Color Measurement on Substrates with Optical Brightening Agents

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Abstract. Yellow and blue Pantone colors were printed on a substrate with high Optical Brightening Agent (OBA) levels and then measured under different measurement conditions as outlined in ISO 13655. Both colors exhibited large DE00 shifts with lighter screen tints, as more paper influenced the measurement. The Pantone colors were further analysed after being printed on two different substrates with varying OBAs. While the solids were color-matched to a DE00 of less than 1.0, the tints resulted in DE00 values above 7.0 due to more paper influence in the lighter screen tints.

Keywords, Color, Florescence, Optical Brightening Agents, Florescent Whitening Agents, Substrates, Brightness, UV, M1, ISO 13655

INTRODUCTION

The measured color of an object is dependent on three factors, the spectral power distribution of the illuminant (SPD), the spectral reflectance of the object, and the spectral sensitivity of the observer. The product derived represents the CIE tristimulus value of the color. This tristimulus value is the basis for color measurement as well as color control of printed materials.

Given that the tristimulus value is the product of the illuminant, the reflectance, and the observer, a change in either the illuminant or the observer can alter the measured color of an object even though there is no change in its spectral reflectance. This property called metamerism creates color matches that are conditionally based on the observer and the illuminant.

1.1. The Standard Observer

The human eye consists of rods and cones. Rods allow us to perceive small quantities of light as gray while cones allow us to perceive color. The eye consists of three different types of cones responding to short, medium, and long wavelengths in the visible spectrum.

Considerable overlapping of each cone's sensitivity allows us to discriminate millions of colors.

To accurately describe color, the International Commission on Illumination (CIE) measured, quantified and defined a "standard observer" as a means to control this variable in color science. The CIE 1931 standard observer is a set of color coordinates designed to match the color perception of the average human population with normal color vision. To describe the standard observer subjects were asked to use two lights to visually match specific primaries. The results were then recalculated to all positive values to enable the design of color measurement devices using three color channels [1].

1.2. Illuminants

Assuming that the CIE 1931 standard observer defines the observer, the SPD of the illuminant becomes a critical component in color measurement. The spectral power distribution of the illuminant used to judge print samples is clearly defined in the ISO 3664:2009 standard as D50 [2]. However, the SPD of illuminants used in real world situations is less well defined. In commercial settings sources of illumination are often chosen for economic or environmental considerations rather than their spectral power distributions. Figure 1 shows that there is a considerable difference in the SPD of D50 and other illuminants, such as illuminant A that represents incandescent lighting, and illuminant F2 that represents cool white florescent lighting.

