TRANSLUCENT BLURRING
ERRORS IN SMALL AREA REFLECTANCE SPECTROPHOTOMETER & DENSITOMETER MEASUREMENTS

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INTRODUCTION

Commercially available print control strips often contain color control target elements that are 5 mm or less in size. In the past, these elements were typically evaluated using small spot reflectance color densitometers. During the past two years, two manufacturers of these densitometers have introduced battery-operated, portable spectrophotometers which measure the CIE colorimetric values in addition to the standard ANSI color density values.

Late last year, the CGATS color science working group which is preparing a draft ANSI standard for SWOP printing, conducted a round-robin measurement series with a set of printing ink exhibits. This involved measuring these ink samples at three different laboratories using a total of five instruments. Each laboratory measured the exhibits with same model 45/0 reflectance portable spectrophotometer. In addition, two of the laboratories made measurements using laboratory bench instruments. The measurements made with the three portable instruments were in very close agreement (1 to 2 CLab units). They did not, however, agree with the values measured with the two laboratory bench instruments.

In a subsequent effort to discover the source of these measurement differences, it was realized that most, if not all, spectrophotometers and densitometers made for measuring the reflectance of small areas (<10 mm²) of photographic and printed materials have a basic design defect which introduces error into the measured values. The magnitude of this error is determined not only by the instrument design, but also by the nature of the sample being measured.

BACKGROUND

To fully appreciate the significance of these errors, they must be viewed in relationship to the more common errors sources present in spectrophotometric measurements. This section gives a short review of these errors.

As a rule, spectrophotometric measurements of a set of samples made with two or more instruments do not agree exactly. (In fact, measurements made with the same instrument on different days often may not exactly agree.) Measurement results from any two spectroreflectometers can differ for a number of reasons. Specific to the present study, results from two 45/0 instruments can differ for any of the following reasons:

- *Spectral Error* - the spectral analyzers in two instruments may not be measuring the same spectral band. This can be caused by:

  - *Wavelength Error* - an instrument may be actually measuring spectral bands centered at wavelengths that deviate from those being reported by the instrument system.

  - *Bandwidth Difference* - the spectral band pass of two instruments may differ. The band pass of various instruments may range from 1 to 20 nm, however, most report data for 10 nm intervals. The algorithms used in obtaining this 10 nm reported data from the actual measured data are typically different for each instrument.

  - *Stray Light* - ideally, the spectral dispersing elements used in the instrument should pass only light in the wavelength band being analyzed. However, some light from other sources can be scattered into the dispersed output light. Fortunately, the modern holographic grating used in most instruments today reduce stray light to an inconsequential value.

- *Photometric Error* - the reflectance value reported may be in error because the measuring system hardware and software used to measure the reflectance values induce errors. This can be caused by:

  - *Photometric Nonlinearity* - The detector used to measure light intensity may not always give an output that has a constant linear relationship to the intensity of the light falling on it. Thus, the detector may not give twice the output for a sample that has twice the reflectance value.

  - *Zero Error* - most laboratory instruments require a separate zero reflectance calibration. Most of the portable instruments examined used an internal zeroing scheme. If this internal zero value is not accurate, measurements of samples with low reflectance values will be inaccurate.

  - *White Calibration Error* - All instruments use some sort of white standard plaque for calibration of the 100% reflectance value. Failure to keep this standard clean or degradation caused by long exposure to intense light can result in the 100% calibration of the instrument being in error. At least one of the portable instruments uses a white enameled panel as a standard. The pigment used in this enamel, rutile TiO_2, has only about 20% reflectance at 400 nm. This low standardizing plaque reflectance value, when combined with an uncertain zero value, can cause added uncertainty in the 100% value at short wavelengths.

- *Computational Errors* - most of the 45/0 instruments provide software routines and/or hardware for computing color coordinates and color densities from the reflected light values. ASTM E308 (1) specifies standard methods for computing the various CIE color coordinates from reflection data. ANSI/ASC PH2.18 (2) specifies standard methods for computing color densities. The computational routines supplied with the instruments may not comply with these standards. (Our practice in evaluating various instruments has been to record only the spectral reflectance data from the instrument and then use software routines based on the cited standards to compute the color and density values. This gives a computationally consistent set of values for instrument evaluation.)

