Periodic Development of Xerographic Background: A Case History

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Abstract

*Xerographic background development is normally associated with toner charge-related issues such as low or wrong-sign charge. Frequently, for two-component developers, carrier or toner aging effects create an increasing level of xerographic background with print count. In the present study, however, a single nominal toner composition was found to give a wide range of background development performance from toner batch-to-batch, even for new developers. For the most extreme toner examples, the rate of background generation was high enough to send almost half of the dispensed toner directly to the cleaning subsystem of a test print engine. From a comparison of print test assessments with a toner production timeline, the periodic background performance was traced to a variation in the quality of a component monomer used in the manufacture of the toner binder resin. While this chemical root cause had no effect on the average **q/m** value of the test toners, it did create differences in toner-to-toner charging performance, and charge spectra taken from toner-to-toner charging tests proved to be sensitive enough to rank toners according to their compatibility.*

Introduction

From the physics of xerographic development, background — the appearance of toner particles in non-image areas — is associated with the presence of wrong-sign or low-charged toner particles in a working developer [1-5]. For heavily-aged carriers in a two-component developer, the average toner charge-to-mass ratio, ***q/m***, will be low [6], with an appreciable population of toner particles in the wrong-sign/low-charged region of the overall charge distribution — as a result, a rapid increase in xerographic background is often the key criterion for developer end-of-life. However, in many cases, developers operating at normal levels of ***q/m*** can also generate excessive xerographic background, and such cases reflect charge admixing problems associated with the dispensing of uncharged toner particles into a charged working developer. For the case of slow charge-admixing [7,8], xerographic background will increase whenever a significant level of toner is dispensed [7]. For ultra-rapid toner-toner charge exchange (where uncharged added toner rapidly acquires a high charge level and "aged" incumbent toner is driven to a low charge level [9-11]), xerographic background will be triggered by abrupt increases in the rate of toner addition (e.g., as driven by print changes from low-area text to high-area pictorial images [12]).

As a result of the processes described above, background generation can also appear to be a random or periodic phenomenon. For example, large increases in ambient humidity may depress the average ***q/m*** of a developer and thereby produce a sudden increase in background development. Similarly, for a developer with poor charge-admixing properties, repeated addition of dispensed toner may further degrade charge-admixing performance and thence lead to a cascading, runaway background failure condition. Background that appears as bands is frequently associated with variability in photoreceptor background electrostatics. In certain cases, background generation may also show an apparent seasonal variability, normally as a result of the influence of temperature/humidity on triboelectric charging or on the process technologies used to produce xerographic materials.

Developed background is an especially significant copy quality defect for black toners, because of the high visual contrast between black toner particles and the non-image areas of a print on white paper. Background, however, can also be a problem in full-color xerography, especially for imaging systems based on relatively non-selective image transfer subsystems — for such cases, hue shifts and color casts may appear in highlight image areas. In full-color imaging systems based on the recharge of multiple toner layers prior to a single-step transfer, polarity reversal of wrong-sign background particles (especially from black toner) will also impact overall image quality [13].

In addition to copy quality issues, xerographic background also affects practical factors such as toner yield rate (i.e., the number of prints produced per unit mass of toner), and the performance of a post-transfer photoreceptor cleaning subsystem. Indeed, for xerographic marking systems based on charge-selective image transfer, excessive background-driven toner consumption may trigger a cleaner failure and high levels of in-machine "dirt" even before visible levels of background are noted on fused output prints.

Theory

Non-image background covers about 95% of the area of a typical text-based print, so that toner particles that develop in the background area can be a significant factor in overall toner consumption. This point can be directly illustrated using a simple nomograph as follows:

Define:

Y = toner yield in terms of prints per gram of toner
S = toner load in grams to the cleaner sump per copy
P = grams of toner developed on a print
T = total grams of toner consumed per print, $(S + P)$
U = fractional toner utilization, $(T - S)/T$

then

$$Y = (1 - U)/S$$

From direct weights of the toner supply and cleaner sump, parameters Y and S can be conveniently monitored during a print

