# Surface Adhesion Properties of Field Charged Toners in a High Speed Toner Applicator

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## Abstract

Single component toners are charged uniformly in an electric field under ionic bombardment from coronal sources within a fluidized bed. Charge acquired by the toner is proportional to the local electric field associated with the corona source yielding a variable charge-to-mass ratio. Surface adhesion properties of these toners have been studied to determine uniformity of the charging process and charge distribution on the toner particle. Adhesion tests were done under dynamic conditions at operational surface speeds from 5 to 75 inches/second. Electric field detachment of the toner demonstrates uniform charge distribution on the toner particles. Also, process studies indicate insensitivity of the detachment process to particle size distribution and toner formulation, including surface additives.

## Introduction

Toner charging is classically done by triboelectrification, where dissimilar surfaces are frictionally rubbed against one another. One surface develops a positive charge; the other a negative one. Moving contact of toner particles with carrier beads, with a frictional blade, or with other dissimilar surfaces inside the hopper are common methods used to produce the tribocharged toners.

Charge exchange during periods of rubbing or surface separation occurs in localized areas on the surface of the toner. Common toner particles are irregular with protrusions and depressions. Studies suggest that typical milled toner particles have an average of 15 high points.[1] As this irregular toner particle is rubbed against another dissimilar surface for the purposes of tribo-charging, these protruding high points of the toner will be the areas on the toner surface which will develop the majority of the charge. Given that the resistivity of the toner is high enough, charge migration on the surface of the toner will be minimal. Therefore, the toner's charge will be concentrated on the assumed 15 high points. The distribution of charge on the toner will therefore be non-uniform and effect the surface adhesion properties.

On a macroscopic scale, the toner appears evenly charged and surface potential measurements on a toner layer with an electrometer[2] or in a Q/M cell demonstrate that a specific charge-to-mass ratio (Q/M) on the "toner" can be achieved. However, when one addresses the problem of removing these individual particles from a smooth conductive surface, the equation for the electrostatic adhesion doesn't seem to fit well with experiment:

$$\mathbf{F}_{ad} = Q^2/(4\pi\varepsilon_0\{2r\}^2) \qquad (1)$$

Of course, this equation assumes only that the charge Q is concentrated at the center of a spherical particle with radius r and that the force of attraction is between this point charge and its electrical image under the plane conductive surface upon which it rests. Other adhesion forces have been suggested to explain the additional apparent surfaces forces present.[3,4]

If one looks into the toner particle microscopically and amortizes the total charge over 15 relatively compact high points, the image force can change considerably. If the toner particle rests on a flat surface on 3 high points or protrusions, 20% of the toner's charge is in very close proximity to the surface. Integrating the adhesion force from these protruding charged points can account for almost an order of magnitude increase in adhesion force calculated from the broad assumptions of equation 1, given the same amount of charge and particle size. Theoretical studies using boundary element methods have also predicted increased particle forces when a non-uniform charge distribution is present.[5] Further experimental studies have shown disagreement between theory and actual adhesion forces present in a toner transfer cell.[6] A model based on the ratio of contact area to total charged area was presented which showed much better agreement to experimental data.

A system which could produce an even charge distribution offers the advantage of a lowered electrostatic adhesion force, thus making image development more efficient allowing for higher speed operation. A process using electrostatic fluidized bed technology has been developed which does produce even charge distributions on the toner particles.[7,8] The system, designed for a high speed electron beam imaging platform has demonstrated an efficient toner development means for imaging speeds from 5 inches/second to 75 inches/second. The efficiency of development and the surface forces have been studied for this development unit. Results have shown that adhesion forces of toners with even charge distributions are approximately an order of magnitude less than those with charge concentrations on the protruding points as found with tribocharging systems.

The technique used to charge the toner is called field charging.[9] It is a commonly used method in powder coating technologies and electrostatic dust precipitators. Toner particles suspended in a fluidized bed are bombarded with ions from high voltage corona sources. Uncharged particles distort the electric field lines of the corona due to the difference of the relative permittivities between the toner and the surrounding gas. Ions follow the field lines to the particle and the particle charges. A limiting charge is reached when the particle's charge creates a repulsion field equal to that of the charging field. The saturation charge, $Q_{max}$, is dependent on the particle size, relative permittivity, and the local electric field. Such a limit was first established by Pauthenier and Moreau-Hanot. The limit is commonly known as the Pauthenier limit and is defined by the equation,

$$Q_{max} = 4\pi\varepsilon_o r^2 p\mathbf{E} \quad (2)$$

where r is the particle radius, p is a dimensionless constant based on the relative permittivities of the toner and surrounding gas ( $p = 3k_t/(k_t + 2)$ ), and **E** is the local electric field strength.[10]

