

The Effect of Mixing Intensity on the Admix Performance of a Xerographic Developer

Robert J. Nash[†]*, Michael L. Grande and Richard N. Muller*
Xerox Corporation
Webster New York, USA
[†]*Present address: Fuji Xerox, Kanagawa-ken, Japan*

Abstract

In a working xerographic developer, a portion of the charged toner particles is removed each time a xerographic image is developed. To balance this loss, an equivalent amount of toner is dispensed into the xerographic developer from a reservoir of uncharged toner. Since uncharged or poorly-charged toner particles tend to develop in the non-image "background" areas of a latent xerographic image, the uncharged/dispensed toner particles must be rapidly brought to a charged state in order to avoid "background" development. Normally, the "added" toner and the "incumbent" toner (i.e., the charged toner particles already present in the developer) merge to a common level of charge. Clearly, the rate at which this merging process occurs (the so-called "admix rate") is an important functional property of any xerographic developer design, and a rapid rate is especially desirable.

In principle, the charge admix performance of any toner can be optimized via judicious adjustments to the chemical composition of the toner particles and/or that of the xerographic carrier particles. However, even for an apparently optimized xerographic toner/developer design, charge admix deficiencies may still be created as a result of extrinsic factors. For example, for certain developer designs, the admix rate can change from "rapid" to "almost-zero" as the degree of developer mixing is changed from "gentle" to "intense"; paradoxically, this latter admix failure mode actually occurs as a result of an ultra-rapid admixing process. In such a case, the added toner acquires a level of charge higher than that of the incumbent toner, and this increased charge is mirrored by an equivalent decrease in charge for the incumbent toner. In an extreme failure condition, the populations of "added" and "incumbent" toner particles scarcely show any tendency to merge to a common intermediate level of charge, and the "added" toner particles remain at a high charge level.

In the present report, experimental data taken on a simple black xerographic developer at various levels of developer mixing intensity (e.g., as created via changes in mixing times and modes of developer mixing), demonstrate a progression from an excellent admixing performance to a non-functional level for a single developer design.

Introduction

The average toner charge to mass ratio, *q/m*, is a convenient measure of the triboelectric state of a two-component xerographic developer — the sign and magnitude of *q/m* are functions of intrinsic toner and carrier properties, and can also be affected by extrinsic factors such as ambient humidity, etc.[1] The *q/m* value is also a useful metric for xerographic development, since major modes of image development normally show a regular (inverse) relationship between *q/m* and the magnitude of a developed image [2]. However, since the *q/m* value (both magnitude and polarity) of any particular toner can be affected by many factors, it is impossible to define *q/m* as a characteristic toner parameter. For example, for a "new/unused" developer, the q/*m* value of initially uncharged toner can be increased via mechanical mixing of the carrier and toner particles, can be systematically increased/decreased by decreases/increases in the ratio of toner to carrier in the developer mixture, and can be significantly altered by changes in ambient humidity.

For a "used" developer, the toner *q/m* can also be affected by the degree of usage-induced changes to the triboelectric charging properties of the carrier particles — a so-called carrier "aging" effect [3-6], and by usage-induced changes in the charging properties of the toner particles [7]. For carrier particles, "aging" normally involves permanent changes such as wear-induced loss of a coating, or long-term "welding" of toner particles to the carrier surface, and as a result, the carrier properties are progressively, and permanently altered with "use". By contrast, usage-induced changes in toner charging properties (e.g., changes created by "loss" of external additives from the toner surface) are frequently minimal and reversible, since a fraction of toner particles in a working xerographic developer is continuously removed (via xerographic development) and replaced (via addition from a toner supply). Thus, while the "age" of the carrier beads in a working developer is normally a simple monotonic function of copy count, the "age" of the toner particles will be governed by the toner residence time (a function of the amount of toner in the developer and by the rate of toner consumption). For simple copy operation, a random mix of text images will produce a stable average rate of toner consumption (and hence an average toner "age"); however, for complex digital printing, the toner "age" will be strongly affected by the ratio of text to pictorial images, and hence can change markedly in response to changes in the image content. As a result, toner "aging" can be a significant factor in digital imaging processes.

Now, while toner "aging" can strongly affect the average *q/m* of a toner (e.g., as a result of excessive "loss" of external additives caused by a low level of toner throughput), the effect of toner "aging" on the distributed toner charge can be major even in cases where *q/m* is essentially unaltered. Accordingly, for studies on toner "aging" effects, it is necessary to monitor the discrete values of a distributed parameter such as the toner charge-to-diameter, *q/d*, in addition to the average *q/m* value [8,9]. This is especially important for a comprehensive understanding of xerographic development, since the development in non-image "background" areas can be strongly affected by the population of particles in the low-charge/wrong-sign charge "tail" of the toner charge distribution [10].

Clearly, the addition of fresh uncharged toner to a working xerographic developer will increase the population of low-charged toners in the developer unless the added toner can rapidly acquire charge and become equilibrated with the incumbent toner particles (i.e., the already-charged toner particles in the developer). Since an average xerographic image "removes" only a small fraction of toner from a working developer (typically only about 0.1 % of the total incumbent toner per image), it might appear that a matching aliquot of dispensed toner could be readily incorporated into and equilibrated with the already-charged incumbent toner (the so-called "admix" process). However, since xerographic development involves only the toner particles actually in the carrier/toner magnetic brush in the development zone, it is important to consider whether the added toner can be effectively charged by the time that it reaches the magnetic brush. From a process viewpoint, factors such as the location of the toner dispense region, the type and extent of developer blending, developer transport, magnetic brush formation and shaping, etc., will all affect the toner in-mixing charging process, while from a developer materials viewpoint, specific chemicals such as charge control agents are frequently incorporated into toner designs in order to enhance the rate of chargeability of toner particles. As a result of such process and toner parameter optimizations, effective xerographic performance can be readily assured for well-controlled conditions of operation (e.g., for a time-zero, limited number of images). Maintenance of a stable level of xerographic development, however, is a significant challenge, especially with respect to the toner "aging" and "admix" processes, and the interaction between these two processes will be demonstrated and discussed in the following sections of this present paper.

