Spectrophotometers & Measuring OBAs (Optical Brightener Additives)

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Abstract

In recent years, several printing paper manufacturers have started adding optical brighteners (OBAs) to their papers, as an economical way of making the paper appear brighter and whiter. These brighteners respond to ultra violet (UV) light, and re-emit this energy as visible light, in the 'blue' part of the spectrum (approx. 430 – 460 nm) (Giordano 2000). This results in 'bluer' colors, which we (the end users) actually perceive as being 'whiter' (or less yellow) (Schroeder 2014).

There are a variety of different standards and specifications that apply throughout the 'color managed' stages of a print production workflow. A key part of this overall process is working with clients and print buyers to manage their expectations of the final visual appearance of the product. Through utilizing standards and specifications, color can be accurately predicted, and contract color proofs can be produced that will closely resemble the final printed project, allowing for a 'Print-to-Proof' match (P2P).

These proofs can be used for iterative content and color approvals prior to final production, as well as during the manufacturing run. They are compared to the press sheets to help verify reproduction and provide information on how to adjust the process, to help achieve the desired results (ex. make it more 'red', or less 'green'…). These comparisons are normally done under controlled, standardized, viewing conditions a viewing 'booth' that has neutral gray walls and standardized bulbs that produce a uniform color temperature of light, known as 'D50' (Idealliance 2015).

The process itself has many inherent variables that can interact to impact the overall effectiveness of the P2P match; substrates, colorants, printing technologies, screening algorithms, fountain solution, speeds, relative humidity, colors and layout of the content, and many others.

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Supporting this scenario requires that the standards be communicated effectively, that measurement devices which accurately capture characteristics and behaviors be used, and quality control measures are implemented and adhered to, in order to ensure conformity to the standard or specification (Chung 2014).

This project focuses on the 'accuracy' and level of 'precision' of the different commercial spectrophotometers with regards to measuring fluorescence in the approx. 430 nm – 460 nm part of the spectrum, where OBAs re-emit UV energy. It also analyzes and compares the devices behavior for M2 (UV Cut) measurement condition, as a reference for the M1 (D50, UV Included) measurement condition.

Background

In general, the printing industry in North America has 'standardized' on using 'D50' color-viewing and D50 color-measurement in an effort to establish common viewing conditions for contract color P2P visual matches. D50 was selected, as it is a mathematical construct of 'natural' outdoor lighting (x-rite n.d.).

A concern is that, prior to the development of newer standards in 2009, established color management workflows and processes did not necessarily account for the UV portion of the spectrum, or different parts of the process accounted for it in different ways. With increased use of OBAs, this has lead to increased differences in P2P visual matches (ISO 2009a as cited in Smyth-Gerlach 2017).

Released in 2009, and effective internationally in 2012, *ISO 3664:2009 Graphic technology and photography (viewing conditions)* was designed in part to define and include the UV portion in D50.

2009 also saw the publication of a second edition of ISO 13655, *"Graphic Technology – Spectral measurement and colorimetric computation for graphic arts images"*. This was updated, in part, to include additional measurement approaches to account for the impact of UV light and OBA infused materials. This standard included four methods for spectrophotomers to measure final color in printed pieces:

> M0—legacy mode (any illumination source, typically illuminant A) – contains 'uncontrolled' UV
> M1—D50, UV-included mode (devices can use two different methods to achieve this mode)
> M2—UV-cut mode (removes all UV light from the illuminant, below 400 nm)
> M3—polarizing mode (e.g., for measurement of wet offset press sheets or metallic inks)
> (ISOb 2009)

The updated M1 measurement approach, ISO 13655:2009 (now ISO 13655:2017), used in combination with the updated viewing conditions specified in ISO 3664:2009 provides better technical alignment of devices and viewing conditions in color managed workflows.

However the use of higher OBA infused substrates in an ISO 13655 compliant workflow meant that P2P comparisons did not ‘match’, visually or numerically, as they may have prior to updated equipment. The OBA press sheets can appear to be ‘too blue’, or the conventional substrate inkjet proofs ‘too yellow’, due to the inclusion of defined amounts of UV light and the resulting blue from the OBAs.

For these discussions, ‘low’ OBA stocks are considered to have a b* greater than -2. ‘Moderate’ OBA stocks measure between -2 and -6, and ‘higher’ OBA stocks have a b* ‘bluer’ than -6.

Literature Review

M1 Measurement Devices

In 2017 a third edition of ISO 13655 was published to, which included updates designed to:

- Clarify the requirements of measurement mode M1
- Restrict the use of unnecessarily wide bandpass and sampling intervals
- Provide more realistic specification for the optical properties of a white backing material
- Restrict the adjustment method of predicting the fluorescent reflectance factor to UV activated substrates (ISOc 2017).

These changes are important for this research project as they outline two different approaches manufacturers can use for M1 (D50) UV measurement conditions. As noted these were implemented to ‘improve the consistency visual assessment of M1 based measurement in ISO 3664 compliant viewing booths’ (ISOc as cited in Sharma et al 2017).

In simple terms the two Measurement Conditions for M1: ISO 13655:2017 - 4.2.2.2 are that the device ‘must emit the actual D50 illuminant’ or that it must ‘emit the correct UV portion and you calculate the visible portion of D50’ (ISOc 2017).

