Field Charging Process Consistency with Single Component Non Magnetic Color Toners

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Abstract

The charging behavior of a group of vibrant color toners (warm red, process blue, cyan, yellow, green, unpigmented clear) and a black toner is described. The toners are charged using a field charging process (coronal ion bombardment) which allows for the consistent and uniform charging of the color toners. The toners require no special charge directive constituents to control the final charge of the toner particle. This behavior is due to the insensitivity of the charging process to the toner formulation. The sign and magnitude of the electrical charge resident on the color toner particle is simply a function of the field magnitude and sign used to generate an electrical corona discharge to which the toner is exposed. The process employs the use of a fluidized bed mechanism to move the toner into the proximity of the corona current and provides for uniform charge distribution over the surface of the toner particles.

Introduction

In both insulative monocomponent (nonmagnetic) and two component toner systems, it is necessary to charge the toner particles so that the electric field of the latent image can exert its Coulomb force.[1] The method employed to charge the toner is however different in the two cases.

In the case of two component systems, the proportional combination of a carrier particle and an insulative toner particle is used to maintain optimum image quality. The toner particles are charged through the frictional contact of the particle with the carrier material. This charge exchange process (or triboelectrification) is thought to occur at specific sites on the surface of the toner particle, which would result in a group of discrete charge sites.[2,3] The choice of materials for both the carrier coating and the toner particles determines the sign, magnitude and stability of charge that results from contact between the two components. The material interaction is highly complex and is influenced by factors such as mixing time, concentration (carrier and toner), particle size, developer age, external additives and environmental effects.[4]

Non-magnetic monocomponent toning systems enjoy a manufacturing cost advantage over dual-component systems as well as the potential to provide bright color toners (as no opaque magnetic material is used). By comparison, such monocomponent systems must address the need to both charge and transfer the toner particles without the addition of a carrier. The charging properties of the monocomponent toner are once again critical in determining overall system performance. Typically, non-magnetic single component toners are charged by friction as is the case in two-component systems. However, the charging process usually involves the frictional contact of the toner against the surface of a donor roller or the surface of a metering device (elastic blade or charging roller).[5] The charged toner is then carried in contact with the surface of the donor roller into a position which presents the toner to the electrostatic latent image. The toner develops the latent image, by either contact or by movement across a gap, under the influence of the Coulombic image forces.

This paper expands on an alternate method of charging and transfer of a single component non-magnetic toner through the use of a field charging process (Pauthenier charging).[6] The system combines the use of a fluidized bed toner supply system and a high voltage coronal source which is located within the fluidized bed. This concept has been extended from the original black toning system, to a series of vibrant color toners that have essentially the same chemical composition. Measurements of charge-to-mass ratios are presented to allow for a direct comparison between toners of varying color, demonstrating the charging insensitivity to changes in the underlying color chemistry.

Background

Pauthenier Charging Model

A representative model that can be used to describe the charging process presented by Pauthenier, is referred to as the Pauthenier or field charging model.[7]

$$q_{\max} = 4\pi\varepsilon_0 p a^2 \mathrm{E} \tag{1}$$

where $q_{\max}$ is the maximum charge on a single particle (Pauthenier limit), a is the particle radius, **E** is the local electric field strength, and p is a dimensionless factor determined by the relative permittivity of the dielectric particle. The dimensionless factor is given by

$$p = 3\varepsilon r / (\varepsilon r + 2) \tag{2}$$

The relative dielectric constants (ε_r) of nearly all insulating materials lie between 1 and 10 so that p will be between 1 and 2.5. Using this approach, it is possible to calculate a theoretical maximum of charge achieved on the surface of a dielectric sphere (i.e., toner particle) under the influence of an electric field (i.e., DC corona), before the repulsive field due to the charge on the particles becomes self-limiting.

Charging Process

In the case of the single component non-magnetic toning system described in this report, it is apparent from the

equation that if the dielectric constant and particle size are maintained at approximately the same value, then the color of the toner can be varied with no impact on the final charge level of the toner. It has also been verified in practice for the dielectric constant and particle size, that the q_{max} is insensitive to small distributions observed for these parameters in a group of particles and for changes to the color chemistry. The charge of the toner (i.e., sign and magnitude) becomes highly dependent on the electric field (**E**) and the "lateral flow" properties of the toner powder.[6] This simple idea has been the driving force behind the development of a group of color toners that perform identically under the same set of process conditions, without necessitating a color dependent variation to the base material composition.