Experimental

The test toner was a simple, negative-polarity, carbon-black based toner, jetted to about a 12 micron mean diameter. A nominal 1 weight percent of external additives (a cleaning lubricant and a fumed silica flow aid, in a 1:2 weight ratio) was blended onto the toner surface. The 100 micron test carrier had a rough metallic, oxidized core partially coated from solution with PMMA.

Sample developers were prepared at a 4 weight percent concentration of toner, and 200 grams of developer were mixed in 100 ml. glass jars. Two modes of mixing were used: a roll mill to provide a smooth, cascading motion, and a paint-shaker to provide a vigorous, erratic, impulse motion. For all of the tests, the developer samples were conditioned at a controlled ambient of 20oC/ 50% relative humidity.

For studies on the effect of mixing type and time on *q/m*, total blow-off measurements were made at regular time intervals (e.g., 2, 5, 10, 20 and 30 minutes of mixing) on small samples of developer using a conventional Faraday cage/air-jet combination. Additionally, at each test point, a "laminar air flow/transverse electric field" charge-spectrograph [11] was used to create a toner "smear", with particles displaced according to the magnitude and polarity of their *q/d* values. Image analysis of the "smear" was used to provide a quantitative map of toner particles on a *q/d* vs. *d* plane, and these data were used to generate a spectrum (e.g., an area-weighted spectrum of *q/d* vs. a peak-normalized population) and a *q/d* vs. *d* contour plot.

At the end of each mixing test, an "admix" test was made, with an additional 2 wt% of uncharged toner being added to the charged developer. (The addition of 2 wt% of toner into a charged developer containing 4 wt% of toner represents a "stress" condition for admix performance, and is an appropriate surrogate test for actual performance under extreme stress imaging conditions in working xerographic systems). The added toner was lightly mixed into the developer, and regular mixing was then continued for 5 additional minutes. At short time intervals (e.g., 15, 30, 45, 60, 120, 180, 240 and 300 seconds), a small sample of developer was examined using a charge spectrograph, and conventional *q/m* total blow-off measurements were also taken at selected post-admix points.

Results

(a) Mixing Effects on Triboelectric Charge Generation

Figures 1a and 1b show the combined q/*m* data (corrected to a uniform 4-wt %) for roll-mill and paint-shake mixing experiments, respectively.

The corresponding *q/d* data (taken as the peak maximum in the charge spectrum) are shown in Figures 2a and 2b. For individual tests, the matching *q/m* and *q/d* data show a simple, direct linear relationship, consistent with:

$$q/m = q \cdot \left(\frac{6}{\rho \cdot \pi \cdot d^3}\right) = \left(\frac{q}{d}\right) \cdot \left(\frac{6}{\rho \cdot \pi \cdot d^2}\right) \qquad (1)$$

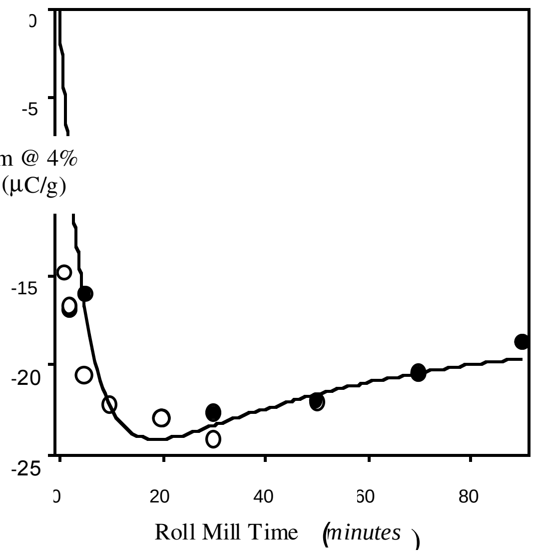

*Figure 1a. **q/m** vs. roll-mill time, for 30 and 90 minutes*

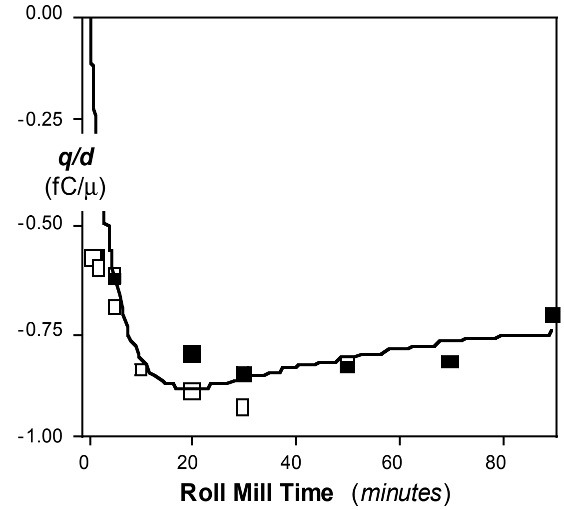

*Figure 2a. **q/d** vs. roll-mill time, for 30 and 90 minutes of pre-admix charging.*

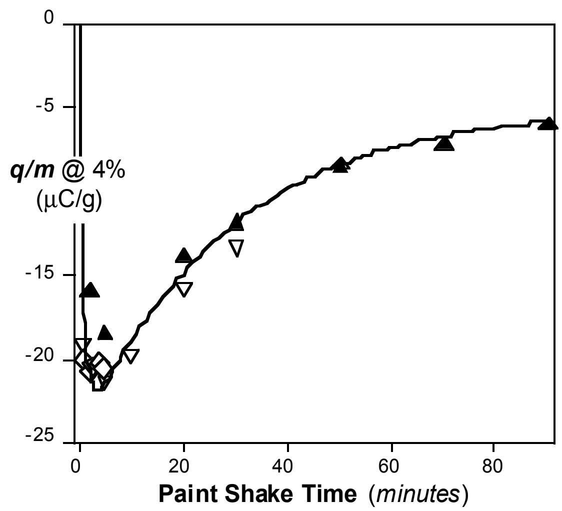

*Figure 1b. **q/m** vs. paint-shake time, for 5, 30 and 90 minutes of pre-admix charging.*