Note that it is outside of the scope of this work for this project to ‘compare’ the two approaches, however important to understand that different approaches could exist in the devices analyzed in this project.

Sharma et al's research demonstrated that the new generations of devices "do show better intermodel agreement when compared with legacy devices, but only for the M1 measurement mode" (Sharma et al 2017). This research did not specifically evaluate the devices behavior with OBA infused substrates.

Several industry groups have analyzed and developed approaches to working OBA infused materials in the printing and publishing industries; ISO TC 130, Fogra (Research Institute for Media Technologies), CGATS (Committee for Graphic Arts Technologies Standards), Idealliance, and others.

Substrate Corrected Colorimetric Aims (SCCA)

One technique for working with OBA infused materials is to use Substrate Corrected Colorimetric Aims (SCCA). This is a mathematical approach developed for adjusting the color for final contract proofs on low to moderate OBA stocks, to better visually compare with higher OBA print samples. A printer can selects their desired dataset target (for example TR006), enter a particular substrate's L*, a*, and b* values, and the required L*, a*, and b* aims for a suitable visual match will be calculated (Chung, Wu 2014).

Custom Profiling

For more acceptable overall matches, some practitioners prefer to develop and apply custom aim points, to better compensate for the effect of the OBAs.

New Characterization Sets

Another alternative, in an effort to support standards and 'get back to the numbers', would be to 'rewrite' the print specifications, basing them on different optically brightened papers.

The Print Properties Colormetric Council is a workgroup of the Idealliance, an international non-profit industry association based in the United States of America. This group's 'Paper Task Force' struck a working group explore the OBA and P2P issues and different parts of the color managed workflow.

Numerous organizations have donated time and resources to the questions surrounding P2P matches and OBAs, including Barbieri, ColorXTC, Epson America, efi, FujiFilm, gti, Komori, Konica Minolta, Rochester Institute of Technology, Ryerson University, Sappi North America, and x-rite.

Three of the previous projects this task force worked on are important for this research project.

CRPC6 as an M1 reference data

The first was to verify the applicability of GRACoL2013 (which is built using CRPC6) as an M1 reference data set for current commercial printing. This was on a range of stocks containing OBAs, available in the North American market.

Proofing targets from dozens of different, approved, 'G7 Master certified sheets' were measured. The analysis showed a 'CIEDE2000' of less than 2, which is within tolerances, slightly visible to a trained eye (efi n.d. as cited in Smyth-Gerlach 2017).

The colorimetry of the solids on moderate OBA substrates, defined as those with a b* ~ -4 were close to the solids represented in CRPC6 (Smyth-Gerlach 2017).

Subjective Visual assessment Print to proof matches

A different project through the Idealliance PPC group was an effort to analyze the subjective 'acceptability' of visual assessments of P2P matches using M1 workflows and controlled ISO 3664:2009 compliant viewing conditions.

The second project comprised three psychometric surveys that captured a variety of perspectives on different P2P matches with OBA infused substrates. Print-to-Proof & OBA Visual Assessments, presented at TAGA 2017 indicted that these techniques do not necessarily provide a consistently 'acceptable' result.

The contract color inkjet proofs and printed samples were combinations of 'low', 'moderate', and 'high' OBA infused substrates.

The press-sheets had been created using either standard color management ('run to the numbers'), SCCA, or profiles built from dedicated OBA infused pressruns.

While subjective color analysis should not be considered conclusive, patterns from the results indicated that substrates with higher OBA values appeared to be more of a challenge to achieve an 'acceptable match', even when both the print and proof material had 'bluer' b* values (Smyth-Gerlach 2017).

In all groups, however, proofing materials with moderately increased amounts of OBAs predicted a more acceptable visual match with prints containing higher levels of OBAs.

This supported the proposal that the North American industry should be developing a standard characterization set, specifically for higher OBA workflows, in order to improve the acceptability of visual P2P comparisons when using OBA substrates.

Pressrun testing and comparisons

The third project, additional press testing and analysis, was undertaken in April 2017, through the Idealliance's Print Properties Colorimetric Council (PPC) and support from industry partners (Komori, Sappi Papers, and Fujifilm Graphics). These press runs were produced with OBA infused paper and proofs, and manufactured to a characterization set built to reflect higher OBA content.

The expert visual assessments of these press runs and comparisons, with a modified characterization set, demonstrated that 'P2P matches' with OBA infused press stock and proofing papers can get 'visually closer' than those without an adjusted characterization set. Subjectively, however, the match was not 'as close' as conventional P2P matches, using non-OBA infused stocks output with unadjusted GRACoL2013 / CRPC6.

Spectrophotometers & Measuring OBAs

This raised the question of what other issue(s) could be contributing to these visual discrepancies. The factor considered in this project is the repeatability and accuracy of the different commercial spectrophotometers in the marketplace, with regards to M1 UV included measurement. These are the devices commonly used for quality management processes, including measurement and building profiles.

A summary of the problem statement is: are measuring differences effectively contributing to the failure of color management to provide an acceptable visual P2P match using M1 workflows with OBA stocks?

Methodology

The analyses and evaluation of how current spectrophotometers, that support M1, are measuring OBAs was achieved by comparing their results with a traceable third party device capable of measuring OBAs at a finer level of detail.

