulombs (10^{-15} coulombs) per micron (fc/µ).

The blowoff tribo charge to mass (Q/M) and the charge spectrograph charge to diameter (Q/D) are independent measurements of the charge on a developer sample. For a given toner the values generally are proportional to one another as each changes due to machine or environmental conditions; however, for toners of different size the relationship between the measurements changes dramatically. Indeed, if we plot Q/D against Q/M, we expect the slope to be proportional to D^2, since the mass is proportional to the volume and hence D^3. This is illustrated in Figure 1 derived from Reference 1 where the charging behavior of two experimental toners is compared. One is a relative large toner with an average diameter from the charge spectrograph image analysis of about 11.9 µm, and the other is relatively small with an average image analysis diameter of about 6.2 µm. These numbers are somewhat smaller than standard volume displacement size measurements on the same toners, which would be 14 and 7 µm respectively.

This paper will explore the more general case of a broad range of toners of differing sizes and test conditions by examining a large database containing selected charge spectrograph data from every sample analyzed by our laboratory in the Xerox Wilson Center for Research and Technology. The data retained for the database consists of the average Q/D values at 6, 10, and 14 µm, the average Q on the toner, the average diameter derived from the projected area in the image analysis, and a volume weighted average diameter. If the blowoff tribo was measured on a given sample, this is included in the database. Also, many of the samples can be linked to a database of volumetric size information for individual base toners (*i.e.*, without surface additives) derived from fluid displacement sizing instruments such as the Coulter Multisizer Iia.

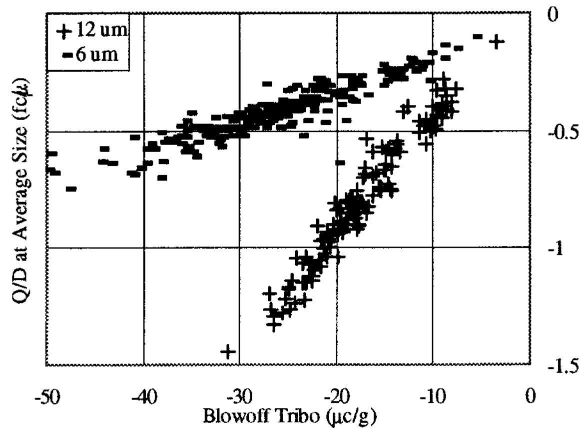

Figure 1. Q/D vs. Tribo for Large and Small Toners.

For the plots included in the paper, the size of the sample was further reduced to about 1000 samples by restricting the samples to the first four on any page in the charge spectrograph log book. This was done to keep the electronic form of the paper to a size that would fit on a single disk (1.35 MB). The process should amount to a random subset of the samples, and indeed the character of the plots do not vary significantly from the full data set. Tables and conclusions are based on the full set.

For this paper samples were selected where both blowoff tribo and fluid displacement size measurements were available, where all the charging measurements were negative, and where a toner concentration was recorded. The last condition restricts the analysis to two component developer samples. Also, to reduce scatter due to image analysis problems and improper transcription of the fluid displacement size measurements, only those samples where the image analysis (IA) average diameter (D_{li}) was greater than .55 times the volume weighted image analysis average diameter (D_{vi}) and the fluid displacement (FD) average diameter (D_{lf}) was greater than .6 times the volume weighted fluid displacement average diameter (D_{vf}) were used. This last pair of conditions in effect eliminated any samples in the database that had not had toner fines removed by classification after the toner was jetted. About 3000 samples remained after all the conditions were imposed.

In practice we use the volume weighted fluid displacement size and the linear image analysis size in describing the size of a toner. These are the most closely matched among the four size measurements. Figure 2 plots the linear diameter from image analysis against the volume diameter from the fluid displacement analysis for the samples. The samples have been separated into three groups by divisions at 8 and 11 µm.

These groups are denoted as 7, 9 and 12 microns in subsequent discussion even though the average for each group varies significantly depending on the particular measure of size used (Table 1).

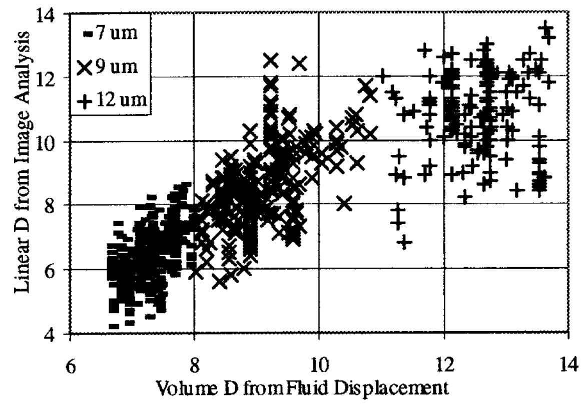

Figure 2. Comparison of Sizes from Two Techniques.