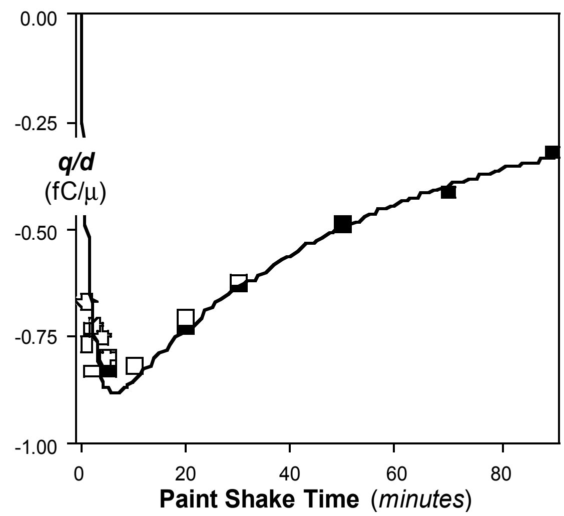

*Figure 2b. **q/d** vs. paint-shake time, for 5, 30 and 90 minutes of pre-admix charging.*

However, the collected *q/m* and *q/d* data all extrapolate through zero in a fan-shaped series of individual linear relationships, even though all of the tests used a common toner — perhaps this result reflects systematic offsets in the *q/m* and *q/d* measurements or mixing-induced changes in toner morphology [12].

As a typical example, Figures 3 shows representative charge spectra for extended paint-shake mixing — in all cases, the charge spectrum is a sharp, single-valued normal Gaussian distribution.

As can be seen from Figures 1 and 2, the mode of mixing can have a major effect on the mode and extent of triboelectric aging — while the roll mill data show a slow increase to eventual high negative values of *q/m* and *q/d*, the paint-shake data show an ultra-rapid rise to a high negative value of *q/m* and *q/d* followed by a major decline to a final greatly reduced level. Now, while the *q/m* and *q/d* data are **toner** charge parameters, they cannot be viewed as reflecting toner properties alone. This can be made clear from a simple charging equation of the form [7]:

$$q/m = \left(\frac{A'}{(C + C_0)}\right) \cdot \left(\phi_{toner} - \phi_{carrier}\right) \cdot \left(1 - \exp\{-\gamma \cdot t\}\right) \qquad (2)$$

where, A' and C_o are constants, (governed by physical factors such as size and density, and by the physics of electrostatics), ϕ_{toner} and $\phi_{carrier}$ describe the charging tendency of the toner and carrier particles (functions of intrinsic properties such as surface composition ~~typ~~e and level of polymer, colorant, internal and/or external additives, and also of the effect of external factors such as ambient humidity on the intrinsic properties), and $(1\text{-}exp\{-\gamma \cdot t\})$ is a simple representation of the mechanics of developer mixing (i.e., the rate constant is a function of mixing efficiency).

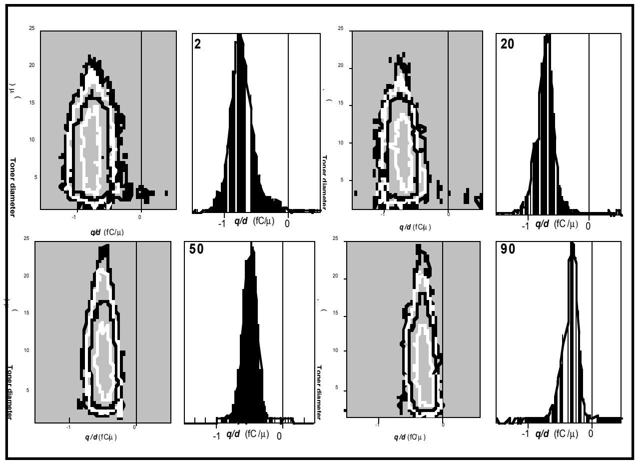

Figure 3. Representative pre-admix charge spectra taken at 2, 20, 50 and 90 minutes of paint-shake charging.

As equation 2 shows, changes in *q/m* (e.g. as shown in Figures 1a and 1b) may reflect mixing-induced changes in the toner charging properties, in the carrier charging properties or a combination of both effects, even though the final measured quantity is associated with the toner particles. As an illustration of just one of several potential complex processes, consider the "loss" of toner external additives: such a "loss" may reflect a "burial" of some of the additive particles into the surface of the toner particles, may reflect a direct transfer of some of the additive materials to the surface of the carrier particles or may reflect some combination of all such processes.

With regard to the toner *q/d* values measured during the developer mixing process, an identical set of conclusions can be reached. However, in the case of toner *q/d* values, post-mixing admix experiments (where fresh, uncharged toner is added to the pre-mixed developer) can provide a distinction between toner-driven and carrier-driven "aging" effects. For example, recent reports[8,9] have demonstrated how the total charge spectrum taken during an admix experiment can be analyzed into component contributions from the incumbent and added toner particles, and have demonstrated the effect of toner properties on the overall admix process. In particular, in model experiments based on the addition of a colored toner into a developer based on a second colored toner (and vice versa), the chemically-dissimilar populations of toner particles were shown to "share" charge, and in certain cases the charge gained by the added toner was mirrored by a charge loss for the incumbent toner.[8] From a detailed model of the various charging processes possible during an admix event, it has been shown that the difference between the intrinsic charging properties of the incumbent and added toner particles is a key factor in the charge-sharing process.[8] For example, the model indicates that a high-charging added toner will tend to increase in charge when added to developer based on a low-charging toner, and that the addition can cause a complementary decrease in the charge level of the incumbent toner. Now, while this effect can be most readily demonstrated using deliberately dissimilar toners, the overall conclusions should be equally valid for cases where the toners are nominally identical but are in fact somewhat dissimilar as a result of toner "aging". For example, for the present tests, if the observed mixing-induced changes in *q/m* and *q/d* shown in Figures 1 and 2 are toner-driven, then the post-mixing admix experiments should indicate charge-sharing between the incumbent and added toner particles (unless masked, of course, by some other more rapid pathway for charging). To illustrate this point, the present admix data (both in terms of *q/m* and *q/d*) will be reviewed in the following section.