It is important to clarify that the intent of this project is not to 'compare and contrast' different devices, or to 'openly reveal' or 'challenge' vendor's internal test methods and protocols. The objective was to make an effort to 'see' what might be happening in the visible spectrum areas where UV is re-emitted. This is done through 'benchmarking' the devices to 'true' known values of the effects of UV, using a practical OBA infused substrate that would commonly be found in the field.

Substrate

The stock selected to represent a substrate with a moderate to higher amount of OBAs was a Sappi McCoy Gloss Cover 80lb/216g/m2. This is a commercial paper, widely available in North America, and a popular choice for commercial and magazine customers.

Dennis Dautrich, Printer Technical Representative with Sappi North America, generously supported this project. Dates of manufacture of the samples of the stock were recorded, and the samples were sent directly from the producing mill to Ryerson University, in Toronto Canada.

At Ryerson, the stock was prepared for measurement; trimmed to required size, an identifying cover applied, and stitched in booklets of 10 sheets. All samples were stored in lightfast bags, and in a climate controlled paper storage facility at Ryerson in an effort to maintain relative humidity and prevent fading of the optical brightener components.

M1 Measurement

The National Research Council, in Ottawa, Canada (NRC) has the ability to measure substrate samples for their total bi-spectral radiance factor, from 300 nm to 850 nm.

The NRC equipment captures information with reliable accuracy and traceability, at 5 nm intervals. Commercial spectrophotometers record and report at 10 nm intervals, and can use different extrapolation approaches. As such, the NRC device can be considered a 'benchmark' measurement, to which others can be compared and contrasted.

The measurement geometry was 45° degree annular illumination and 0° viewing (45°/0°), and the instrument bandwidth was 5 nm. The irradiated sample area was approx. 10 mm in diameter, in the center of prepared test sample. Measurements were performed at ambient temperature (23 +/- 1° C), and for a relative humidity of (34 +/- 5 %).

The reflected spectral radiance factor data were recorded from 300 nm to 850 nm, at 10 nm intervals. This was interpolated with a cubic spline function to give data every 5 nm. The bispectral luminescent radiance factor data were recorded over the excitation range of 300 nm to 460 nm, and emission range of 370 nm to 620 nm, at 10 nm intervals (Zwinkels personal communication, Oct. 13, 2017).

The nonfluorescent reference standard is traceable to NIST, has absolute spectral radiance factors from 300 nm to 850 nm (NRC n.d.).

See Figure 01 for the results of the McCoy 80lb measured at the NRC Ottawa:

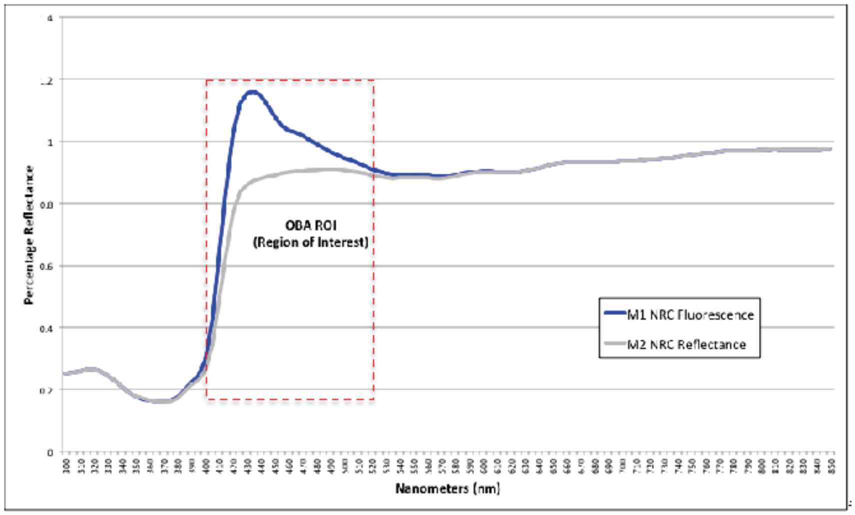

Figure 01: *McCoy 80lb Measured at the NRC, Ottawa, Nov. 2017*

The region of interest (ROI) for the OBA ultra violet (UV) activity is highlighted by the red rectangle, ranging from approximately 400 nm to 520 nm.

The samples were then measured using a variety of commercially available spectrophotometers, capable of reading in both M1 and M2 measurement conditions. Each of the devices had been recently checked by their manufacturers and calibrated. Both handheld and 'strip' readers were included in analysis and comparison. The specific devices and models tested were:

- barbieri LFP qb
- Konica Minolta FD-7
- Techkon SpecDens
- Techkon SpectroDrive
- x-rite i1Pro2
- x-rite eXact
- x-rite iSis2

The devices were assigned unique identifiers; the purpose of this project is not to identify and compare specific devices.

The results of each device were based on 'averaged data' from 10 readings, taken from different positions on the sample. These were captured by a direct connection between the device and laptop, and not transposed manually.