- *Errors Caused by Instrument Structure* - ASTM E1164 (3) gives the standard practice for obtaining spectrophotometric data for object-color evaluation. Included in this standard are the illumination and viewing geometries for 45°/Normal (45/0) and Normal/45° (0/45) measurement of reflectance factor. While instrument wavelength errors are easily measured, failure to meet these geometric requirements can not be so readily determined. Considering the small structures and low power light sources used in portable instruments, one may speculate that these geometry specifications are not met by some instruments. Also, the ASTM standard does not specify minimum values for stray light scattered by the instrument structure into the viewing optics.

- *Errors Caused by Sample Interactions with the Instrument* - Most spectroreflectometers and densitometers are designed to have maximum accuracy when used to measure some nearly ideal sample such as a high gloss standard plaque. Graphic Arts products exhibit considerable deviation from these ideal samples. These samples effectively interact with the instrument to give measurement errors. Some of the physical factors of the samples that can cause these less perfect results are:

    - *Fluorescence* - many printing stocks and proofing materials add fluorescent dyes to enhance the product brightness. The UV in the instrument illumination excites these dyes. Since the amount of UV in the light source varies from instrument to instrument (even when the same model instrument is used), the resulting measured values will vary.

- *Surface Gloss Variations* - 45/0 instruments are designed to measure light from diffusing samples with high gloss surfaces. When the sample does not exhibit these characteristics, the effects of otherwise minor variations in geometry and light scattered from the structure are disproportionately enhanced.

- *Bronzing* - the index of refraction of the sample surface may be altered by the application of inks with high pigment loadings. This index change can affect the value of the gloss in largely unpredictable ways. Since the instrument calibration assumes constant gloss, the measured values can be affected.

- *Translucency* - if the sample is translucent and some of the illuminating light scatters laterally to points outside of the area viewed by the instrument detector, the reported reflectance value will be lower than it would be if all of the reflected light were collected.

TRANSLUCENT BLURRING - THE MECHANISM

Translucent blurring error occurs when the instrument illuminating light diffuses laterally (sideways) in the sample and emerges at point outside the area viewed by the instrument detection system. As such, it is an interaction between the translucency of the sample and optical configuration of the instrument. The effect is not a problem if the sample is opaque.

Instruments which define the area to be measured by placing an aperture plate in contact with the sample surface will be most sensitive to sample translucency. The plate insures that the area illuminated and the area viewed by the instrument are exactly the same. Any light that diffuses sideways in the outward radial direction before emerging from the surface is blocked from instrument viewing by the plate.

Jack J. Hsia published a NBS Technical Note (594-12) in 1976 (4) which gives a detailed mathematical explanation of the translucent blurring error. Just as we would not have a fluorescence problem if none of the samples measured contained materials that fluoresce, we would not have translucent blurring problem if the samples being measured were all totally opaque. With the exception of metals, all of the commonly used graphics arts substrates are translucent to some degree.

The standards defining the measurement geometries for reflectance density and spectrophotometry functionally recognize the translucent blurring problem - many of the instrument manufacturers have ignored the portions of the standards which are included to minimize the blurring effect. ISO 5/4 (5), Part 4, is a standard for the geometric conditions to be used in reflection density measurement. Paragraph 4.3 states that "The irradiated area of the specimen shall be greater than the sampling aperture, and its boundary shall lie at least 2 mm beyond the boundary of the sampling aperture." To the best of the author's knowledge, none of commercially available small aperture reflectance densitometers meet this specification.

ASTM E805 (6) deals primarily with procedures for reporting colorimetric measurement results. Paragraph 5.1.4 specifies the method for reporting the measurement aperture size. A note at the end of the paragraph states: "Where light penetrates past the opening and into the specimen as a result of coarse texture, translucency, or crepes construction, it is desirable to have the illuminating beam significantly smaller than the viewing beam, or the converse to minimize edge effect. The difference in radii should approximate the depth of penetration of light into the specimens." This paragraph note gives Jack Hsia's NBS tech note as a reference. Interestingly, the previously mentioned ASTM standard for spectrophotometric measurement, E1164, which was published seven years later, does not specify the relation of illumination and viewing areas.

