WHITENESS DETERMINATION OF OPTICALLY BRIGHTENED TEXTILES

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Introduction

An estimated 15 to 20% of all textile products are white, the determination and control of whiteness is thus of primary importance to the textile industry. There have been a number of different formulae proposed as whiteness indices [1], but today there are only two of them widely used in the textile industry: the Ganz-Griesser and the CIE whiteness index. In spite of their importance and over 30 years of industrial usage, there are still a number of open questions regarding the application – or, indeed, the adequacy – of these formulae:

- Is the Ganz-Griesser calibration significantly better than CIE? If so, G-G should be made an international standard, if not, it should be discarded.
- Is it correct to transfer the primary calibration values of national standardizing laboratories (NRC, BAM, NPL) measured with 45/0 geometry to industrial spectrophotometers using sphere geometry? Should a correction be applied, and if so, how?
- Can the current formulae be used for illumination conditions other than D65? Would the visual and/or instrumental ranking change with the change of illumination?
- Are the CIE whiteness limits applicable in the textile industry, or should a different formula such as those proposed by Uchida [2] or Coppel [3] be accepted?

The CIE Technical Committee TC1-77 [4] has started to investigate these application issues, but due to the complexity of the questions no quick (and simple) answers are to be expected.

1. *CIE or Ganz-Griesser?*

The current form of the CIE whiteness and tint formulae for the CIE standard illuminant D65 was published in the latest edition of CIE Publication 15:2004 [5] as:

$$W = Y + 800\left(x_n - x\right) + 1700\left(y_n - y\right) \tag{1}$$

$$W_{10} = Y_{10} + 800\left(x_{n,10} - x_{10}\right) + 1700\left(y_n,10 - y_{10}\right) \tag{2}$$

$$T_w = 1000(x_n - x) - 650(y_n - y) \tag{3}$$

$$T_{w,10} = 900(x_{n,10} - x_{10}) - 650(y_{n,10} - y_{10}) \tag{4}$$

where Y is the Y-tristimulus value of the sample, x and y are the x,y chromaticity coordinates of the sample, and x_n, y_n are the chromaticity coordinates of the perfect diffuser, all for the CIE 1931 standard colorimetric observer. Y_{10}, x_{10}, y_{10}, $x_{n,10}$ and $y_{n,10}$ are similar values for the CIE 1964 standard colorimetric observer.

The application of the CIE formulae is restricted to samples that

- are called “white” commercially;
- do not differ much in colour and fluorescence and
- are measured on the same instrument at nearly the same time.

The first of these restriction will be discussed in more detail in *Chapter 4.(CIE whiteness limits).*

The second restriction is rather vague and has never been quantified: its practical consequence is that samples treated with fluorescent brightening agents (FBA’s) of VERY different tint are not supposed to be compared using the CIE formula. This is of minor practical importance; in textile practice it is rather rare to have to compare a distinctly reddish sample with a distinctly bluish or greenish one; or to compare a non-FBA treated sample with a fluorescent one.

The real problem for the textile industry lies in the third restriction. It basically means that not even instruments of the same model can be used to comparatively evaluate the whiteness degree, i.e. within a factory having multiple instruments only results obtained in one of them may be used for comparative evaluations. This makes the communication of whiteness values impossible within the factory (e.g. among the laboratory, the dyehouse, and the QC department), let alone among different plants within a company, not to mention the all important communication between supplier and customer.

One possibility to overcome these difficulties was suggested by Griesser [6]. The Ganz-Griesser method is based on using the Ganz whiteness and the Ganz-Griesser tint formula:

$$W_{GANZ} = DY + Px + Qy + C \qquad (5)$$

$$TV_{G\text{-}G} = mx + ny + k \qquad (6)$$

where W_{GANZ} is the Ganz whiteness value, $TV_{G\text{-}G}$ is the Ganz-Griesser tint value, Y is the CIE Y tristimulus value, x and y are the CIE chromaticity coordinates. D, P, Q, C, m, n and k are instrument-specific parameters, which also determine the formula’s tint preferences, and adjust the formula according to the 2^o or 10^o observer. Equations (5) and (6) were originally developed for CIBA-GEIGY and have routinely been used since 1971 [7]. The CIE formulae (Equations 1 to 4) are in fact special cases of the Ganz-Griesser formulae; using constants instead of instrument-specific parameters.

