Determination of Wrong-Sign Toner Content by Reflectance Technique

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Abstract

Photoconductor reflectance after toner developement is shown to provide a quick, highly effective technique for estimating the wrong-sign toner content. The idea is based on the relationship between reflectance and toner coverage, a dependence that can be calculated using few approximations. The measured and calculated results were verified here to be reasonably close. Toners with widely varying characteristics were tested. The technique worked well with black irregular and chemical toners and can be extended to color.

Introduction

In electrophotographic printers wrong-sign toner (WST) can strongly affect performance. High WST content is associated with poor image edge acuity and increased background.[1] Untransferred toner removed by the cleaner decreases yield. Since many factors affect wrong-sign toner generation,[1,2] tracking the relevant trends is desirable.

Traditionally, a charge spectrometer is used to determine the toner charge distribution, including the wrong-sign fraction. The Lewis design has produced numerous results[3] since its introduction in 1981. Present commercial instruments include the E-Spart[4] and the Epping.[5] Charge spectrometers should be quite accurate[6] for the toner processed. But the test sample must mirror the toner population distribution. Unless the calculated toner charge-to-mass ratio (*q/m*) obtained from the charge spectrometer comes close to that obtained by other independent means, the results are suspect. Gee[2] showed that a specially-designed inlet against a soft monocomponent developer roll (DR) produced comparable charge spectrometer and vacuum lift-off *q/m*. But for many hardware configurations, only the lowest charged toner can be drawn into the spectrometer. Hence even great effort may not ensure an accurate WST result.

One simple way to assess the WST content is to examine the photoconductor (PC) after development. On a white page only WST, possibly paired with right-sign toner,[7] should attach to the PC, and just the WST should remain after transfer. On a developed image the toner remaining after transfer is also believed to be wrong signed. Hence to study toner differences and hardware changes that affect wrong-sign generation, just tracking the PC toner[1] may be sufficient. Indeed, the PC toner manifests the relevant WST effects even if it does not directly provide the absolute WST content.

The PC toner coverage can be estimated using computerized video techniques, which also provide size distribution information. But for sufficient resolution and statistics, a large sample population would be required. A simpler and less expensive method is to simply look. The PC is highly reflective. Toner scatters and absorbs. Hence the coverage can be obtained by measuring the relative PC reflectance with and without developed toner. Traditionally PC reflectance has been used to determine solid-area development density[8] as a feedback signal to control the toner concentration in two-component mixes. More recently Lee[9] used this technique to monitor residual toner coverage after cleaning. In this work we calculate the PC reflectance as a function of toner coverage and compare it with measured results. We use the technique to examine the relevant WST content.

Theory

The reflectance from the PC typically decreases with increasing toner coverage. In the simplest approximation we can assume the toner occludes the much more reflective PC surface. Hence the reflectance R is given by

$$R = 1 - A_R \tag{1}$$

where A_R is the ratio of the occluded area A_t to the total area A. Here the clean PC reflectance is taken to be 1. Naively one may think that A_R increases linearly with toner mass-per-area (*m/A*). But the dependence should be sublinear as explained below.

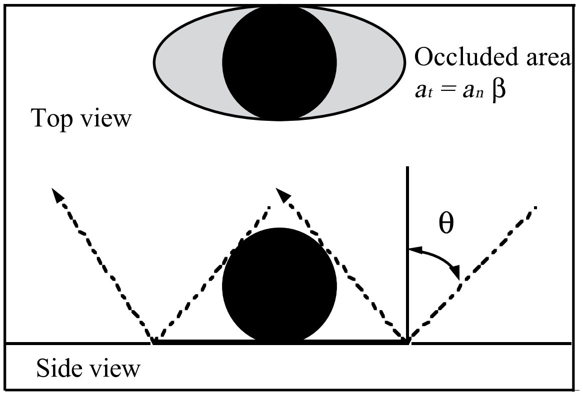

Figure 1. Increased toner occluded area at non-normal incidence. Incident light at angle θ. Solid black circle represents toner. Ellipse in top view encompasses occluded area.

Suppose the projected area for a single particle at normal incidence is a_n. If the incident light is normal, A_R is just the product of the number of particles and the average a_n divided by A, assuming isolated particles. At any other angle θ the measured reflectance is lower because the single-particle projected area is larger than a_n as shown in Figure 1. For a single spherical particle with diameter d, its projected area ad can found from geometry to be

$$a_d = \pi\, d^2\,(1 + \sin\theta) / (4 \cos\theta) \tag{2}$$

$$= a_n\, \beta \tag{3}$$

where $a_n = \pi\, d^2/ 4$ is again the normal projected area of the particle and $\beta = (1 + \sin\theta) / \cos\theta$ is the angle factor.

