The Effect of Toner and Carrier Composition on the Average and Distributed Toner Charge Values

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Abstract

The average toner charge-to-mass ratio (*q/m*) is an important metric for two-component xerographic developers since xerographic development of solid and line or dot images is normally a simple inverse function of *q/m*. However, *q/m* is a distributed function, and for other non-image processes such as background development and machine dirt generation, the "tails" of the charge distribution are more important than the average *q/m* value. Thus, a detailed assessment of any particular xerographic developer should involve the measurement and analysis of the entire charge spectrum. This viewpoint will be illustrated in the present paper by a comparison of simultaneous average *q/m* data (from a total-blow-off procedure) and distributed charge/size (*q/d*) data (from a charge spectrum). In particular, the direct connection between these two types of charge measurements will be highlighted, both for normal charging processes and for admix processes that involve the addition of uncharged toner to a charged developer. Additionally, both positive and negative charging processes will be considered, with a common set of test toners being driven to both polarities via specific carrier coatings.

Introduction

For idealized charging models, the toner *q/m* generation process can be expressed as the product of terms related to the physics of charging, the chemistry of charging and the mechanics of charging[1]. The "physics" and "mechanics" terms affect only the **magnitude** of *q/m*, e.g., via toner/carrier size effects and intensity of toner/carrier mixing. The "chemistry" term, by contrast, can affect both the **magnitude** and **polarity** of *q/m* since this term involves differences between the charging properties ϕ_t and ϕ_c of the toner and carrier.

Conceptually, then, any single toner can be driven to a positive or negative polarity via an appropriate choice of carrier "chemistry":

For a **negative** polarity toner: $\phi_{toner} < \phi_{carrier}$
For a **positive** polarity toner: $\phi_{toner} > \phi_{carrier}$

Since toner particles must be functional in all xerographic subsystems from development to fusing, the use of carrier "chemistry" to manipulate toner charging properties is potentially a most valuable tool for developer designers. This is especially true for toner designs in cases where the xerographic marking technology is transitioning from a "light-lens" analog copier mode to a "laser/LED" digital copier/printer mode, since the former mode is based on charged-area development (CAD), while the latter mode can be either CAD or discharged-area development (DAD). For the case where the digital development mode is DAD, then the polarity of the "copier" version of the toner must be reversed.

Unfortunately, the successful manipulation of toner charging properties to produce a functional xerographic developer involves design considerations not explicitly accounted for by Eqn. (1). Experimentally, the concept of a functional "universal" toner cannot be demonstrated, and certain specific toner/carrier combinations can be empirically identified as being best suited for positive or negative toner applications. A major reason for this specificity, lies in the fact that toner charging involves distributions of toner size and charge, and important xerographic metrics can be adversely affected by the non-average population of these distributions. For example, the level of machine "dirt" and unwanted xerographic development in non-image areas can be driven by the population of toner particles having low or reverse charge. As a result, specific "charge-control agents" (CCA's) and/or surface particulate additives are frequently added to toner recipes in order to promote fast and homogeneous charging of toner particles, so that functional "positive" and "negative" toners frequently differ significantly in their overall chemistry.

In this paper, some of the problems associated with the "universal toner" concept will be illustrated via charging measurements taken on a set of simple model toners and carriers designed to produce either a positive or negative polarity for any individual toner. In particular, the average toner charging properties (*q/m*) measured at fixed levels of developer mixing will be compared with simultaneous measurements of the distributed charging values (expressed in terms of charge per unit size, *q/d*).

Theory

As detailed in previous reports[1,4], the relationship between the sign and magnitude of the *q/m* of a toner at a toner concentration *C* can be related to the physicochemical properties of the toner and carrier particles in a two-component xerographic developer according to an equation of the form:

$$q/m = (A'/(C+C_o)) \cdot (\phi_{toner} - \phi_{carrier}) \cdot (1 - \exp\{-\gamma\cdot t\}) \quad (1)$$

where the A' term chiefly contains contributions from carrier physical parameters (e.g., size and mass), the C_o term is controlled by toner and carrier physical parameters (e.g., size and density), and the materials charging terms — ϕ_{toner} and $\phi_{carrier}$ — reflect the chemistry of the respective charging surfaces. (The $1 - exp\{-\gamma\cdot t\}$ term is a parametric representation of the saturating exponential nature of triboelectric charge generation, as a function of developer mixing time t).

Generally, xerographic toners and carriers are based on several distinct components, and conceptually the ϕ_{toner} and $\phi_{carrier}$ parameters can be expressed in terms of surface-weighted sums of contributions from these components [1,2,3,4,] e.g.:

$$\phi = \mathbf{P}_i \cdot \mu_i + \mathbf{P}_j \cdot \mu_j + \quad (2)$$

where the fractional weights $\mathbf{P}_i$, $\mathbf{P}_j$ etc., add to unity, and the parameters μ_i and $\mu_{j,}$ etc. are charging factors for the various surface components.

For a toner particle, the parameters μ_i, μ_j etc. represent contributions from constituents such as the base resin and secondary polymers such as waxes, the colorant, CCA's, external additives, and even chemical impurities. For a carrier particle, the charging parameters may be affected by contributions from the base carrier core (for cases where the carrier bead is only partially coated), from the coating resin (or resins), and from dopants added to the carrier coating.

A test toner can be readily driven to a positive or negative polarity, either through the appropriate selection of carrier and/or toner constituents, thus allowing the charging properties of a test toner to be evaluated for both polarities. Similarly, the level of charge generated for any particular toner can be systematically altered, so that in theory a toner can be evaluated over a wide range of charging conditions.

