# How Yellow and Some Magenta Process Inks Acerbate Lateral Diffusion Error

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Keywords: color, error, measurement

**ABSTRACT:** Most process printing ink sets, including those used by color office printing equipment, use yellow inks which have very little absorption in the green-red wavelength spectral region. Since these inks are also quite transparent, the green-red spectral reflectance of media coated with these inks is determined, in large part, by the media reflectance. Reflectance measuring errors can occur when the measuring system collection optics fail to observe all of the reflected portion of instrument illumination which was assumed in the instrument design. These errors have been termed lateral diffusion errors (LDE) because they result from lateral diffusion of light within the sample.

The excellent transmission and low scattering of dye based yellow process printing inks result in the green-red reflectance LDE of the solid printed areas being almost as great as the LDE of the unprinted paper. However, since the LDE also reduces the reflectance difference between the red and blue ends of the spectrum, there is also a reduction in the CL*a*b* C* (chroma or color purity) which is often two or more times larger than the CL*a*b* L* (lightness-darkness) error.

Yellow and magenta process inks on high quality paper typically exhibit peak reflectances of 95% or more in the red spectral region. In an evaluation of eight ink-jet systems, cyan inks printed on good paper had a peak reflectance ranging from 62 to 89 %, dependent on the printer system, and, additionally, all exhibited lower reflectance in the green and blue regions of the spectrum. The illuminating light and the reflected light both pass through the ink layer prior to being detected by the instrument. This dictates that at the very least that the LDE should be proportional to the square of the sample reflectance. Also, the LDE of the paper layer at the cyan wavelengths is typically half that of the LDE at the red wavelengths. These factors greatly reduce the lightness and chroma errors experienced with cyan sample relative to those experienced with red and yellow samples.

Many of the BCRA tiles, which are made by firing a transparent colored glaze over a ceramic tile base, also show chroma errors similar those experienced

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with exhibits made with red and yellow process inks printed on paper. The coatings used in the MacBeth Color Checker® are relatively opaque and generally do not exhibit LDE induced chroma errors similar to those experienced with process printing inks.

## BACKGROUND

Reflectance measuring errors can occur when the measuring system collection optics fail to observe all of the reflected portion of instrument illumination which was assumed in the instrument design. In the literature such errors have been termed edge-loss error (Atkins, Billmeyer, 1966), translucent blurring error (Hsia, 1976), and translucency error (Hunt, Harold, 1987). Lateral diffusion error (LDE) was first used to describe this error mechanism in a paper (Spooner, 1993) presented at the 1993 annual meeting. The author felt that terminology more accurately described the physical process causing the error.

This 1993 paper primarily dealt with examination of the error characteristics in a verity of media and instrument configurations. An unexpectedly large chroma error was observed when the LDE of a proof of 100% process yellow ink was measured. Figure 1 shows plots of the spectral reflectance of the proofing paper and the yellow proof measured with an instrument employing 4mm diameter viewing and 31mm and 4mm diameter illumination. Table I details the CL*a*b* color differences between the measurements of proofing paper and proofs made with yellow, magenta, and cyan process inks.