$\theta = 0$ is much more difficult to implement in hardware than $\theta >> 0$. In our work $\theta = 30°$, giving $\beta = 1.73$ for spherical particles. Hence just 0.6 monolayer coverage is theoretically enough to eliminate specular reflection from the PC surface. In practice, this is insufficient because toner placement is not spatially uniform. A fraction can sit at least partially in others' shadow, and that fraction increases with coverage. Thus the reflectance decreases sublinearly with toner coverage.

The functional dependence can be estimated using simple assumptions. Consider k identical spherical particles in area A. To first order the probability that any one particular particle sits in shadow is proportional to k. For k such particles the fraction in shadow should be proportional to k^2. Thus A_R should be of the form

$$A_R = \beta\,(\gamma - \nu\gamma^2) \tag{4}$$

where $\gamma = a_n\, k/A$ is the fractional area taken up by the toner confined to a monolayer. ν can be estimated by considering toner in a close packed lattice which occurs at $\gamma = 0.9$. There A_R is certainly 1. Using these conditions and Equation 4, $\nu \approx 1.23\,(0.9 - 1/\beta) = 0.398$. But for convenience we choose instead $\nu = \beta/4$ (=0.433) to produce a smoother reflectance curve as explained below. Here $A_R = 1$ at $\gamma = 2/\beta$. Actually the A_R dependence on γ should increase more slowly than Equation 4 at close to monolayer coverage because toner tends to pile on top of others long before the first layer is filled. But the coefficient of this higher power term cannot be simply estimated. So A_R is left as in Equation 4.

For coverage far beyond a monolayer little or no PC surface is likely exposed. Yet reflectance is typically not much below 3% for black toners. Aside from exposed PC, this residue may be due scattering off test hardware or toner facets oriented at just the right angle. Hence a constant η should be added for completeness to Equations 1 and 4 to give

$$R(\gamma) = 1 - \eta\beta\,(\gamma - (\beta/4)\,\gamma^2) \qquad \text{for } 0 < \gamma < 2/\beta \tag{5}$$

$$= 1-\eta \qquad \text{for } \gamma \geq 2/\beta. \tag{6}$$

R is continuous and differentiable across $\gamma = 2/\beta$. γ can be written in terms of m/A for a given average particle size by noting that

$$\gamma = a_n\, k/A = 1.5/(\rho d) \times m/A \tag{7}$$

where ρ is the toner density and β =1.5 links the projected area to volume for spherical particles. At $\theta = 30°$, $\beta\gamma = 2.60/(\rho d) \times m/A$. For convenience we call $s = 2.60$ the nominal slope of the reflectance curve. Although the above analysis uses identical particles, the same arguments can be extended to a distribution by assuming that each size independently adds to γ. The effect turns out to be small. Compared to monosized particles, a gaussian distribution with 7 µm average size and 4 µm half width produces a γ that is only 3% higher at the same m/A.

Conventional irregular toner is more angular than spherical toner. As an extreme, consider cubic particles. A similar analysis shows that β, which now depends on the particle orientation relative to incident light, averages around 2.47 at 30°. Although this is significantly more than β for spherical particles, s remains nearly unchanged because it depends also on b which is just 1 for a cube. The resultant $s = 2.47$, just 5% smaller than the 2.60 for spherical particles. For irregular toner intermediate between the two extremes, s is likely around 2.54. So Equation 5 should closely match the measured results at low coverage irrespective of the exact particle shape, provided ρ and d are accurately measured.

Experimental

The experiments were performed using various commercial and experimental toners in two printers, a Lexmark Optra R+ and an OkiData OL400e. The Lexmark developer works well with irregular toner for which it was designed but had some problems with chemical toners. The Oki comes with a spherical chemical toner. Both developers can be readily cleaned leaving little of the residues that can affect subsequent toners to be tested.

In both printers the transfer roller resides directly beneath the PC. Thus the pre-transfer side lies on one side of the PC bottom and the post-transfer on the other. The test module has a center HP HLMP-C100 AlGaAs LED at 650 nm driven with 20 mA and two Advanced Photonix SD 172-11-11-221 Si photodiodes arranged so that both the pre- and post-transfer sides can be observed simultaneously. The signals are amplified with an LMC6482AIN dual op amp and monitored with two HP 34401A Multimeters. The reflectance testbed is shown in Figure 2. The developer cartridge sits over the rail on which the test module slides. In a typical experiment the developed PC reflectance is obtained at 10 preset module positions along the rail. The PC is then cleaned and remeasured at the same positions. The results are averaged. The entire measure-clean-measure sequence takes about 200 s.

m/A was derived by determining the toner mass removed from a known area using a Mettler ME162 balance. Two methods were needed. The convenient vacuum pencil worked adequately for $m/A > 0.1$ mg/cm^2 but suffered at lower coverage because a vacuum-induced weighing instability[2] loomed large. Fortunately, Scotch 600 transparent tape worked very well in removing toner down to 0.01 mg/cm^2 without the instability. Thus a sufficient fraction of the curve could be verified. The wide *m/A* range was obtained by using white and black pages for low and high coverage, respectively, and extending those regions by adjusting the printer development voltage.