Experimental Procedures

A range of simple 9-10μm model carbon-black/polymer toners were prepared by conventional jet-milling and classification. For toners based on an external particulate additive, the toner particles were blended with 0.2 wt% of 8 nm hydrophobic fumed silica particles via roll-milling along with 3 mm. diameter stainless steel balls. The test toners were gently pre-mixed with nominal 100μm or 130μm solution-coated or powder-coated carrier beads to produce two-component developers at a nominal 3wt% toner concentration. The test developers were conditioned overnight in a controlled RH-chamber set for a "cold/dry" condition of 16°C and 20% RH. For *q/m* generation, the jars were capped before removal from the RH-chamber to a "paint-shaker" developer agitation station. After each agitation interval, the main developer sample was returned to the RH-chamber, and a small sample taken for a *q/m* measurement via a total blow-off procedure. At selected test points, a small sample of developer was also used to inject toner into a charge spectrograph[5], and the resulting spectrum ("smear") of toner particles was scanned to produce a two-dimensional set of data tabulated by toner size (*d*), and by toner charge to diameter (*q/d*).

Since charged toner particles are constantly being removed (via development) from a working xerographic developer, and are constantly being replenished (via addition of uncharged toner particles from a dispensing reservoir), the rate at which a charged developer incorporates added toner is an additional important charging metric[6] (especially for digital and/or color xerography, since pictorial images can consume much more toner than that needed for simple text imaging). To evaluate this property, charge spectra were collected for the test developers following the addition of 1 wt% of uncharged toner to a fully-charged developer containing 3 wt% of toner. These "admix" tests were made following competion of the preliminary charge build-up tests.

Results and Discussion

(a) Negative Toner Polarity Tests

Figure 1 shows the *q/m* vs. mixing time data, and Figure 2 shows the corresponding *q/d* vs. mixing time data for four test toners driven to a negative polarity. In these Figures, toners PE1 and PE2 are polyester-based, and differ only in that PE2 has 0.2 wt% of an 8 nm SiO_2 blended onto its surface (tests I and II). Similarly, toners SA2 and SA1 are styrene-acrylate-based, with and without 0.2 wt% of 8 nm SiO_2 respectively (tests IV and III). For this data set, a single acrylate-coated/conductive carbon-black-doped carrier (CD) was used. Clearly, in its base condition, the styrene-acrylate toner, SA1, cannot generate an effective level of negative charge against the CD carrier, but addition of SiO_2 to the surface of this toner was effective at increasing the negative charge level for this toner thus producing toner SA2.

In general, the relationship between average *q/m* values and corresponding mean *q/d* values should be an inverse function of d^2. For example, for an idealized spherical toner particle:

$$q/m = q \cdot (6/(\rho\pi d^3)) = (q/d) \cdot (6/(\rho\pi d^2)) \quad (3)$$

For the present data, Figure 3 is a comparison of the *q/m* and *q/d* measurements taken at common mixing times. From this plot, several points can be highlighted:

- The *q/m*:*q/d* relationship is directly linear, with a slope consistent with Equation (3)
- The relationship is maintained even as the developer charge properties increase/decrease during the developer charging mixing process
- The relationship holds for both base and external additive toners

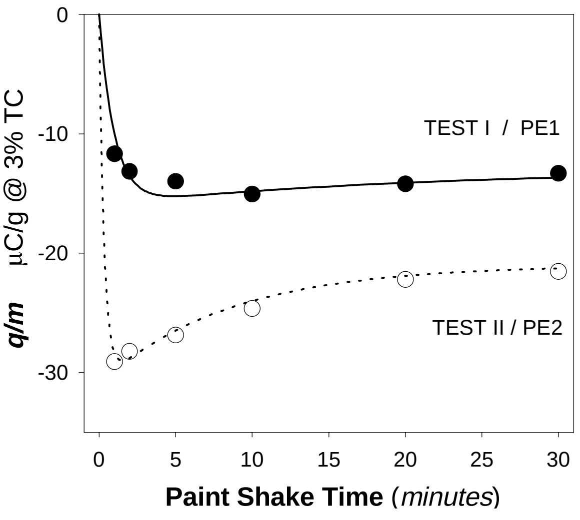

Figure 1a. q/m vs. mixing time for apolyester-based toner with and without SiO_2 (PE2 and PE1) against a carbon-black-doped carrier, (CD).

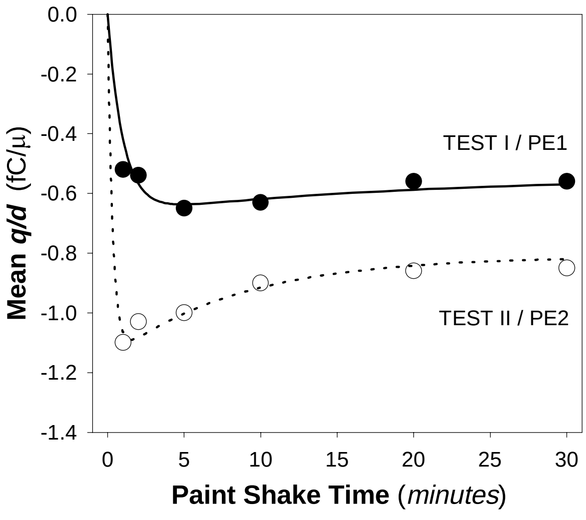

Figure 2a. q/d vs. mixing time for a polyester-based toner with and without SiO_2 (PE2 and PE1) against a carbon-black-doped carrier, (CD).

