

The Shendye-Fleming OBA Index for paper and paperboard

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ABSTRACT: We are proposing a new one-dimensional scale to calculate the effects of optical brightening agents (OBA) on the bluish appearance of paper. This index is separate from brightness and whiteness indices.

In the paper industry, one-dimensional scales are widely used for determining optical properties of paper and paperboard. Whiteness, tint, brightness, yellowness, and opacity are the most common optical properties of paper and paperboard. Most of the papers have a blue cast generated by addition of OBA or blue dyes. This blue cast is given because of the human perception that bluer is whiter, up to a certain limit. To quantify this effect, it is necessary to determine how much blue cast paper and paperboard have.

As the printing industry follows the ISO 3664 Standard for viewing, which has a D50 light source, this also plays a very important role in showing a blue cast. Color perception is based on light source and light reflected from an object. The ultraviolet (UV) component in D50 interacts with OBA to provide a reflection in the blue region of the visible spectrum.

Use of a UV blocking filter results in measurements without the effect of emission in the blue region. This difference is used in determining the OBA effect in the visible range of the paper. This equation is known as the Shendye-Fleming OBA Index.

Application: The new OBA index proposed here provides a new one-dimensional scale for measuring the effect of OBAs.

In the paper and printing industries, the whiteness of paper is very important. The perception of color depends on the type of light source used for viewing. In the printing industry, D50 is used as the standard illuminant. The D50 illuminant approximately represents horizon daylight [1,2,3]. In the paper industry, illuminant “C” [4] is used for the calculation of color values. Practically, illuminant C is not a readily available light source for viewing conditions. As a result, the CIE discontinued illuminant C and replaced it with D65 [1,2,5]. The difference between these two illuminants is that D65 is richer in the ultraviolet (UV) region than illuminant C [6].

Ideally, the illuminant used for calculation and its corresponding light source should be used for visual inspection of paper. This would allow for better correlation between color scales and perception of color. For our experiments, a D50 (CRI [7]-95) was used because the majority of paper made for the printing industry and printing is viewed under a D50 illuminant. A D65 (CRI-90) was also tested because it, too, is used as a daylight illuminant [1].

The lightness value of a coated paper has an impact on the perception of paper whiteness. In the CIE $L^*a^*b^*$ color space, theoretically, a paper with color values of $a^*=0$ and $b^*=0$ with a lightness value (L^*) of 100 are accounted as standard white, although paper white always has some tint. If the amount of tint increases, white is no longer standard white. So, it is important to define a boundary where white is no longer white, but is a light shade of color. Measurement numbers should match what the eyes perceive.

One-dimensional color scales

In assessment of optical properties of color of a material, many one-dimensional color scales are used. Brightness, whiteness, and yellowness are common one-dimensional scales used to specify optical properties of paper or other white substrates.

Optical brightening agents (OBA) are widely used in paper to provide a blue cast, but there is no index available to measure the effect of an OBA in the blue region of the visible spectrum. When a sample of white paper is considered, it may have a bluish tint or a creamy tinge to it. This is because it is very difficult to create a cast-free white paper that will reflect all the colors of the spectrum equally. The ideal white spectrum is a straight line of spectrum in the visible range with full reflection. A blue white shade reflects in shorter wavelengths more than in red and green regions of light, while a cream white or yellowish white shade absorbs more light in the blue region. So, to quantify, a change in reflection in the blue region of visible light, caused by excitation of OBA from a UV component of light, needs a new one-dimensional color scale.

Brightness of paper

Papers containing OBA require ultraviolet radiation in light source in wavelengths below 400 nm. This causes excitation of the OBA and the emission of light in the blue region of the visible spectrum. It brings the peak reflectance wavelength to around 457 nm, the exact wavelength at which brightness is measured according to TAPPI Standard Test

Method T 452 “Brightness of pulp, paper, and paperboard (directional reflectance at 457 nm).” TAPPI T 525 “Diffuse brightness of paper, paperboard and pulp (d/0) – ultraviolet level C” measures brightness using a geometry instrument. TAPPI Test Method T 534 “Brightness of clay and other mineral pigments (d/0 diffuse)” also employs a geometry instrument, as does TAPPI T 646 “Brightness of clay and other mineral pigments (45/0).” As brightness is measured at 457 nm, which is in the blue region, an OBA is added to the paper to increase the apparent “reflection” in that region. Thus, the addition of the OBA helps to increase the measured brightness of paper. The limitation of brightness in accounting for the effect of OBA is that brightness is measured only at a particular wavelength and does not consider the entire spectrum affected by OBA excitement. This limitation is covered by the Shendye-Fleming OBA Index.

Whiteness of paper

TAPPI T 560 measures “CIE whiteness and tint of paper and paperboard (d/0 geometry, C/2 illuminant/observer),” and TAPPI T 562 om-10 measures “CIE whiteness and tint of paper and paperboard (45/0 geometry, C/2 illuminant/observer).” Both have an equivalent method in ASTM E313 “Standard practice for calculating yellowness and whiteness indices from instrumentally measured color coordinates.”