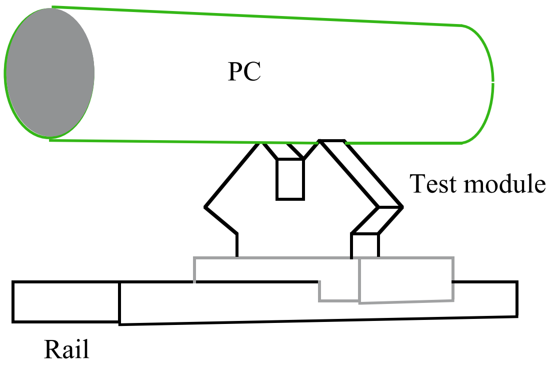

Figure 2. PC reflectance test apparatus. PC cartridge sits on two end stands and back stabilizer (not shown).

Results and Discussion

We first check how close Equations 5 and 6 come to correctly predicting the reflectance curve as a function of *m/A*. The result for a 1.05 g/cm^3 irregular black toner is shown in Figure 3. The toner on the DR has a 5.6 µm numerical median diameter with a 2 µm half width, as determined by a Coulter Counter. Development conditions can affect the PC toner size, which has a large effect on reflectance at a given *m/A*. But we assume without verification that the size remains the same as that on the DR. From the theory section *b* = 2.00 and *b* = 1.27 would be reasonable for irregular toner. *h* = 0.9724 was chosen to match the reflectance at high coverage. The resultant theoretical curve comes close to the observed values throughout. On the low coverage side the near coincidence is not surprising since the calculation is based on geometry with minimal assumptions. In the intermediate region the deviation is only slightly larger even though n is a rough estimate.

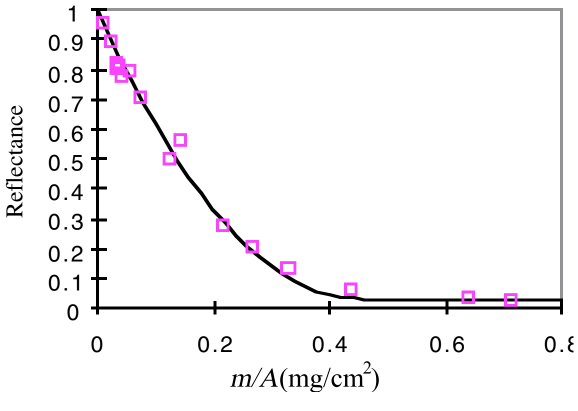

Figure 3. Reflectance vs. m/A for irregular black toner. Curve shows calculated result.

Figure 4 shows the reflectance curve as a function of *m/A* for a 1.02 g/cm^3 black chemical toner with a 6.3 µm DR median diameter. Here we use the parameters for spherical toner: β = 1.732 and β = 1.50. The calculated curve again comes close to the measured reflectance values at small *m/A*. The deviation is significantly larger at intermediate coverage, probably because the spherical toner produced a less uniform layer on the PC which could cause more toner stacking before the PC is covered. A higher order term to account for the stacking could close the gap between data and theory but was not included for reasons discussed above. The residual reflectance at large *m/A* is higher for spherical particles with η = 0.943. Unlike irregular particles that must be properly oriented to reflect light into the detector, every spherical particle has a region at the correct angle facing the light source.

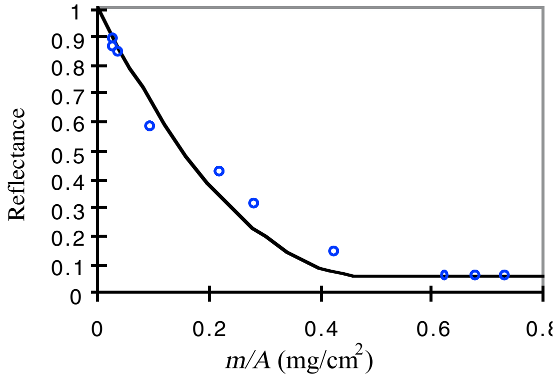

Figure 4. Reflectance vs. m/A for chemical black toner. Curve shows calculated result.