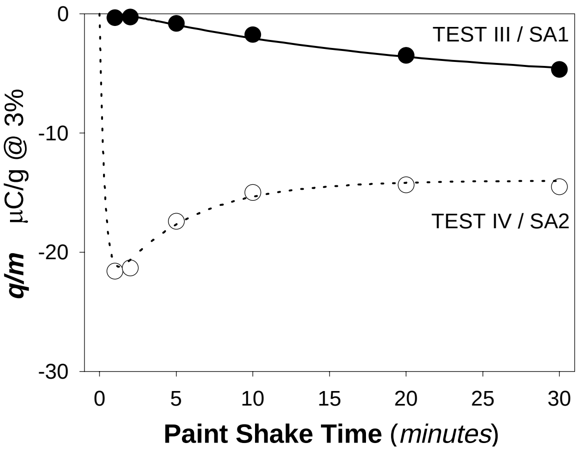

Figure 1b. q/m vs. mixing time for a styrene-acrylate-based toner with and without SiO_2 (SA2 and SA1) against a carbon-black-doped carrier, (CD).

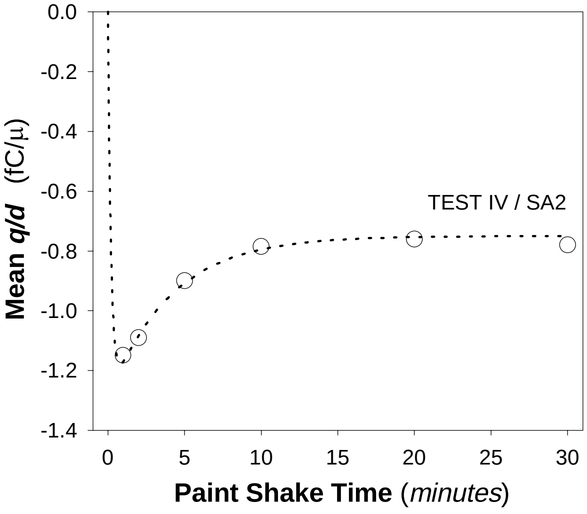

Figure 2b. q/d vs. mixing time for a styrene-acrylate-based toner with SiO_2 (SA2) against a carbon-black-doped carrier, (CD).

- The increase in negative charge level seen in *q/m* data for SiO_2-based toners is exactly mirrored in the corresponding *q/d* data — i.e., the addition of SiO_2 to the surface of a toner truly affects the charging properties of the actual toner particles, and is not an artifact created by the addition of highly charged negative SiO_2 particles to the developer).

(The observed minor differences from test-to-test may reflect actual differences in toner physical properties (size, shape, density, cohesion, etc.) and/or systematic errors in the *q/m* or *q/d* measurements.)

To further explore the charging performance of the test developers, the charge-admixing performance was evaluated at 15, 30, 60,120, 240, 300 and 600 seconds after the addition of 1 wt% of uncharged toner to the test developer following the initial 30 minutes of developer agitation. For the charge-admixing tests, the developer was agitated on a paint shaker for each admix test time interval, and a small sample of developer was removed for charge-spectrum testing at each point.

While the charge-admix response of a developer can be used as an initial, qualitative screening metric, to identify fast-charging developers for further study, for mechanistic understanding, "poor", slow-charging developers are of perhaps the greatest interest, since severe deficiencies in charging behavior allow the kinetics of the charging process to be clearly revealed. In the following section, this point will be illustrated using experimental data from the test developers shown in Figures 1 and 2.

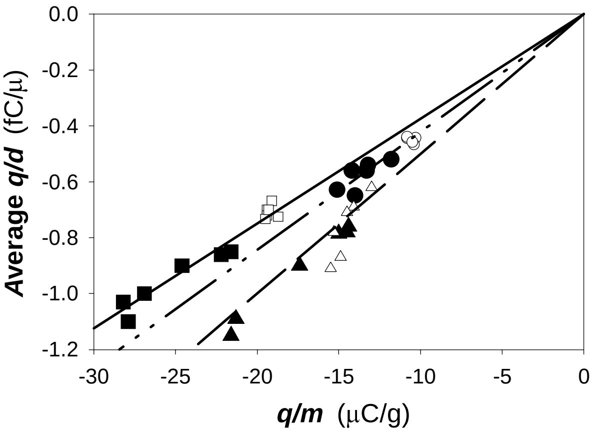

Figure 3. q/m vs. q/d for data taken during mixing experiments, and during admix experiments. Squares: PE2/CD; Circles: PE/CD; Triangles: SA2/CD. (Small symbols are for data from admix tests).

The evaluation of a toner charge spectrum from an admix experiment can be made at several levels of sophistication[5,6]. An approximate level of quantification can be rapidly generated via a direct visual identification (under low optical magnification) of the position of the peak and of the spread in the actual toner spectral "smears". For increased analysis, a digital image of the individual toner particles in the "smear" can be scanned to provide a distribution in terms of toner *q/d* and *d*. While such distributions are based on quantitative information, they are also frequently used in a qualitative mode, with "before admix" and "after admix" spectra being visually compared. However, since the shape of the individual peaks in any charge spectrum follow a normal Gaussian distribution, it is relatively simple to deconvolute the resultant summed envelope into quantitative contributions from the original ("incumbent") and "added" toner particles. From such a procedure, the overall kinetics of the charge-admix process can be assessed, and mechanisms operative in the charging events may be revealed. (Just as with chemical processes in general, there is an important distinction to be made between the "potential" for a charging process — e.g., the difference in energy levels — and the "kinetics" for the process — e.g., the possible pathways or catalysts for the process). As an illustration of this point, Figures 4 and 5 are the respective qualitative and quantitative kinetic representations of the admix test data taken for the developers shown in Tests I, II and IV in Figure 1 (charge spectra were not taken for the combination of toner SA and carrier CD, since the overall developer *q/m* value was very low).