(b) Mixing Effects on Charge Admix Performance

Figure 4 shows the *q/m* admix data taken after the test developer had been pre-mixed for 30 minutes on a roll mill. For reference, the small inset figures show the charge spectra distribution and contour data taken during the admix test. The initial pre-admix *q/m* point is for a 4 wt% toner concentration; all subsequent points are for 6 wt%. As expected (e.g. as per equation 2), the addition of 2 wt% of uncharged toner to the developer containing charged toner at a 4 wt% level created a decrease in *q/m* to a stable lower level (according to the inverse relationship between *q/m* and toner concentration shown in equation 2, the pre- and post-admix *q/m* values should be in a ratio of $(6 + C_o)$: $(4 + C_o)$, so that for a C_o value of 1, the expected *q/m* ratio should be 7:5).

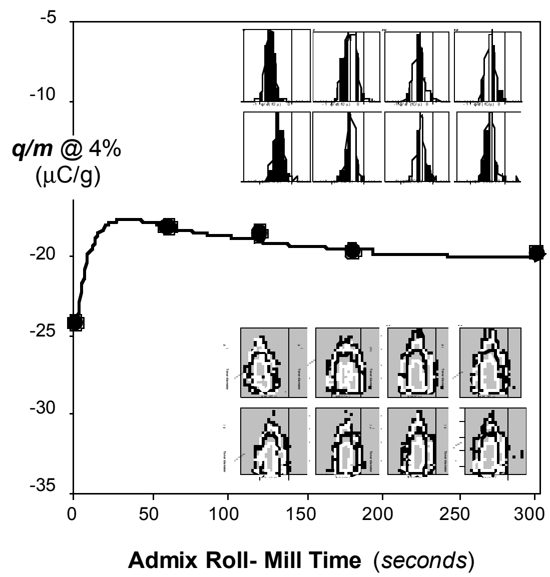

Figure 4. ***q/m*** *vs. admix time after 30 minutes of roll-mill charging. The inset figures show the charge spectra at 0, 15, 30, 45, 60, 120, 180 and 300 seconds of admixing.*

The corresponding *q/d* measurements shown in Figure 5, indicate a rapid admixing process for the test developer, with the added and incumbent toner particles equilibrating at a common reduced level of *q/d*. For this test, then, the added and incumbent toner particles must be identical, and the observed pre-admix "aging" (i.e., the increase in *q/m* and *q/d* with pre-admix mixing time) must reflect a carrier-based "aging" process. (The small point in Figure 5 represents the weighted average value for *q/d* for the initial admix point — i.e., the only admix sample in this test that showed a distinction between the added and incumbent toner particles. As can be seen, this average value matches the subsequent common value seen in the remainder of the admix test).

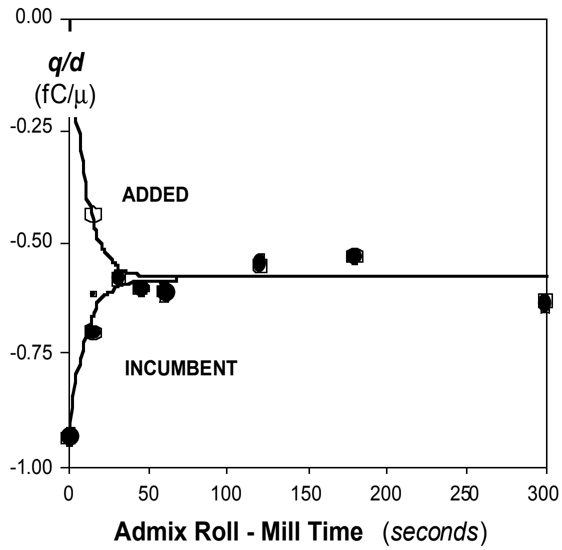

*Figure 5. **q/d** peak values vs. admix time for the incumbent and added toner populations, after 30 minutes of roll-mill charging.*

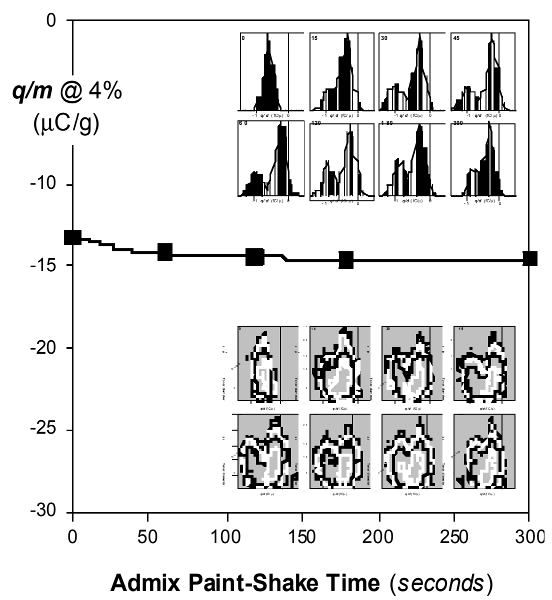

*Figure 6. **q/m** vs. admix time after 30 minutes of paint-shake charging. The inset figures show the charge spectra at 0, 15, 30, 45, 60, 120, 180 and 300 seconds of admixing.*