The blurring error gets worse as the sample area gets smaller. Since the sideways scatter is a function of the sample translucency and not a function of instrument sampling area, an instrument with a 3 mm diameter illumination and viewing area would have a blurring error 100 times greater than for an instrument with a 30 mm diameter areas when measuring the same translucent sample.

TRANSLUCENT BLURRING - A PORTABLE INSTRUMENT EXAMPLE

As mentioned in the introduction, late last year, we found that the measurement of ink sample exhibits made at 3 different laboratories using 45/0 portable spectrophotometers made by one manufacturer agreed very closely. However, the data from the portables did not agree with the data from 45/0 bench top spectrophotometers at two of the laboratories.

In an effort to determine the source of these differences, we measured an uncalibrated set of British Ceramic Research Association (BCRA) standard colored tiles with a laboratory Gardner color machine spectrophotometer and a portable instrument. (These BCRA tiles are often used for instrument evaluation studies.) The measurements of the 3 gray tiles in the set indicated the two instruments exhibited about the same photometric linearity and that the zero and 100% level tracked well. Measurements of the red, orange, and yellow tiles indicated that the two instruments did not have the same wavelength scale.

While we felt that the Gardner had an accurate wavelength scale, the close agreement of the 3 portables in the ink test gave some concern. In order to allay this concern, we purchased a set of 12 calibrated color standards from Fredrick T. Simon, Inc., P. O. Box 391, Clemson, SC 29633. When we measured these calibrated standards with both instruments, we found that the differences between the Gardner measured values and the calibration data was about one-quarter of the differences between portable values and the standards data. (The portable still appeared to have a wavelength error. We have talked to a concern that is selling this portable unit on an OEM basis. They suggest that a translucent blurring error could appear to be a wavelength error. They are currently making an independent measurement of the wavelength calibration of several portables.)

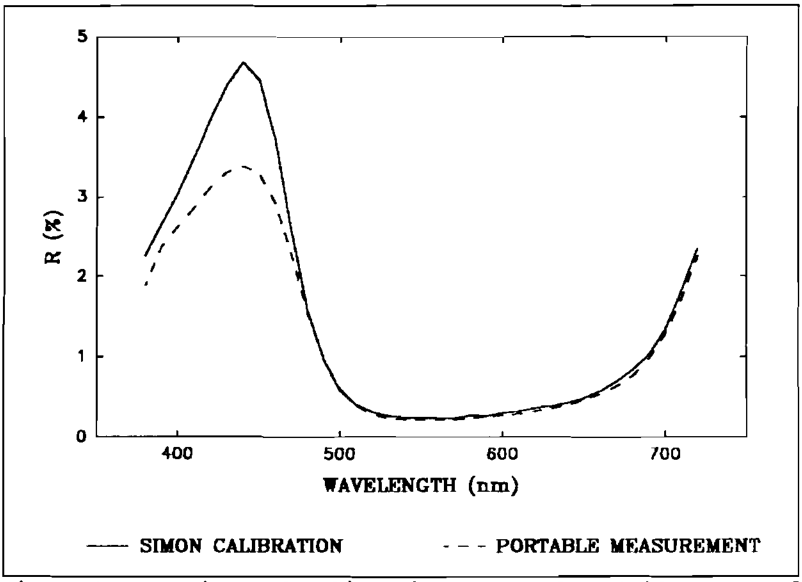

Figure 1 *Comparison of calibration data and portable measured data for the Simon Deep Blue 15 standard.*

During a conversation with Fred Simon about our calibration efforts, he mentioned that he was reformulating the bright yellow and deep blue standards because they were slightly translucent. Figures 1 compares the calibration data for the deep blue standard and the portable instrument measured data. The low measurement value at 450 nm shows that the portable is not collecting all of the light being reflected by the chip. (Subsequent examination of the measurements of the BCRA tile set also showed a blurring error in the portable data. The colored glaze on some of these tiles is quite translucent. Therefore, they may not be suitable for calibrating small aperture instruments.)

HOW CAN THE TRANSLUCENT BLURRING ERROR BE MINIMIZED ?

The portable instrument shows a sizeable blurring error. Considering the fact that this error arises from the illumination and viewing areas being about the same size, we might ask how much bigger does the illumination or viewing area have to be to reduce this error to an inconsequentially small value ? The sample area illuminated by the portable could not be readily increased without major modifications to the instrument. On the other hand, our laboratory Gardner color machine does allow us to change the illumination area while using a constant, small, viewing area.