The experimental data obtained from a charge spectrograph form a population "map" on a *q/d* vs. *d* plane, and the distributed data can be graphed in several ways. In Figure 4, the total data set has been utilized to produce an overall charge spectrum weighted by d^2 (i.e., an area weighting, since the image analysis is based on the toner size in terms of a projected cross-sectional area), with the resulting distribution being normalized in terms of the highest component peak[6]. Normally, the overall envelope shows clear contributions from the incumbent and added toners, and since the present admix tests were based on the addition of 1 wt% of uncharged toner to a charged developer at a 3 wt% toner concentration, the respective peaks in the spectrum should be in a 1:3 ratio. Note, however, that the respective peak heights will be in the 1:3 ratio only if the toner particles are injected into the spectrograph in a non-selective manner[6], and only if the component peaks share a common standard deviation. For most of the data taken for the present study, the toner particles in the spectral "smear" are in the expected 1:3 ratio for added to incumbent toner particles. However, this may not be clearly evident from a simple qualitative analysis since the component peak heights will also reflect any changes in the standard deviation of the spectra peaks. Quantitatively, the envelope of the summed peaks can be described by the following type of algorithm:

```
F = 0.75
col (1)=data (3,-1,-0.05)
qbyd=col (1)
;
; **** incumbent peak ****
;
mean1=1.35
stdev1= 0.37
pi = 3.142
peak1= exp(-((qbyd-mean1)/stdev1)^2/2) /(sqrt(2*pi)*stdev1)
col(2) = peak1*F
;
; **** added peak ****
;
mean2 = 0.24
stdev2 = 0.30
peak2 = exp(-((qbyd-mean2)/stdev2)^2/2)/(sqrt(2*pi)*stdev2)
col (3) = peak2*(1-F)
col (4) = col (2) + col (3)
col (5) = col (4)/max (col (4))
col (6) = col (2)/max (col (4))
col (7) = col (3)/max (col (4))
```

where column 5 is the summed envelope normalized to the highest individual peak, columns 6 and 7 are the normalized individual peaks, and F is the fraction of the toner population as incumbent particles.

For the present data set, Figure 5 shows the mean *q/d* values for the incumbent and added component peaks, deconvoluted from the actual envelope data with F fixed at 0.75 for all test points. (The standard deviation values for the component peaks were also treated as a variable in the deconvolution routine — usually, though not invariably, the peaks "sharpened" as a function of mixing time).

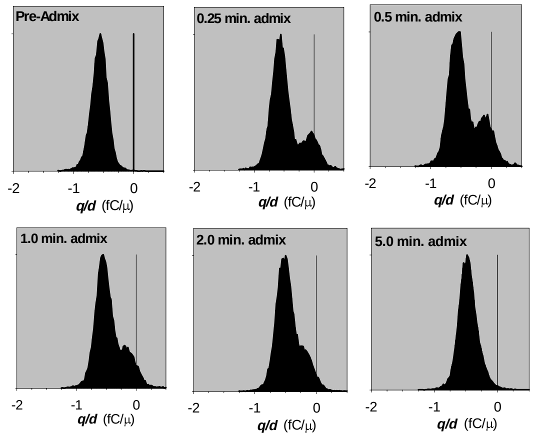

Figure 4a. Charge distribution admix data for developer PE1/CD.

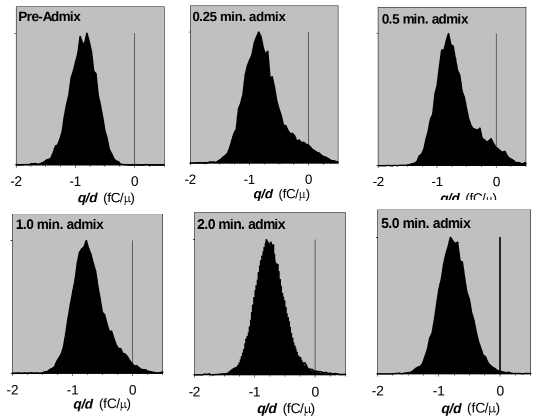

Figure 4b. Charge distribution admix data for developer PE2/CD.

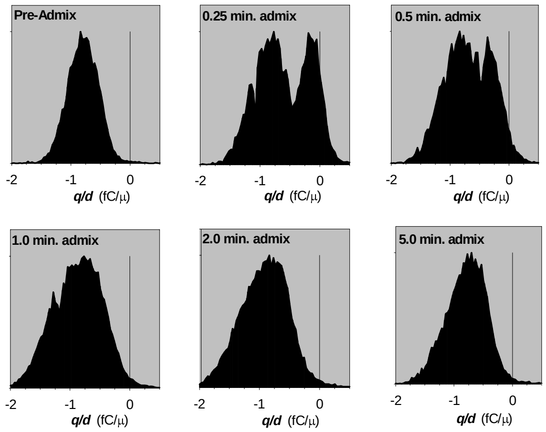

Figure 4c. Charge distribution admix data for developer SA2/CD.

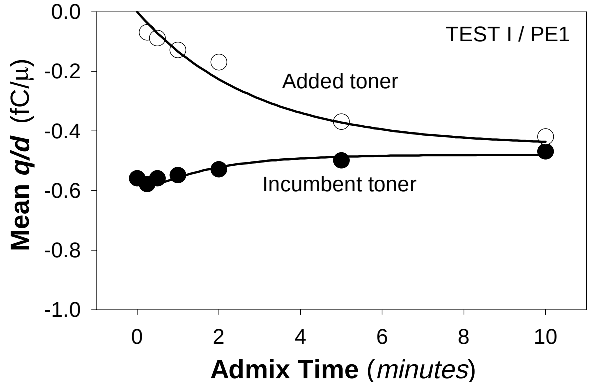

Figure 5a. Deconvoluted mean q/d data for incumbent and added toner for developer PE1/CD.