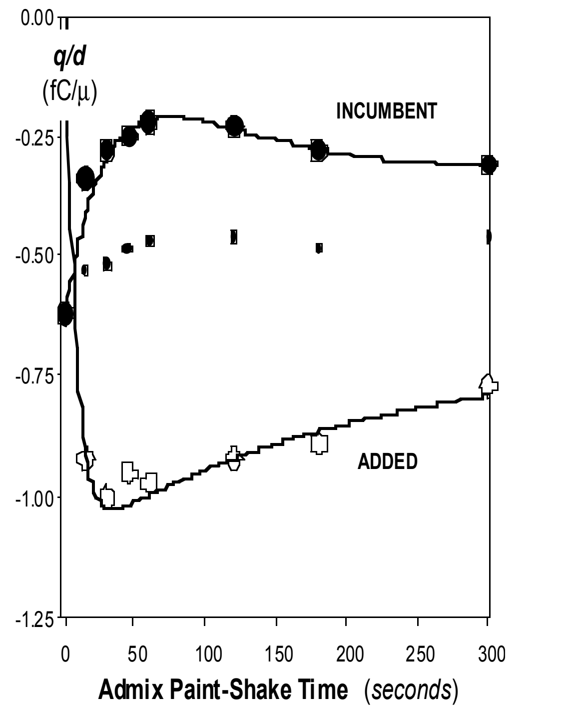

*Figure 7. **q/d** peak values vs. admix time for the incumbent and added toner populations, after 30 minutes of paint-shake charging. (The small points are for the weighted average **q/d** values).*

By contrast, Figures 6 and 7 show the post-admix *q/m* and *q/d* values for a developer pre-mixed for 30 minutes on a paint shaker. For this test, the post-admix *q/m* data seem quite unexceptional, except for the fact that the *q/m* value is scarcely changed pre-admix to post-admix.

From an average *q/m* viewpoint, this might appear to be a desirable "stable" result; however, the corresponding *q/d* data, Figure 7 shows that major component charge differences are in fact hidden within the average *q/m* properties. To produce Figure 7, the envelope of each charge spectrum was deconvoluted into a 2:1 ratio of an individual "incumbent toner" peak, and an "added toner" peak.[9] In Figure 7, the data points represent the peak values of the component normal Gaussian peaks, while the small points in the figure represent the weighted average values. For this test, the incumbent toner has been clearly "aged" during the pre-admix developer mixing process, since the added toner gains a high level of charge in the admix process and the incumbent toner *q/d* declines by almost 70%. The mismatch between the toner populations is also clearly reflected in the slow rate of equilibration between the added and incumbent toner particles.

Figures 8 and 9 show the admix data from a test that produced an extremely high level of toner "aging", namely a 90 minute paint-shake developer mixing condition prior to the admix testing. In this test, the developer *q/m* value after 90 minutes of mixing was only -6 µC/g, and addition of fresh toner produced an increase to a stable value of almost -

10 μC/g. However, as shown in Figure 9, the component *q/d* data show an extreme condition of charge heterogeneity~~for~~ this test, the incumbent toner is driven to a zero charged state, and the two toner populations show no significant trend towards equilibration (after the admix event, since the toner/carrier system is still charge neutral, and since the majority of the toner particles are near zero charge, there will be no effective mechanism for developer mixing/triboelectrification~~the~~ developer has been transformed into a pathologically "stable" state).

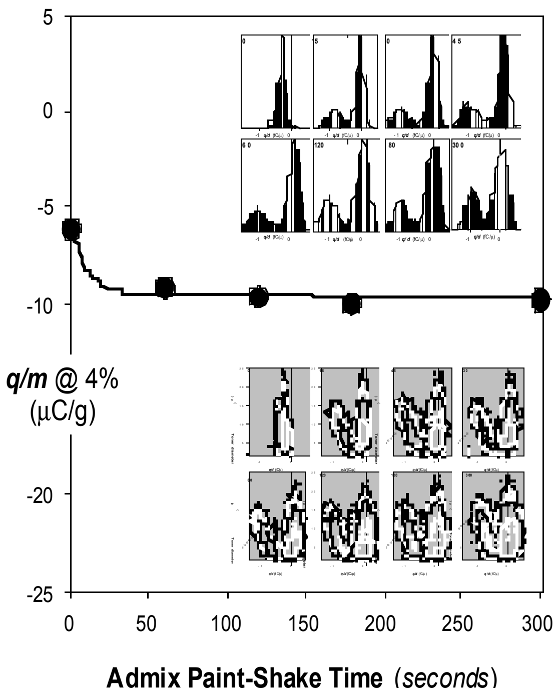

*Figure 8. **q/m** vs. admix time after 90 minutes of paint-shake charging. The inset figures show the charge spectra at 0, 15, 30, 45, 60, 120, 180 and 300 seconds of admixing.*

To illustrate the relative effect of toner "aging" and carrier "aging" on the admix process, the tests shown in Figures 10 and 11 were conducted. Here, the "used" carrier from the previous 90 minute paint shake test was de-toned, re-toned with fresh toner, and then mixed for 30 minutes on a roll mill. (The developer was mixed on a roll mill in this test, in order to minimize any additional mixing-induced "aging"). As shown in the inset figures, the pre-aged carrier gave a lower, but stable level of *q/m* and *q/d* during the developer mixing step, and fast admix to a common *q/d* level for incumbent and added toner in the admix test, Figure 11. Thus, though the "used" carrier produced a low-charged developer, the admix performance was quite normal since the incumbent and added toner were essentially identical.

