LATERAL DIFFUSION ERRORS CAUSED BY LAYERED STRUCTURE OF GRAPHICS ARTS PRODUCTS

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ABSTRACT: A paper presented at the 1991 annual TAGA meeting discussed the errors caused by failure of reflectance measuring instruments to collect all of the light reflected by translucent papers, white plastic sheets, etc. At the time of presentation, the author had recognized that placing absorbing and/or thick transparent layers on top of translucent substrates would affect the magnitude of this lateral diffusion (or translucent blurring) error; however, at that time he had not characterized the extent or mechanisms associated with these changes. The present paper investigates changes in lateral diffusion error caused by layering various transparent inks and/or plastic films on top of translucent substrates.

INTRODUCTION

Print control strips often contain color control elements that are 5 mm or less in size. A paper (1) presented at the 1991 annual TAGA meeting discusses errors that may be present in spectral reflectance and density measurements of these control elements. Most, if not all, commercial instruments designed to measure these control elements fail to collect all of the light reflected from the target area. This phenomena has been referred to in the literature as translucent

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blurring error (2). We prefer to use the term lateral diffusion error (LDE) since it is more descriptive of the actual physical process that causes the error (i. e. light is lost by sideways or lateral diffusion out of the detector viewing area). In this paper we expand on our 1991 TAGA paper and further examine the effects of applying transparent colorant films (e. g. ink) on top of translucent substrates (e. g. paper).

BACKGROUND

Basically, reflectance measurements are made using a light source, which illuminates the sample, and a detector, which measures some fixed portion of the light reflected by the sample (e. g. in 0/45 geometry instruments, all or a portion of the light reflected at or near 45° relative to the surface normal is collected).

When light strikes the sample surface, it penetrates the sample to some depth. In the case of a front surface mirror, this depth may be only one atom's thickness. However, in the case of most, non-metallic, opaque materials, the penetration depth will range from a few microns to a millimeter or more. (Note that the exact distance is dependent, in part, on how the terms "opaque" and "penetration depth" are defined.) While the direction of penetration of the upper layers of the material is, for the most part, in the direction of the incident light, the light is scattered in an isotropic manner as it travels into the sample. This scattering results in a portion of the light being diffused, or dispersed, to portions of the sample that are outside the light path.

Figure 1 (next page) shows how this lateral diffusion can cause a measurement error in an instrument that is not designed to collect this out of illumination area light. The sample area is illuminated by a collimated beam of light at normal incidence and viewed at 45° by a detector. An opaque mask is placed on top of the sample to

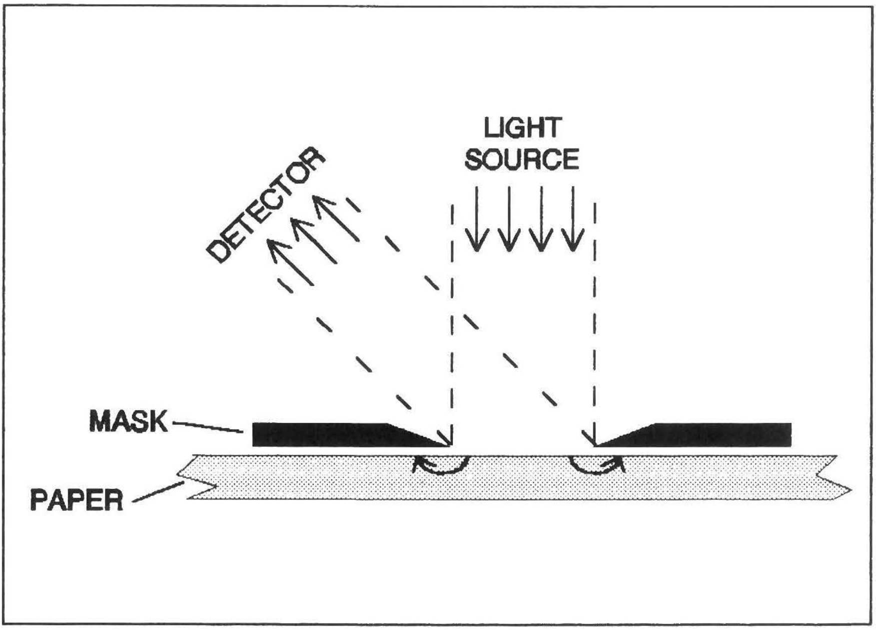

Figure 1 *When the illumination and viewing apertures are the same size, some reflected light may not be seen by the detector.*