TAPPI T 560 and T 562 use illuminant C, which has a correlated color temperature of 6774 K. CIE has discontinued illuminant C and recommended replacing it with D65. The TAPPI Standards have not been updated, so C illuminant is still used. The method for calculating CIE whiteness is given in the “CIE whiteness formula” section of this paper.

The Fleming-Aksoy whiteness [8,9] formulas N_{FA} and W_{FA} have been proposed to cover some limitations of the CIE formula. These are further discussed in the “Fleming-Aksoy whiteness formulae” section of this paper.

WHITENESS FORMULAE

Illuminants

An illuminant is a set of numbers defined by a relative spectral power distribution that may or may not be physically realizable as a source [10,11]. Illuminant and light source are distinctly different concepts:

- An illuminant is defined by mathematical data, which are used in colorimetric calculations.
- A light source is a physical source, which emits electromagnetic radiation in the visible region.

Not all illuminants have physical light sources. Light sources are made by targeting illuminant data, and the difference between target (illuminant) and light source is characterized by the color-rendering index [7].

All illuminant data are published by CIE. **Table I** is a summary of those discussed in this work [12]. These CIE standard illuminants are also described in the following sections.

Illuminant	Temperature, K	Simulating Source
A	2856	Tungsten/incandescent
C	6774	North sky daylight
D ₆₅	6504	North sky daylight
D ₅₀	5000	Daylight

I. Summary of CIE illuminant data discussed in this work [12].

CIE Standard Illuminant C

The CIE Standard Illuminant C [4,13] is derived from Illuminant A, a standard based on a tungsten-filament source (2856 K). It was originally chosen because this light source was the basis of incandescent lighting in the 20th century and early 21st century. Illuminant C, based on early daylight or overcast sky sources, has a correlated color temperature of 6774 K. According to CIE recommendations [5], illuminant C should be replaced with Illuminant D65 (a noontime daylight, discussed further in the next section). The paper industry still uses C, as TAPPI Standards have not been updated.

CIE “D” Series of illuminants

The method of calculation for the CIE “D” series of illuminants [1,14] is based on a correlated color temperature, and D65 is recommended by CIE [5] as a standard illuminant. It represents daylight at noon with a color temperature of 6504 K. Also, D50 has been adopted by the graphic arts industry in the United States as a standard illuminant, and it represents horizon sunlight with a color temperature of 5000 K.

ISO 13655 and OBA

The ISO 13655:2009 Standard “Graphic technology – Spectral measurement and colorimetric computation for graphic arts images” defines measurement conditions for use with a 0/45 geometry spectrophotometer and was released around 2010. This standard defined measurement conditions for light sources used in the spectrophotometer, and we have used it in our method for measuring papers with high OBA content. This standard defines four color measurement modes:

- **M0** – This measurement condition uses the tungsten lamp as per old spectrophotometers. This light source contains less UV and does not show much impact due to OBA in measurements.
- **M1** – This is the new mode based on D50 lighting. This light source used in the spectrophotometers contains a UV component, and it is designed to have better visual-numerical correlation under ISO 3664:2009 “Graphic technology and photography – viewing conditions” as the illuminate to accurately measure printed results on papers with high OBA content.

- **M2** – This measurement uses a UV cut filter, which is the replacement for the current UV instruments. Adding all these modes in a single instrument eliminates the need for keeping different instruments.
- **M3** – To avoid dry back effect in measurement of density, a polarization filter is used. This measurement mode defines use of a polarization filter for measurement of wet printed sheets.

Selection of the correct measurement conditions for measurement is important. Also, selection of measurement conditions for measurement of optical properties of paper plays an important role in visual-numerical correlation.

ISO 3664 and OBA

The ISO 3664:2009 Standard “Graphic technology and photography – viewing conditions” defines viewing conditions for viewing of color and printed images for the printing industry. The light source spectrum and its intensity play an important role in perception of color. ISO 3664 specifies using D50 illuminant as a reference to make light sources and viewing conditions for viewing printed images. These new light sources are much closer to the amount of UV energy present in reference D50 viewing conditions and are thus closer to typical M1 measuring conditions so that we get a better correlation between visual assessment and measurement of color.

In ISO 3664, various parameters are defined for creating a standard viewing condition. When paper contains an OBA and it is viewed under the ISO 3664 viewing condition, the UV component of D50 light source interacts with the OBA and increases apparent “reflection” of light in the blue region. This causes the substrate to look bluer. ISO 3664, which specified increased levels of UV activity in D50 graphic arts lighting, gives a standard that is closer to “real” daylight. At the same time, D50 exposes even more strongly some of the problems caused by the mismatch between OBA-free proofing papers and OBA-containing printing papers.

ISO 15397 OBA specification

The ISO/DIS 15397:2014 Standard “Graphic technology – Communication of graphic paper properties” specifies the list of relevant properties of paper substrates to be communicated between the paper and printing industries. This standard recommends to specify brightness, CIE whiteness, gloss, color measurement, and fluorescence along with mechanical properties of paper. Here, the fluorescence component is calculated as the difference between the whiteness/brightness measured with a source of light having a UV-content corresponding to the chosen illuminant vs. that where that excitation band is absent. Specification of OBA on a one-dimensional scale will help fluorescence caused by OBA in paper to define properties of paper affected by reflection of light.