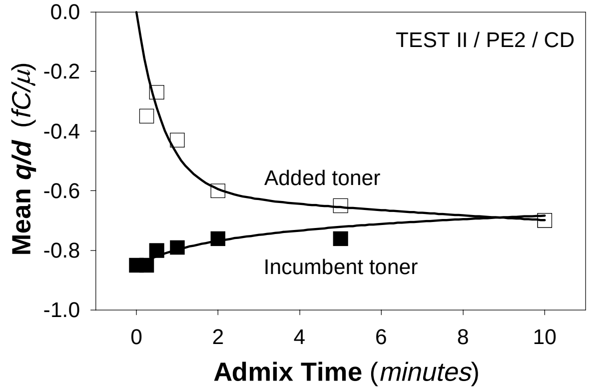

Figure 5b. Deconvoluted mean q/d data for incumbent and added toner for developer PE2/CD.

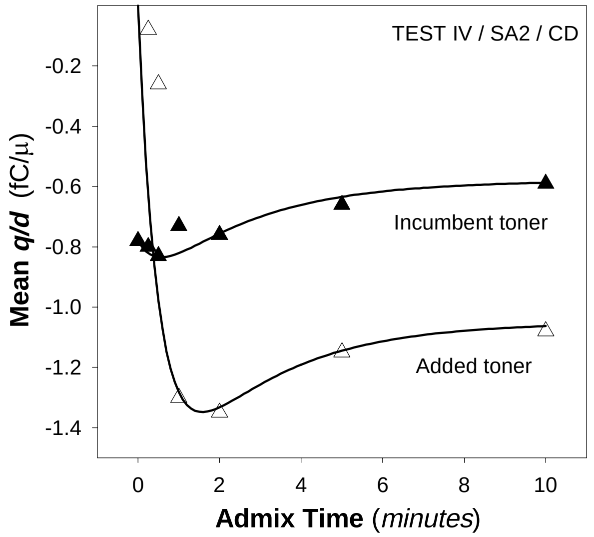

Figure 5c. Deconvoluted mean q/d data for incumbent and added toner for developer SA2/CD.

By definition, at time-zero in an admix test the mean *q/d* value for the incumbent toner particles is that of the toner particles after the specified pre-admix agitation, with the added toner having zero charge. During the admix experiment, the two populations of toners will ideally mix to form a single population with respect to *q/d*, and developers can be classified in terms of their admixing performance by the time of admix mixing required to achieve a final homogeneous state. As examples, Figure 5a shows a rapid, and completely collapsed admix response, while Figure 5b shows a response where the added toner only slowly gains charge. By contrast, Figure 5c shows an extremely rapid increase in the mean *q/d* value of the added toner, though in this case the added and incumbent toners do not achieve a common value of mean *q/d* — the added toner in this case actually charges to a mean *q/d* value higher than that of the incumbent toner.

Now, from Equation 1, the addition of 1wt% of uncharged toner to a charged developer at a pre-admix toner concentration of 3wt%, should lead to a final re-equilibrated $q/m_{4\%}$ value of:

$$q/m_{4\%} = (q/m_{3\%}) \cdot (3+1)/(4+1) = 0.8 \cdot (q/m_{3\%}) \qquad (4)$$

(where C_o for the present developers has been taken as 1).

Since Figure 3 indicates that the average *q/m* and mean *q/d* values are directly related (i.e. $q/d = \lambda \cdot q/m$), then:

$$q/d_{\text{after admix}} = 0.8 \cdot q/d_{\text{before admix}} \qquad (5)$$

where $q/d_{\text{before admix}}$ is the mean *q/d* value of the incumbent toner particles, and $q/d_{\text{after admix}}$ is the mean *q/d* value of the equilibrated incumbent + added toner particles (assuming, of course, that the admixing event is too short to create any further triboelectric charging or triboelectric degradation).

Similarly, during the admix event, the average *q/m* value (fixed at $0.8 \cdot q/m_{\text{before admix}}$) will be the sum of contributions from the added and incumbent toner particles, i.e.:

$$(1/\lambda) \cdot (F \cdot (q/d)_{\text{incumbent},t} + (1 - F) \cdot (q/d)_{\text{added},t}) = 0.8 \cdot q/m_{\text{before admix}} \qquad (6)$$

where F is the population fraction as incumbent toner (e.g. 0.75 for the present tests), and $(q/d)_{\text{incumbent},t}$ and $(q/d)_{\text{added},t}$ are the respective mean *q/d* values for the incumbent and added toner particles at any admixing time t.

Tables 1, 2 and 3 compare the observed average *q/m* values (expressed at a toner concentration of 3wt% for t = 0, and at 4 wt% toner concentration for all other admix times) with the average *q/m* values calculated from Equation 6, using the observed individual mean *q/d* values.

The data shown in Tables 1, 2 and 3 illustrate that the incumbent and added toner particles act as discrete populations during the admixing event, and that equilibration proceeds not via a random homogenization but via systematic changes to both toner populations. In the case of Test IV, (where the negative charging ability of the toner chiefly reflects the external SiO_2 additive), the added toner can accept negative charge to a higher level than that of the incumbent toner, and the "25%" contribution of the former toner particles therefore actually increases the overall charging performance of the test developer. As a result, even though the toner concentration was increased from 3wt% to 4wt% toner concentration during the admix event, the total average *q/m* value remained almost constant in Test IV. From a qualitative perspective, the existence of a minor "high-charged" population in Test IV creates only a small perturbation to the overall envelope of the charge spectrum, but quantitatively this population makes a significant contribution to the overall *q/m* value.