better define the area illuminated and viewed (e. g. such a mask is often employed in small area measuring instruments to minimize anomalous readings caused by light scattered by the optical elements and structures of the instrument that, of necessity, must be very close to the sample surface). In this example, the light that is laterally diffused outside of the sample area can not by viewed by the detector.

The error caused by this uncollected light would not be a problem if instrument were calibrated using a standard that had the same degree of transparency as the samples that are to be measured. Unfortunately, the sample transparency, and thus the amount of light lost, changes when absorbing layers, such as ink, are applied to the sample surface.

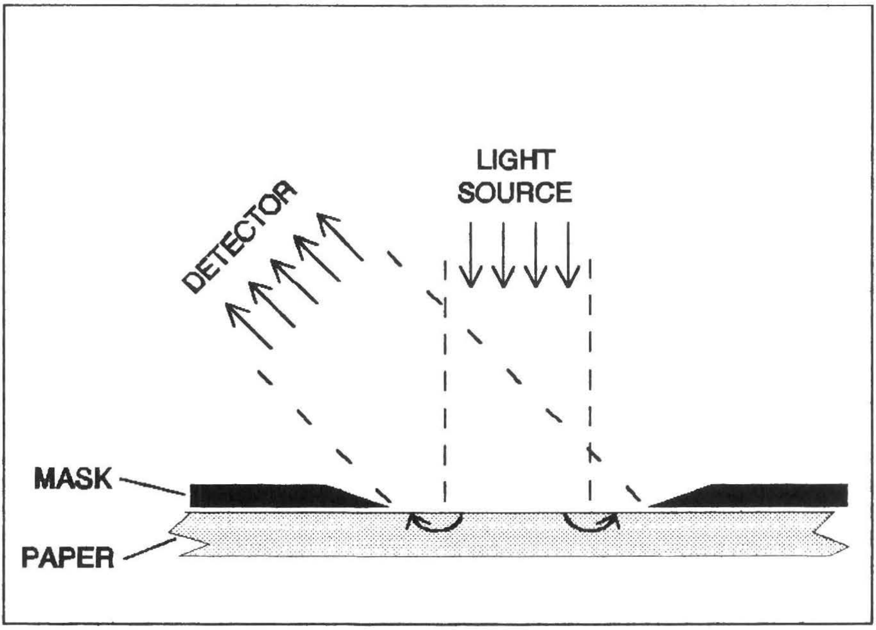

Figure 2 *Enlarging the field of view of the detector allows all of the reflected light to be seen by the detector.*

The conventional way to overcome this light collection problem is to allow the detector to view the area adjacent to the illuminated area as well as the illuminated area. An example of such a configuration is shown in figure 2. The extent of this added viewing area that is needed for accurate measurement is dependent on the translucency of the sample and the surface gloss. ASTM E805 (3) suggests that the lateral diffusion distance should be about the same as the penetration distance of light into the sample, however, we have found that this lateral distance is usually much greater than the penetration depth because of "pipelining" caused by total internal reflection from the under side of the sample surface. ISO 5/4 (4) suggests that the boundary of the viewed area should be at least 2 mm beyond the edge of the illuminated area. Our earlier work shows that this reduces the LDE considerably but does not totally eliminate it in most applications.

Figure 2 is a 0/45 configuration with the detection area larger than the illumination area. The principal of optical reciprocity dictates that a 0/45 instrument with the illumination area larger than the detector view area should give equivalent results. Also, 45/0 configuration with the view area larger than the illuminated area or the illuminated area larger than the view area should be equivalent to the configuration shown in Figure 2.