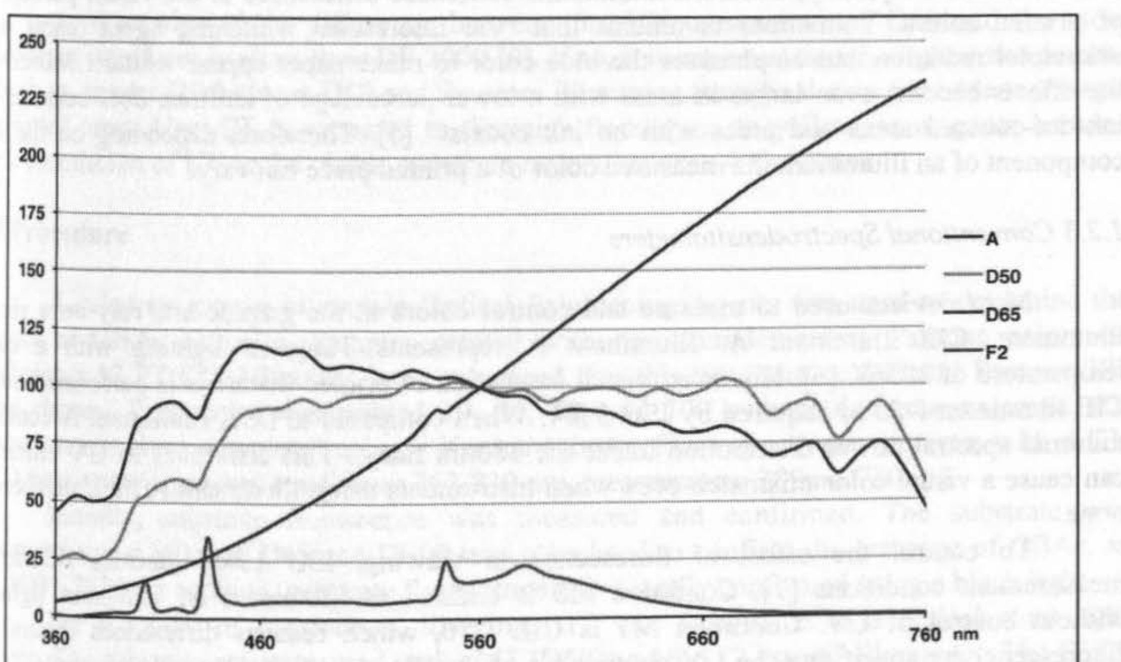

Figure 1. Relative Spectral Power Distribution of Illuminants Source Data: Fairchild, M. D., [3].

1.2.1 Fluorescence

In addition to differences in the visible region of the spectrum (about 380nm–760nm), differences also occur in an illuminant's ultra-violet (UV) component. It is important to consider the UV component of the illuminant because of florescence. Fluorescence is a property where a substance absorbs radiation in the non-visible UV range of the spectrum and reemits it as visible light. To increase brightness and correct for undesirable qualities florescent whitening agents, also called optical brightening agents (OBAs), are added to a variety of products, such as detergents, plastics, and paper substrates. The addition of OBAs to brighten paper substrates is both economically and environmentally preferable to additional bleaching processes. Typically, these "Florescent whitening agents (FWA's) absorb ultraviolet radiation between about 300 and 400nm and reemit this radiation as light between 400 and 500nm" [4].

1.2.2 Optical Brightening Agents

Virtually all substrates with an ISO brightness above 88–89 use optical brightening agents. Rothe stated it is difficult to achieve brightness above 88 without the use of OBAs [Rothe, M., personal communication, 3/8/2012]. Therefore, fluorescence should be a consideration in accurate color measurement for all high-bright substrates. The amount of florescence a particular substrate will exhibit varies depending on the UV component of the illuminant. Consequently, different illuminants can cause differences in the visual perception of printed colors. Yamamoto comments that "the fluorescent whitening agent reacts with ultraviolet radiation and emphasizes the blue color to make paper appear whiter…Moreover, the effects become even larger in areas with a lower percentage of halftone dots because the ink-dot-covered areas and areas with no ink coexist" [5]. Therefore, depending on the UV component of an illuminant the measured color of a printed piece can vary.

1.2.3 Conventional Spectrodensitometers

Most devices used to measure and control colors in the graphic arts rely on a single illuminant, CIE illuminant A. Illuminant A represents Tungsten lighting with a color temperature of 2856K [6]. However, visual inspection of printed materials is performed under CIE illuminant D50 as required by ISO 3664. When compared to D50, Illuminant A contains minimal spectral power distribution under the 380nm range. This difference in UV emission can cause a visual color mismatch even when instruments using Illuminant A indicate there is none.

To control the effect of florescence in viewing, ISO 13655 defines illuminant measurement conditions [7]. Condition M0 is defined as illuminant A, Tungsten lighting without control of UV. Condition M1 is CIE D50, which reduces differences caused by fluorescence by specifying the UV component of the illuminant. McDowell comments, "M1, which requires a close match to D50 including the UV portion, is very close to the previous reflectance measurement condition and also matches the standard viewing condition." [8].