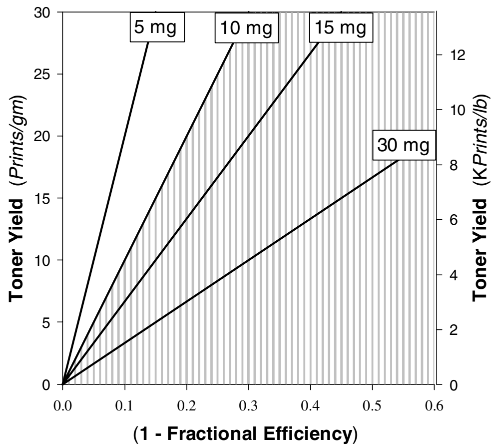


Figure 1. *Nomograph for toner yield as a function of development efficiency, for four levels of background toner per print.*

run, and nomograph plots of Y:U or Y: (1-U) can then be used to identify imaging problems such as high background, variable image densities, reduced transfer efficiency, etc. Such plots can also be used to indicate a performance specification , as shown in Figure 1, where the shaded area represents an excessive toner load to the cleaner sump. (Typical values for a text print from 10µ toner: 35 mg of toner per print; 5 mg of residual image toner per print; 3 mg of background toner per print; 23 prints per gram of toner).

In general, the rate at which toner accumulates in a cleaner sump will not be constant, since toner properties such as transfer efficiency and background generation will tend to change as a function of developer life. As noted earlier, operative factors may include charge admix problems and age-induced decreases in toner charging. Additionally, for systems based on constant image density control, changes in imaging set-point (e.g. toner concentration) with developer usage may also affect toner consumption, and such changes may even be triggered by non-toner extrinsic factors such as age-induced changes in photoreceptor charging performance.

For a first-order view , it is convenient to split the cleaner sump fill rate into initial, R_i, and final rates, R_f, with the overall rate, R, being set by a weighted sum of the two fill rates, e.g.:

$$R = (N_i/N).R_i + (N_f/N).R_f \qquad (1)$$

where N_i/N and N_f/N are the fractions of the total toner population, N, in the initial and final states.

If the change from the initial to the final toner state follows a random process, then:

$$(N_i/N) = exp\{-k.\text{ copy count}\}$$

and

$$(N_f/N) = (1 - exp\{-k.\text{copy count}\})$$

where k is the apparent rate constant for the changeover process.

Integration of equation (1) yields the cleaner sump load, L, at any copy count:

$$L = R_f.\text{copy count} + (R_i - R_f).(1 - exp\ \{-k.\text{copy count}\})/k$$

In a stable xerographic marking system, non-transferred/residual images will provide a steady flux of toner to the cleaning subsystem, at a rate R_i. For background-generating marking systems, the added increase in cleaner sump load can be significant even for relatively light levels of background since most of a typical text document is background area. For such cases, $R_f >> R_i$, and non-transferred background toner may increase the cleaner sump load by a factor of two or more.

The concepts outlined above will next be used as a framework for a discussion of experimental data taken using toners having a range of background performance.

Experimental

Test Materials

Toner: Negative polarity; linear polyester base resin (melt-esterified, derived from propoxlyated bisphenol A and fumaric acid); about 10 wt% of furnace carbon black; external additives: SiO_2/zinc stearate in a 2:1 ratio.

Carrier: Rough, iron powder, solution-coated with a partial coating of PMMA.

Print engine: Laser scanned, charged-area development (CAD); corotron transfer; blade-cleaned photoreceptor; target patch in inter-print area for image density control via proportional feedback to the toner dispenser.

Test Procedure

Text image prints of about 5% area coverage were generated with the print engine set to produce a fixed image density (typically a solid-area density of about 1.2 o.d.), and developer triboelectric properties were evaluated at regular print intervals. By direct weighing, toner consumption and toner accumulation in the cleaner sump was also monitored at the test points.