Data for the '91 TAGA paper and this paper were collected using The Color Machine (TCM) spectrocolorimeter manufactured by Byk-Gardner. Unlike most small area instruments, the design of the TCM is such that the illumination and viewing areas can be readily modified. The '91 measurements were made using a 5.5 mm diameter viewing area with illumination diameters of 6, 8, 10, 15, and 31 mm. The work reported in this paper used a 3 mm viewing diameter with 4, 6, 8, 10, 15, and 31 mm illumination diameters.

The white calibration standard supplied with the TCM is a 5 cm square of Japanese opal glass. While this standard is quite good for standardizing the instrument in the 31 mm illumination - 25 and 5.5 mm viewing modes, its translucency causes problems at some of the smaller illumination sizes. Particularly, reflectance value of the standard measured by the instrument at small aperture sizes is lower than it should be. This results in the standardized instrument readings being higher. Figure 3 (next page) plots the calibrated reflectance value for the standard (solid line) and its measured value with a 4 mm source - 3 mm view configuration (dashed line).

Obviously, the opal glass is not a good reflectance standard for calibrating our instrument with small apertures because it has a large lateral diffusion distance. Pressed barium sulfate, which is often used as a reflectance standard, also is translucent (though not as much so as the opal glass). In fact, all of the white materials that are commonly used for instrument calibration are

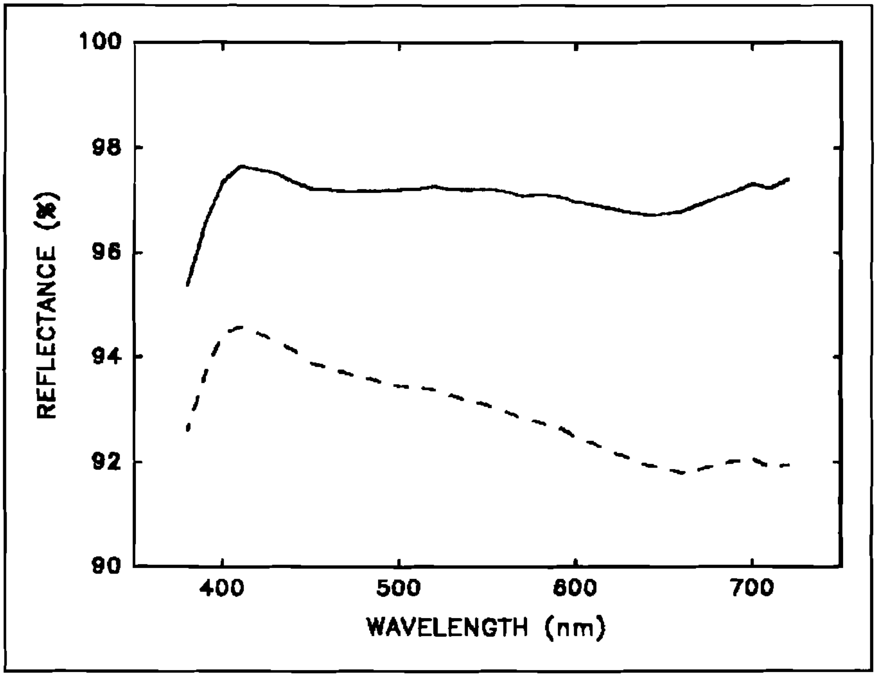

Figure 3 *The white glass standard is translucent. The upper curve is the R value for 31-3 apertures, and the lower is R for 4-3 apertures.*

translucent. The Kubelka-Munk model (5) indicates that the hiding of a given thickness of a diffusing media can be increased by increasing the absorbance of the media. Increased hiding means that the light penetration distance is reduced and thus the lateral diffusion distance is reduced. Therefore, a gray material should be useful as a calibration standard which is not compromised by LDE.