In spite of the fact that a D50 setting is available in all industry spectrodensitometers, the actual illuminant used is Illuminant A. The D50 setting merely represents a software correction to that light source. Since illuminant A has minimal emission in the UV range, the affect of florescence on printed pieces cannot be determined by devices relying on illuminant

A. Furthermore, the actual viewing of a printed piece may take place under conditions well removed from D50.

1.2.4 Measuring Florescence

When a sample with OBAs is measured with an illuminant that contains UV radiation, it is expected that that radiation will be reemitted in the visible 400-500nm range of the spectrum. According to ISO 13655, Section D.2, a test for florescence can be made by measuring the CIELAB difference of a sample under both Illuminant A and D65. These two illuminants have a considerable difference in SPD, in particular in the UV region of their spectral distribution. "The resultant spectral data is then used to compute the tristimulus values, relative to D50, for both sources. The CIELAB difference between them is a measure of the fluorescence"[7]

2.1 Methodology

This research seeks to answer the following question. Do printed substrates containing OBAs exhibit significant color differences when measured under illuminants containing different amounts of UV radiation?

The first step is to confirm substrate florescence based on ISO 13655, D.2. Once substrate florescence is confirmed, the second step is to confirm substrate florescence between D50 and a typical store illuminant. After printing tint patches on the tested substrate, the third step is to determine if the difference between the UV component of D50 and the store illuminant significantly alters their DE 2000 [9]. If so, it is expected that the lighter tint patches will show greater DE between D50 and the store illuminant than the darker tints due to a larger unprinted area. Also, DE is expected to diminish from cyan, to yellow, to magenta because peak reemission of UV in the visible spectrum occurs between 400-500nm

2.2 Procedure

A substrate known to contain Optical Brightening Agents was used to determine the impact of OBAs on color. Samples printed with two complementary Pantone colors on Technicote 12 PT C1S Ultra Tag were measured. For this test Pantone 305 and Pantone 387 were chosen. Each color was printed 10, 25, 50, and 100 percent dot area coverage. All measurements were completed using a Konica Minolta FD-7 spectrodensitometer with a UV LED light source (spectral irradiance: 360-730 nm, measurement 380nm-730nm).

Initially, substrate florescence was measured and confirmed. The substrate was measured using M0, and D65 and DE00 was calculated to confirm the presence of OBAs, as per ISO 13655, In addition, substrate florescence was visually confirmed using a black light.

For purposes of comparison, illuminant F2 was designated as a typical store light source. The substrate was measured under M1 (D50) and the F2 "store" illuminant. The DE00 of the substrate between the two illuminants was calculated, as was the DE00 of solids and tints of both Pantone colors.

Finally, color-matched prints were compared as printed on two substrates. The Technicote 12 PT C1S Ultra Tag has a rated brightness of 90. Spinnaker Coating Ultra Matte™ Litho has a rated brightness of 89. Matched colors were compared on these substrates using M0, M1, and M2 (UV Cut).

3. RESULTS

Measuring the unprinted substrate under illuminant A and D65 yielded a DE00 of 4.64. Furthermore, a measurement under illuminant A and D50 resulted in a DE00 of 1.94, and measurement under D50 and illuminant F2 resulted in a DE00 of 4.08. Figure 2 shows that the DE is due to changes in the 420-520nm range of the visible spectrum, indicating that fluorescence was causing the change.