Given these variable factors in the equation, the toner related factors r and p have been found to be less consequential than the local field strength **E**. Toner formulation and size distribution have small effects on system performance, so long as they are held within reasonable limits. Critical to the process is the mixing or flow within the fluidized bed. To insure that a reasonably tight distribution of limiting charge is maintained, particles must be mobile enough to insure that they all be exposed to similar electric field levels, especially very near the corona wires. An important part to the process is the control that it renders over variable charging, charge-to-mass ratios and mass-to-area coverage ratios. Since the application of this development unit is ultimately used on a variable speed printing press, development speed needs to address a significant range, so the variable capability is imperative. Application to fixed speed imaging technologies is easily possible within an imaging speed range from 5-75 in/sec.

Simultaneous with the charging, the toner is transported through a dual roller delivery system to the latent electrostatic image via electrical forces. Transport from the fluidized bed to the first delivery roller is by the electric field between the corona and the roller. Upon contacting the moving conductive roller, the toner is held in place by the electrostatic adhesion force and other existing surface forces. Detachment of this toner from the first roller and transport to a second conductive roller is done by the electric field force between the rollers. It is at this point of the process that one further important step is accomplished. Possible wrong sign toner that has been manufactured in the charging process is not transferred to the secondary roller. Thus, by using the field detachment process with the dual rollers, a toner polarity filter is established at this transfer point.

Secondary roller dynamics and development of the latent electrostatic image are the same in nature as the first roller-to-roller transfer process.

## Apparatus

Figure 1 shows a schematic diagram of the applicator unit used to conduct the experiments. The toner reservoir containing the monocomponent resistive toner provides a means to levitate or fluidize the toner with a slowly rising uniform column of air. This column is created by pressurized air passing through a semi-porous plate in the bottom of the bed. Toner in the reservoir is suspended on the rising air current and behaves in a similar manner to a liquid with low viscosity.

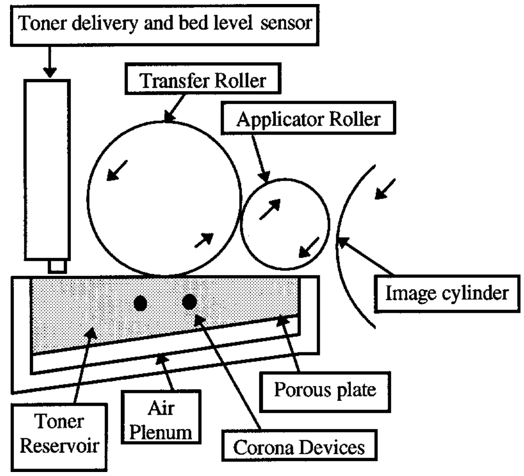


*Figure 1. Schematic diagram of the toner applicator system*

The toner exhibits a turbulent appearance on the surface of the bed with many random currents and overall lateral surface flow. It is this mixing which must be maintained to insure a tight charge distribution on the toner particles. Since the toner is bombarded by positive ions in the presence of the diverging electric field near the corona devices, toner flow and mixing insure that each particle will receive approximately the same charge-to-area (Q/A) coverage. The Pauthenier limit is variable in such a divergent field so a charge distribution (and Q/A distribution) is experienced.

In the experimental work, the corona potential was set at +7.1 kV. In actual operation, this is a variable potential to account for the change in M/A coverage needed for variable speed operation.

The roller system (transfer and applicator) is a counter-rotating system with both rollers having the same surface speed. Both rollers have hard polished outer surfaces and are conductive. For the experiment, the applicator roller was held at ground potential while the transfer roller varied to create peak electric fields from -0.5 V/mM to +3.0 V/µM. Experimental surface speed was held at a constant 12 inches/second.

Toner migrates from the fluidized bed to the transfer roller via electric field forces. Once on the transfer roller, on approximate monolayer of 0.70 mg/cm$^2$ is formed. Measurements of the field detachment of the toner were done dynamically by actual timed scrapings of the toner from the rollers. The scrapings were weighed and the fraction of toner transfer was calculated. These results were verified in actual print testing on a printing engine after additional calculations for development efficiency and transfer efficiency were done.