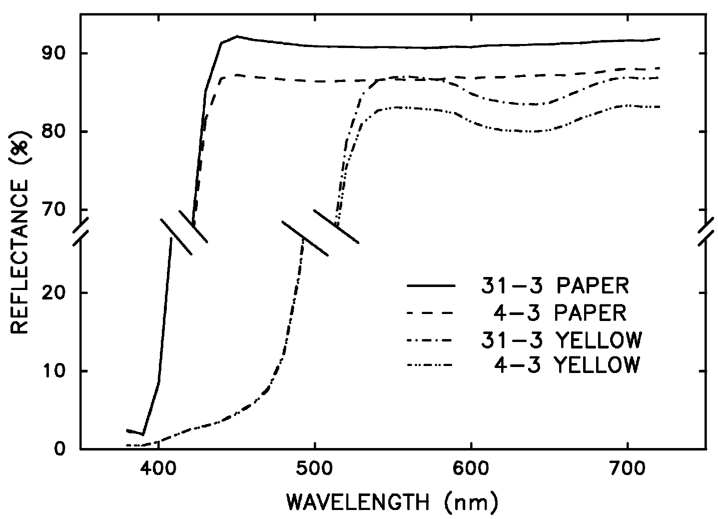


**Figure 1** Comparison of spectral reflectance curves for 31-3 and 4-3 apertures**.**

**TABLE I**

| Sample | ΔL | Δa | Δb | **ΔE** | ΔC |
|---|---|---|---|---|---|
| Paper | -1.74 | 0.10 | 0.22 | 1.76 | 0.18 |
| Cyan | -0.62 | 0.14 | 0.36 | 0.73 | -0.36 |
| Magenta | -0.51 | -0.75 | -0.41 | 1.00 | -0.80 |
| Yellow | -1.56 | 0.13 | -1.83 | 2.41 | -1.83 |

Note that the ΔC for the magenta and yellow proofs is higher than the ΔL while the ΔC for the paper and cyan proof is much lower than the ΔL. These anomalies were not investigated in 1993 because of more pressing work at the time. In 2003, the author began the long overdue investigation of these anomalies. The present paper is a report on this investigation.

## A MEASUREMENT PROGRAM

Are the large chroma errors for magenta and yellow reported in Table I unique to the samples measured in 1993 or do all/most magenta and yellow process inks exhibit similar properties ? To answer this question, a nine color target, using the color coordinates detailed in Table II below, was prepared with

**TABLE II**

| Color | Red | Green | Blue |
|---|---|---|---|
| RED | 255 | 0 | 0 |
| ORANGE | 245 | 122 | 0 |
| YELLOW | 255 | 255 | 0 |
| GREEN | 0 | 255 | 0 |
| CYAN | 0 | 255 | 255 |
| MAGENTA | 255 | 0 | 255 |
| BLUE | 0 | 0 | 255 |
| PURPLE | 124 | 0 | 249 |
| WHITE | 0 | 0 | 0 |

Corel WordPerfect Presentations software. This target was exported to as JPEG file and aa Adobe Acrobat PDF file. This target was then printed on Jet-Print Photo® Multi-Project Glossy Photo Paper using 12 different model printers (seven ink jet, one dye-sublimation, and four laser printers). Each color of each target print was cut into a 1.75" diameter exhibit using a punch and die in order to aid in accurate placement of the samples on the measuring instrument. (Note: Jet-Print paper was used because it does not have printing on the back side.)

The exhibits, backed with Japanese opal glass, were then measured on a Byk-Gardner Color Machine configured with 31mm illumination-3mm viewing (31/3) and 4mm illumination-3mm viewing (4/3). The exhibits made with the seven ink-jet printers and the dye-sublimation exhibited similar spectral reflec-tance patterns, but the four laser printers had spectral reflectance patterns that were somewhat different from those of the inkjet printers. Therefore, the evaluation of the laser printer exhibits was delayed until more laser printer exhibits could be procured.

From past experience it was determined that the 31/3 measurement should be free of errors caused by lateral diffusion of light. The wavelength by wavelength difference between 31/3 reference and the 4/3 measurements is the spectral lateral diffusion error (LDE). The LDE can also be expressed as the color difference (e.g. CL*a*b* DE) between the two measurements.