What level of gray should be used ? Darker grays exhibit less LDE, however, the process of standardizing with a gray tends to amplify measurement noise (e. g. a 0.1% uncertainty in the calibration measurement of a 20% gray standard would result in a 0.5% uncertainty in near 100% measurements made by the calibrated instrument). The calibration standard used for obtaining the data for the '91 paper was a pressed pellet of a mixture of barium sulfate and chromium dioxide. Its reflectance level, about 40%, was a reasonable compromise which gave minimal LDE and noise amplification errors.

The pressed pellet had a soft surface which was easily scuffed in normal handling and use. After the '91 work, we attempted to formulate a durable glossy gray paint (made with a high refractive index white pigment) that could be used to make standard plaques. We were initially surprised to find that, for a given gray level, the standards made with the gray paint exhibited much greater LDE than the equivalent $BaSO_4$ gray pellet. Subsequent analysis indicates that the greater LDE of the paint was due to the previously mentioned pipelining effect as well as a reduction of the effective scattering of the pigments by the wetting action of the paint vehicle. We are still looking for materials suitable for making a LDE calibration standard, however, for this work we have chosen to continue to use a pellet pressed from a $BaSO_4$ - CrO_2 mixture.

Generally in an instrument configuration that employs fixed viewing area and a variable illumination area, the corrected reflectance value of a high reflectance sample decreases with decreasing illumination area. The color difference between the largest source aperture color values and the color values for a smaller aperture generally increases as the illumination aperture size is decreased. In the data taken in '91 paper, we found that, for some unknown reason, the 10 mm aperture color difference readings did not fall smoothly into line with the other aperture size readings. Therefore, we decided not to plot the 10 mm readings.

In the data taken for the present paper, we also found that the 10 and 6 mm aperture data did not fall into line. If these points were included in a line plot of the data, the resulting curve would be rather jagged. Instead, we chose to plot an exponential function that was fit to the data. This procedure makes it easier to compare LDE curves for various samples. The function is of the form:

$$LDE = a*exp(-b*(I_d-V_d))$$

where:

LDE is the lateral diffusion error

I_d is the diameter of the illumination aperture

V_d is the diameter of the viewing aperture

and a and b are the fitted equation parameters.

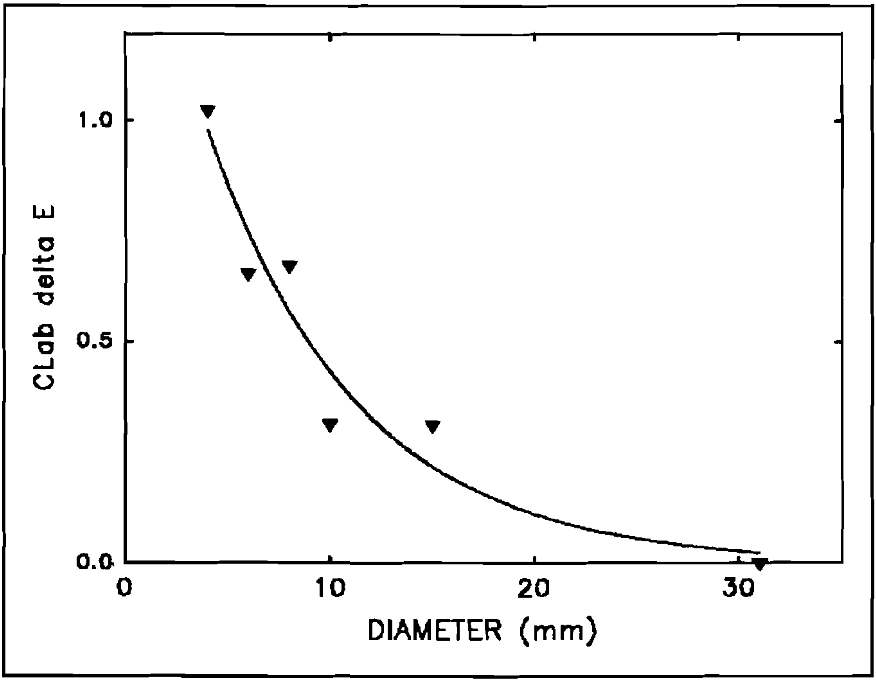

Figure 4 *An exponential function fit is used to make comparison of LDE curve less confusing.*

Figure 4 gives an example of a point plot of the measured data and the fitted exponential curve.

