

Tribocharging of Three-Component Powder Mixtures

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Background

Triboelectrification, electrical charging by rubbing two materials together, is the oldest known manifestation of electricity. Although not well understood, tribocharging of powders can be controlled very precisely making it possible to use tribocharged particles to make high quality images in electrophotographic copiers and laser printers.

In electrophotography, a charged photoconductor is exposed to the image to be reproduced. Exposed areas of the photoconductor are discharged leaving a latent image consisting of a charged pattern on the photoconductor. Electrostatically charged polymer particles of the appropriate color, toner, are dusted over the photoconductor and adhere to it where it is charged. The developed image is transferred from the photoconductor to paper and fixed to the paper by heat and pressure.

In high-speed copiers, the toner particles used to develop the latent image are brought into contact with the photoconductor by mixing them with magnetic particles (carrier). The toner and carrier are chosen so that they exchange charge when they are brought together and become oppositely charged. Electrostatic forces cause the smaller toner particles to adhere to the larger carrier particles. The mixture of toner and carrier is transported magnetically to the photoconductor and brushed against it. Toner is removed from the carrier and deposited on the photoconductor under the influence of the electrostatic fields associated with the latent image. The carrier is returned to the developer station where it picks up fresh toner.

The triboelectric behavior of toner and carrier materials are the focus of this study.

Toner particles are 10-15 micrometers in diameter and are made from a pigmented polymer in order to produce an image of the desired color. The rheology of the toner polymer is chosen so that the image can be thermally fixed to the paper. In most cases, pigmented polymer does not tribocharge properly for the operation of a copier. Additives, called charge control agents or charge agents, are therefore included in toner formulations to control the sign and magnitude of the toner charge. Toner particles are usually prepared by melt-compounding the toner constituents and grinding to the desired particle size.

Carrier particles range from 30-200 micrometers in diameter. They are made from ferromagnetic metals or oxides so that they can be used to transport the toner, be separated from the toner magnetically and retained in the copier. They are often coated with a polymer so that the carrier imparts the proper charge to the toner particles.

Charging Models

Two Component Mixtures

Several models of charging of two-component powder mixtures have been proposed. The model used in this study is referred to hereafter as the "surface state model."¹⁻⁴ This model treats charging as exchange of electrons between carrier and toner surfaces. The amount of the charge exchanged is determined by thermodynamic equilibrium of electrons in energy levels available on the surface of the toner and the carrier.

The particular version of the surface state model used in this study is based on the assumptions that:

1. The surface of each powder is populated with electron accepting and donating sites;
2. The density of states of the donating and accepting sites can be represented by narrow bands all of which have the same energy; and
3. Charge is exchanged between donor and acceptor sites until equilibrium is established.

Analysis of the equilibrium charge exchanged between donating and accepting charge sites on both the toner and the carrier leads to the following relationship between the mass to charge of the toner particles, m/q , and the mass ratio of toner to carrier in the mixture, T/C :

$$m/q = Q' \left\{ (D_c + A_c) / S_t (D_t A_c - A_t D_c) + T/C (D_t + A_t / S_c (D_t A_c - A_t D_c)) \right\} \quad (1)$$

In Eq.(1) A and D stand for the concentration per unit surface area of acceptor and donor electronic states respectively. S is the specific surface area, and Q' is a constant. The subscripts t and c refer to toner and carrier.

This equation predicts a linear relationship between m/q and T/C . The slope and intercept depend upon the surface area of the particles and the concentration of donating and accepting sites on their surfaces.

Multi-Component Mixtures

In this paper, the model is extended to multi-component mixtures. In developing the model which leads to Eq. (1), it was assumed that the charging sites on all particles in a mixture are in chemical equilibrium. Practically, this means that the mixing in the powder during charging is vigorous enough that the acceptor and donor charging sites on each component of the mixture come in frequent contact with one another. In order to extend the model to multi-component mixtures, one can treat the mixture as if it were

a two-component mixture. The first component is one of the actual components in the mixture. The second, referred to as a "pseudo-component," is a composite of the other materials in the mixture. The charging site densities on the first component are those which are assigned to it in a binary mixture. The acceptor and donor charging sites assigned to the pseudo-component are the sums of the acceptor and donor charging sites respectively of the rest of the materials in the mixture. Thus, equation

(1) can be rewritten as

$$m_1 / q_1 = \frac{Q' [\sum f_j S_j (D_j + A_j)]}{S_1 [D_1 \sum f_j S_j A_j - A_1 \sum f_j S_j D_j]} \quad (2)$$

where m , Q' , S , D , and A are defined as in Eq. (1), the subscript, 1, refers to the component of interest. f_j is the mass fraction of component j , and the sums are taken over all components in the mixture including component 1.

Eq.(2) predicts that m/q for each component of a mixture should be a linear function of its mass fraction. The ratio of the slope to the intercept of the line gives the ratio of the total number of charging sites on the material of interest to the sum of the charging sites on all of the other components.