ISO 2470 and OBA

The ISO 2470-1:2016 Standard “Paper, board and pulps – Measurement of diffuse blue reflectance factor – Part 1: Indoor daylight conditions (ISO brightness)” specifies a method for measuring the diffuse blue reflectance factor (ISO brightness) of pulp, paper, and paperboard. This is an indication of the amount of OBA present in the substrate, expressed as a percentage. As per this standard, brightness is measured at wavelength 420 nm (but with total UV blockage). The delta UV is the difference between both values. If, in the case of fluorescent samples, measurements are made with a filter with a cutoff wavelength of 420 nm placed in the light beam, it is possible to determine the ISO brightness of the non-fluorescent substrate and thus to calculate the contribution of the fluorescent whitening agent to the ISO brightness:

$$\Delta UV (\%) = R_{457} - R_{420} \quad (1)$$

where:

R_{457} = brightness at 457 nm (red/green cutoff)

R_{420} = brightness at 420 nm (UV cutoff)

The biggest limitation of this standard is that the UV affects the sample measurement throughout the 400 nm to 550 nm region. The amount of fluorescence effects in this region impacts visual perception, and yet there is no fluorescence effect over at least a portion of that region. So, the calculation method of ISO 2470 has poor visual numerical correlation for the ISO 3664 viewing condition.

OBA and color reproduction

Process color inks are transparent and measured as the amount of light reflected from print that passes through specific filters. The color gamut [15] of print is based on the ink and substrate combination. The International Color Consortium (ICC) White Paper 14 (2005) summarizes CIE Publication 163 (2004) [16], which says that “the results indicate and quantify that the fluorescence of the substrate can be measured in both solid ink areas and halftone ink areas, with the effect being far larger in the latter.” This means the colors reproduced by papers with and without OBA are different, and the methods to predict or correct the OBA effects are important for color reproduction.

CIE whiteness formula

The TAPPI Standard Test Method T 562 om-10 is used to calculate whiteness for paper. The CIE whiteness formula is based on the belief that bluer is whiter. The CIE recommended an equation for whiteness in 1981 [17]. This formula was inspired by the work of Ganz [18,19]. It uses the CIE chromaticity coordinates of the sample and illuminant along with the Y tristimulus value [20].

The CIE whiteness formula is used for the relative evaluation of whiteness by the same instrument and without

reference to a white scale. This system of equations does not clarify whether the whiteness has any component of blueness or yellowness. Evaluations with the formula are significantly improved if the sample illumination is stabilized and fitted as closely as possible to a desired illuminant. This also improves the matching of different measurement instruments for whiteness, but the tint deviation or hue value can still not be adequately matched.

A restriction of the CIE formula is that samples should not differ greatly in tint and fluorescence. The formulae produce relative, not absolute, whiteness assessments. It would seemingly be adequate for commercial use in many cases. However, a method that considers bluer to be whiter may not match visual perception if the blueness becomes so high that the sample is no whiter, but instead a light shade of blue. Again, the measuring instruments must have illumination resembling daylight.

If the sample illumination is stabilized, assessments with the CIE formulas are significantly improved, and samples to be compared do not have to be measured at the same time. This also improves the matching of different measuring instruments for whiteness. The remaining problem is that tint deviation or hue value can still not be adequately matched to that of visual perception.

In 2009, the CIE formed TC1-77, "Improvement of the CIE-whiteness and tint equations," as recommended by Joanne Zwinkels [21]. Among the issues raised by Zwinkels were factors such as:

1. Measurement geometry
2. Illumination
3. Limited range of validity
4. CIE whiteness limits

EXPERIMENTAL

Fleming-Aksoy whiteness formulae

Recently, Aksoy proposed two new whiteness formulas [8] based on a combination of theoretical and empirical considerations. One formula, N_{FA} , corresponds to a maximum whiteness at the perfectly reflecting diffuser, i.e., zero chroma in the CIE $L^*a^*b^*$ space [16] (or HunterLab space).

The other formula, W_{FA} , is based on the assumption that observers prefer a more "blue" white, but only if it is not too blue. Thus, a local maximum in whiteness is expected. The coefficients in W_{FA} were determined from the CIE formula by requiring that the two formulas have the same value and derivatives with respect to a^* and b^* at zero chroma ($a^*=b^*=0$) for a given Y (or L^* value).