MEASUREMENT STUDY

The objective of this study was to systematically investigate the effects of colorant layers on LDE. The basic test target used consisted of 64 35 mm square elements arranged in an 8 x 8 array. Each target element had a different combination of CMY screen colors made with systematic combinations of 0, 25, 50, and 100% negative screens. While we would have liked to have printed the test targets using various printing inks and papers, the available systems in our laboratory made the use of pre-press proofing products a much more viable choice.

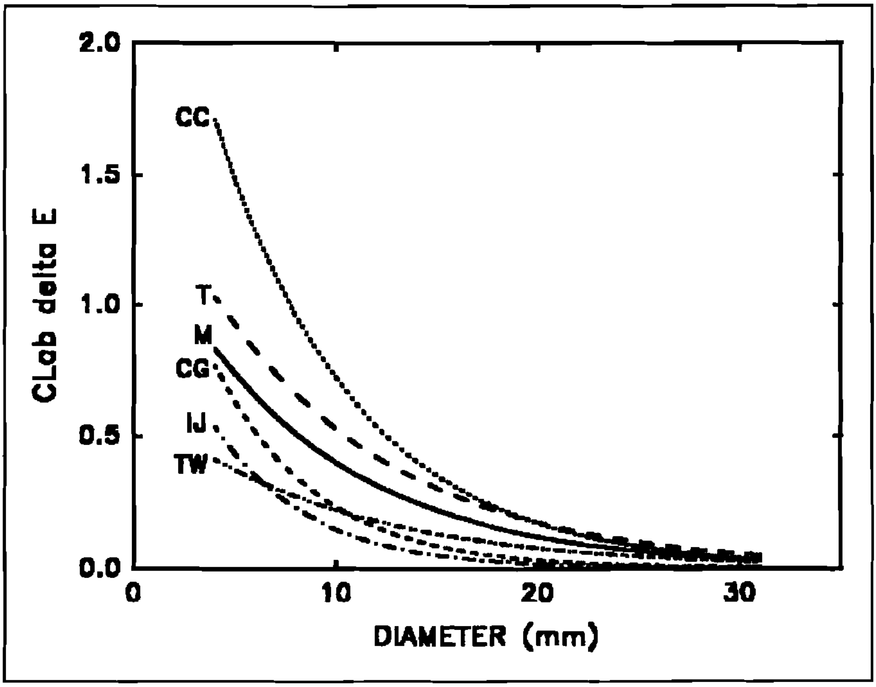

Figure 5 *Comparison of LDE for paper/substrates used in the measurement program. See text for identification.*

Three proofing systems were used: a custom color (CC) system, a pre-colored laminated system, and an ink-jet (IJ) system. The CC and IJ targets were prepared on one paper (i. e. receptor) each. The pre-colored laminated system was used to prepare targets on four substrates: TextWeb (TW), Centura Gloss (CG), 70# TiO_2 containing paper (T), and a 175 μm thick white plastic sheet (M). Figure 5 (previous page) plots the LDE for these 6 substrates.

In the work reported in our '91 TAGA paper, we included measurement results for one set of ink on paper samples (see figures 6 & 7, pg 141, 1991 TAGA proceeding). At the time, we were surprised that the application of yellow ink to the base paper actually increased the LDE. Our current measurement results confirm that the colorimetric LDE always increased by the application of a yellow colorant to the surface of the paper or receptor. An example of this phenomenon is shown in figure 6 which plots the LDE vs illumination aperture size for yellow (Y), paper (P), magenta (M), and cyan