The Color Machine(tm) normally illuminates and views a 31 mm diameter sample area. The light reflected by the sample is collected by a 4 mm diameter fiber optic bundle. The area of the sample viewed is determined by the 4 mm bundle and a 10 mm aperture stop mounted between the bundle and the sample. This arrangement appears to give the highest sensitivity at the center of the sample area with a gradual tapering off (feathering) at the edge of the sample area. An accessory lens can be used to replace the aperture stop when a smaller viewing area is desired. This lens gives a sharp edged 5.5 mm diameter viewing area.

To test the effects of varying illumination area with a fixed viewing area, we made sample aperture plates for the color machine with openings of 6, 8, 10, and 15 mm diameter. When we used the accessary lens, these new apertures (along with the standard 31 mm plate) gave us the capability of varying the illumination area from 28 to 755 mm^2 in five steps while holding the viewing area constant at 24 mm^2.

The white opal glass that is used to standardize the color machine is somewhat translucent. This caused the instrument to standardize at progressively higher levels as the illuminating aperture size was decreased. To overcome this problem, we included two opaque gray samples (about 20 and 40 % reflectance) in the series of measurements and derived an adjustment from the measured values of the gray samples.

Figure 2 (next page) plots the measured values for the 6, 8, and 31 mm diameter apertures with the calibration data for the Simon Deep Blue 15 standard. To make the curves more easily read, only three of the five illumination area curves are plotted in the figure. While these curves do show the effects of area on measured reflectance, they do not indicate the colorimetric differences.

Table I (next page) compares the colorimetric values of the calibration data, the Gardner measurements, and the portable measurement of the Deep Blue 15 standard. When measuring this chip, the Gardner with a 5.5 mm diameter view and 6 mm illumination diameter has about the same translucent blurring error as the portable instrument.

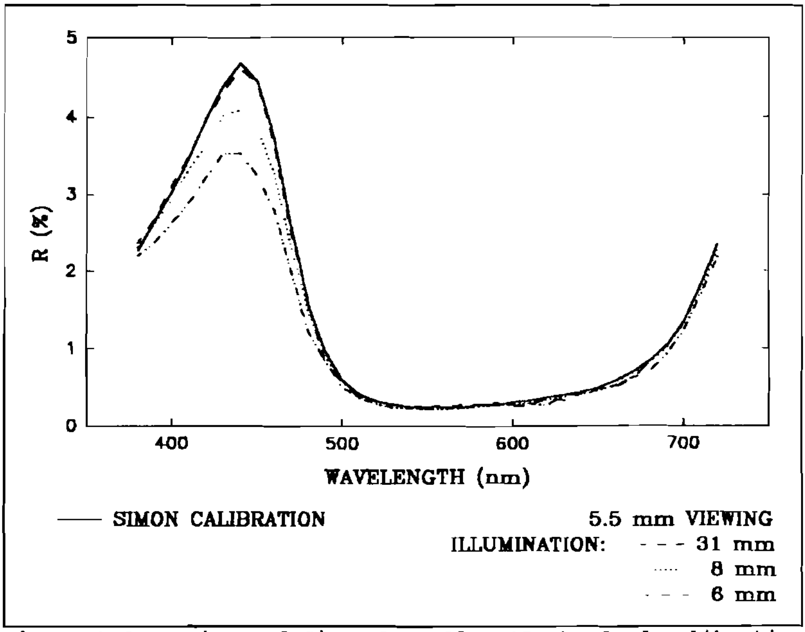

Figure 2 *Comparison of Simon Deep Blue 15 standard calibration data and measured data for 3 different illumination sizes.*

Table I *Colorimetric shifts caused by reducing the illuminated area on Deep Blue 15.*

DATA	L*	a*	b*	deltaE
SIMON	3.43	21.92	-33.38	----
31 mm	3.34	21.73	-33.27	0.24
15 mm	3.70	20.77	-32.43	1.52
10 mm	3.25	21.55	-32.43	1.04
8 mm	3.25	20.18	-31.36	2.67
6 mm	2.98	18.54	-29.14	5.44
PORTABLE	3.16	17.56	-29.11	6.11

While the spectral plots show the effects of aperture changes for one sample, using them to compare the results for two or more samples can result in a plot which is crowded and difficult to interpret. For purposes of comparison of the translucent errors of two or more samples, we prefer to plot color difference (using the large aperture measurement as standard) as a function of illuminating aperture size. Thus, we could plot the five aperture size delta E values of Table I as one uncluttered curve.