Griesser [8] claims, that using formulae (5) and (6) the differences between instruments, even of different models or even of different makers, can be nearly eliminated.

There are, however, serious problems in the application of the Ganz-Griesser method.

1. It has never been standardized
   Having been developed for intra-company application within CIBA-GEIGY in the early 1970’s the method was widely promoted by Griesser [6-8], but has never found acceptance as a national, let alone international standard. There is only one institute issuing the four calibrated textile standards that are necessary for the calculation of the instrument specific parameters.

2. There are only a few commercially available spectrophotometers in which the Ganz-Griesser method has been implemented.

3. It has not been proven by independent research that it is really better than the internationally standardized CIE method.

Previous studies conducted in the SENAI/CETIQT Colour Institute [9], [10] indicated that when properly calibrated, very different instruments yield acceptably low differences also using CIE W (within ± 2 to 3 whiteness units). These studies, however, didn't consider the differences in tint and a new series of experiments are under way [11] to compare the effect of the UV calibration method and the whiteness and tint formulae (CIE or Ganz-Griesser) on the reproducibility of the results.

2. *Measurement geometry*

For the measurement of reflecting specimens in the textile industry either sphere (de:8° or di:8°) or directional (0°:45°a) CIE geometries are used. There is only one commercially available spectrophotometer model having UV-calibration capabilities with 0°:45°a geometry, the vast majority of industrial colour measuring spectrophotometers uses sphere geometry. These sphere instruments, however, may present problems when measuring fluorescent samples; Alman and Billmeyer [12] recommend in this case to employ – whenever possible – instruments with directional geometry.

National standardizing laboratories (NRC, NPL, BAM) use research instruments with directional geometry to calibrate primary and transfer fluorescent standards. The two industrial laboratories which supply calibrated textile standard for industrial whiteness measurement (AATCC [13] and Hohenstein [14]) trace their measurements to NRC, but use these values for sphere geometry instruments. To complicate matters more, AATCC supplies the standards for specular included (SPIN) sphere geometry (di:8°) while Hohenstein for specular excluded (SPEX) sphere geometry (de:8°). Both have their good reasons. AATCC [15] claims that there are several reasons:

> 1. *This procedure is designed for textiles, and nearly all textile measurements are made using SPIN. This is because textiles are generally pretty matte and have no gloss to be excluded using SPEX.*
> 2. *The specular exclusion in sphere instruments is notoriously different between makes and even within same models.*
> 3. *The differences [AATCC] found between SPIN and SPEX were about 1 CIE whiteness unit, so it was not a major difference anyway, and differences between spectros in SPEX mode easily can exceed that difference.*

Hohenstein simply follows their traditional approach of using SPEX, because it is more recommended for the measurement of fluorescent specimens, and is nearer to the 45°:0° geometry used by NRC.

We have calibrated a DC 650 (sphere geometry instrument) using an NRC calibrated Spectralon fluorescent standard, and measured the same Spectralon standard as well as the AATCC and the Hohenstein textile standards in both SPIN (di:8°) and SPEX (de:8°) modes. The CIE W_{10} and $T_{W,10}$ values thus achieved are shown in *Table 1.*

Table 1. Whiteness and tint values of Hohenstein and AATCC calibrated textile standards measured with SPIN and SPEX geometries on a sphere instrument

	W_{10}			$T_{W,10}$		
	Nominal	SPIN (di:8°)	SPEX (de:8°)	Nominal	SPIN (di:8°)	SPEX (de:8°)
NRC-461*	**123.9[1]**	**123.44**	**124.04**	**0.8[1]**	**0.42**	**0.37**
HOH37-1	84.92[2]	84.10	84.85	-0.56[2]	-0.87	-0.92
HOH37-2	107.08[2]	106.04	106.33	-0.82[2]	-1.33	-1.37
HOH37-3	134.43[2]	133.55	134.03	-0.76[2]	-1.58	-1.63
HOH37-4	152.85[2]	152.80	154.04	0.48[2]	-0.71	-0.76
HOH38-1	85.12[2]	85.16	85.81	-0.56[2]	-0.86	-0.91
HOH38-2	107.00[2]	105.99	106.17	-0.81[2]	-1.33	-1.38
HOH38-3	133.92[2]	132.73	133.25	-0.78[2]	-1.58	-1.64
HOH38-4	153.86[2]	152.98	154.48	0.42[2]	-0.71	-0.76
AATCC-53	129.18[3]	127.74	128.77	n/a	-1.35	-1.40
AATCC-54	128.64[3]	127.39	128.04	n/a	-1.33	-1.36

*NRC calibrated Spectralon tile used for the calibration of the spectrophotometer

[1] NRC calibration (45°:0°) [2] Hohenstein calibration SPEX (de:8°) [3] AATCC calibration SPIN (di:8°)

Interesting conclusions may be drawn from these results (based admittedly on a rather limited number of samples).