Experimental

Measurements of m/q as a function of T/C were made as follows: Powder mixtures were agitated in an AC coil by the magnetic field for 30 seconds to tribocharge the toner. After charging, approximately 0.15 gram of the mixture was placed in a stainless steel dish. A permanent magnet was rotated (2000 rpm) under the dish to agitate the mixture. A DC electric field (approximately 2000 volts/cm) was applied between the dish and a flat metal plate above the dish and separated from it by about 1 cm. The electric field and rotating magnet were switched on for a preset time interval. When both the rotating magnetic field and the electric fields are applied, toner is released from the carrier by the magnetic agitation and transported to the plate by the electric field. The carrier remains on the dish. This proce-

dure was repeated 10-15 times to remove all of the toner from the carrier in increments. The charge on the toner collected on the plate was measured with an electrometer, and the weight of the toner collected on the plate was determined. The amount of toner removed and its m/q were recorded.

These data were used to construct a plot of m/q as a function of T/C , hereafter referred to as a T/C series. As expected from eq.(1), m/q was found to be a linear function of T/C . (See Table I.)

Results

Seven T/C series for two-component mixtures made using three toners (1, 2, & 3) and three carriers (A, B, & C) were measured. Five ternary mixtures were also made as shown in Table I. Two cases of a mixture of two toners on one carrier are included in this set of materials. In these cases, the toner was a 50-50 mixture of the two toners. The colors, magenta and cyan, were chosen so that differences in the ratio of the two toners could be easily determined by their color as they were removed from the carrier. In these examples, the color remained constant indicating that the ratio of the two toners in each increment of toner removed remained at 50-50. That is, the two toners were removed at the same rate from the carrier. The carrier was treated as the component of interest and the toner mixture was treated as a pseudo-component for the purposes of searching for the best set of charging site densities. For the three mixtures of one toner and two carriers, the toner was treated as the component of interest.

Charge to mass was measured by the method described above. Plots of m/q as a function of mass fraction in the ternary mixtures were made. Table I shows that these relationships were also linear.

The data were fit to the surface state model as follows: First, an initial guess for the concentrations of donor and acceptor charging sites on each of the toners and carriers was made. Eq. (1) was then used to calculate m/q for each data point of the T/C series. The root mean square (RMS) differences between the measured and calculated m/q values were determined. A search routine was used to find a set of charging site densities which minimized the RMS difference.

Table I. Results of Toner Concentration Series and Charging Site Analysis

| Toner | Carrier | Slope | Intercept | Corr. Coef. | RMS Error (all data) | RMS Error (binary data) |
|-------|---------|-------|-----------|-------------|----------------------|-------------------------|
| 1 | A | 2.2 | 0.026 | 0.85 | 13.3% | 9.7% |
| 1 | B | 0.65 | 0.025 | 0.98 | 9.3% | 9.1% |
| 2 | B | 0.30 | 0.016 | 0.96 | 7.0% | 5.8% |
| 3 | B | 0.29 | 0.020 | 0.99 | 4.9% | 3.8% |
| 1 | C | 0.20 | 0.020 | 0.93 | 10.6% | 10.0% |
| 2 | C | 0.21 | 0.011 | 0.97 | 9.7% | 7.5% |
| 3 | C | 0.13 | 0.014 | 0.82 | 6.8% | 11.0% |
| 3 | B + C | 0.21 | 0.016 | 0.96 | 8.6% | 9.6% |
| 2 | A + B | 0.92 | 0.002 | 0.99 | 16.9% | 28.9% |
| 1 | A + C | 0.39 | 0.021 | 0.99 | 5.3% | 10.5% |
| 2 + 3 | C | 0.16 | 0.012 | 0.98 | 10.9% | 12.9% |
| 2 + 3 | B | 0.32 | 0.017 | 0.99 | 4.0% | 4.3% |

Table II. Estimated Charging Site Densities

| Toner | Fit to all data | | Fit to binary data only | |
|----------------|-----------------|---------|-------------------------|---------|
| | Acceptors* | Donors* | Acceptors* | Donors* |
| 1 | 53 | 117 | 52 | 113 |
| 2 | 34 | 169 | 22 | 132 |
| 3 | 18 | 115 | 16 | 107 |
| Carrier | | | | |
| A | 2.7 | 4.0 | 4.9 | 7.8 |
| B | 4.5 | 4.7 | 4.7 | 4.8 |
| C | 8.0 | 3.1 | 8.5 | 3.0 |

*Relative Units

Fitting was done in two ways. In the first case, all 13 of the T/C series were used to estimate charging site densities. The best fit set of charging sites is given in Table II. The RMS error between the measured and calculated m/q values for each T/C series is also given in Table I to illustrate how well the calculated m/q values match the experimental data. In the second case, only the binary data was used to determine the charging site densities. The best fit set of charging sites using the binary data only is given in Table II. Table I also shows the RMS error between the measured and calculated m/q values for each T/C series for this case.

Conclusions

The relative RMS error between measured and calculated m/q values when both the binary and ternary mixtures were used to determine the charging site densities was less than 20% for all series. (See Table 1.) In most cases, it was much smaller. Thus, experimental charging measurements of two and three-component mixtures were well represented by the surface state model of charging. This indicates that the assumptions above of thorough mixing and equilibrium are consistent with the tribocharging performance of the materials. The relative RMS errors for the three-component mixtures found when only the binary data was used to estimate the charging sites densities are slightly larger than those when all of the data was used. This indicates that the charging site densities assigned to the materials are related to inherent triboelectric properties of each material and are independent of the other materials in a mixture. It also demonstrates that the surface state model can be used to predict charging behavior of ternary mixtures from measurements using only binary mixtures.

References

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