Table 1. Diameter Measurements for Toner Set

	7µ	9µ	12µ
Linear from IA (D_{li})	6.4	8.4	10.8
Volume from IA (D_{vi})	9.6	12.4	15.8
Linear from FD (D_{lf})	5.1	6.8	9.1
Volume from FD (D_{vf})	7.2	9.1	12.6
Average of all 4	7.1	9.2	12.1

Toner sizes from fluid displacement measurements tend to be smaller than those derived from image analysis. This may be because toners in the latter tend to lie on their flatter surfaces, leaving their larger dimensions exposed to the image analysis. The difference between the linear fluid displacement diameter and the volume image analysis diameter is almost a factor of two. The linear image analysis diameter will be used in the plots comparing tribo, Q/D, Q, and their derived quantities. Table 3 in the discussion section shows that choosing another measure of size (the linear fluid displacement diameter) easily changes the comparison by a factor of two, although it does not change the character of the plots significantly.

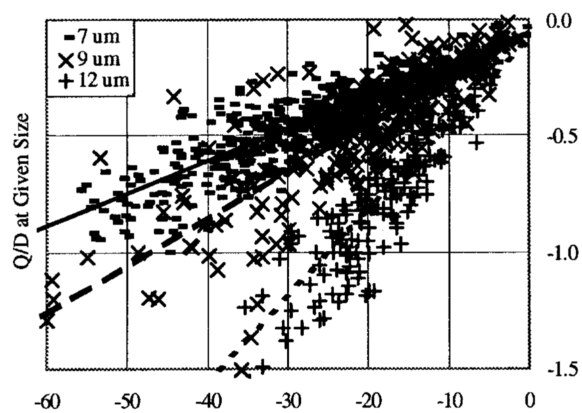

Figure 3. Q/D vs. Blowoff Tribo for Different Sizes.

Figure 3 plots Q/D versus blowoff tribo for the different size ranges in Figure 2. Q/D was computed for the characteristic size by interpolation from the database values at 6 and 10 µm for the 7 and 9 µm cases and from the values at

10 and 14 µm for the 12 µm case. Earlier papers have discussed the linear dependence of Q/D on D_{li}.[6,7] In this and subsequent plots the trend line for the 7 µm toner is the solid line, for the 9 µm the dashed line and for the 12 µm the dotted line.

A "charge spectrograph tribo" can be derived from the database in two ways: either by starting with Q and dividing by D_{li}^3 or by calculating Q/D at D_{li} and dividing by D_{li}^2. Figure 4 shows the first case, and Figure 5 shows the second.

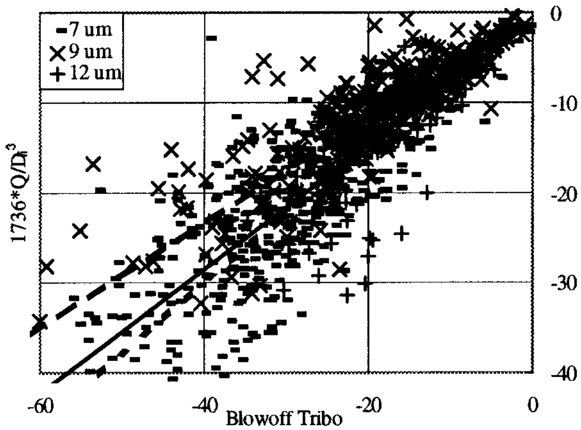

Figure 4. CS Tribo vs. Blowoff Tribo.

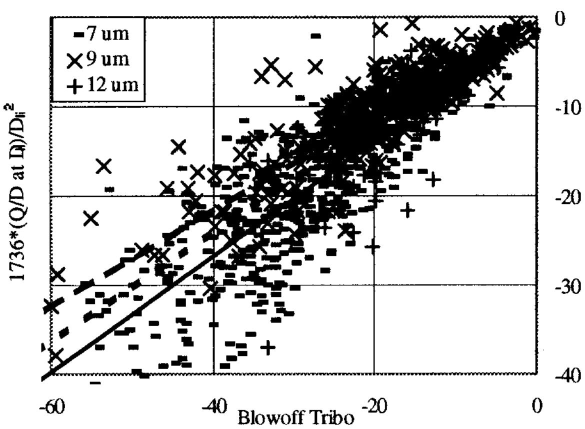

Figure 5. Tribo from Q/D vs. Blowoff Tribo.