Apparatus

The toner applicator used in this study has been described extensively in previous work from this lab.[3,6] However, a brief explanation of the system and system parameters will be presented in this section. The applicator unit includes a toner reservoir with a high voltage DC corona source located within the air fluidized toner. The toner behaves as a low viscosity liquid, suspended (fluidized) through the use of a pressurized air which is passed through a porous base plate. The level of the toner is controlled in the fluid bed through the use of a closed-loop control that automatically feeds toner to maintain the correct level. The toner particles interact with the ions created by the corona source, with the final charge level of the toner dependent on the uniform movement of the particle within the field created by the same DC corona source. Subsequent to charging, the toner is attracted to the surface of a rotating biased "transfer" roller, due to the forward electric field between the corona and the transfer roller. The next step is again a field mediated movement of toner from the transfer roller to the rotating system "applicator" roller, by which it is finally presented to the latent electrostatic image. It has been observed that the field controlled movement of toner from the transfer to applicator roller provides for some filtering of incorrectly charged ("wrong sign") toner which has a positive impact on decreasing image background development.[8] The toner layer thickness has been measured experimentally to be approximately 14 μm at the surface of the transfer roller, with a mass per unit area of 0.7 mg/cm^2. Both the transfer and the applicator rollers are mechanically scraped on each successive rotation, which results in the removal of the thin toner layer at the surface of the rollers. A variable high voltage DC corona source is used in order to operate the system over a range of imaging speeds, from 12 to 190 cm/sec. This results in a range for the parameter **E**, leading to a speed dependent Q/M (charge-to-mass) ratio for the toner particle.

Experimental

Toner

The toner is a simple blend of a base resin system with pigmentation and surface blended additives to improve flow properties and electrical stability within the applicator system. Mean particles sizes for the toners tested was approximately 11-13 μm. As noted previously, toner mobility is extremely important in the uniformity of charge deposited at the surface of the toner particle by the DC corona source used in the process. The different colors studied in this report included black, process blue, yellow, cyan, green, warm red, and a non-pigmented clear toner. The only variation in the case of each of the colors listed, was a change to the underlying pigment (or lack thereof) in the base resin system to impart the specific color desired. Comparisons were also made between different colored toners within the same additive material class, with the classes differentiated as High Lateral Flow (HLF) and Moderate Lateral Flow (MLF) type toners.

Charge-to-Mass (Q/M) Ratio Measurement

In order to perform one of the studies presented in this paper, the toner applicator described above was modified slightly to include a high voltage non-contact voltmeter. The voltmeter was a Trek Model 344 ESVM that includes a remote high voltage noncontact sense head. The voltmeter remote head is mounted in a position slightly above the system transfer roller (approx. 6 mm), the first of two system rollers (the second being the system applicator roller) which is coated by the field charged toner. For the purposes of the experiment, the applicator roller was disabled so that none of the field charged toner was transferred from the transfer to applicator rollers. The transfer roller surface speed was fixed at 50 cm/sec and the DC corona voltage was fixed at 7.1 kV. This allows for the measurement of a layer surface voltage on the roller which can be used to experimentally determine the Q/M ratio, a method developed by Fowlkes to nondestructively determine the charge present in a toner layer.[9] A block diagram of the simplified apparatus is presented in Figure 1.

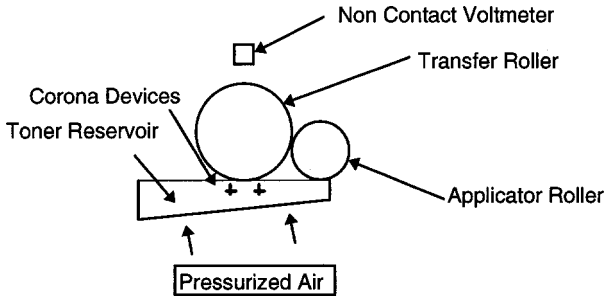

Figure 1. Block Diagram of Q/M Measurement Configuration.