M1 Results and Discussion

The M1 results of each device were analyzed and compared to the NRC measurements. This was done in an effort to determine if their approaches to measuring UV energy re-emitted as blue light by OBAs could be contributing to the 'failure' of color management to provide an acceptable visual P2P match using M1 workflows with OBA stocks. Both the NRC curve with fluorescence (NRC F Curve), and the NRC curve for reflection only (NRC R Curve) are included. The NRC R Curve is shown as reference for areas where OBAs are fluorescing rather than reflecting only. Please see Figure 02:

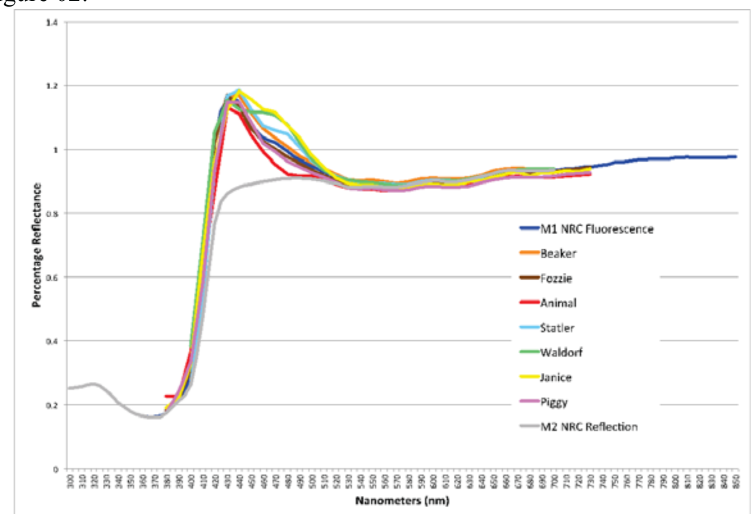

Figure 02: *McCoy 80lb M1 Averaged Readings to NRC Curves*

The devices identified as 'Beaker', 'Fozzie', and 'Piggie' appear to closely follow the NRC F Curve. The devices identified as 'Animal', 'Waldorf', 'Janice', and 'Statler' do not follow the NRC F Curve as closely.

When measuring spectral reflectance the shape of the curve as defined by the relative differences between measured wavelength is most important because this determines the color of the sample. Also, important is the overall relative reflectance of all wavelengths together, which essentially determines the overall lightness of a sample.

Both of these factors can be affected by small amounts of device error inherent in any system. This research is looking at the differences primarily in color, therefore all measurements were normalized at 560 nm (Hunt 2004), to bring the overall relative reflectance more inline with the NRC 'benchmark', while leaving any colour difference due to the measurement of fluorescence alone. See Figure 03:

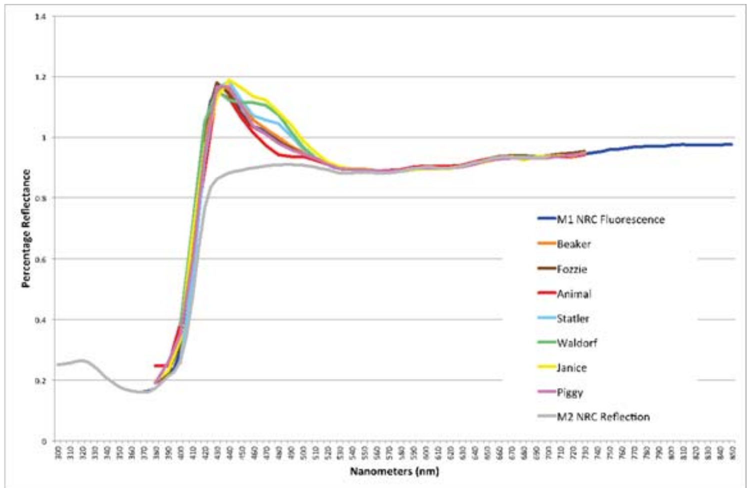

Figure 03: *McCoy 80lb M1 Normalized to 560nm*

Normalizing the data reduces some of the differences and allows for a better device-to-device comparison of devices to the NRC curve. There is clear variability in the violet – blue region of the spectrum. See Figure 04 for an expanded view of the ROI for the OBA effect:

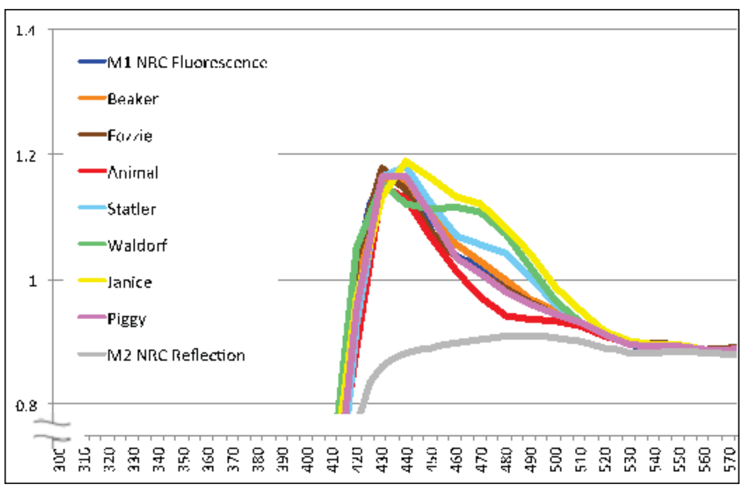

Figure 04: *expanded view 'Region of Interest' McCoy 80lb M1 - Normalized to 560nm*

Considering the normalized data in the ROI, the devices 'Beaker', Fozzie', and 'Piggy' are closely following the NRC fluorescence results. However, 'Animal' is reading lower than the NRC fluorescence curve, while 'Janice' and 'Waldorf' are showing higher readings in the region between approx. 460 and 500 nm. This area corresponds to the blue, transitioning to green, part of the visible spectrum (Giordano 2000). The 'Statler' readings are slightly higher than the NRC F Curve in this range as well.