For color toners the reflectance technique works if the toner strongly absorbs at the LED wavelength. The reflectance of an irregular cyan toner at full coverage (1.3 mg/cm^2) was 0.028, the same as that of black toner. Results at lower coverage follows a similar dependence as that in Figures 3 and 4. On the other hand the full-coverage reflectance of yellow and magenta toners were significantly higher, around 0.56 and 0.47, respectively. The light apparently penetrates the material, undergoes reflections, and makes its way to the detector. Hence our analysis, which assumed that the toner eliminates (nearly) all specular reflection from the PC, is inadequate. Optical absorption measurements confirm that neither toner significantly absorbs 650 nm radiation. To use the reflectance technique, a source must be available which is both absorbed by the toner and compatible with the PC. Our particular magenta and yellow formulations both absorb around 500 nm, away from the undesirable UV region. So the possibility remains.

The above results confirm that PC reflectance provides a reasonable measure of toner coverage. In particular the dependence of the relevant WST content on a printer parameter can readily be obtained. As an example, consider doctor blade bias, which is commonly used to suppress background.[2] For negative toner a negative blade bias is used. Figure 5 shows the white-page pre- and post-transfer PC reflectance as a function of bias relative to the DR. The dependence is similar to published results[2] obtained by other techniques. The print shows a similar change in background coverage. Interestingly, the pre- and post-transfer reflectance curves are nearly coincident. This is surprising since some toner is transferred. Indeed, Reference 2 suggests that the print background coverage is about the same as that on the PC and is derivable from the toner wrong-sign content. We examined white-page PC toner captured on transparent tape. By particle counting the toner coverage on paper was determined to be around just 3% of the PC coverage at large positive voltage, increasing to 8% at large negative voltage. At 0.99 reflectance, 8% coverage difference is equivalent to going from, say, 0.990 to 0.991. Thus the pre- and post-transfer reflectance should be quite comparable.

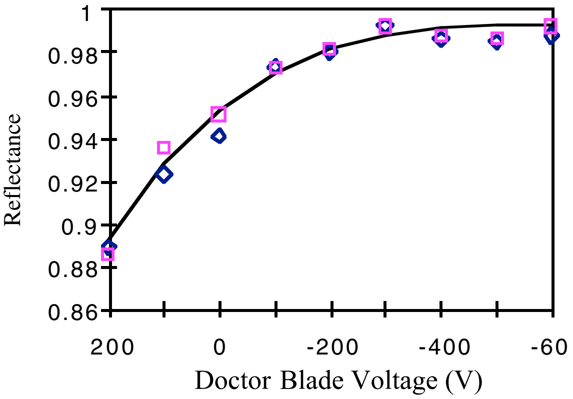

Figure 5. Reflectance vs. doctor blade voltage for irregular black toner. Diamond and square represent pre- and post-transfer, respectively. Curve shows approximate dependence.

Table 1. PC reflectance for several toners operated under standard printer conditions.

		PC Reflectance		
Toner	Printer	White pre-	White post-	Black post-
A (irr)	Lexmark	0.990	0.990	0.874
B (irr)	Lexmark	0.985	0.989	0.826
C (chem)	Oki	0.935	0.938	0.924
D (chem)	Oki	0.951	0.957	0.847
E (chem)	Oki	0.814	0.769	0.869

For the same hardware and voltage conditions, toner comparisons can also be enlightening. Table 1 shows the reflectance results for several commercial and experimental toners developed under standard printer conditions. Few toners had white-page reflectance in the reasonable > 0.97 range. Lower reflectance points to poor charging or other defects. The worst toners produced non-uniform layers, which causes highly varying measurements. While the wide performance range is due largely to the toner quality itself, hardware and operating parameters also play a part. So for reasonable behavior, the toner and hardware should be closely fitted together. For apparently comparable toners the average particle size should also be considered. At the same reflectance larger toner can generally be better seen by the naked eye. So if the toner transfers, the larger size may well produce a worse visual background.

Conclusions

In this work we studied photoconductor reflectance after toner development as a method for estimating the effective wrong-sign toner content. We showed that the reflectance as a function of toner coverage can be calculated, and the resultant curve closely matches measured values. At high coverage the residual reflectance is small and depends on the toner. Irregular toner appears to reflect less than spherical in proportion to the surface fraction that can scatter light into the detector. For color toners comparable results can be obtained if the toner absorbs the probe radiation. At our 650 nm wavelength cyan works quite well while magenta and yellow have high saturation reflectance. As a test of effective WST content, the PC reflectance is assumed to be directly dependent on the WST toner coverage while printing white. While results vary widely, the best toners have white-page reflectance > 0.97.

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