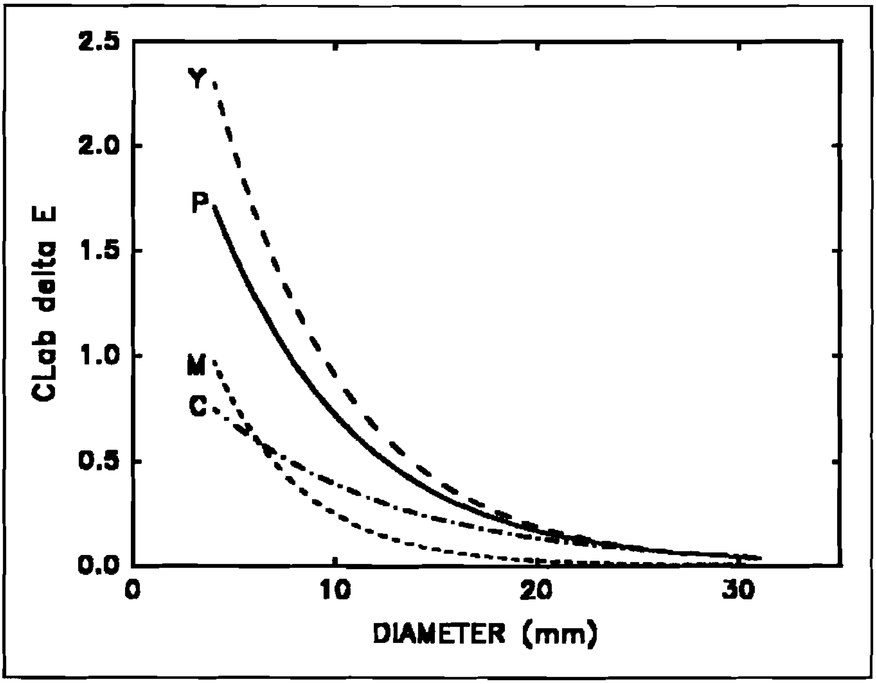

Figure 6 *Applying yellow colorant to the substrate increases the LDE.*

(C) samples made with the custom color proofing system.

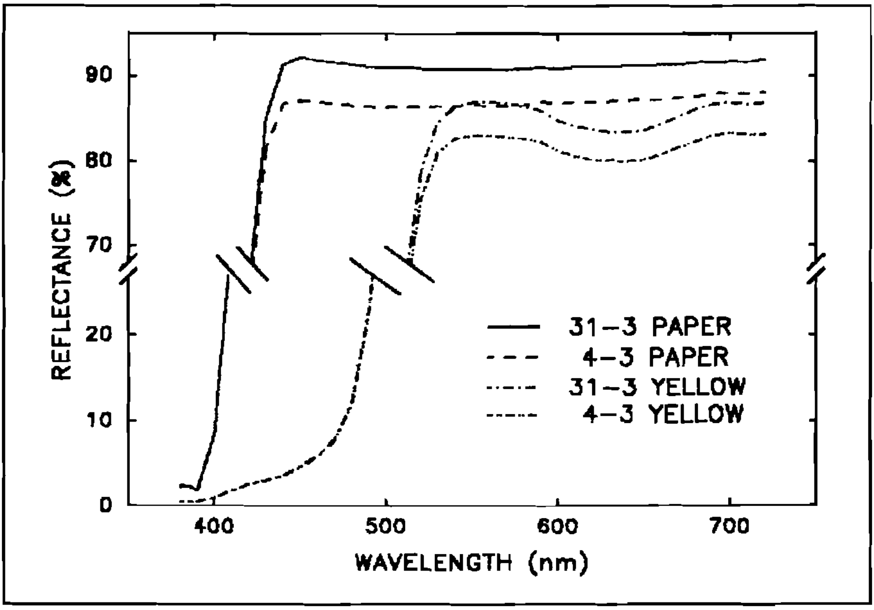

Figure 7 *Comparison of spectral reflectance curves for 31-3 and 4-3 apertures.*

The cause of this increase in yellow colorimetric LDE is not apparent when we examine the reflectance curves of the paper and yellow samples. Figure 7 shows plots of the spectral reflectance curves of the paper and yellow samples with 31 mm and 4 mm illuminating apertures. The average reflectance difference between the two yellow curves is only about two thirds that the difference between the two paper curves. This is in sharp contrast with the 25+% higher colorimetric LDE for the yellow shown in figure 6.

