Two Component Electrophotographic Developer Time Dependent Charge Properties

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Abstract

This paper presents methods for quantitatively analyzing the effect of developer age and the effects that electrophotographic process system noises have on the triboelectric charge level of a developer. The replacement cycle for a developer mixture can be several hundred thousand to several million prints. During its usable life, the developer encounters a number of process noises such as toner concentration variations, environmental changes, and document toner coverage differences. Developers that have little to no change in charge level and low responses to process noise effects are desirable because they will have stable printer operation and consistent print quality. In practice, developers can have significant shifts in charge level in "early life". These effects can be confounded with system noises. In "late life", the developer charge may be slowly shifting which requires very long tests to estimate the developer duty cycle. Statistical and semi-empirical models can be used to separate and quantify the early and late life effects. This information can be useful for identifying material formulations that have long developer life and predicting noise conditions that show good developer performance.

Introduction

The toner charge to mass ratio, Q/m, in an operating printer is dependent on the time that the developer has been run (print count) and noise factors such as document toner coverage, precision of toner concentration control, and the environment including temperature and %RH, of the printer. Toner replenishment rate can vary, depending on document coverage. The maximum developer age is determined by the service interval. Environmental conditions are set by the ambient printer conditions or a printer may be designed with humidity and temperature control systems. Developer age cannot be controlled except by recommending a replacement interval.

The process often used to quantify these effects is the collection of Q/m data at normal toner concentration, document coverage, and environmental conditions during a print run. Measurements are also made when the printer is run at fixed toner concentration, document coverage, and environmental conditions offset from normal print conditions. This is done at several intervals during a print run to determine if developer charge changes with developer age and system noises.

Results form three different developers showing a range of Q/m life characteristics are analyzed.

Toner Concentration

The understanding of the effect of developer toner concentration on toner charge to mass ratio is significant in several areas. This information can be used to understand the effect of random toner concentration Q/m variability and to design process control systems for controlling toner Q/m. As developers age, Q/m can be adjusted in a printer process feedback control system to maintain a constant Q/m.[1] Toner triboelectric charge was measured on developer samples from an operating printer in two ways: at nominal running toner concentration where variation of the toner concentration was only dependent on the stability of the toner replenishment and toner concentration process control system, and at high and low levels where the toner concentration setpoint was offset from the normal running level. Data was taken at intervals over a print test to understand the interaction of developer age on the Q/m, toner concentration model.

Figure 1 illustrates the Q/m and toner concentration relationship with increasing print count for Developer A. Developer A is a polymeric coated ferrite carrier and toner made with a styrene copolymer, a charge agent and a carbon black pigment. The toner was not surface treated with any other fine particles. This graph shows two characteristics typical of two component developers: Over a long print run the charge level of a developer at fixed toner concentration decreases and the slope of the Q/m versus toner concentration also decreases. Both of these effects can be explained by a reduction of toner or carrier charging sites as a developers ages. Site concentration models of the toner-developer charging process predict a linear relationship between developer toner concentration and the inverse of Q/m.[2] These types of models are useful over a large range of toner concentrations. For small variations in toner concentration, on the order of one percent, a linear model of Q/m versus toner concentration is adequate.

Charge Equilibration

Processes such as mass transfer between toner particles, toner surface treatment particles, carrier particles, and carrier coatings can affect the initial charge response. Other processes may also occur, such as a shift in the particle size distribution of the toner in the developer station. These can be modeled as first order rate processes. The difficulty is that there are multiple effects with different time constants occurring in parallel. For the example illustrated, modeling the initial Q/m rise as a single first order kinetic process does not give a good fit to the data. James Anderson, Heidelberg Digital, L.L.C. suggested that a triboelectric charging model published by Robert Nash (3) could be applicable.

$$Q/m_k = Q/m_o + \delta Q_1(1\text{-}exp(1\text{-}k/t_1)) - \delta Q_2(1\text{-}exp(1\text{-}k/t_2))$$

Where:

Q/m_k = *toner charge at k print counts*
Q/m_o =*Toner charge at print count 0*
δQ_1, t_1 *toner delta charge and time constant for charge rise*
δQ_2, t_2 *toner delta charge and time constant for charge decay*

This model describes the toner and developer triboelectric charging process as two parallel processes, one that exhibits a charge increase with time and a second parallel process with a charge decay.

Figure 2, Developer A, shows data from a long print test with the best fit line using the model drawn through the data points. In this example, the delta Q/m and time constant for charge rise was -17.7 μC/gm and 38.3 K prints. The delta Q/m values and time constant for charge decay were -27.2 μC/gm and 312K prints. In terms of minutes the time constants were 269 minutes and 2197 minutes.

Developer charging rates, the time to reach a maximum level, without toner replenishment, are typically less than 10 minutes. The mean toner residence time in the developer station can be computed from the weight of developer mix in the toning station, toner concentration of the developer and the toner replenishment rate. For this particular test the mean toner residence time in the developer station was 35 minutes. The mean residence time, 35 minutes, is much smaller than the time constant for charge rise, 269 minutes. This indicates that mass transfer processes between toner and developer particles and equilibration of the developer station composition to an equilibrium composition are affecting the initial charge response.