Differences to NRC

All spectral measurements for each device were recorded at the individual system's functional range (either 380nm - 730nm, or 400nm - 700nm). Ten individual measurements were averaged together at each wavelength interval to reduce measurement error. The averaged spectral reflectance curve was used to calculate colorimetric (L*a*b* D50/2˚) values as per ISO 13655. These colorimetric values were then used to calculate the color difference using the CIE 1976 and CIE 2000 color difference equations also specified in ISO 13655. See Table 01:

	Averaged Normalized				+ is Darker	+ is Greener	+ is bluer	ΔE00 to NRC
	L*	a*	b*	ΔEab to NRC	ΔL* to NRC	Δa* to NRC	Δb* to NRC	
NRC w/Fluorescence	96.20	3.03	-9.57	0.00	0.00	0.00	0.00	0.00
Beaker	**96.21**	**3.09**	**-10.25**	**0.68**	**-0.01**	**-0.06**	**0.68**	**0.48**
Fozzie	96.26	3.11	-9.37	0.22	-0.06	-0.08	-0.20	0.21
Animal	**96.17**	**2.83**	**-7.76**	**1.82**	**0.03**	**0.20**	**-1.81**	**1.33**
Statler	96.26	3.02	-11.11	1.54	-0.06	0.01	1.54	1.12
Waldorf	**96.33**	**3.05**	**-11.91**	**2.34**	**-0.13**	**-0.02**	**2.34**	**1.67**
Janice	96.45	2.95	-13.02	3.46	-0.25	0.08	3.45	2.47
Piggy	**96.16**	**2.99**	**-9.67**	**0.11**	**0.04**	**0.04**	**0.09**	**0.10**
NRC Reflection	95.94	0.20	0.88	10.85	0.56	2.83	-10.46	9.30

Table 01: *Devices CIEDE76 (ΔEab) & CIEDE2000 (ΔE00) Differences from NRC fluorescence results McCoy 80b M1 D50/2˚ L*a*b*- normalized*

The normalized data in the chart highlights the impact of trends from the spectrum curves comparison. Reviewing the differences in ΔE_{ab} to the NRC fluorescence results, with 2.0 being considered a just noticeable difference; 'Piggy' (0.11) and 'Fozzie' (0.22) are very close the NRC results, and the difference of 0.68 for 'Beaker' can also be considered a negligible difference.

The results for 'Statler' (1.54) approach the tolerance, and 'Animal' is slightly under it at 1.82. The difference for 'Waldorf' (2.34) and 'Janice' (3.46) would be visible differences, according to our allowable tolerance of 2.0.

CIEDE76 (ΔE_{ab}) and CIEDE2000 (ΔE00)

The L*a*b* color space was designed to be a uniform, three-dimensional, color space. In practice it developed that this was not the case. In some areas observers are more prone to seeing differences than others, especially closer to neutrals and in pastels (CIE 2001 as cited in Habekost 2009).

While CIEDE76 remains a common metric to analyze perceptual color differences, several different equations have been developed in an attempt to compensate for this. CIEDE2000 was published by the ISO in 2014, as the updated approach to use in their standards and tolerances (Melgosa 2013 and ISOd/CIE 2014).

If CIEDE2000 is utilized, instead of CIEDE76, the differences from the NRC fluorescence curve are notably reduced. This is more evident for the devices that deviated the most from the NRC results under CIEDE76. Reviewing CIEDE2000 calculations, 'Janice' (2.47) remains the only device outside of the '2.0 Delta E' tolerance.

Differences Chart

Plotting each device's spectral readings, against the NRC F Curve highlights the area, and importantly the direction, of any differences from the NRC results – see Figure 05:

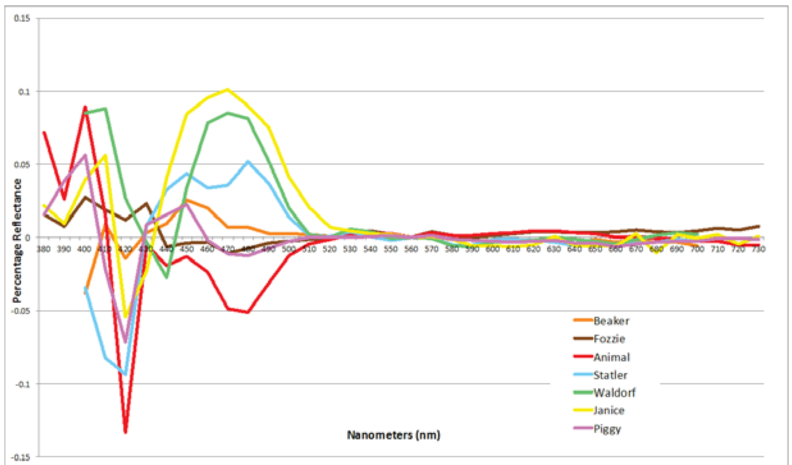

Figure 05: *McCoy 80lb M1 Normalized – Differences to NRC*

Reviewing the results plotted on the difference graph reveals trends. Five of the devices, except for 'Fozzie' and 'Waldorf' are reading below the NRC F Curve between approx. 410 nm – 430 nm, with a sharp decrease at 420 nm. This is the violet part of the spectrum, where OBAs would be absorbing more of the light energy

There are also significant differences between approximately 450 nm – 500 nm, with 470 nm showing either a higher level on four of the devices, or lower ones. This is the blue area of the spectrum, where OBAs would be re-emitting most of their energy.