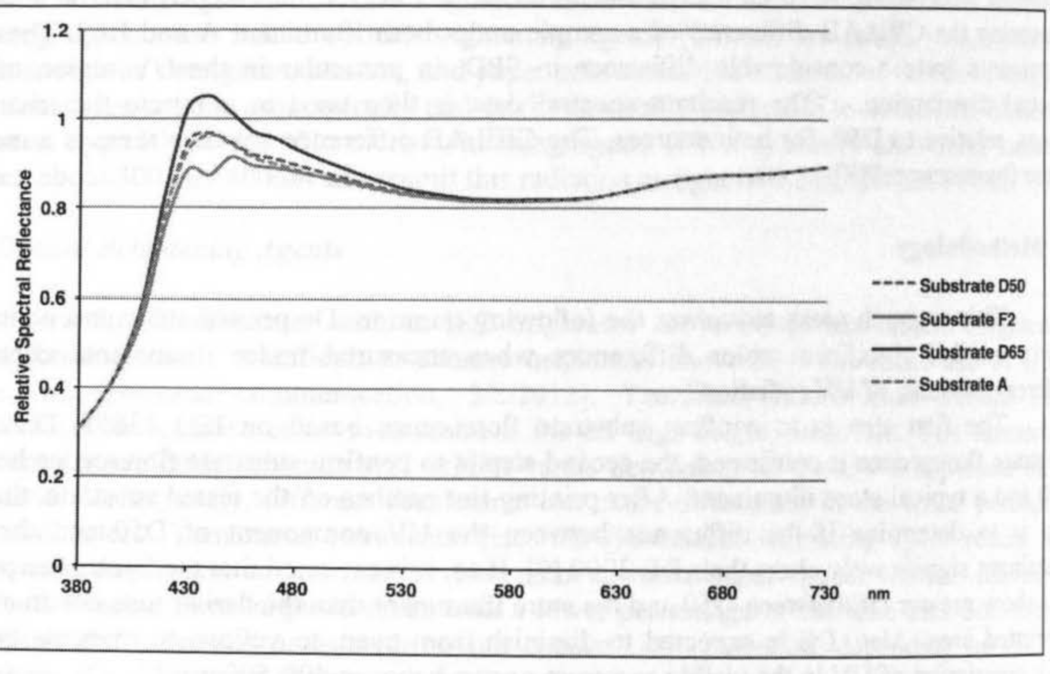

Figure 2. Spectral reflectance of substrate at D65, D50, F2, and Iluminant A.

Table 1. Sample Measurements.

DE A-D65	PMS 387	PMS 305
10%	4.17	2.65
50%	1.31	2.05
75%	0.62	1.79
100%	0.29	1.61
DE A-D50		
10%	1.52	1.10
50%	0.51	0.78
75%	0.25	0.68
100%	0.12	0.61
DE D50-F2		
10%	3.79	2.63
50%	1.14	2.34
75%	0.49	2.03
100%	0.19	1.83

The largest DE in the printed patches occurs in the 10% tints, and DE diminishes as more of the measured area is printed (Table 1). This indicates that the unprinted substrate played a significant role in color difference.

Figure 3 compares the relative spectral reflectance of the 10% tint of both colors under D50 and illuminant F2. The difference in reflectance peaks at 430nm for both colors. This indicates that fluorescent reemission was the major component in the color difference between the two illuminants. An interesting result was that a larger DE occurred in the 10% tint of PMS 387 (yellow) than in PMS 305 (blue). This result was unexpected. It is speculated that the large unprinted substrate area with peak reemission in the blue region of the visible spectrum caused a large change in the hue of the yellow tint; thereby, creating a larger DE.