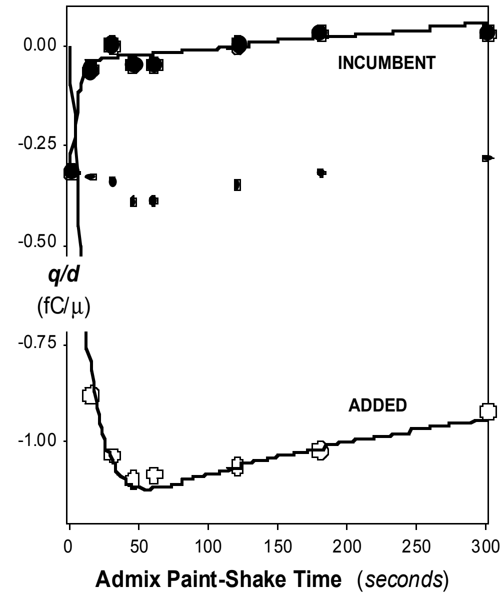

*Figure 9. **q/d** vs. admix time for the incumbent and added toner populations after 90 minutes of paint-shake charging. The small points are for the weighted average **q/d** values).*

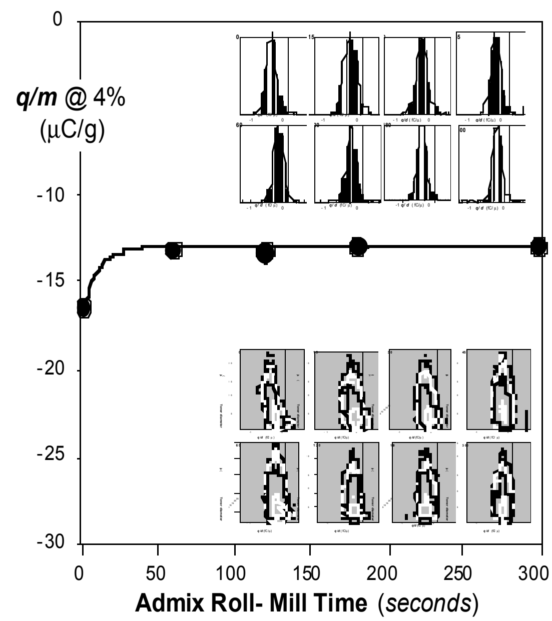

*Figure 10. **q/m** vs. admix time after 30 minutes of roll-mill charging. (The carrier in this test was de-toned from the previous 90 minutes of paint-shaking test). The inset figures show the charge spectra at 0, 15, 30, 45, 60, 120, 180 and 300 seconds of admixing.*

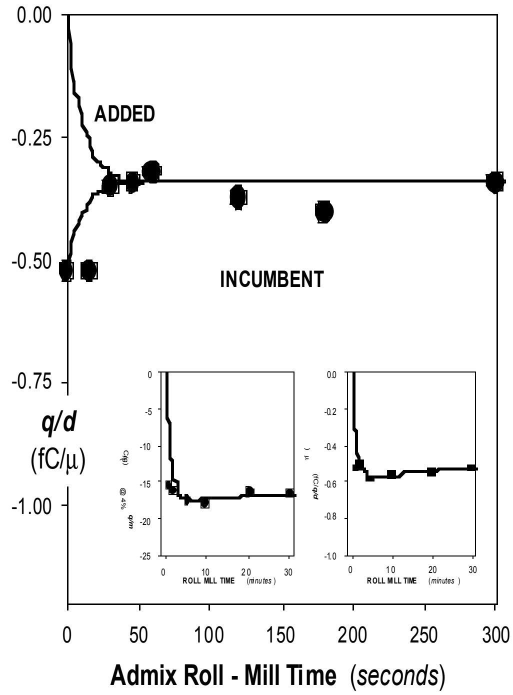

Figure 11. ***q/d*** *peak values vs. admix time for the incumbent and added toner populations, after 30 minutes of roll-mill charging. (The carrier in this test was de-toned from the previous 90 minutes of paint-shaking test). The inset figures show the q/****m*** *and* ***q/d*** *data taken during the 30 minutes of roll-mill charging.*

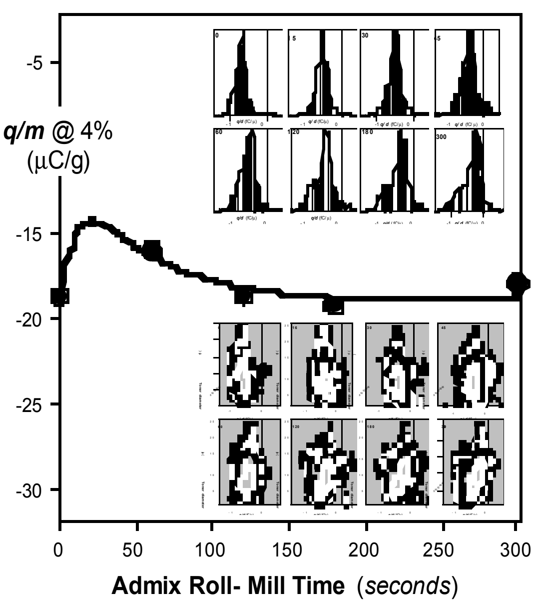

Figure 12. q/m vs. admix time after 90 minutes of roll-mill charging. The inset figures show the charge spectra at 0, 15, 30, 45, 60, 120, 180 and 300 seconds of admixing.