Table 1 : Test I

Admix Time (*minutes*)	Measured *q/m* (μC/g)	**Calculated** *q/m* $0.75 \cdot q/m_{\text{incumbent}} + 0.25 \cdot q/m_{\text{added}}$ (μC/g)
0	-13.3	-13.3
0.25	-10.4	-10.7
0.50	-10.3	-10.5
1.00	-10.8	-10.6
2.00	-10.8	-10.4
5.00	-10.4	-11.1
10.00	-10.5	-10.9

Table 2:Test II

Admix Time (*minutes*)	Measured *q/m* (μC/g)	**Calculated** *q/m* $0.75 \cdot q/m_{\text{incumbent}} + 0.25 \cdot q/m_{\text{added}}$ (μC/g)
0	-21.6	-22.7
0.25	-18.7	-19.4
0.50	-19.1	-17.8
1.00	-19.4	-18.7
2.00	-19.4	-19.2
5.00	-19.5	-19.6
10.00	-19.3	-18.7

Table 3 :Test IV

Admix Time (*minutes*)	Measured *q/m* (μC/g)	**Calculated** *q/m* $0.75 \cdot q/m_{\text{incumbent}} + 0.25 \cdot q/m_{\text{added}}$ (μC/g)
0	-14.5	-15.6
0.25	-13.0	-12.4
0.50	-14.1	-13.8
1.00	-14.9	-17.4
2.00	-15.5	-18.2
5.00	-15.3	-15.6
10.00	-14.5	-14.2

(b) Positive Toner Polarity Tests

Figure 6 shows the *q/m*:mixing data for toners PE1, PE2, SA1 and SA2 when paired with a mixed-coating carrier, CFA (70 fluoropolymer : 30 acrylate). For all of the test toners, this carrier created a positive toner polarity, with the styrene-acrylate toner being charged to an especially high level. To illustrate the *q/d* and admix behavior of this set of developers, the spectral data will be displayed as contour plots as shown in Figures 7.

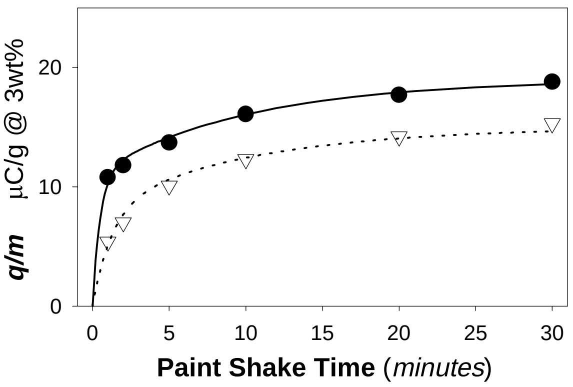

Figure 6a. q/m vs. mixing time for a polyester-based toner with and without SiO_2 (PE2 and PE1) against a fluoropolymer/acrylate carrier, (CFA).

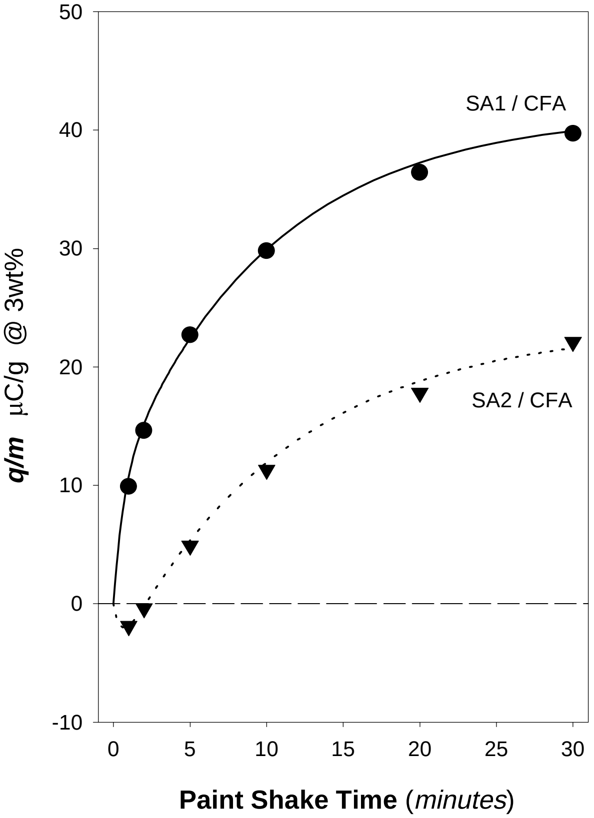

Figure 6b. q/m vs. mixing time for a styrene-acrylate-based toner with and without SiO_2 (SA2 and SA1) against a fluoropolymer/acrylate carrier, (CFA).

The *q/m* : mixing time profile for Test V with developer SA1/CFA, Figure 6a, shows an unusually slow development of a maximum charge, and the corresponding charge spectra, Figure 7a, reveal a major change in the distribution of charge as the mixing process proceeds. In the previously-discussed negative polarity tests, the charge distribution "sharpened" as the test developers were mixed — i.e., the toner population moved towards the mean value of *q/d*, as reflected by a decrease in the standard deviation of the spectral peak, even as the mean moved to higher values with mixing. By contrast, Figure 7a shows that the slow increase from an initial + 10 µC/g to an eventual maximum *q/m* value of + 41 µC/g reflects an increase in the mean *q/d* value from 0.45 to 1.90 fC/µ **and** a major increase in the standard deviation of the charge spectrum from 0.23 to 0.65 fC/µ. Interestingly, the relationship (in the positive quadrant) between *q/m* and *q/d* for this positively-driven toner lies on a common line with the data (in the negative quadrant) obtained from the previously-discussed negatively-driven toner test — the outstanding difference between the two tests is only the respective widths of the charge spectra. Thus, while toner SA1 can be charged to a high positive polarity, the charge homogeniety of the toner particles decreases with increased mixing, presumably reflecting the absence of a dominating charging process for this particular toner/carrier combination. Indeed, for practical positive-polarity toner designs a positive polarity charge control agent (CCA) is frequently added in order to enhance the average and distributed charging performance.