The answer to this anomaly can be found by examining the CLab components that are combined to get the ΔE value. Table I (next page) lists the ΔL (lightness-darkness), Δa (red-green), Δb (yellow-

Table I *The increase in LDE caused by application of yellow colorant is primarily caused by a large decrease in chroma.*

	ΔL	Δa	Δb	ΔE	ΔC	Δh
P	-1.74	0.10	0.22	1.76	0.18	0.17
C	-0.62	0.14	0.36	0.73	-0.36	-0.14
M	-0.51	-0.75	-0.41	1.00	-0.80	-0.30
Y	-1.56	0.13	-1.83	2.41	-1.83	0.08

blue), ΔE (color difference), ΔC (chroma or color purity), and Δh (hue) values for the paper, cyan, magenta, and yellow samples measured with the 4 mm illumination aperture compared to the 31 mm values. As we might have gathered from examining the paper and yellow reflectance curves, the lightness error is reduced when a colorant layer is applied to the paper. Conversely, the chroma error is increased by the application of the colorant layer. In the case of the cyan and magenta colorants, the decrease in the lightness error more than compensates for the increase in the chroma error and the net ΔE is decreased. In the case of the yellow, the decrease in the lightness error does not cancel the increase in the chroma error.

The yellow chroma error is negative indicating that the use of the smaller aperture illumination causes the chroma value to decrease. The cause of this decrease is readily apparent when we examine the yellow spectral curves in figure 7. While the reflectance value at the short wavelength is not affected by the change in aperture size, the long wavelength reflection is changed by several per cent. This also results in a slight decrease in the slope of the absorption edge portion of the curve (480 to 520 nm). Both of these changes result in a reduced chroma value.

We might expect that other sharp cut off colors, such as red and orange, might similarly increase the colorimetric LDE when applied to paper. We looked at a red sample which was produced by applying yellow over magenta and found that this was not the case. Considering that the chroma of a red made by overprinting is considerably lower than that which can be realized using a colorant made up with a red pigment, it may well be possible that some red or orange colorants made from single pigments will produce an effect similar to that observed with the yellow colorant. However, in the gamut available with 4 color process printing it seems unlikely that this will occur in any but a small region of near yellow combinations.

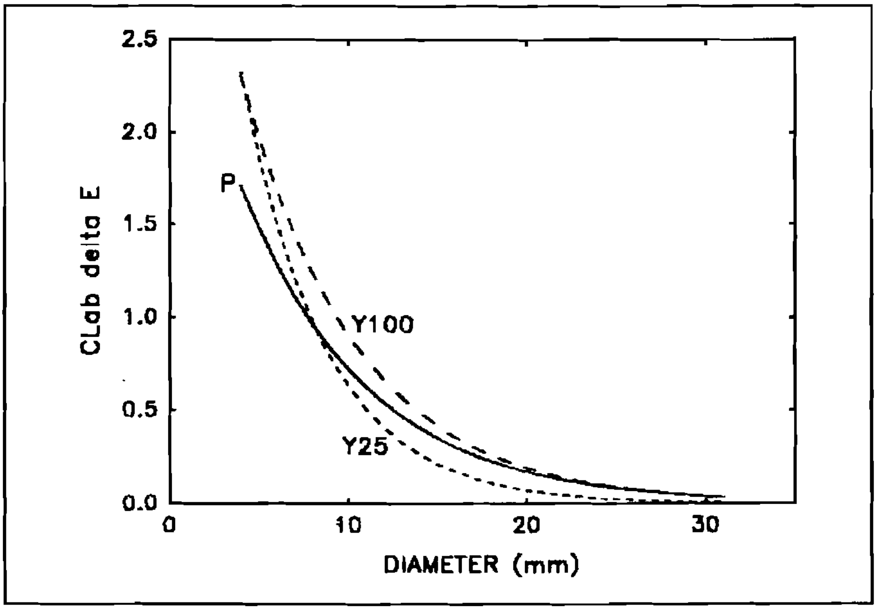

Figure 8 *Application of yellow colorant in a screen pattern also increases the LDE.*