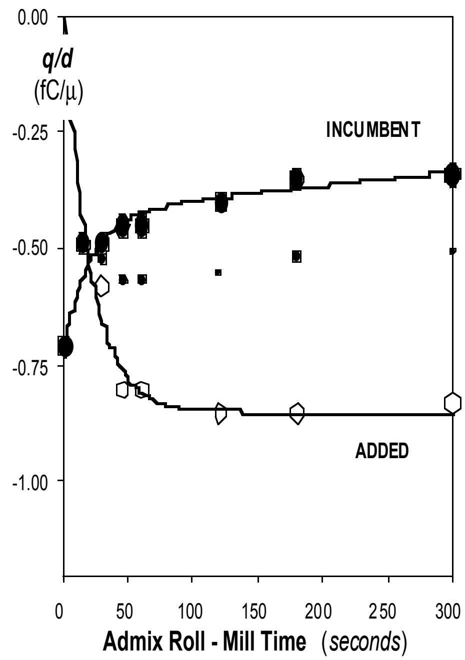

Figure 13. ***q/d*** *peak values vs. admix time for the incumbent and added toner populations, after 90 minutes of roll-mill charging. (The small points are for the weighted average* ***q/d*** *values).*

Since Figures 1a and 2a show that long-term roll-mill mixing produces a stable, high-charging developer with the present test materials, it is noteworthy that the admix behavior of such a developer can still be poor. Evidently, the pre-admix stability in *q/m* and *q/d* is not the result of zero "aging" (of both toner and carrier) since the admix data, Figures 12 and 13 once more show a significant degree of charge-sharing between the incumbent and added toner particles. Apparently, the pre-admix "stability" must reflect a balancing of toner "aging" and carrier "enhancement", since the fresh, added toner proves to have a higher charging tendency than the incumbent toner in the subsequent admix step.

As a final test (data not shown) of the effect of developer mixing on admix performance, a test was made using just 5 minutes of paint-shake agitation. From a comparison of charge spectra data from the earlier tests, this level of agitation was judged to be equivalent to 30 minutes of roll-mill agitation, and the 5 minute paint-shake developer sample indeed gave a completely normal and rapid admix response.

Discussion

Since the present admixes tests were made on a closed system, the results must represent the extreme condition of zero toner-throughput in an actual working xerographic developer. Since the toner particles in an operational xerographic imaging system will actually have a range of "ages", it is useful to examine what degree of toner "aging" may lead to a excessive level of admix failure. For a full accounting, all aspects of the charging process must be considered [8], but a zero-order analysis can help to illustrate the major effects.

For example, if the admix process is assumed to involve only a redistribution of charges (i.e., no post-admix triboelectric charging in the conventional sense), then the pre- and post- admix charges can be directly equated. As discussed earlier, the population weighted average charge for the post-admix toners should be a simple ratio of the pre-admix value ~~e.g.~~, for the present test, the addition of 2 wt % of toner into an original 4wt% should produce a post-admix average *q/d* value that is $5/7^{th}$ that of the pre-admix value. However, while this level of charge will be reflected in a lowered stable value of *q/m*, with respect to *q/d* the average can be achieved via an infinite number of complementary contributions from the incumbent and added populations of toner particles.

Thus, at any admix time, *t*, the following equality will be true:

$$\left(\frac{(C_{inc}+C_0)}{(C_{inc}+C_{add}+C_0)}\right)\cdot q/d_{inc,0} \equiv \left(\frac{C_{inc}}{(C_{inc}+C_{add})}\right)\cdot q/d_{inc,t} + \left(\frac{C_{inc}}{(C_{inc}+C_{add})}\right)\cdot q/d_{add,t} \quad (3)$$

where, C_{inc} and C_{add} are the incumbent and added toner concentrations, $q/d_{inc,0}$ is the *q/d* value at the end of the initial developer mixing step, $q/d_{inc,t}$ and $q/d_{add,t}$ are the *q/d* values for incumbent and added toner particles at a post-admix time , *t*.

For identical incumbent and added toner particles, the admix process will be complete when $q/d_{inc,t}$ and $q/d_{add,t}$ reach a common value.

For all other cases, a mismatch between the charging tendencies of the incumbent and added toner particles is assumed to provide a driving force for toner-toner charging, providing there is a suitable pathway to support such a process.[8] Since usage-induced changes in toner properties cannot be entirely eliminated in practical systems, it will be useful to predict the potential severity of toner-toner charge-sharing as a function of the degree of toner "aging", and for any single system a simple assessment can be made. (For the general case, where both carrier and toner "aging" effects must be considered explicitly, a simple assessment cannot be made. Likewise, observations from any particular case cannot be generalized — e.g., the admix response for the case of a low pre-admix *q/d* created by toner "aging" will not match that from a low pre-admix *q/d* situation created solely by carrier "aging", even if both approaches give an identical pre-admix value of *q/d*).

For a fixed mode of mixing and a specific toner/carrier combination, a charge-sharing added toner will acquire charge up to some characteristic *q/d* value (e.g. about -1 ƒC/μ for the present test toner and carrier mixed with paint-shake agitation). In turn, the incumbent toner will lose charge to maintain the equality given in Equation (3). For the extreme case where the incumbent toner is driven to zero charge, equation (3) predicts that (for the present study) this will occur when

$$\left(\frac{5}{7}\right)\cdot q/d_{inc,0} = \left(\frac{2}{6}\right)\cdot q/d_{add,t} \quad (4)$$

(obtained by setting $q/d_{inc,t} = 0$ in Equation (3)) i.e., when

$$q/d_{inc,0} = 0.47\cdot q/d_{add,t} \quad (5)$$

and since by definition $q/d_{add,t}$ must be equivalent to the *q/d* value of "unaged" toner, then an age-induced 53% decrease in the *q/d* value of the incumbent toner is predicted to be sufficient to create a total admix failure, and this will be true for any admix case involving the addition of 2 wt% of toner into 4 wt% of toner, for any value of $q/d_{inc,o}$, providing that the decrease in q/d_{inc} is the result of toner "aging". (In general, of course, the degree of charge-sharing, and hence the degree of acceptable toner "aging" will be affected by other factors such as the ratio of incumbent to added toner, and by the presence/absence of developer component materials that promote or inhibit charge-sharing).