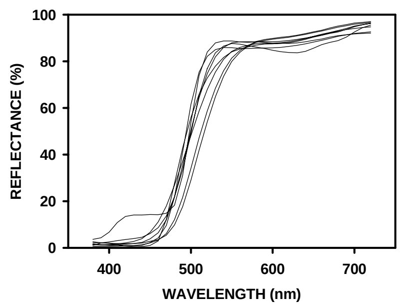


**Figure 2** *Yellow curves from eight printers*

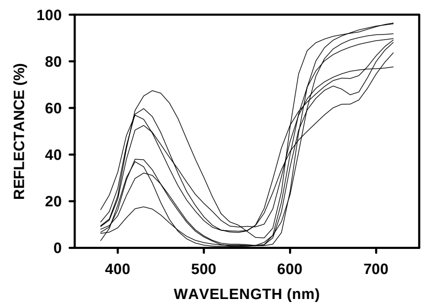


**Figure 3** *Magenta curves from eight printers*

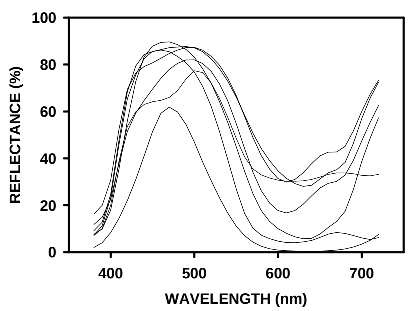


**Figure 4** *Cyan curves from eight printers*

Figures 2, 3, and 4 are plots of the 31/3 measurements of the yellow, magenta, and cyan exhibits printed by each of the eight printers. All of the printers except one had yellow inks with good blue extinction (i.e. less than 5% blue reflection). Four of the magenta inks had good green extinction and only three of the cyan inks had good red extinction. While all of the yellow exhibits were probably printed with yellow ink only, there may be some question as to the magenta and cyan exhibits being printed with magenta and cyan inks only. If the ink colors used by the printers does not match the ideal ink color, then printer software will often cause printing of the exhibits with a combination of inks.

The ink color plotted in figure 1 was from measurements of proof press exhibits produced with a single ink. The good colorimetric characteristics of yellow inks most likely assures that a digital yellow input to the printer will result in the exhibit being printed with a single ink. However, there is no way, short of cut-and-try experimentation, of printing exhibits with only one of the other two inks being used.

Figures 5 through 8 show plots of the 31/3 and 4/3 spectral reflectance of one each selected red, yellow, magenta, and cyan exhibits. The CL*a*b* (D50, 2°) dL, dC and DE differences between the 31/3 reference and the 4/3 measurements are shown in the upper left corner of the graphs. With the three sharp cutoff colors, the chroma is largely a function of the difference of the reflectance at the high corner of the cutoff and the lower corner of the cutoff. Thus, the LDE reduction in the upper corner reflectance also results in a reduction in chroma.