These formulae are given by [8,9]:

$$N_{FA} = L^* \left(\frac{1}{2} \right)^{(C/C_0)^2} \quad (2)$$

and

$$W_{FA} = Y \left(\frac{1}{2} \right)^{[a^*(a^*-2a_1^*)+b^*(b^*-2b_1^*)]/C_2^2} \quad (3)$$

where $C = (a^{*2}+b^{*2})^{1/2}$ is the chroma and C_0 and C_2 are char-

acteristic chroma values determined from the boundary region of applicability defined by inequalities from the definition of CIE whiteness [20]. The a_1^* and b_1^* variables are the coordinates for the local maximum whiteness at constant lightness Y (or L^*). They are determined by equating the corresponding derivatives of W_{FA} and W_{CIE} with respect to a_1^* and b_1^* to one another. The expressions are:

$$a_1^* = \alpha(Y_n/Y)^{4/3}C_2^2/(200\ln 2) \text{ and} \quad (4)$$

$$b_1^* = -\beta(Y_n/Y)^{4/3}C_2^2/(200\ln 2) \quad (5)$$

where:

$\alpha = 3x_n(900y_n - 800z_n)/500$ and $\beta = 3z_n(800x_n + 1700y_n)/200$, with Y_n , x_n and y_n being the illuminant luminance and chromaticity values. The W_{FA} formula shows good agreement with observer surveys [9].

Proposed equation for the OBA Index

The proposed equation for the Shendye-Fleming OBA Index is:

$$\text{Shendye - Fleming OBA Index} = 100 * \left[\frac{\int_{400nm}^{550nm} d\lambda ((R(M1)-R(M2))*D50)}{\int_{400nm}^{550nm} d\lambda D50} \right] \quad (6)$$

The Shendye-Fleming OBA Index can be used with any spectrophotometer with ISO 13655 M1 and M2 measurement modes having 0/45 instrument geometry like the i1pro2 (X-Rite; Grand Rapids, MI, USA), eXact (X-Rite), or Techkon (Techkon; Königstein, Germany) spectrophotometers used in the printing industry. It uses illuminant data of D50. A normalization constant is derived from illuminant data from beginning of the blue region to 550 nm, so it does not require separate hardware like a Ciba-Geigy scale or Laetus fluorescence sensor. As the concept is based on measurement of the fluorescent effect in the visible region, it can also be called Shendye-Fleming Fluorescent Index.

Applications of Shendye-Fleming OBA Index

Application of the OBA index is for use in the paper and paperboard industry as a quality control tool. The Shendye-Fleming OBA Index can be used to compare blue cast between two papers in production. It can also be used for comparing the amount of OBA added between two papers.

As the Shendye-Fleming OBA Index uses D50 illuminant along with M1 and M2 measurement conditions, it gives a better visual-numerical correlation under the ISO 3664 viewing condition for comparing OBA of the paper. The blue cast of paper plays a very important role in color reproduction, as it has an impact on color appearance and measurements. The Shendye-Fleming OBA Index can help in color management to determine the impact of OBA on blue and yellow colors on a device profile.

Substrate	CIE L*a*b* (M1)	CIE L*a*b* (M2)	CIE WI (Tint)	WFA	S-F FI
Calibration tile	92.08, 1.09, -0.55	92.08, 1.09, -0.55	82.77(-1.84)	82.77	0
Tissue paper	95.12, -0.32, 3.09	95.11, -0.31, 3.19	75.17(-0.97)	74.57	0.15
Corrugated white paperboard	86.08, 0.95, 0.70	85.99, 0.23, 3.44	65.21(-2.37)	63.95	1.85
Coated recycled paperboard	91.13, 0.06, -0.01	91.04, -0.63, 1.73	82.21(0.34)	81.89	1.89
Coated paper	92.20, 0.63, -5.47	92.05, -0.05, -1.43	104.34(1.74)	91.85	3.19
Bristol board	92.33, 2.79, -6.89	92.08, 1.09, -0.55	110.87(-1.63)	88.52	4.99
Copier paper	93.31, 3.08, -10.08	93, 0.46, -1.28	126.17(-0.38)	94.16	7.14

CIE L*a*b* = CIE-defined color space; CIE WI = CIE whiteness; WFA = Fleming-Aksoy whiteness; S-F FI = Shendye-Fleming Fluorescent Index.