The devices 'Animal', 'Waldorf', 'Janice', and to a lesser extent 'Statler' show the most variability from the NRC F Curve, as demonstrated by their CIEDE2000 values.

M1 Summary

Referring to Table 01 and Figure 05 to compare normalized device-to-device M1 results, the 'L*', the overall lightness, is measuring very close to the NRC F Curve, for all devices. The 'a*', the red/green, is also measuring closely. The 'b*', blue/yellow shows significant differences from the NRC F Curve; 'Statler' (1.54) and 'Animal' (-1.81) are approaching the tolerance of 2.0, while 'Waldorf' (2.34) and 'Janice' (3.54) are beyond it. If these devices were used in the same workflow, it could create a total difference of 5.26, in the blue region. This could cause a visible difference between outputs color managed to the same specification by the two devices.

Comparing device-to-device M1 results, the CIEDE2000 values and measured values could be in different 'directions' in the L*a*b* color space. While one device was found to have a CIEDE2000 from the NRC curve larger than 2.0, if different devices were used at various stages of a color-managed workflow, the combined differences could create a Delta E larger than 2.0, and contribute to a visual difference.

M2 Results and Discussion

In addition to M1, each device's ability to measure substrates without the impact of UV in the readings was also measured. This was done in an effort to identify and analyze each device's ability to measure a reflection only (M2) curve, to be used as a comparison for their ability to measure M1.

These results demonstrate how each device measures reflection only, without the fluorescent impact of OBAs. As with the M1 readings, the results of each device were based on 'averaged data' from 10 readings, in different areas of the sample, and captured using a direct connection. Please see Figure 06 below:

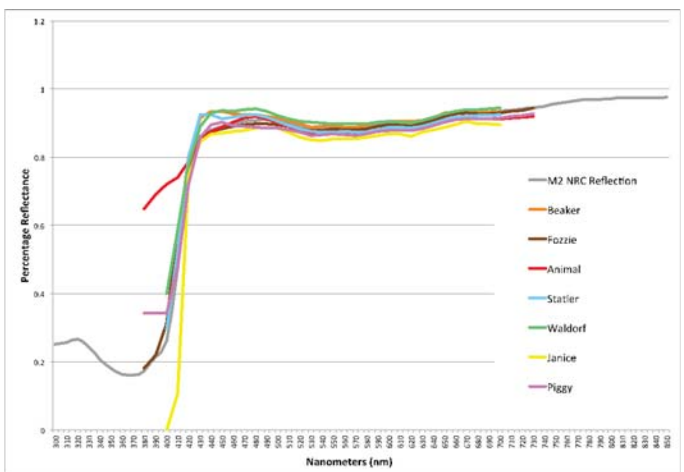

Figure 06: *McCoy 80lb M2 Averaged Readings NRC Reflection Curve*

All seven of the devices evaluated appear to closely follow the NRC reflection curve, with some reading above and some below. However there appears to be relatively larger amounts of variances from the NRC curve in the region of approx. 410 nm – 500 nm, which is the same region where OBAs actively re-emit their light energy.

This raises the question of if there is something inherent in the device's construction that is impacting readings in both modes at for these spectral values.

Normalizing the data, again using 560 nm as the reference, helps us better compare the results between the different devices - see Figure 07 below:

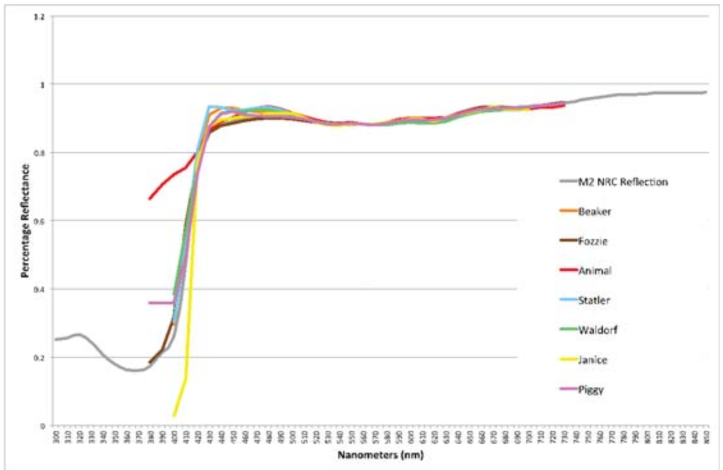

Figure 07: *McCoy 80lb M2 Normalized to 560nm*

Normalizing the data reduces the differences between the devices, compared to the NRC R Curve. However the data shows the pattern of variances from the NRC curve in the 410 nm – 500 nm, violet – blue, spectrum area.