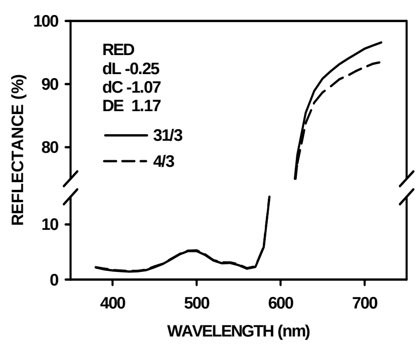


**Figure 5** *Red 31/3 & 4/3 plots*

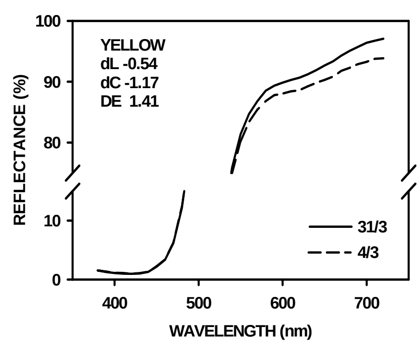


**Figure 6** *Yellow 31/3 & 4/31 plots*

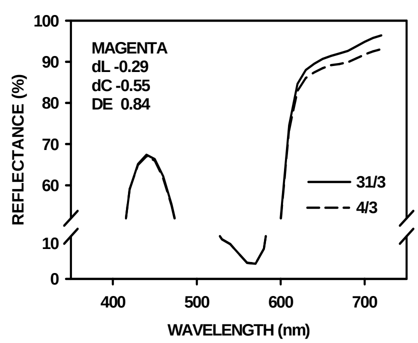


**Figure 7** *Magenta 31/3 & 4/3 plots*

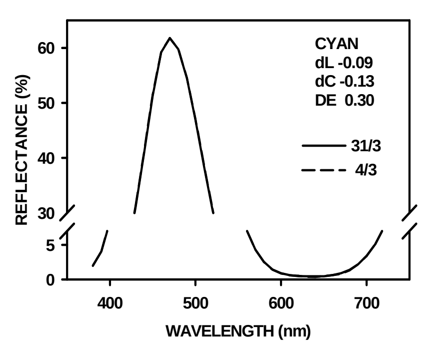


**Figure 8** *Cyan 31/3 & 4/3 plots*

**TABLE III**

| Color | dL | dC | DE |
|---|---|---|---|
| | -0.80 | 0.44 | 0.93 |
| Paper | **-0.71** | **0.34** | **0.81** |
| | -0.48 | 0.24 | 0.57 |
| | -0.58 | -1.21 | 1.24 |
| Red | **-0.31** | **-0.72** | **0.98** |
| | -0.13 | 0.55 | 0.73 |
| | -0.49 | -1.20 | 1.31 |
| Orange | **-0.24** | **-0.80** | **1.08** |
| | 0.08 | -0.48 | 0.71 |
| | -0.88 | -1.29 | 1.58 |
| Yellow | **-0.60** | **-0.90** | **1.19** |
| | -0.23 | -0.25 | 0.44 |
| | 0.35 | -0.57 | 0.78 |
| Green | **-0.14** | **-0.28** | **0.49** |
| | -0.30 | -0.01 | 0.16 |
| | -1.09 | -0.63 | 1.45 |
| Cyan | **0.35** | **-0.32** | **0.61** |
| | 0.09 | 0.14 | 0.30 |
| | -0.66 | -0.55 | 1.19 |
| Magenta | **-0.30** | **-0.18** | **0.78** |
| | -0.07 | 0.48 | 0.52 |
| | -0.51 | -0.17 | 0.73 |
| Purple | **-0.07** | **0.18** | **0.35** |
| | 0.24 | 0.47 | 0.09. |
| | -0.52 | 1.13 | 1.27 |
| Blue | **-0.11** | **0.27** | **0.43** |
| | 0.05 | -0.12 | 0.03 |

Table III summaries the average (bold type) and maxima and minima values of the dL, dC and DE of the measurements of the exhibits produced by the eight printers. Some anomalous results such as an increase in the chroma of the papers when measured with 4/3 instrument configuration are present. These problems are being investigated by on-going work and the results will be presented in a future paper.

## DISCUSSION

Many of the BCRA tiles are made by firing a transparent colored glaze over a white ceramic tile base. This structure is analogous to transparent process ink printed on a white media. Figures 9, 10, & 11 show that the BCRA red, orange and yellow tiles have LDE chroma problems similar to red, orange, and yellow colors made with process inks. Note: the coatings used in the Mac-Beth Color Checker® are relatively opaque and generally do not exhibit LDE induced chroma errors similar to those experienced with process printing.