II. Shendye-Fleming OBA Index of different substrates.

RESULTS AND DISCUSSION

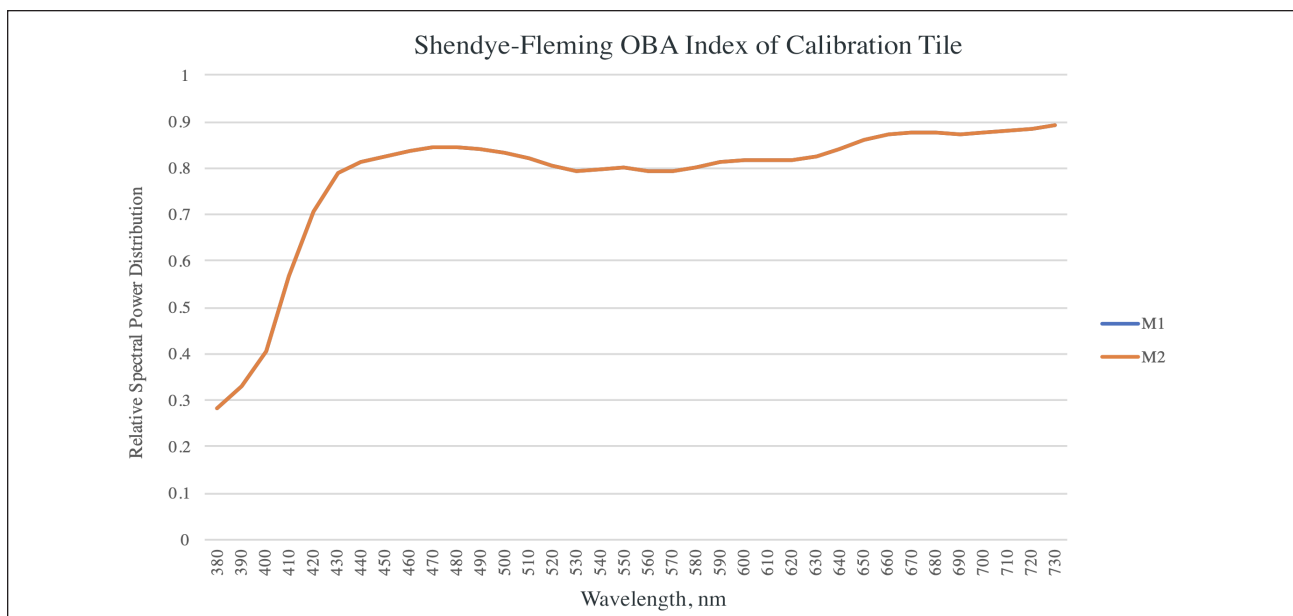
The Shendye-Fleming OBA Index was calculated for various substrates and a comparison was conducted. Optical brighteners are also known as fluorescent whitening agents, so the Shendye-Fleming OBA Index can also be called as Shendye-Fleming Fluorescent Index and can be denoted as “S-F FI” or “S-F OBA Index.”

In **Table II**, M1 measurements are used along with D50/2 illuminant/observer combination to calculate CIE whiteness and Fleming-Aksoy whiteness. The CIE tint value is given in brackets, along with CIE whiteness (CIE WI).

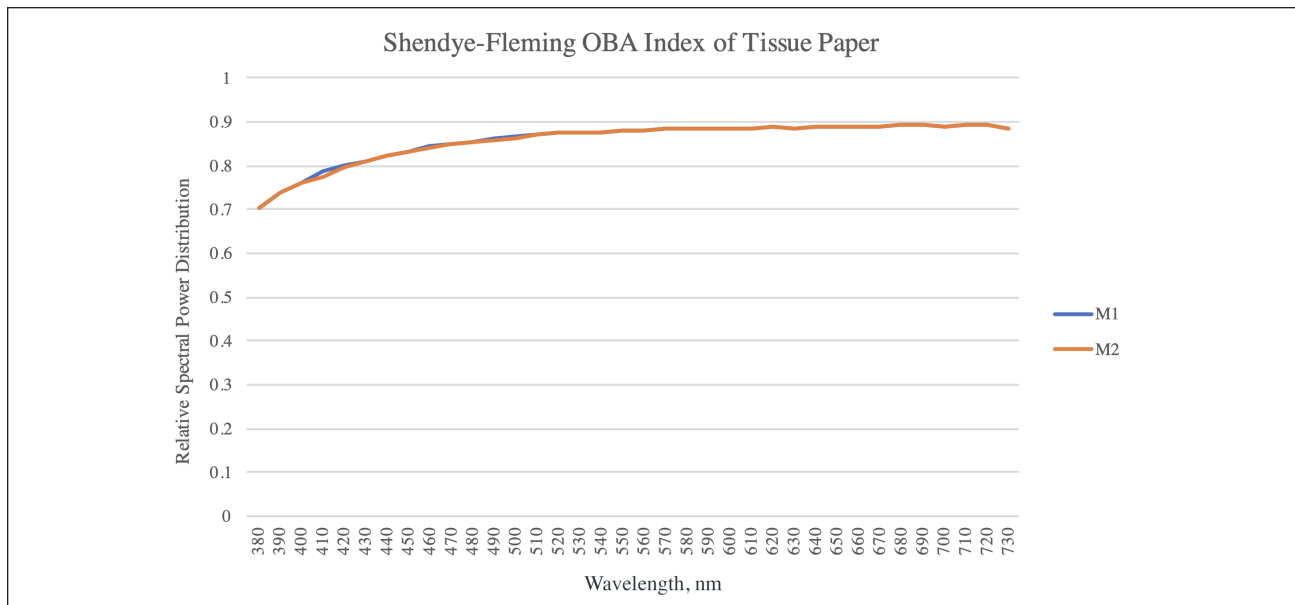
Table II shows that the white calibration tile of the spectrophotometer has an OBA index of zero, as no OBA is used while manufacturing calibration material for a spectrophotometer. Tissue paper has no added OBAs, so its OBA index, at 0.15, is close to zero. The CIE L*a*b* values are calculated by D50/2 with M1 (UV component present) and

M2 (UV component filtered out) measurement conditions and are shown in Table II. These show that the greater the difference between M1 and M2 measurements in the CIE b* value, the higher the OBA index number. A greater difference in the Shendye-Fleming OBA Index is indicative of higher OBA levels. As paper has a higher amount of OBA, it gets a bluer cast, and the Fleming-Aksoy whiteness formula shows paper is no whiter and reduces its whiteness value. This observation can be related to the Shendye-Fleming OBA Index to determine at which OBA index the Fleming-Aksoy formula shows higher whiteness. This way, the Shendye-Fleming OBA Index can be used for determining the correct amount of OBA in paper manufacturing and can become a good quality control index for OBA dosage monitoring as well.