Results and Discussion

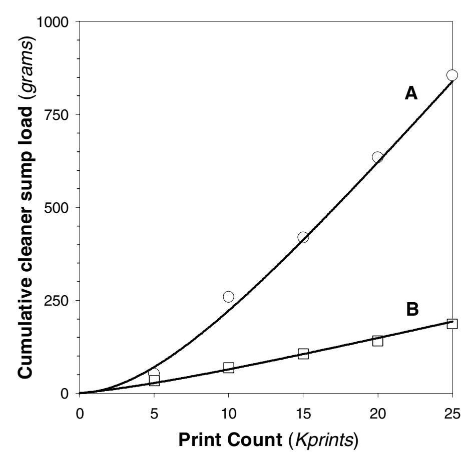


Figure 2. *Cleaner Sump load vs. print count for "bad" toner A and "good" toner B.*

Figure 2 shows non-image toner as a function of print count for test toners A and B. Though identical in nominal composition, these toners clearly differ in their xerographic imaging performance, and the test data indicate a major batch-to-batch toner variability. The set-point behavior for these test toners,

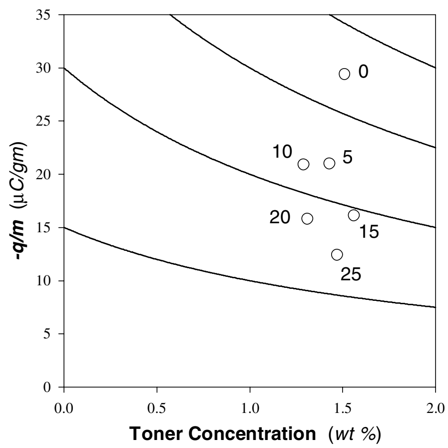


***Figure 3. q/m**: toner concentration plot at the noted print counts (in Kprints) for "bad" toner A.*

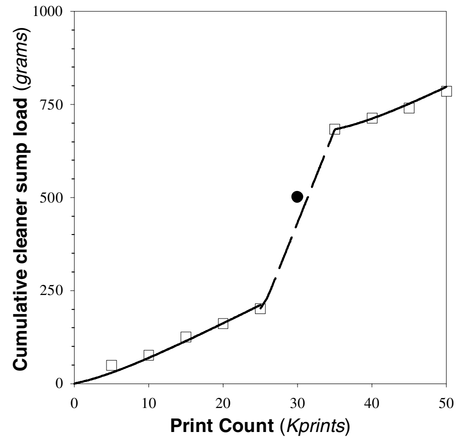


***Figure 5.** Cleaner Sump load vs. print count for "good" toner C to "bad" toner D and back to C.*

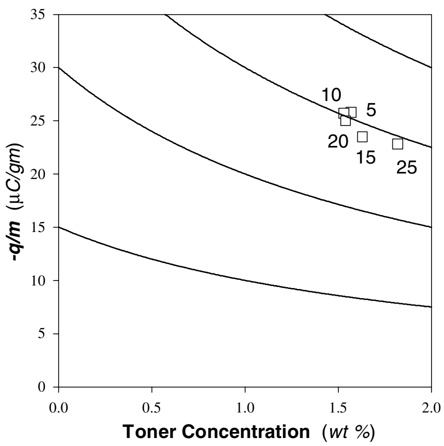


***Figure 4. q/m**: toner concentration plot at the noted print counts (in Kprints) for "good" toner B.*

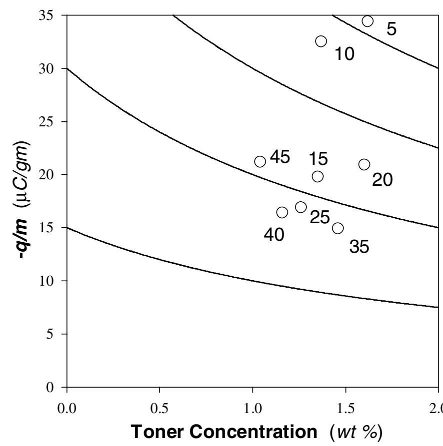


***Figure 6. q/m**: toner concentration plot at the noted print counts (in Kprints) for "good" toner C.*

shown in Figures 3 and 4, further reveals that the triboelectric properties of the toner A-based developer degraded throughout the print test, while the developer based on toner B remained triboelectrically-stable. (Each contour in Figures 3 and 4 represents the ***q/m***:toner concentration response for a specific developer "age"). As shown, the net xerographic effect for toner A was a decrease in set-point ***q/m*** value — a likely cause for the observed increase in cleaner sump load.