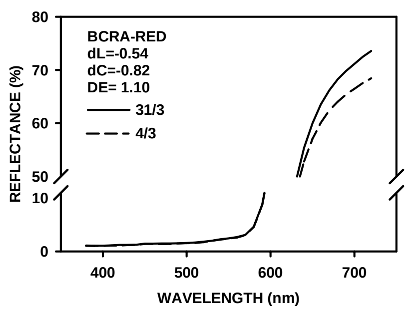


**Figure 9** BCRA-RED tile - 31/3 & 4/3 plots

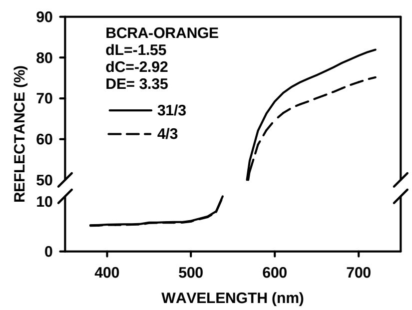


**Figure 10** BCRA-ORANGE tile - 31/3 & 4/3 plots

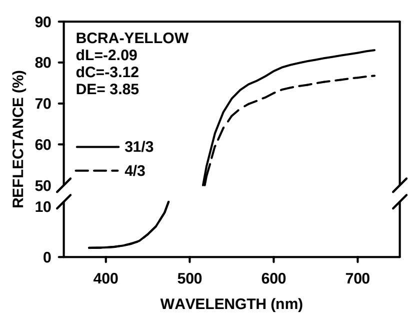


**Figure 11** BCRA-YELLOW tile - 31/3 & 4/3 plots

In the eight ink-jet systems evaluated, cyan ink on good paper had a peak reflectance ranging from 62 to 89 %, dependent on the printer system. Additionally, all exhibited somewhat lower reflectance in the green and blue regions of the spectrum. The illuminating light and the reflected light both pass through the ink layer prior to being detected by the instrument. This dictates that at the very least that the LDE should be proportional to the square of the sample reflectance. Also, the scattering within the paper layer at the cyan wavelengths is typically twice as great as it is at the red wavelengths. This results in the LDE of the unprinted paper in the blue-green spectral region being about half that of the LDE in the red region. The cyan ink plotted in figure 8 has a spectral LDE at its 480nm peak of 0.88% and a reflectance 85.75%. The jet-print paper (figure12) that the cyan ink is printed on has a spectral LDE of 1.53% at 480nm. Modifying the paper spectral LDT with a normalized square of the cyan 480nm reflectance gives a calculated spectral LDE for the cyan 480nm peak of about 1.1% - considerably higher than the 0.88% measured value. There is something else going on in paper. The author's experience with computer color matching, which typically uses a correction of surface internal reflection (Saunderson, 1942), suggests that internal surface reflections may play a roll in reducing LDE at lower reflection values. The peak reflectance in figure 12, which is greater than 100%, is caused by the inclusion of a florescent whitening agent (FWA) in the paper. The florescent dye in the paper absorbs UV light and remits at a longer wavelength. When cyan ink is printed on top of the paper, it absorbs the UV light and prevents fluorescence in the paper. This may also contribute to the lowering of LDE in the cyan sample.

## INSTRUMENT CALIBRATION

The Japanese opal normal used by the Byk-Gardner Color Machine as a calibration standard is translucent. The calibration data provided with the standard by Byk-Gardner is for a specific set of illumination and viewing aperture sizes. The apertures used in the present work different from those used when the standard was calibrated by the manufacturer. A pressed barium sulfate pellet was used to calibrate the instrument before and after each set of measurements. Figure 13 plots the reflectance of the Japanese opal for the two aperture sets used in this work. In previous work, measurement of a pressed pellet of a mixture chromium dioxide and barium sulfate (~50% reflectance) determined that with the 4/3 configuration, a pressed barium sulfate pellet had a LDE of less than 0.2%.

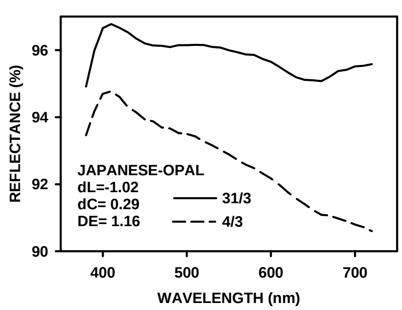


**Figure 13** Japanese Opal 31/3 & 4/3 Plots

## CONCLUSIONS

Yellow process inks, particular those formulated with dyes, exhibit nearly ideal characteristics. They have low absorbence and scattering in the red through green portion of the spectrum and high blue absorbance. By comparison, magenta and cyan inks are far from ideal process inks. While both usually exhibit low scattering, they all have absorbances much higher than the typical yellow process ink.

This study dealt with inkjet inks which are typically made with dyes. Process inks used for on-press printing are typically formulated with pigments. While pigment yellow inks are generally not as fugitive as dye based inks, they exhibit more scattering than their dye based counterparts. Unfortunately grinding yellow pigments to reduce particle size, and thus the scattering, also shifts the color toward green.

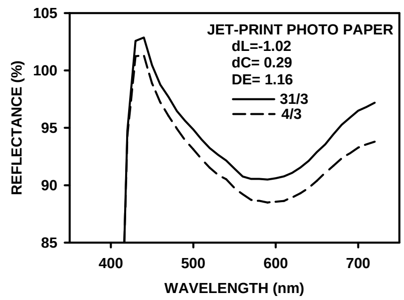


**Figure 12** Jet-Print photo paper - 31/3 and 4/3 plots

Future investigations need to be done using pigmented ink exhibits produced with proof presses, laser printers, and additional inkjet printers. A more exact model of media and printed process ink LDE needs to be developed.

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