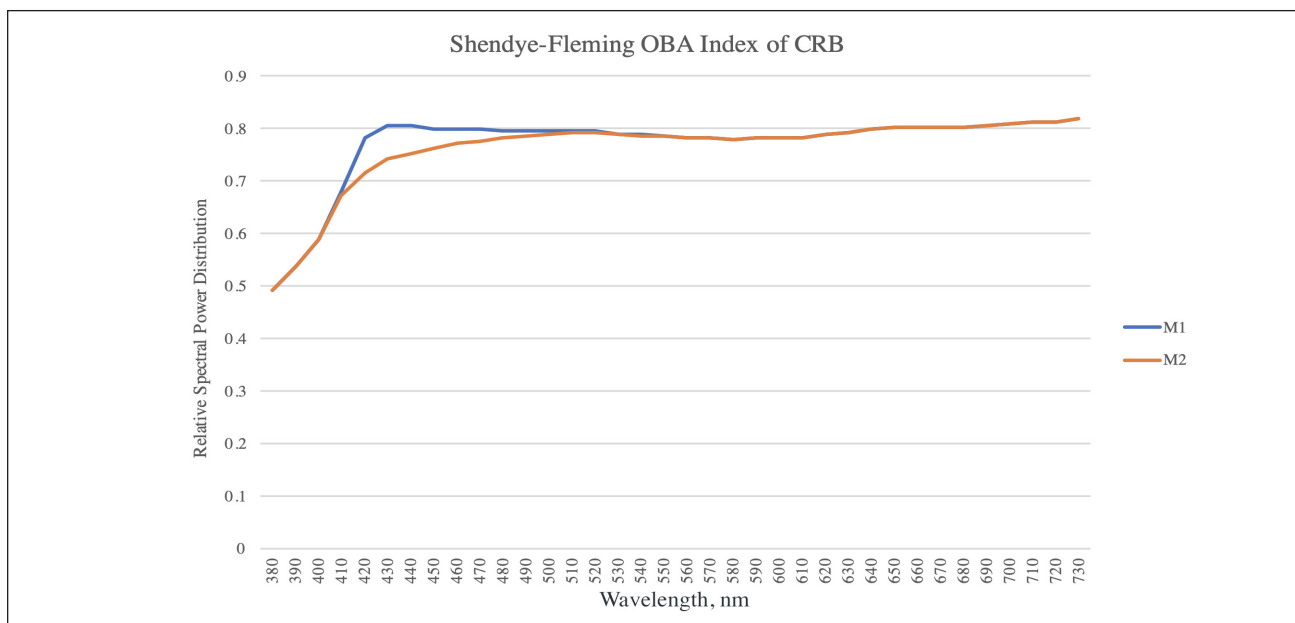
The reflectance graph of the calibration tile of the spectrophotometer in **Fig. 1** shows there is no difference in M1



1. Reflectance graph of calibration tile by M1 and M2 measurements.



2. Reflectance graph of tissue paper by M1 and M2 measurements.



3. Reflectance graph of coated recycled paperboard (CRB) by M1 and M2 measurements.

and M2 measurements. No OBA is added in the calibration tile, as it is a requirement for the calibration standard; as a result, the OBA index is zero.

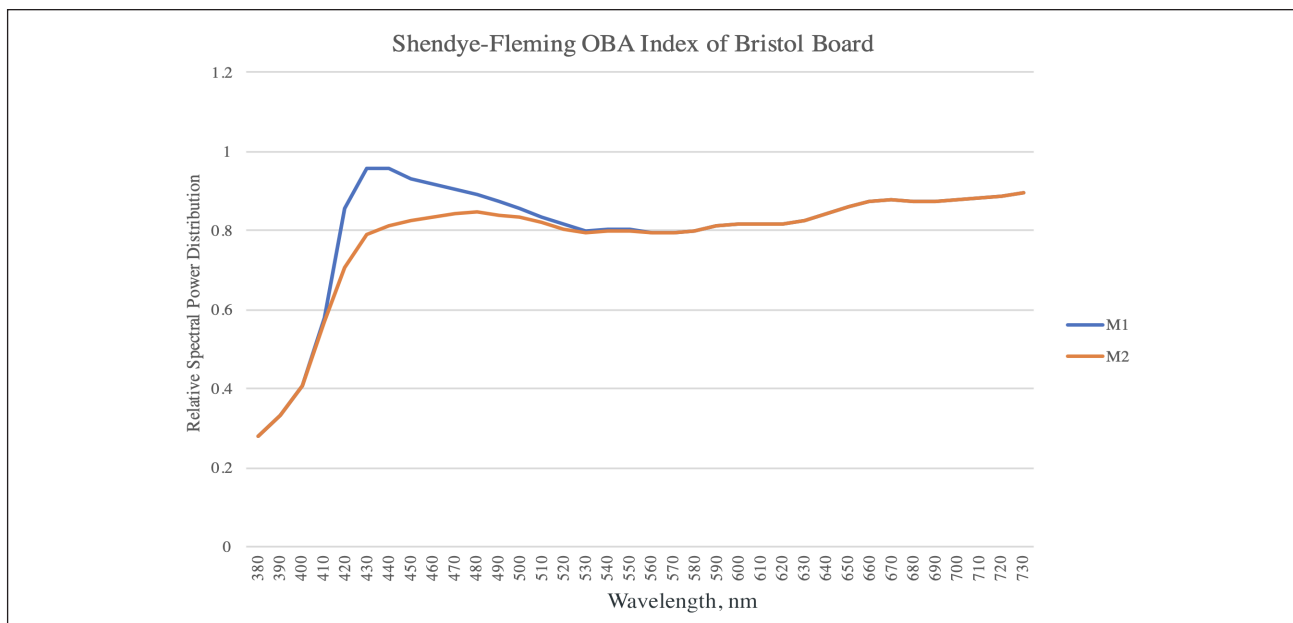
Tissue paper has a very short shelf life and color or high whiteness or brightness is not required. As it is not printed, no OBA is added in tissue paper. Tissue paper is bleached to appear white. This can cause a very small difference in M1 and M2 measurements, which results in an OBA index of 0.15 (Fig. 2). The OBA index of tissue paper is very small and close to zero.