Toner Stability Voltage (V_{stab}) Measurement

It is also possible to measure a system stability voltage that is representative of the stable operational voltage supplied to the DC corona used to charge the nonmagnetic toners. In actual operation, this system parameter can be determined using the measured optical density of a developed (and fused) test pattern. For testing purposes, the measurement of V_{stab} was made by determining the corona voltage required to coat the transfer roller surface with the single component toner so that none of the underlying transfer roller is visible through the toner layer. The actual system was designed to operate at a range of imaging speeds, and typically makes use of a variable voltage DC source for the corona. For these tests the roller surface speed was

fixed at 50 cm/sec and the DC corona voltage was varied until V_{stab} was determined using the conditions described above. The measurement of V_{stab} is carried out on the same modified applicator fixture as described in the preceding section.

Results and Discussion

By using equation 1 it is possible to calculate a theoretical maximum charge for the toner particles studied using the experimental configuration described above. Typical values for the nonmagnetic process described in this study would result in a self-limiting charge on a 12 μm toner particle of approximately 9.6×10^{-15} Coulombs. This would result in a calculated charge-to-mass ratio of 10.6 μC/gm assuming that the magnitude of the electric field to which the particle is exposed is 1.0×10^{6} V/m.

For comparison purposes, the Q/M was calculated for three groups (two classes) of toner using the method developed by Fowlkes[9] and is presented in Table 1. The Q/M values for the HLF, MLF1 and MLF2 groups was determined using the following relationship

$$Q / M = \frac{V_T 2\varepsilon_0[(5 + 4\rho_m / \rho_t) / (5 - 2 / \rho_m / \rho_t)]}{\rho_m h^2} \quad (3)$$

where V_T is the measured layer voltage, ρ_m/ρ_t is the layer packing fraction, h is the height of the toner layer. The values measured for V_T are included in Table 1, the layer packing fraction is approximately 0.5 at a measured toner layer height of 14 μm. It is apparent for both of the classes of toner, that charging levels are very similar within the distinct groups. It is also interesting to note that the Q/M values for the two groups show a dependence on the flow properties of the toner, with the HLF type toners charging to a higher Q/M level than the MLF type toners.

Table 1. Measured Layer Voltage (V_T) and Q/M Values for High and Moderate Flow Toners

Toner Number	Type	Color	V_T (volts)	Q/M (μC/g)
T121	HLF	Black	59	18.6
T123	HLF	Cyan	53	16.7
T124	HLF	Yellow	53	16.7
T120	MLF1	Black	45	14.2
T280	MLF1	Cyan	44	13.9
T169	MLF1	Yellow	43	13.6
T299	MLF2	Black	48	15.1
T303	MLF2	Cyan	45	14.2

Performance for the different pigmented toners is virtually identical within the given class groupings. The calculated values also show a close correspondence to the theoretical Q/M value of 10.6 μC/g determined using the Pauthenier model. The difference in the experimental and theoretical values is likely due to the difficulty in determining the exact local field strength to which the particle is exposed.

Comparisons were also made between the measured toner stability voltages for a larger group of color toner variants, and these results are shown in Table 2.

Table 2. Measured Stability Voltages for Colored Single Component Toners

Toner Number	Color	V_{stab} (kV)
T121	Black	6.85
T169/T172	Yellow	6.88
T170/T171	Cyan	6.84
T174	Green	6.81
T175	Blue	6.87
T176	Warm Red	6.83
T178	Clear	6.67

The table lists results for toners which differ in their pigmentation chemistry, but remain consistent with respect to other material constituents. The measured V_{stab} values show an expected consistency with respect to the Pauthenier model, demonstrating the field charging process is chiefly dependent on the local electric field through which the toner particle is moved. The specific toners, black (T121), warm red (T176), yellow (T169/T172), cyan (T170/T171), green (T174), and blue (T175) all show a stability voltage value of approximately 6.8 kV. It is also interesting to note that the clear toner (T178), which contains no pigmentation, exhibits behavior which is consistent with the other members of this class of toners.

Conclusions

- The results suggest a direct dependence of Q/M on the flow properties of the toner. Toners that have an inherently better lateral flow performance yield higher Q/M values. This supports the premise that the lateral flow properties of the toner are one of the two critical parameters in determining the final charge level for the toner.
- The field charging process (and the resulting toner Q/M value) within each toner class is demonstrated to be independent of the color chemistry necessary to provide the individual toners. This demonstrates the overriding importance of **E** (over size and dielectric constant) in determining the q_{max} (Pauthenier limit).
- The toner Stability Voltage (V_{stab}), which reflects the system process conditions necessary to maintain a consistent toner coverage per area, is color independent.

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