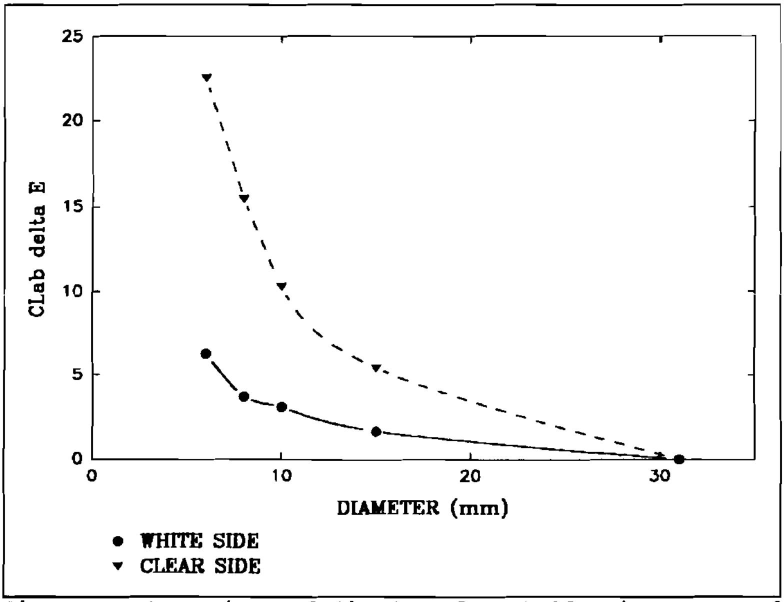

Figure 3 *Comparison of the translucent blurring error of measurements of the two sides of a piece of flash opal glass.*

Figure 3 is an example of a delta E comparison plot. This plot compares the translucent blurring error for a flash opal glass sample as viewed from each of the two sides. (The opal glass sample measured was 0.110" thick disk. The top side of the disk was milky white to a depth of about 0.032"; the remainder of the disk was clear.) The error in the opal (milky) side measurement is much less than that for the clear side measurement.

In addition to illustrating the ease of comparison errors for different samples, this plot also shows that the effects of adding a transparent layer on top of a translucent sample. The clear side measurement is equivalent to a sample of 0.032" opal glass covered by a layer of clear glass about 0.080" thick. This is an