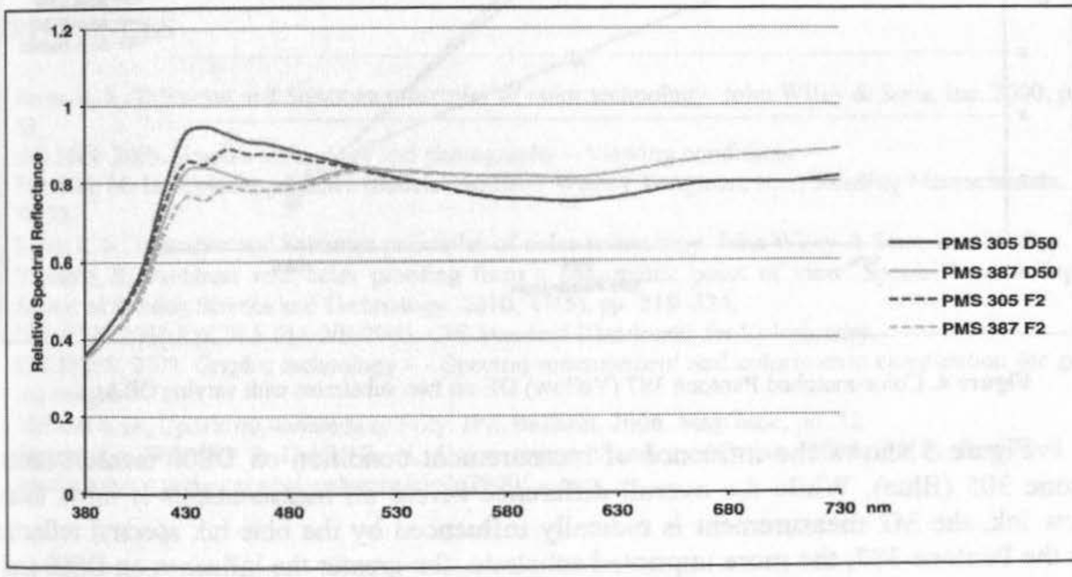

Figure 3. Change in Spectral Reflectance of 10% tints between D50 and F2.

When comparing color-matched inks printed on different substrates, the impact of the substrate was noticed when comparing DE measurement conditions, especially in the tints. Table 2 shows the L*a*b* and DE00 values of the unprinted substrate.

Table 2. Brightness and L*a*b* Values of Comparison Substrates.

Substrate	Rated Brightness	L*	a*	b*	DE00 (other substrate as reference)
Technicote 12 pt C1S Ultra Tag	90	93.19	2.9	-8.32	6.29
Spinnaker Coating Ultra Matte Litho	89	94.75	0.6	-0.4	5.95

Inks were adjusted on press to create both a visual and quantitative match with a target of ≤1.0 DE00. Pantone 387 (yellow) was modified for the two substrates to achieve a DE00 of 0.68 at the solid (100%) between the two substrates. The Pantone 305 (Blue) solid was matched to a DE00 of 0.65 between the two substrates.

M0, M1, and M2 measurement conditions were used to measure the solid, 50% tint, and 10% tint areas of the printed colors. Figure 4 shows that Pantone 387 did not show substantial value differences between the two substrates with measurement conditions M0 and M1, though the DE00 did increase substantially as more unprinted substrate influenced the measurements. M2, with the UV-cut approach varied from the other two at the 50% tint, though not as radically as with the second ink color. M0, M1, and M2 exhibited different results when measuring the 10% tint.