There is little difference between them. In each case the calculated numbers are multiplied by $(6/\pi\rho)*1000$ to convert from femtocoulombs per micron^3 to microcoulombs per gram. If we take the density of the toner ρ to be 1.1, this factor is 1736. The density will vary with the polymer used in the toner by about 10%. Because this is uncontrolled, it is an additional noise factor in making comparisons. The graphs should have a 1 to 1 relationship. In actuality the charge spectrograph numbers are about 60 to 70% of the blowoff derived numbers. This will be discussed later.

Gutman has advocated comparing the average charge on the particles from the charge spectrograph with the tribo times the average d^3 from fluid displacement size measurements.[9,10] This size is not one of the numbers retained in the database, but examination of several fluid displacement readouts indicates that it would fall between the linear and volume measurements from that source and would be closer to the linear measurement. This would make it smaller than the linear image analysis measurement used in the plots. In Figure 6 we use the same numbers as in Figure 4 to do the comparison in Q space rather than tribo space. Now the spectrograph number is perhaps 50% of the tribo derived number. As Table 3 will demonstrate, using a number closer to the linear FD number would give better agreement.

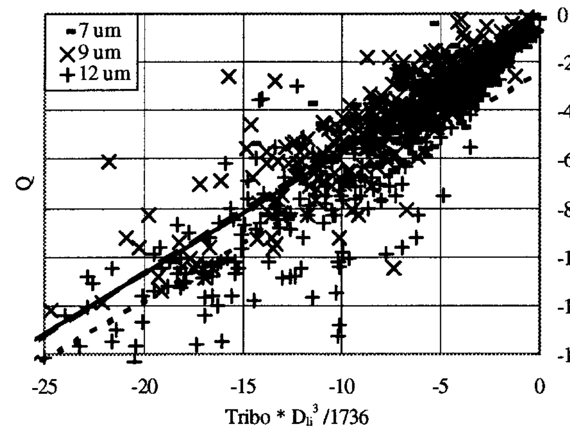

Figure 6. CS Q vs. Q from Tribo for Different Sizes.

Discussion

Table 2 summarizes the correlation between the different derived quantities, and Table 3 gives the slope of the relationship. These numbers were generated without the constraint that the trend line pass through zero. Typical intercept values were quite small; Figure 6 is the worst case where the large numbers of samples with Q values much higher than average but below a trend line between the bulk of the distribution and zero leads to lower slope values than when the comparisons are done in tribo space. The use of the fluid displacement size enables better numerical agreement between Q/D and tribo since the smallest of the image analysis sizes still gives too large a diameter for agreement. However, the use of the fluid displacement size of the original toner degrades the correlation probably because we are using one size to characterize all toners made from the same base toner independent of the test conditions.

Table 2. Correlation Coefficients for Various Relations

	7µm	9µm	12µm	Combined
Tribo from Q (IA)	0.82	0.87	0.77	0.85
Tribo from Q/D (IA)	0.83	0.88	0.75	0.85
Tribo from Q (FD)	0.80	0.82	0.62	0.82
Q from Tribo (IA)	0.85	0.89	0.82	0.91
Q from Tribo (FD)	0.81	0.83	0.61	0.85
Q/D vs. Tribo	0.87	0.87	0.83	

Table 3. Trend Line Slopes for Various Relations

	7µm	9µm	12µm	Combined
Tribo from Q (IA)	0.69	0.61	0.76	0.70
Tribo from Q/D (IA)	0.64	0.56	0.58	0.64
Tribo from Q (FD)	1.27	1.03	0.85	1.27
Q from Tribo (IA)	0.49	0.52	0.49	0.56
Q from Tribo (FD)	1.02	1.05	0.66	0.93

If the main purpose is to correlate charge spectra data with blowoff tribo data, there is no advantage to comparing charge spectra to blowoff data in either a calculated tribo or a calculated Q over using a plot of Q/D versus tribo for the target size of the toner. When using a single toner for a period of time, the correlation between Q/D and blowoff tribo is even better established. The average size in a developer may change due to selective development of large or small particles, and this will indeed affect the relationship between Q/D and blowoff tribo, but all three quantities should be retained for a true picture of what is happening. The third quantity serves as a consistency check on the validity of the other two. While image analysis probably overestimates size, the size generated is still useful for comparing Q/D and blowoff tribo.

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