A recycled paperboard requires a white coating to provide printable surface. In paper coatings, small amounts of

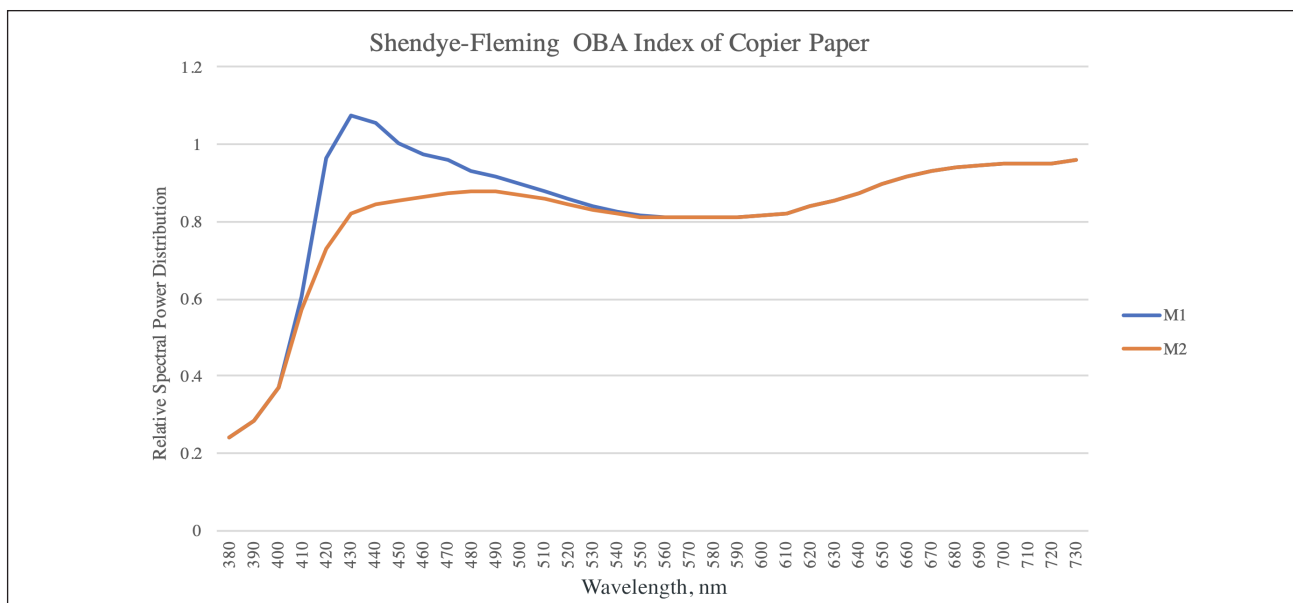
OBAs are added to provide blue cast, as this coating cannot provide high lightness and whiteness due to the recycled nature of paperboard. Figure 3 shows a small amount of OBA added to coated recycled paperboard.

This Bristol board has a CIE b^* value of -6.89 by M1 measurement, which shows it has a good amount of OBA added for blue cast (Fig. 4). The difference between CIE b^* value of M1 and M2 of solid bleached sulfate (SBS) pulp is 6.34, which shows a higher Shendye-Fleming OBA Index value of 4.99.