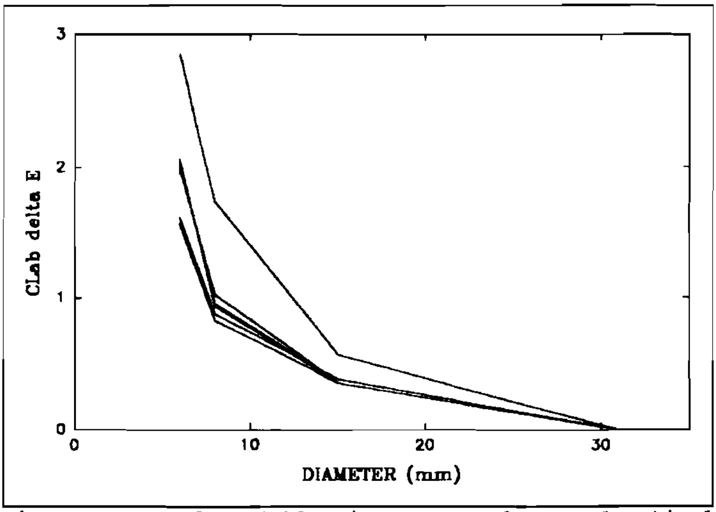

Figure 4 *Translucent blurring errors of several optical proofing materials.*

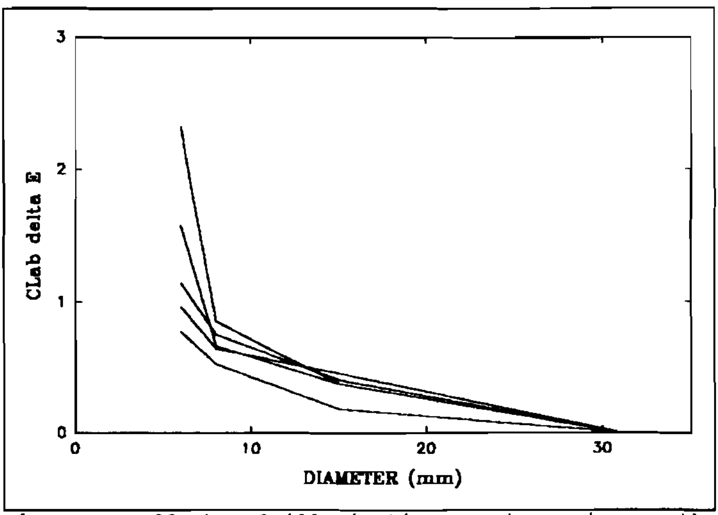

Figure 5 *Effects of illuminating aperture size on the measured values of several different types of paper.*

exaggerated version of the situation that exists for optical proofing materials. In these materials, a translucent base layer is overlaid by several layers of clear polymer.

Figure 4 shows the effects of illumination aperture size on the measurement of white areas of several different optical proofing materials. The viewing area is, as before, 5.5 mm.

Figure 5 illustrates that similar size effects are also present when various papers are measured. Comparison of figures 4 & 5 indicates that small area portable instrument measurements of prepress proofs and on press proofs might result in offset errors as high as 2 CLab delta E units if the translucencies of the pre-press and press base papers differ greatly. (When these errors are combined with errors caused by proof paper fluorescence and surface roughness, it is possible that disagreements between observed and measured color differences as high as 5 delta E can occur.)

COPING WITH TRANSLUCENT BLURRING ERRORS

Jack Hsia, in his NBS tech note, derives equations which predict translucent blurring error as a function of illumination and viewing aperture sizes and the scattering function of the sample being measured. He illustrates the usefulness of these equations by calculating the error that would result if a Vitrolite glass standard is used to calibrate an instrument with a particular set of view and lighting apertures. His calculated error, 2.2%, was nearly the same as the measured error of about 2%.

Hsia's example clearly shows that if enough is known about the instrument geometry and the scattering nature of the sample, it is possible to predict the translucent blurring error. Knowing the error allows the measured value to be corrected. Unfortunately, in actual practice, the parameter values and facility for making these error calculations are generally not available to the instrument user. Furthermore, our measurements show that overprinting ink on a paper of known translucency will affect the blurring error in a way that is not easily characterized.

Figure 6 (next page) shows the blurring errors for 3 process colors printed on paper. The application of ink to the paper, P, changes the pattern of the error trace. Furthermore, each colored ink produces its own characteristic error trace. The application of the magenta, M, and cyan, C, inks actually reduces the error relative to the paper with the 6mm aperture while the yellow, Y, increases the error relative to that of the paper. These results would seem, at first, to indicate that it is doubtful that a simple correction for translucent blurring error exists.

One might ask if these unequal color differences are the result of the non-linear transformation of the CIE tristimulus values which are used to calculate the CLab values. This is not the case. Examination of the reflectance curves of the yellow ink for various illuminating apertures, indicates that the blurring

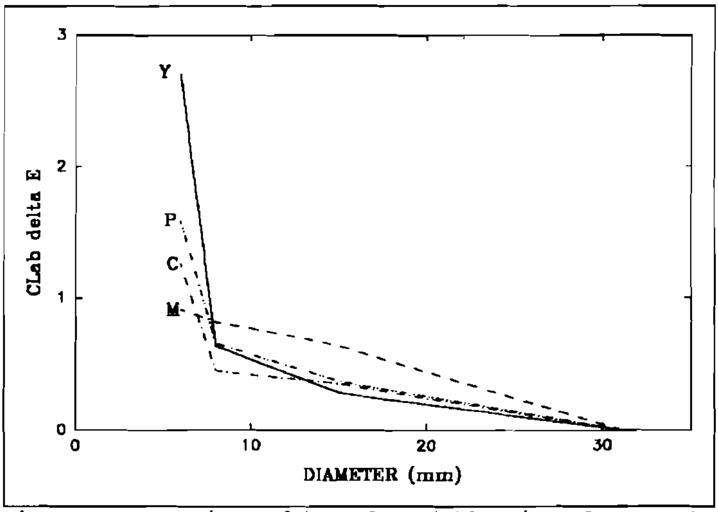

Figure 6 *Comparison of translucent blurring of paper, P, and overprinted colors yellow, Y, magenta, M, and cyan, C.*