See Figure 08 below for a detailed view of this ROI for the M2 measurements:

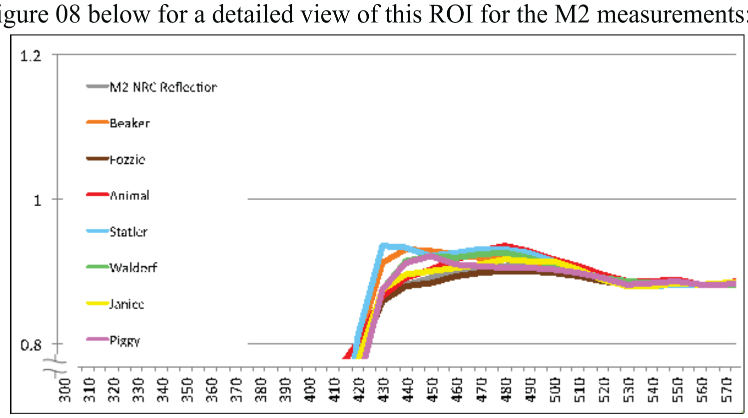

Figure 08: *'Region of Interest' McCoy 80lb M2 Normalized to 560nm*

Considering the normalized data, six of the devices, with the exception of 'Fozzie', are reading values above the NRC reflection curve in the region between approx. 420 nm - 500 nm. 'Beaker' and 'Statler' show the largest variances.

Summaries of the calculated CIEDE76 and CIEDE2000 differences from the NRC reflection curve for the different devices see Table 02:

	Averaged Normalized				+ is Darker	+ is Greener	+ is bluer	ΔE00 to NRC
	L*	a*	b*	ΔEab to NRC	ΔL* to NRC	Δa* to NRC	Δb* to NRC	
NRC No Fluorescence	95.65	0.30	0.91	0.00	0.00	0.00	0.00	0.00
Beaker	95.71	0.84	-1.04	2.02	-0.06	-0.54	1.94	2.05
Fozzie	95.57	0.36	0.99	0.13	0.08	-0.07	-0.08	0.13
Animal	95.78	0.37	-.042	1.33	-0.13	-0.08	1.33	1.31
Statler	95.60	0.82	-1.60	2.56	0.05	-0.53	2.50	2.54
Waldorf	95.53	0.13	-0.82	1.73	0.12	0.17	1.72	1.71
Janice	95.59	0.15	0.63	0.32	0.06	0.15	0.28	0.34
Piggy	95.60	0.52	-0.06	1.00	0.04	-0.23	0.97	1.02

Table 02: *Devices CIEDE76 (ΔE_{ab}) & CIEDE2000 ($\Delta E00$) Differences from NRC reflection results McCoy 80b M2 D50/2˚ L*a*b*- normalized*

For the M2 reflection curve, the devices 'Fozzie' and 'Janice' are very close to the NRC R Curve results. 'Beaker' (2.05) and 'Statler' (2.54) show CIEDE2000 difference larger than our tolerance of 2.0, with the remaining three devices between 1.00 and 1.71.

Note that the underlying weighting functions of the DE00 calculations do not appear to be as affected by the lack of 'blue' difference in these M2 measurements

A differences chart shows the direction of the deviation from the NRC R Curve results – see Figure 09 below:

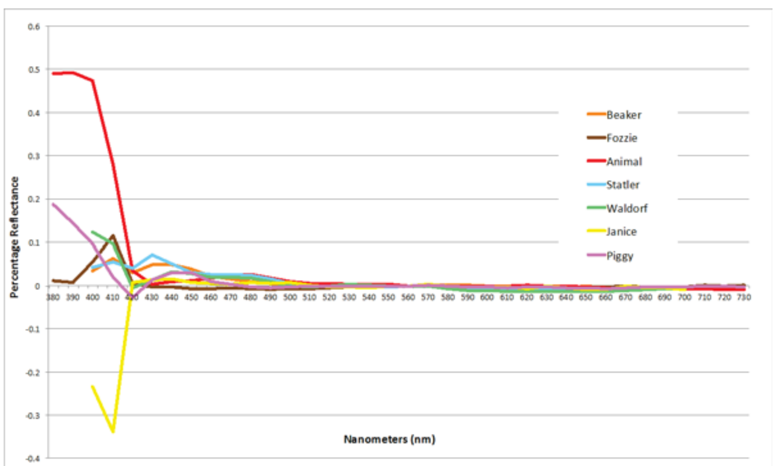

Figure 09: *McCoy 80lb M2 Normalized – Difference to NRC*

The M2 differences are less than those reported in the M1 analysis, with some variability from 400 nm – approx. 450, gradually tapering off until approx. 520 nm. Interestingly this area encompasses the spectrum impacted by OBA fluorescence.

M2 Summary

The 'Fozzie', 'Piggie', and 'Animal' devices are each reporting some responses below 400 nm. - if the device reported 380-400nm it was in the reported L*a*b* calculation.

Note, however, that the ISO standard requires that the measurement illuminant not emit below 400nm in 'UV Cut' M2 workflows (ISOc 2017). This leads to the question of if this extraneous data is being picked up, and applied, during any of the device's L*a*b* calculations.