Copier paper uses a lot of OBA to give blue cast to the paper. More emission in the blue region also gives higher



4. Reflectance graph of Bristol board by M1 and M2 measurement.



5. Reflectance graph of copier paper by M1 and M2 measurements.

brightness, as brightness of paper is measured at 457 nm. **Figure 5** shows the reflectance graph of copier paper by M1 and M2 measurements. The difference between M1 and M2 measurements of CIE b^* value for copier paper is 8.8, which is very high. The Shendye-Fleming OBA Index for copier paper is 7.14. This demonstrates that different amounts of OBA can impart different blue casts to paper, and it can be measured and compared using the Shendye-Fleming OBA Index. There were several attempts made using the b^* value, but if we have to compare two papers just for OBA with b^* values close to one another, then Δb^* is not enough. This is because b^* values can come from

blue tint printed on paper during proofing for paper background simulation or even blue dye used in paper, which is not fluorescent in nature. Paper could be bluish but not necessarily have OBA. It could be bluish because of blue dye or ink printed on it. When $I^*a^*b^*$ values are calculated, the entire spectrum from 400 nm to 700 nm is used, so the b^* value has data from the green and red region of the spectrum, which is not affected by OBA. Also, b^* values are impacted by selection of measurement mode; M0, M1 and M2; illuminant (D50, D65, etc.); and observer (2° and 10°) used to calculate $I^*a^*b^*$ values.

Currently, the paper and printing industries are not on

the same page for using illuminant and observer. The paper industry uses illuminant C or D65 and 10° settings, but the printing industry uses D50 and 2° settings. As a result, the b^* value is not good for OBA comparison.

In our equation, we are using the fluorescence property of OBA, and only the spectral area affected by OBA is under consideration. This avoids illuminant and observer differences between the print and paper industries so that both industries can use Shendye-Fleming OBA Index, as it is purely spectral based and uses CIE illuminant D50 for normalization to align with ISO 3664 and ISO 13655. That is why the Shendye-Fleming OBA Index equation is an accurate one-dimensional scale for the effect of OBA in visual perception of color.

In the paper and printing industries, several attempts have been made to measure the effect of OBA on the visual appearance of paper. The OBA in paper plays an important role in color management, color perception, and security printing. Most printers and paper manufacturers have spectrophotometers, so we developed this one-dimensional scale using spectrophotometric data. This means that printers and paper manufacturers do not have to invest in new hardware. The one-dimensional scale supports the following applications:

1. Paper mills can use it as a quality control tool for batch-to-batch comparison.
2. Printers can use it to compare two different papers for OBA amount.
3. In color management, proofing paper is required to be brighter, whiter, and with more OBA than printing paper. Therefore, printers can use the Shendye-Fleming OBA Index, along with brightness and whiteness formulas, for selection of proofing paper.
4. By knowing the amount of OBA in paper, printers can select the correct measurement mode for color management.
5. Paper used in security printing should not have any OBA, as it interferes with UV-fluorescent features. The Shendye-Fleming OBA Index can be used to identify OBA-free paper.

The Shendye-Fleming OBA Index will help paper manufacturers and printers, as it derived by considering existing standards like ISO 3664 used for standard viewing conditions and ISO 13655 used in color measurement.

CONCLUSIONS

The Shendye-Fleming OBA Index was successfully implemented for evaluation of the OBA's effect on the blue tint of paper. This index will benefit OBA manufacturers, paper manufacturers, and printers.

- The Shendye-Fleming OBA Index can be calculated for any white paper with M1 and M2 measurement mode by 0/45 or 45/0 geometry spectrophotometer.
- The Shendye-Fleming OBA Index calculates the difference between M1 and M2 measurements from 410 nm to 550 nm.

- The CIE whiteness has no relationship to the Shendye-Fleming OBA Index.
- The difference between CIE b^* values and M1 and M2 measurements can be correlated with this index. The higher the difference in b^* , the higher the OBA index.
- The Shendye-Fleming OBA Index and the Fleming-Aksoy whiteness formula can be used together for evaluating whiteness of paper.
- The Shendye-Fleming OBA Index is compatible with ISO 3664 viewing conditions, as it uses D50 illuminant and M1 measurement conditions.
- A higher OBA index number is indicative of a higher level of OBA added to the paper.

Future work on the Shendye-Fleming OBA Index

This research provides a basis for further research on the Shendye-Fleming OBA Index. Further research will benefit the paper industry in standardizing procedures for the OBA index as a standard method, allowing users to:

- Obtain reflectance data for M1 and M2 from a d/8 geometry spectrophotometer with specular mode included to calculate OBA index.
- Calculate Fleming-Aksoy whiteness and Shendye-Fleming OBA Tint Index with a 0/45 geometry instrument and d/8 geometry instrument to determine optimized OBA levels for whiteness. Reductions in OBA dosage are often possible.
- Conduct psychophysical tests for the OBA index under ISO 3664 viewing conditions.

Implementation

For commercial use of Shendye-Fleming OBA Index, software called "ColorScale" has been developed and is available for use [22]. With this software, whiteness and OBA index may be calculated for comparison between two papers. **TJ**

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ABOUT THE AUTHORS

We studied this topic because there is no OBA index available for easy use. Our study was different than previous ones because we introduce a new mathematical formula. Deriving this new equation was the most difficult aspect of our study, but we found that it is possible to solve current problems with the new Shendye-Fleming OBA Index.

For mills, the Shendye-Fleming OBA Index would be a simple and easy quality assurance tool to use. Our next step is to implement this method at a mill.

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