In Figure 5, a change from test toner C to test toner D at the 25 Kprint point produced an immediate and major increase in the cleaner sump load. Again, this behavior indicates batch-to-batch toner variability, since all toners used in the tests were based on a single nominal composition. Figure 5 further shows that a change back to toner C as the dispensed toner was effective at returning the cleaner sump load rate to that seen in the initial stage of the test. The set-point plot for this multi-toner test is shown in Figure 6 — toner C is clearly superior to toner A or D since it gave a reduced level of background development (e.g. at test points from 35 to 50Kprints) even though it operated in the same general ***q/m*** region as the background-generating toners A and D.

Significantly, the background performance of toner D could be drastically improved through a simple change in electrostatic set-up, as illustrated in Figure 7. Nominal settings for the test xerographic print engine were : image potential = 850 volts; background potential = 75 volts; development bias = 225 volts. In the print test of toner D shown in Figure 7, the development bias was reduced by 50 volts at the 10 Kprint point, and this clearly produced an immediate reduction in the background level. Normally, background suppression improves as developer bias is **increased**, so that the present test result might appear counter-intuitive. However, the companion set-point plot, Figure 8, reveals that the observed improvement in background performance at a reduced developer bias is a reflection of a major decrease in the operating toner concentration, a change driven by the automatic density control system of the print engine — since a decrease in developer bias effectively increases the image development potential (i.e., 850 – 175 = 675 volts vs. the original 850 – 225 = 625 volts), operation at the initial toner concentration of 1.5 wt% will lead to an over-developed image at a reduced bias setting, thus leading the automatic density control system to reduce the toner concentration in order to restore the developed image density to the set-point value. The result shown in Figure 7 is an instructive example of a total imaging system impact on

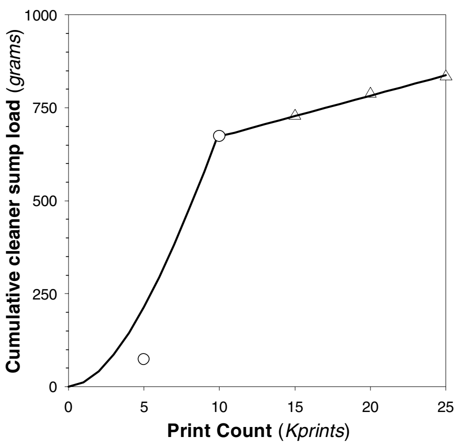


Figure 7. *Cleaner Sump load vs. print count for "bad" toner D with a reduction in the development bias by 50 volts at the 10 Kprint point.*

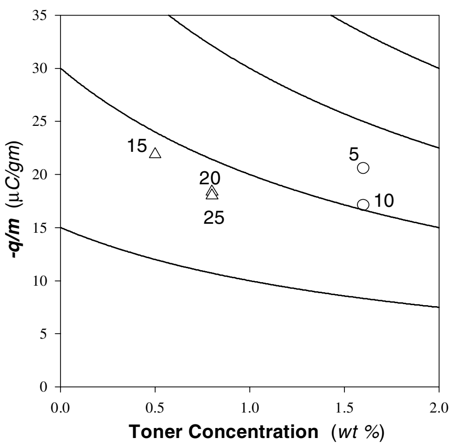


Figure 8. q/m*: toner concentration plot at the noted print counts (in Kprints) for "bad" toner D. Note the large decrease in toner concentration following a 50 volt decrease in development bias at the 10 Kprint point.*

toner performance, and also illustrates the need for adequate system latitude for stable operation.

When toner D was evaluated in an entire test run at a reduced developer bias and at a 1.5 wt% toner concentration, a low level of cleaner sump load was achieved, as shown in Figure 9. (This result obtained at a reduced developer bias coupled with a nominal toner concentration suggests that the background toner generated by toner D is induced wrong-sign toner [7]. Unfortunately, despite the generally improved background performance in the modified test, variability in the photoreceptor background potential produced visible bands of background — the reduced developer bias was not high enough to suppress background development in areas of the photoreceptor with increased background potential. From an overall system latitude viewpoint, therefore, operation at a reduced developer bias is not a workable solution to the toner background problem.