With respect to admix characteristics, the developer in Test V appears to be almost totally dysfunctional (see Figure 7b), but the poor admix spectra actually reflect both design deficiencies and experimental artifacts. For example, the toner population centred around zero charge is the major component of the experimental spectral "smear", and is from the added toner. Indeed, during the admix event, the average *q/m* value remained at +30 µC/g, and the charge spectrum could be deconvoluted into a pair of high and low components in a ratio of 1:3. Since the admix test used incumbent:added toner in a 3:1 ratio, the deconvoluted result appears reversed. However, the result is valid, and reflects an problem inherent in the experimental spectral analysis of poorly-charged toners. For such toners, the spectral "smear" is not an accurate representation of the entire population of toner particles — it is enriched with respect to poorly-charged particles since they are most readily removed from the test developer. In such a case, to avoid over-development of the test "smear", toner sampling into the spectrograph is curtailed before the developer is totally de-toned. This then leads to a population of toner in the *q/d* measurement that is deficient in high-charged particles with respect to the population sampled in the "total-blow-off" *q/m* measurement. Thus, for Test V, the toner sample for spectral analysis was (coincidentally) in a high/low ratio of 1:3 while the true ratio for the total distribution was 3:1. Table 4 illustrates this point, with a *q/m* prediction based on a 3: 1 *q/d* ratio being close to the observed *q/m* values in the admix event, and with the prediction based on a 1:3 *q/d* ratio only approaching the experimental *q/m* values at long admixing times (at such times, the added toner has moved away from zero charge, and as a result the toner injected into the spectrograph becomes more representative of the total population).

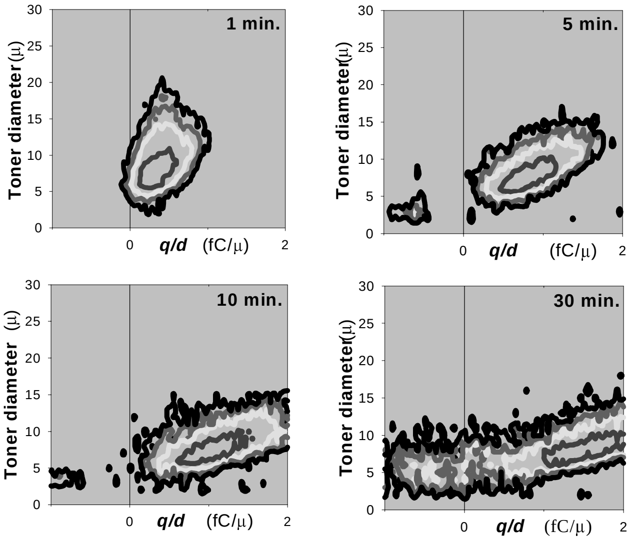

Figure 7a. Charge distribution contours as a function of developer mixing time, for styrene-acrylate toner SA1 with fluoropolymer-acrylate carrier, CFA.

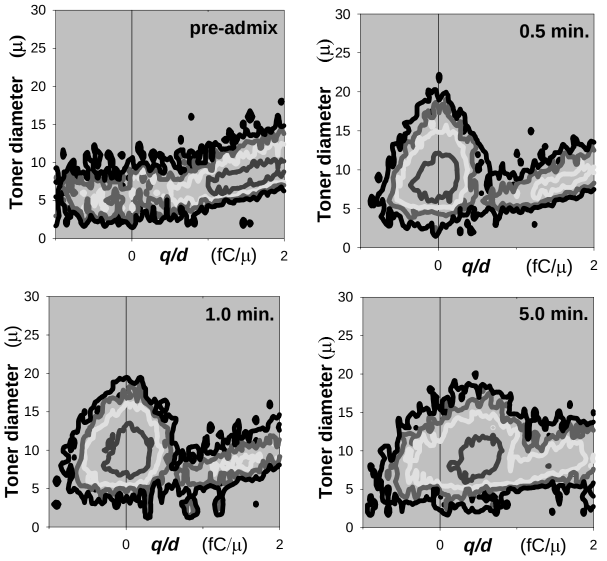

Figure 7b. Charge distribution contours as a function of admix time. For styrene-acrylate toner SA1 with fluoropolymer-acrylate carrier, CFA.

Table 4. Test V

Admix Time (*minutes*)	Measured *q/m* @ 4 wt% (μC/g)	**Predicted** *q/m* Incumbent:Added = 3:1 (μC/g)	**Predicted** *q/m* Incumbent:Added = 1:3 (μC/g)
0.25	+30.8	+32.9	+11.5
0.50	+30.2	+30.8	+9.90
1.00	+30.0	+29.2	+9.20
2.00	+30.0	+30.4	+12.9
5.00	+30.0	+34.0	+19.1
10.00	+31.2	+38.9	+23.7

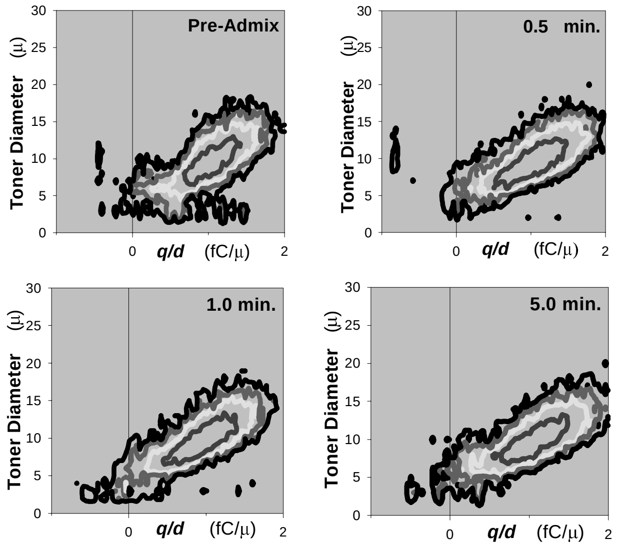

Figure 7c. Charge distribution contours as a function of developer mixing time, for styrene-acrylate/SiO$_2$ toner SA2 with fluoropolymer-acrylate carrier, CFA.