Thus far, we have discussed the effects of applying solid colorant layers to the paper substrate. What happens if a half tone pattern of color is applied ? Figure 8 are plots of the LDE vs aperture for a paper (P), a solid yellow (Y100), and a 25% screen yellow (Y25). The LDE at the 4 mm aperture for the Y100 and Y25 samples are almost identical. However, at larger apertures, the Y25 LDE is less than the Y100 value.

Table II *Comparison of 25, 50, and 100% yellow screen overprint color coordinates.*

	ΔL	Δa	Δb	ΔE	ΔC	Δh
P	-1.74	0.10	0.22	1.76	0.18	0.17
Y25	-1.78	0.22	-1.54	2.36	-1.55	0.07
Y50	-1.69	0.16	-1.61	2.34	-1.62	0.09
Y100	-1.56	0.13	-1.83	2.41	-1.83	0.08

Table II, which is like table I, compares the CLab component differences (4 mm vs 31 mm aperture) for paper (P), 25% screen yellow (Y25), 50% screen yellow (Y50), and solid yellow (Y100). The small decreases in ΔL going from Y25 to Y100 are almost exactly offset by small increases in ΔC to give an almost constant ΔE.

DISCUSSION

The Byk-Gardner color machine spectrocolorimeter used to make these measurements is one of the few instruments available that allows the illumination aperture size to be varied over a large range. Most of the other instruments designed for small area measurement will not readily permit changing the aperture sizes without compromising the integrity of the instrument. While Gardner originally supplied only two aperture plates and one set of small area view optics (6 mm) with the instrument, we have been able to easily make the aperture plates needed for this work. Gardner has also supplied a design for 3 mm view optics which we tested and used in the work reported in this paper.

The Gardner color machine in the small area configuration suffers from a scattered light problem, a problem that is common to most commercial (and portable) small area measuring instruments. In order to collect sufficient light from the small sample area, these instruments must use large numerical aperture optics. The desire to make the instrument measurement head as small as possible requires that the optical elements be placed very near the sample surface. This also places much of the optics supporting structures near the sample surface. The net result is that more light is scattered within the measurement head than is the case in most laboratory type instruments. This results in the sensor receiving some light from outside the designed viewing area (i. e. stray light).

We do not know how this scattered light affects our assessment of LDEs. We also plan to set up a lab bench 45/0 reflectometer that is specifically designed to minimize scattered light and compare its measurements of LDE with those made with the Gardner color machine. We plan to use various sized aperture plates to define the illuminated area in both bench and Gardner instruments.

We believe that surface gloss level can affect the magnitude of LDEs. We attempted to gage this effect by measuring custom color proofs made with a glossy top coat and a matte finish top coat. The results were inconclusive. We hope to investigate this further in the future using white and gray samples.

CONCLUSIONS

In a first approximation, LDE of a given material is lower at lower reflectance values. This is so whether the lower reflectance is obtained by mixing an absorbent into the material (e. g. dying the material) or by placing an absorbent layer on the surface (e. g. applying ink). LDE is also reduced by applying a patterned absorbent layer (e. g. screen printing).

While reporting LDEs in colorimetric terms is very meaningful to the instrument user, anomalous results (e. g. the increased error caused by applying yellow colorant) can occur. We know that the application of any absorbing material to the surface of the paper or substrate always causes the reflectance LDE to be reduced. In future study of this phenomena, more meaningful data might be obtained by evaluating results on a single wavelength reflectance difference basis instead of using colorimetric differences. This would alleviate the need to use spectral reflection measuring instruments and allow the use of simple filter photometers.

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