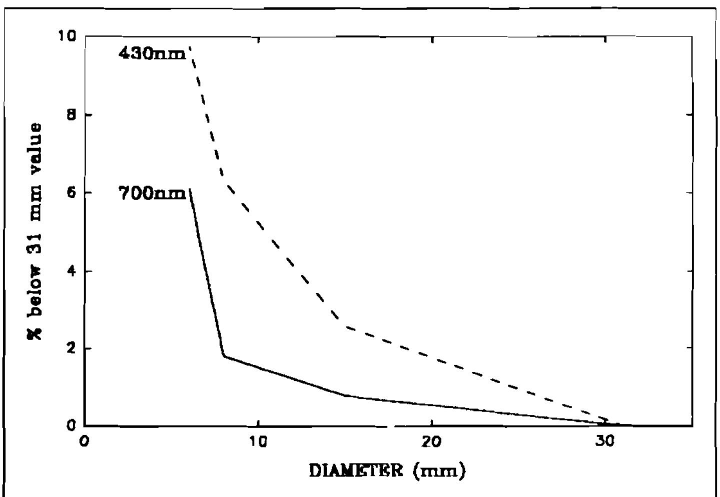

Figure 7 *Plot of the relative differences (per cent) of reflectance at 430 and 700 nm as a function of illuminating aperture size.*

error is very much a function of the reflectance value. At the near peak reflectance (700 nm) going from a 31mm illumination aperture to a 6mm aperture reduces the fractional reflectance value by almost 0.05 (0.808 to 0.759). At the maximum absorbance for the ink (430 nm), the value is reduced by only 0.0034 (0.0349 to 0.0315). The lower absolute error value at the lower reflectance value is consistent with the physical mechanisms that cause translucent blurring error.

From the prospective of error correction, error values proportional to the reflectance values would be very desirable. The plots in figure 7 clearly illustrate that the blurring error values are not proportional to reflectance.

CONCLUSIONS

Translucent blurring errors are significant when small aperture spectrophotometers and densitometers are used to measure prepress proofs and graphic arts printed material. The magnitude of these errors are dependent on the illumination and viewing areas of the instrument, the translucency of the paper, and any colorant (ink) layer that may be of the paper.

The effects of various illuminating and viewing apertures have been simulated and measured using a standard laboratory spectro-colorimeter fitted with various sized aperture plates. Measurement results using this simulation indicate that a simple, first-order, correction of the errors is not possible.

White glass reflectance standards, which are commonly used to calibrate spectrocolorimeters, are generally translucent. When such a standard is used to calibrate an instrument that is capable of measuring with more than one aperture size, translucent blurring may cause a calibration error. For this reason, it is recommended that a highly opaque, non-translucent, standard should be used for instrument calibration.

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REFERENCES

(1) "Standard Method for COMPUTING THE COLORS OF OBJECTS BY USING THE CIE SYSTEM", ASTM Designation E 308 - 85, American Society for Testing Materials, Philadelphia, PA

(2) "Photography - Spectral Conditions", ANSI/ASC PH2.18, American National Standards Institute, 1430 Broadway, New York, NY 10018

(3) "Standard Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation", ASTM Designation E 308 - 85, American Society for Testing Materials, Philadelphia, PA

(4) Hsia, J. J., "Optical Radiation Measurements: The Translucent Blurring Effect - Method of Evaluation and Estimation", NBS Technical Note 594-12, October, 1976

(5) "Photography - Density measurements - Part 4: Geometric conditions for reflectance density", ISO Ref. No. 5/4-1983 (E)", International Organization for Standardization

(6) "Standard Practice for IDENTIFICATION OF INSTRUMENTAL METHODS OF COLOR OR COLOR-DIFFERENCE MEASUREMENT OF MATERIALS", ASTM Designation E 805 - 81, American Society for Testing Materials, Philadelphia, PA