In general, for moderate degrees of pre-admix toner "aging", the admix mode will drive the incumbent toner to a non-zero level of charge, and this effect can be explored using Equation (3), since it can be rearranged to predict (a) the relationship between the pre- and post-admix values of q/d_{inc}, and (b) the post-admix difference between q/d_{inc} and q/d_{add}. For example, for the case of 2 wt% of toner added into the 4 wt% charged developer used in the present study, the specific relationships are:

$$q/d_{inc,\max} = \left(\frac{(5\cdot 3)}{(7\cdot 2)}\right)\cdot q/d_{inc,0} - \left(\frac{(1\cdot 3)}{(3\cdot 2)}\right)\cdot q/d_{add,\max} \quad (6)$$

and

$$\left(q/d_{inc,\max} - q/d_{add,\max}\right) = \left(\frac{(5\cdot 3)}{(7\cdot 2)}\right)\cdot q/d_{inc,0} - \left(1+\left(\frac{(1\cdot 3)}{(3\cdot 2)}\right)\right)q/d_{add,\max} \quad (7)$$

where the q/d_{max} values are taken as the respective *q/d* values after completion of the charge-sharing event (e.g. after about 60 seconds of admixing in the paint-shake tests).

Since $q/d_{add,max}$ is taken to be a constant (i.e., the *q/d* value for "unaged" toner), then both Equations (6) and (7) predict a simple linear relationship with respect to $q/d_{inc,o}$ (i.e. the pre-admix *q/d* value of the "aged" toner), for all values of $q/d_{inc,o} < q/d_{add,max}$.

To recap, for all cases where toner/toner charge -sharing is enabled, the simple analysis indicates that added toner will acquire a characteristic maximal amount of charge whenever $q/d_{add,max} > q/d_{inc,o}$, i.e. whenever there is any level of "aging" for the incumbent toner. For any reasonable scenario, the incumbent toner can provide sufficient charge to the added toner, and the severity of the post-admix decrease in q/d_{inc} will be simply related to the degree of pre-admix toner "aging". For minor degrees of toner "aging", the difference between q/d_{inc} and q/d_{add} will be sufficiently small that the two toner populations will form a single, slightly asymmetrical *q/d* charge spectrum peak. For such cases, it will be difficult to detect the charge-sharing process, and the admix will be merely viewed as a desirably fast event, especially if the admix evaluation is not continued beyond the first few time increments.

Summary and Conclusions

In the present report, toner/toner charge-sharing has been demonstrated for interactions between fresh and "aged" toner particles, and the driving force for the process has been associated with the difference between the charging tendency of the two types of toner. For large differences between the two populations of toner, the failure effect will be amplified since in such a case a small amount of "fresh" added toner will accept charge from a larger amount of "aged" incumbent toner. By inference, prevention of this mode of charge admixing requires a totally stable toner design, and a simple additive-free toner might be viewed as meeting this severe requirement. However, toner additives are often used to enhance the performance of post-development subsystems such as transfer and cleaning, so that an additive-free toner may be sub-optimal from an overall system viewpoint. Also, though free of charge sharing, additive-free toners may show an overall slow admix response. Additionally, even for a simple toner, there can be significant differences between incumbent and added toner if the surface of the incumbent toner receives material fragments from the carrier beads.

From a xerographic development process viewpoint, "gentle" development housings would certainly help to minimize the "aging" of incumbent toner, but the current trend towards compact development housings runs somewhat counter to this approach. Toner "aging" may also be an especially difficult problem in full-color digital printing processes, since the toner residence time in any particular housing will be a stochastic function driven by variations in color content of the printed images. The potential influence of development housing dynamics may also limit the general applicability of any particular toner design ~~a~~ design that is stable in a "gentle" housing may show reduced performance when evaluated in other more stressful housings. (Similarly, in R&D studies, it is clearly important to evaluate toners under realistic conditions ~~a~~ "gentle" test may not provide a clear distinction between "robust" and "fragile" toners).

From a xerographic development viewpoint, it is clear that the combination of incumbent toner driven to zero charge plus high-charged added toner may provoke multiple modes of imaging failure — the uncharged incumbent toner will produce maximum amounts of xerographic background and general dirt, while the high-charged added toner will tend to reduce the level of image development by causing a premature collapse of the development field. Under closed-loop process control, the latter deficiency in image development may also trigger a runaway mode of failure, if the rate of toner dispense is increased in an attempt to increase image development. Indeed, once triggered, an admix-driven mode of segregated toner charge may irreversibly drive a xerographic developer to a non-functional failure state.

Finally, the continued evolution towards small colored toners, is another important factor for admix performance, since the *q/d* values for small toners will be inherently low for corresponding nominal levels of *q/m*. Accordingly, for such toners it will be important to minimize aging processes that promote significant levels of toner charge sharing.

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Biography

Robert Nash received his Ph.D. in Physical Chemistry from the University of Bristol, England. He joined the Xerox Corporation in 1970, and is currently a Principal Scientist in the Materials Technology and Concepts group. His research and modeling studies have focused on the design and evaluation of xerographic toners, carriers and developers, with especial emphasis on "aging" mechanisms. Starting with the 4th. International NIP Congress in 1988, he has yearly presented the results of his studies at the IS&T NIP Conference. In 1990, he served as Publication Chairman for the 6th. NIP Congress, and in 1992 he was Chairman of the IS&T Honors & Awards Committee. In 1999, he was named as a Fellow of the IS&T.

For the past fifteen years, he has traveled yearly to Japan for technology interchanges between the Xerox Corporation and Fuji Xerox. In April 1998, he began a new assignment at Fuji Xerox, Takematsu as the Senior Manager, Resident for the Xerox Supplies Development & Manufacturing Services organization. In this assignment, he is broadening his area of interest to include the science and technology of photoreceptor design and manufacture.

In their spare moments, he and his wife Ann are now enjoying developing a cross-cultural English-Welsh-Japanese garden around their hillside home at Itabashi/Odawara, and are gradually adapting to a sub-tropical style of horticulture after many cold years in USDA zone #5.