M1 and M2 results summary

Considering the Delta E's for both the 'M1' measuring condition to the NRC fluorescence curve, and the 'M2' measurement condition to the NRC reflection curve, reveals that some of the devices analyzed tend to come closer to the NRC 'benchmarks' for one condition over the other – please see Table 03 below:

	M1 ΔEab to NRC	M1 ΔE00 to NRC	M2 ΔEab to NRC	M2 ΔE00 to NRC
Beaker	0.68	0.48	2.02	2.05
Fozzie	0.22	0.21	0.13	0.13
Animal	1.82	1.33	1.33	1.31
Statler	1.54	1.12	2.56	2.54
Waldorf	2.34	1.67	1.73	1.71
Janice	3.46	2.47	0.32	0.34
Piggy	0.11	0.10	1.00	1.02

Table 03: *M1 (NRC F Curve) and M2 (NRC R Curve) CIEDE76 (ΔEab) and CIEDE2000 (ΔE00)*

From the results:

'Fozzie' is the closest to NRC for both M1 and M2
'Piggy' is very close for M1, but approx. 1.0 for M2
'Animal' is within tolerance for both, approx. 1.3
'Statler' is good on M1 but out of tolerance for M2
'Waldorf' is close to tolerance for both M1 and M2
'Janice' is out of tolerance for M1, but very close to NRC in M2
'Beaker' is close to NRC for M1 but at the 2.0 tolerance limit for M2

If the NRC results are to be considered a benchmark, 'Fozzie' achieves the best results for both M1 and M2 conditions, with the other devices are varying levels of tolerances for each condition.

Conclusions

Commercially available spectrophotometers, used in color management and quality control systems in the graphic communications industries, do not equally measure the fluorescence of OBAs.

While the differences of these measured readings can be considered negligible in some cases, in others it could be a contributing factor preventing the same confidence in P2P matches that exists in non-OBA impacted color managed print workflows.

It is understood that clients and vendors in large, color critical, campaigns and projects can specify which make and model of spectrophotometers to use in the workflow. However this is not practical in all commercial work.

It is also important to note when discussing comparisons that the impact of OBAs on the P2P match is also influenced by the content contained. For example imagery with extensive highlight detail, where more of the unprinted paperstock is visible, is more susceptible to the effect. The coverage, density, and hue of the colorant also contributes to the relative scale of the OBA effect; imagery with heavy amounts of cyan would not 'block' the OBAs, and appear 'bluer', while yellow could 'absorb' a significant amount of the OBA effect, and magenta with its inherent deficiencies for the reflection of blue could also be a factor (Kayell n.d.).

In some cases the differences in the devices measured could be contributing to a cumulative difference from the benchmark that is large enough to be visible to the eye, and impacting final acceptance of the proof to press (P2P) match.

For example, when using measuring readings, if the device reports reading more 'blue' than is actually emitted, a color-managed workflow could apply more compensation than required to 'get back to the numbers'. If the device is reads less, it could not apply enough. For projects and processes that involve multiple stakeholders using different equipment, this could create a cumulative effect, even if the individual devices are within tolerances.

Future Considerations

Using an OBA infused proofing material with OBA infused substrate that with a 'close' visual match white point predicts better P2P results (Smyth-Gerlach 2017). There are now increasing varieties of commercially available OBA infused inkjet-proofing medias for outputting GRACoL2013 / CRPC6 compliant final contract color proofs.

However this approach requires different proofing stocks for OBA substrates. Arguably, this is counter to the overall objective of color management; uniform appearance across different medias through 'running to the numbers'.

One of the major approaches to working with OBAs discussed would be to 'rewrite' the print specifications, basing them on different levels of optically brightened papers. This would be a challenge to develop and determine the new specifications, especially as it appears that the amount and application of OBAs is continuously developing and changing based on market needs. How the devices measure the fluorescent component could impact the results.

The ISO TC 130 Group

The International Organization for Standardization (ISO) Technical Committee (TC) 130 is one of the main ISO groups responsible for color management and printing. The committee is responsible for the development and update of a variety of standards, including *ISO 12647 process control for the manufacture of halftone color separations, proof and production prints* (ISOf 2013). This is the standard that covers various printing conditions - ISO 12647-2: 2013 covers offset and heat-set printing, the majority of commercial printing in North America (PIA 2017).

Global standardization is a challenge when considering OBAs. Research from international members of the TC 130 group demonstrates that the whitepoint of grade 1 commercial paperstocks are not globally uniform. North American premium coated sheets are 'brighter', and 'bluer' compared to Europe markets, while the Japanese market seems to favor premium sheets with less brighteners, more 'natural' yellow compared to the European ones.

The ISO TC 130 group is currently exploring two options; building characterization subsets for premium stocks; 'bluish', 'neutral', 'yellowish' using new M1 characterization data and ICC profiles from L*a*b* values based on ISO 12647-2:2013 and inks from ISO 2846-1:2017 (TC 130 2017).

The group is also considering maintaining the existing characterization data, however with larger tolerances on Δb^*.

There is also the question of if the devices are matching the intent of the ISO standard (ISO 13655). A non-vendor third party using a spectral radiometer could help analyze the devices, and verify their behavior. A related question could be is there 'discernable visual differences' between the two M1 methods supported by the standard.

Additional Psychometric Evaluations

Lastly, an effort to determine if the differences found here could be materially contributing to the subjective differences. This could be tested through a series of controlled psychometric evaluations, in verified viewing conditions, using contract color proofs containing a range of visual test targets, output from profiles made from each different device against a 'benchmark print'.

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