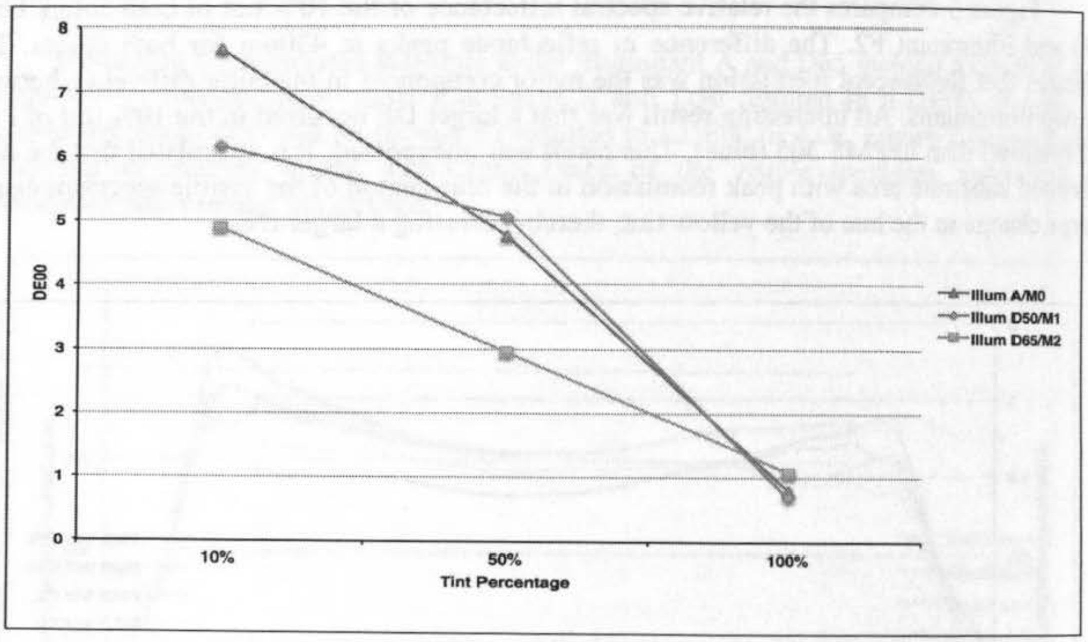

Figure 4. Color-matched Pantone 387 (Yellow) DE on two substrates with varying OBAs.

Figure 5 shows the influence of measurement condition on DE00 measurements for Pantone 305 (Blue). While the overall difference across all measurements is lower than the yellow ink, the M2 measurement is radically influenced by the blue ink spectral reflectance. Like the Pantone 387, the more unprinted substrate, the greater the influence on DE00 and the more significant the measurement condition plays in the measured value.

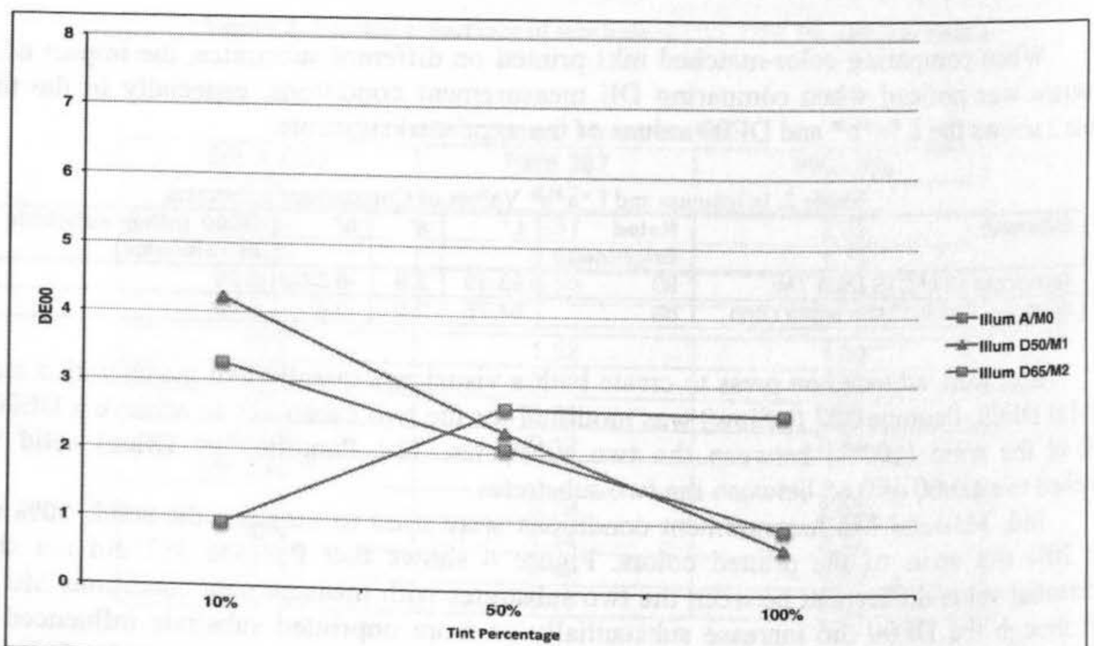

Figure 5. Color-matched Pantone 305 (Blue) DE on two substrates with varying OBAs.

4. SUMMARY

This study demonstrated that the unprinted substrate as well as the spectral reflectance of the ink needs to be taken into account when measuring DE00. The area of unprinted substrate allows for reemitted light, due to fluorescence, to alter DE00. Furthermore, greater alteration of DE00 takes place in low tint percentages of colors that have minimal spectral reflectance in the region of fluorescent reemission. Further study is needed to determine if some form of scaling method is necessary to compensate for these variables.

5. REFERENCES

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