For the charge decay process the time constant of 312k prints was about one third of the total test length of 1,000K prints. This information can provide insight as to whether a larger quantity of developer in the printer will increase the developer replacement interval. Since the developer print cycle was three times the time constant for toner charge decay, increasing the mass of developer used in the developer station would give a nearly proportional increase in the developer replacement interval.

Modeling this process can be very useful in reducing the testing time required for product development. Running print tests of reasonable length, but not necessarily as long as the developer replacement cycle gives a quantitative measure to compare different compositions. The toner and developer compositions with the best estimated life cycle can then be selected and longer tests performed to verify improvements.

The following examples demonstrate that this analysis can be applied to developers that show extreme examples of toner charge variation over a developer life cycle.

The materials used in developer B were a polymeric coated ferrite carrier and a polystyrene copolymer toner containing a charge agent and a carbon pigment. The toner was surface treated with fumed silica as a flow aid. The developer toner concentration was nominally 10 weight percent. Testing was performed in a temperature and humidity controlled environment of 73F and 50% RH and on a test fixture that simulated the development process but did use not paper or a photoconductor. The device used a proportionally smaller developer station and biased drum to simulate a photoconductor. The developer station included a toner concentration monitor feedback control loop to maintain constant toner concentration in the test developer. Toner throughput could be adjusted by altering the bias development conditions. Tests were 100 hours in length, approximating 600,000 prints based on the toner throughput rate. Data from the test include: periodic measurement of the toner charge-to-mass, toner concentration, toner replenishment rate, and relative humidity.

Figure 3 shows Q/m versus run time for developer B. The data shows that the developer performs with a stable Q/m for all but the very early part of developer life. Near the end of the test, the toner throughput rate was cycled between high and low values relative to the nominal value. The toner throughput changes appear to have no affect on the developer Q/m.

Developer C contained a ferrite carrier, similar to that used for developer A, mixed with a toner containing a polyester binder, a charge agent, a carbon pigment, and a wax additive. This toner was also treated with fumed silica as a flow aid. The data in Figure 4 show that as developer C is aged the Q/m is much less stable. The Q/m for developer B shows an initial charge rise with subsequent charge decay. Developer C was also subjected to cycles of high and low toner throughput after 100 hours. The Q/m of developer C was more sensitive to toner replenishment rate than developer B.

Document Toner Coverage

The rate of toner consumption in a printer is dependent on print speed and document toner coverage. In high speed printers the mass of toner and developer in the developer station may be such that the toner charging rate time constant is on the order of the developer station residence time. At high toner consumption rates, the toner may not reach its equilibrium charge level. At low toner consumption rates the residence time may be long enough that mass transfer effects that reduce toner charge may be observed. Non-uniform mixing of replenishment toner with the developer increases the magnitude of these effects. For the test presented here, the normal coverage and toner replenishment rate was equivalent to a ~6% document coverage. High and low coverage documents were also printed. For these documents the mean toner resident time in the developer station was 202 minutes at low document coverage and 12.8 minutes at high document coverage.

To quantify the effect of document coverage or toner replenishment rate on toner charge / mass level the measured toner Q/m and toner concentration was adjusted to 10% toner concentration. Q/m was corrected to a value equivalent to 10% toner concentration by using the measured toner concentration and the regression data for Q/m dependence on toner concentration with varying developer age. The marginal mean Q/m was computed at high and low document coverage levels and then compared to the value that would have been predicted for the same developer age and equivalent print count at normal document coverage and environmental conditions. A percentage Q/m shift was then calculated across the data from 0 to 1 million prints.

Table 1. Developer A toner charge shifts as a result of varying document coverage and toner residence time.

Document Coverage	Toner Residence Time, minutes	Q/m shift from normal	Statistically Significant?
High	12.8	4.0%	Not significant
Normal	35	Reference point	
Low	202	18%	Yes

Increasing document toner coverage and decreasing the toner residence time did not significantly affect the toner charge level. Replenishment toner is rapidly equilibrating and mixing with developer. Low document coverage and increased toner residence time did raise the toner charge level. The main factor effecting toner charge level was still developer age, but longer toner residence time caused by low document coverage resulted in a charge rise relative to the "normal" residence time and document coverage.

Environmental Effects

Toner charge sensitivity to environmental effects was analyzed similarly to the document coverage effect. Conditions used were 75 F / 75 %RH, 70 F / 50 %RH, and 80 F / 10 %RH. The toner charge level response to document coverage and environmental noises was evaluated as one array with two noise factors, document coverage and environmental conditions, at three levels for each noise factor. Noise factors where varied at 150, 550, and 900K prints. Higher variability in toner Q/m can be seen at these points. The marginal mean toner Q/m was computed at high, normal, and low humidity conditions. The Q/m percentage shift for each document coverage and environmental factor level was calculated as a response. Figure 5 shows a comparison of actual Q/m and the modeled Q/m when all noise factors are included. Measured toner Q/m and Q/m estimated from developer age and noise factor level show good correlation.