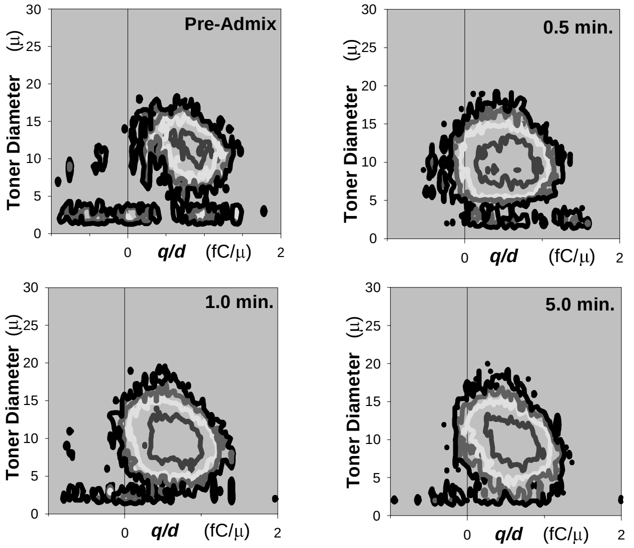

Figure 7d. Charge distribution contours as a function of developer mixing time, for polyester toner PE1 with fluoropolymer-acrylate carrier, CFA.

Figure 7c shows the relative improvement in *q/d* achieved when the test styrene/acrylate toner is treated with hydrophobic, negative SiO$_2$. This surface additive treatment reduces the overall positive charge on the toner, and after 30 minutes of mixing the surface-treated toner achieves approximately the *q/m* level achieved by the base toner after 5 minutes of mixing. The charge spectra contour plots show a similar result — after 30 minutes of mixing, the developer combination of SA2/CFA gives a toner charge spectrum that is broad but still “right-sign”. For the subsequent admix data, the surface-treated toner maintains a broad spectrum, but with a a rapid incorporation of the added toner (see Figure 7c).

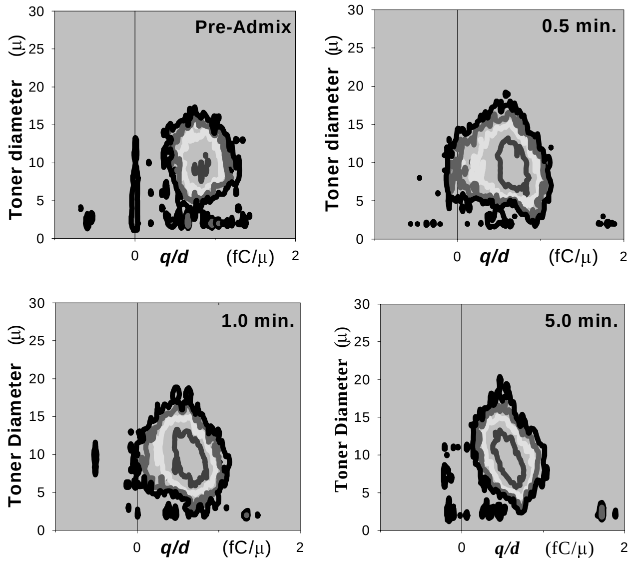

Figure 7e. Charge distribution contours as a function of developer mixing time, for polyester/SiO2 toner PE_2 with fluoropolymer-acrylate carrier, CFA.

Figure 6b shows the *q/m* response for the polyester-based toners with carrier CFA. Compared to the previous styrene-acrylate-based data, the test toners PE1 and PE2 show reduced positive *q/m* values, but an increased rate of charge generation. The charge spectra data, Figures 7d and 7e, are also in marked contrast to the earlier styrene-acrylate data. For the polyester toner, the spectra are relatively sharp, and the admix response is rapid. This is especially evident for the combination of the SiO_2-treated polyester test toner, PE2 and the CFA carrier. Unlike the styrene-acrylate toner, then, the polyester toner generates a “right-sign” positive polarity with carrier CFA without a need for a positive CCA.

Summary and Conclusions

The present data set clearly demonstrate that simultaneous *q/d* data can aid in the analysis of complex *q/m* data, especially if the *q/d* data are quantitatively analyzed. In particular, the *q/d* data can help explain the divergent admix behavior of developers that otherwise exhibit closely similar average *q/m* values. The charge spectral data also give a clearer, microscopic picture of the charging events, and a careful assay of the “tails” (both low and high) of the charge spectrum may help reveal the underlying causes for unexpected changes in xerographic performance.

The present data set also reveal the large variability in charging performance driven by both toner and carrier intrinsic properties. For completeness, the experiments should be extended to include other extrinsic factors such as ambient relative humidity, and extended wear-related “aging” effects. Also, since the present toners were merely carbon-black-based, the present conclusions cannot be applied to the performance of toners based on other colorants or charge control agents, etc. As is usual in the development of xerographic toners and carriers, research studies should match specific target applications, especially since many of the charging mechanisms apparently reflect cooperative behaviour between specific toner and carrier components.

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Biography

Robert Nash received his PhD in Physical Chemistry from the Universityof Bristol, England. He is a Principal Scientist in the Materials Technology and Concepts group of the Xerox Corporation, USA. His research and modelling studies have focused on the design and evaluation of xerographic toners, carriers and developers, with especial emphasis on mechanisms. In April 1998, he began a new assignment at Fuji Xerox, Takematsu as the Senior Manager, Resident for the Xerox Supplies Development & Manufacturing Services organisation. In this assignment, he is broadening his area of interest to include the science and technology of photoreceptor design and manufacture.