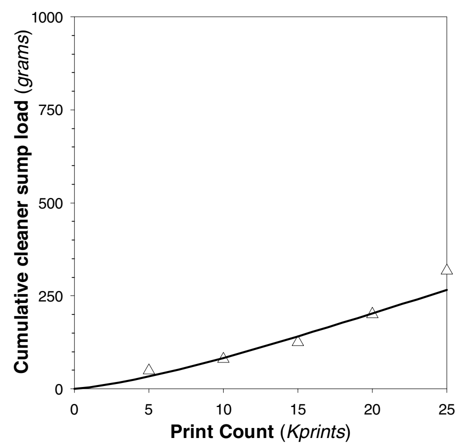


Figure 9. *Cleaner Sump load vs. print count for "bad" toner D when operated with a 50 volt reduction in development bias.*

Root Cause

Since the above background problem followed a toner batch-to-batch pattern, a chronological review of key raw materials and processing procedures was made. Though toner resin is normally specified chiefly in terms of functional rheological properties (to achieve a desired image fusing performance), commercial-scale resins may also affect the charging performance of xerographic toners, either through the influence of the major polymeric components or through residual catalysts, initiators, inhibitors, surfactants, monomers etc. For the present toners based on a polyester resin, a careful timeline comparison of toner performance with polyester resin batch revealed that the batch-to-batch xerographic background problem could be associated with a batch-to-batch change in the supply of the bisphenol A monomer used in the polyester resin production. Bisphenol A is an important monomer for many commercial polymers, and is produced in large volumes at a variety of purity grades [14]; apparently, however, certain grades of this starting monomer may affect toner background performance, despite the many process steps involved in toner production. While a mechanism for the presently observed triboelectric charging shortfall remains unclear, the observation is an instructive example of the sensitivity of the physics of triboelectric charging to toner chemistry. From a practical viewpoint, the root cause analysis highlights the importance of well-documented materials/processing control records.

Bench-scale evaluation

Since the root cause of the periodic background failure was traceable back to the toner chemistry, a toner-only charging test was evaluated for use as a rapid, bench-scale screening tool. Charge spectra taken for toner-toner charging [15] between test toners and a high-performance control toner proved to be an effective analytical procedure, with a high correlation between the homogeneity of the charge spectrum and eventual performance in a xerographic printer. As shown in Table 1, while identical toners (i.e., "good" vs "good" or "poor" vs "poor") gave a single toner charge peak at a low negative value, "good" vs. "poor" toners

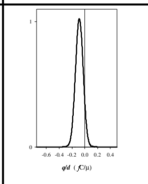
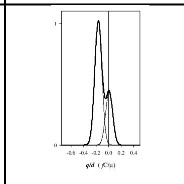
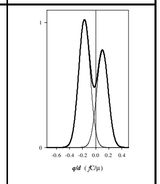
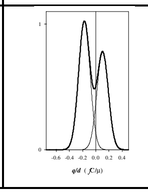
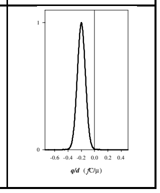
	GOOD	INTERMEDIATE	POOR
GOOD			
POOR			

Table 1. *Toner-toner charge spectra for the noted pairs.*

gave a distinctly bimodal charge spectrum, and "good" vs. "medium quality" gave an intermediate shouldered peak spectrum (with actual print test data being used to classify the quality of the toners). Though the charge values generated in toner-toner charging tests are lower than the values seen in toner-developer charging, the present data indicate that a characteristic range of charge spectra can be generated from the charging of dissimilar toners.

Conclusions

While developed xerographic background is normally viewed as a visual print defect, it can also create a significant reduction in the utilization rate of a toner (expressed as prints per unit weight of dispensed toner). It may also create a high stress condition for post-development subsystems, especially photoreceptor cleaning subsystems. While background image development is often associated with the low ***q/m*** values that result from overall developer "aging", the present test results illustrate that toner-based charging deficiencies can also create large levels of xerographic background even at high values of ***q/m***. For the present test toners, the root cause of an observed periodic toner-driven background problem was traced to changes in the quality of a monomer used to create the toner binder resin. Finally, the charging properties of various batches of test toner made from a range of binder resin could be rank ordered via a simple bench-scale toner-toner charge spectra test.

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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. From 1998 until the end of 2000 he was an expatriate at Fuji Xerox, Takematsu, Japan. He now consults on topics from xerographic materials to cross-cultural interactions with Japan. In 1999, he was named as a Fellow of the IS&T, and in 2002 he received, jointly with John Bickmore, IS&T's Chester Carlson Award.