## Experimental

Given the test conditions set forth above, the layer voltage measurements taken with a TREK 344 electrostatic voltmeter gave a calculated Q/M of +14.2 µC/gm. Measured voltage on 12 µM toner with a M/A coverage of 0.7 mg/cm$^2$ was 45 volts. As measured, the charge on a typical 12 µM toner particle would be 13 fC. The adhesion force for such a typical particle would be 11 nN if polarization corrections are ignored.

Theoretical calculation of the Pauthenier limit in a dynamic fluid situation yields a Q/M of +10.6 μC/gm. A problem exists with this calculation, however, over the exact level of the electric field **E** near the corona. A value of $10^6$ V/M was used in the calculation, but the rapidly varying field near the corona and the random nature of the toner motion make this value an estimate only.

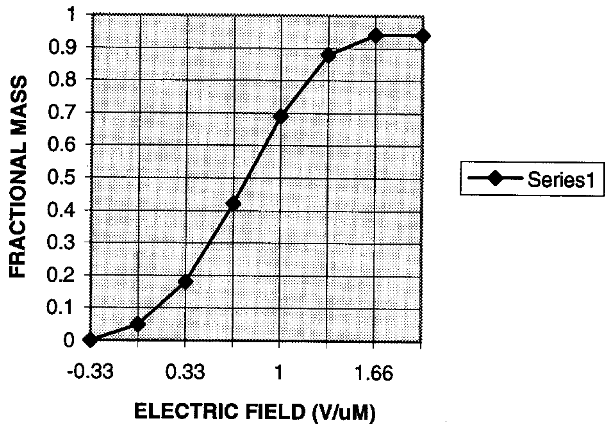


*Figure 2. Fractional mass of toner transferred for a given applied electric field* ***E****.*

Figure 2 shows a plot of the cumulative fractional mass of toner transferred to the applicator roller. Toner actually begins to transfer before any forward electric field is applied. This is probably due to an amount of toner "stacked" on the first layer having a much lower adhesion force. Total transfer of over 90% was achieved with a detachment field of 1.66 V/μM and above.

Further analysis of Figure 2 shows that approximately 50% of the toner is transferred to the secondary roller at a forward applied field of 0.66 V/μM. This amounts to a detachment force acting on the toner of about 9 nN which is close to the calculated adhesion force of 11 nN. The detachment force needed to remove the toner was found to be about an order of magnitude less than experiments done with tribocharged toners.[1,6] Polarization coefficients have been neglected for the adhesion and detaching field forces, but they are nearly equivalent for a sphere with a dielectric constant equal to 4. The actual polarization force was also ignored as it is dependent on the square of the field strength and would be negligible in low fields used here.

Particle detachment occurs simply when the field forces on the toner exceeds the adhesion and surface forces present;

$$Q\mathbf{E} > Q^2/(4\pi\varepsilon_o\{2r\}^2). \quad (3)$$

But given a constant Q/A density ratio on the toner, the equation for the detaching field can be rewritten and found to have no dependence on the actual particle size;

$$\mathbf{E} > (Q/A)(1/4\varepsilon_o). \quad (4)$$

Field detachment experiments confirm this as no selective size depletion has been noted in experiments conducted.

Uniformly charged spherical particles should all detach with the same field. However, the data shows a proportional dependence of toner transferred against the applied electric field from -0.33 to +1.66 V/μM. Two factors probably introduce such an analog dependence of transferred toner on the applied field:

The $Q_{max}$ on the particle has a large dependence on the local field from the corona. Statistically, toner would have a distributed charge based on the minimum distance achieved with the corona wires.

Because the toner is irregular in shape, some differences in contact area will be experienced. Also, surface areas on the particles will differ and the charge distribution relative to the contact surface will also introduce some variations into the adhesion forces.

## Conclusions

- Field charging of toner particles creates an even charge distribution on the surfaces of the particles.
- Field charging of toners is a useful method for achieving variable Q/A, Q/M, and M/A ratios on the toners in the development system.
- Particles with even charge distributions exhibit a lower electrostatic adhesion force than particles with uneven distributions. The adhesion force is about one order of magnitude lower.
- Electrostatic adhesion forces on individual particles ac count for the majority of the total surface force acting on a singular particle.
- Field charging of toners provides an efficient means for delivering toner over a wide range of operating speeds (5 - 75 inches/second) along with continuously variable speeds operation.

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