Conclusions

Exponential charging and charge decay models can be applied to toner developer systems that show a wide range in charging rate and levels with good results. Noise factors such as developer toner concentration, toner consumption or document coverage, and environmental factors can be modeled and coupled with the exponential charging model to describe system performance. This type of analysis is useful in defining an operating window for a toner and developer system.

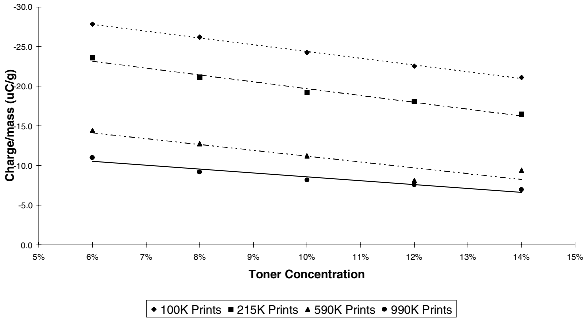

Figure 1. Developer A toner charge / mass dependence on print count (developer age) and developer toner concentration.

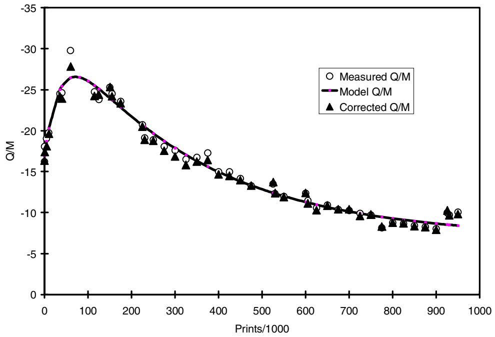

Figure 2. Developer A Q/m modeled as two increasing and decreasing exponential processes. Data is at constant temperature, relative humidity, and nominal 10% toner concentration. Model fitted to Q/m adjusted to constant toner concentration.

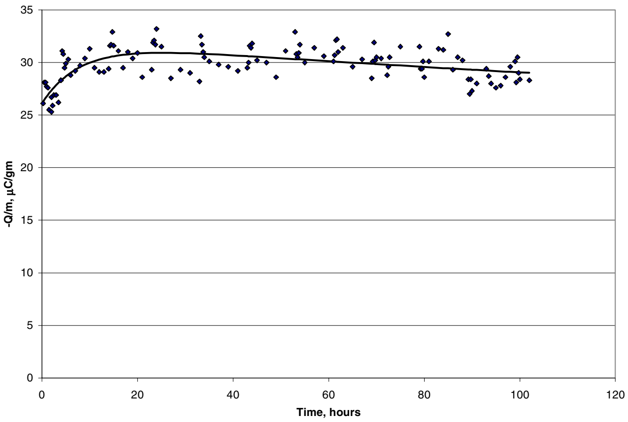

Figure 3. Developer B showing small initial developer charge rise and very slow charge decay.

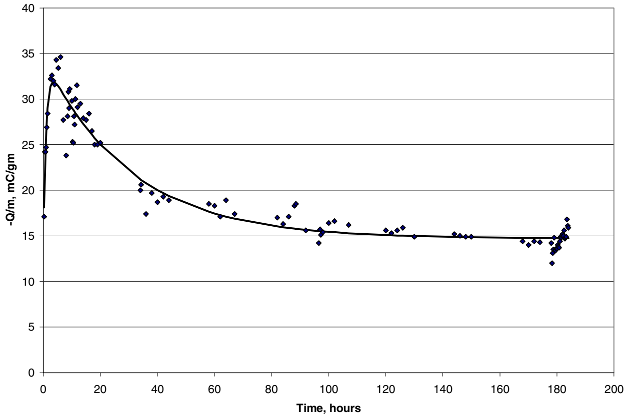

Figure 4. Developer C Q/m response has a large and rapid time dependent charge responses.

Acknowledgements

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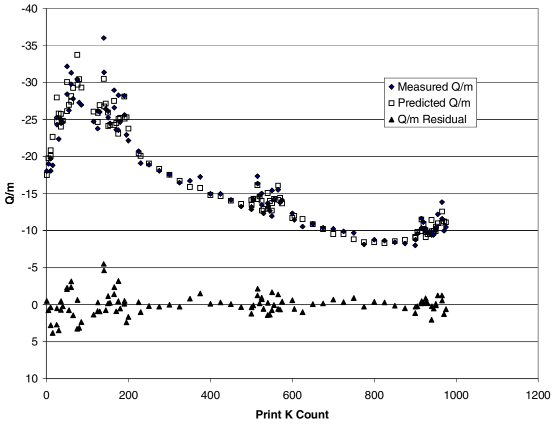

Figure 5. Developer A Q/m for printer test that includes toner concentration, document coverage, and relative humidity noise effects. Measured and predicted Q/m data are plotted.

References

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Biography

Robert D. Fields received a Ph.D. degree in Chemical Engineering from Cornell University in 1973. He is a Senior Scientist at Heidelberg Digital L.L.C. For the majority of his career he has been involved in process development and manufacturing of electrophotographic toners and developers. He is the holder of several patents in the area of toner formulations. Currently he is working on commercialization of toning materials for electrophotographic printers. He is a member of the IS&T.