1. The differences between SPEX and SPIN measurements for these specimens are very small, in the order of 1 CIE W_{10} unit (confirming thus the statement of AATCC), and about 0.5 CIE $T_{w,10}$ units. The selection of the measurement geometry (SPIN or SPEX) has thus to be based on other consideration, such as the reproducibility of the measurements between different instrument models.
2. The differences between the 45°:0° nominal values and the SPIN and SPEX measured values of the Spectralon transfer standard are in the order of ± 0.5 CIE W_{10} units, it may thus not be necessary to apply a geometric correction when transferring nominal data from the national standardizing laboratories to the industrial users.

3. Different illuminants

The CIE whiteness formula was developed for illuminant D65, and the CIE recommendation [5] does not mention its application for any other illuminant. Yet in practice several other types of illumination may have to be considered. The ASTM Standard Practice [16] gives coefficients to calculate the CIE indices for illuminant C and D50, in addition to D65, but warns that those "for Ill. C and Ill. D50 and both observers are unofficial and should be used for in-house comparisons only". In textile industrial practice other light sources (e.g. CWF, TL84) may also be of interest, there has been no attempt yet to adequate the formulae for these. There have been no research results published on how changes of illumination effect the validity of whiteness formulae, but, according to Ganz [17] changing from illuminant D65 to illuminant A may even reverse the ranking order of some fluorescent sample pairs (see another example of this reversal below).

Whereas the reflectance of non-fluorescent specimens does not change with the illumination, in the case fluorescent specimens changing the illuminant changes the total spectral radiance factor (TRF), as illustrated in *Figure 1.* This figure shows the TRF of a hypothetical white specimen defined in the CIE Standard S 012 [18] for three CIE illuminants.

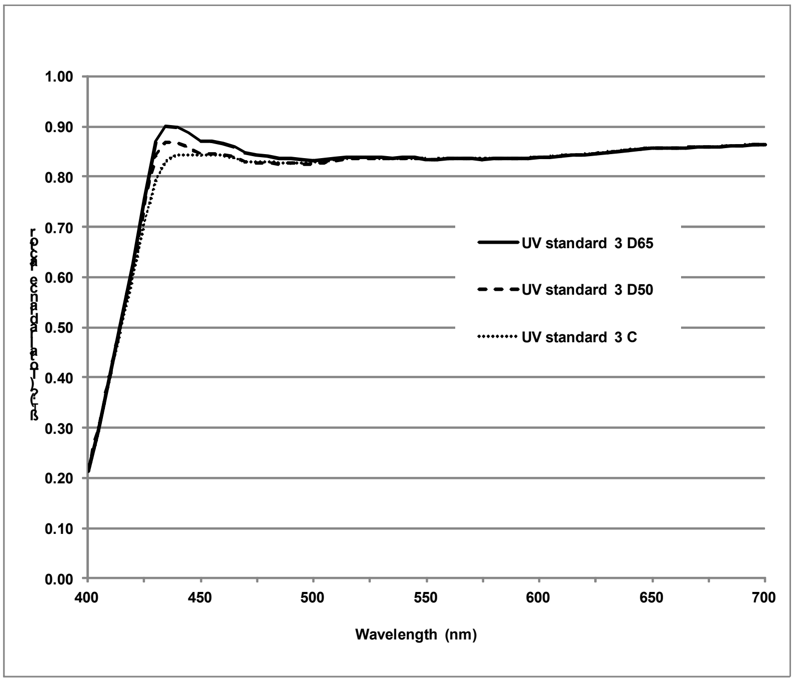

Figure 1. Total spectral radiance factor calculated for three illuminants for a hypothetical fluorescent white specimen, based on CIE Standard S 012 [18].

From among the three selected illuminants C has the lowest and D65 the highest relative UV content as its effect is clearly shown in the TRF curves above. *Figure 2.* shows the chromaticity coordinates of the same specimen as illuminated by the three illuminants.

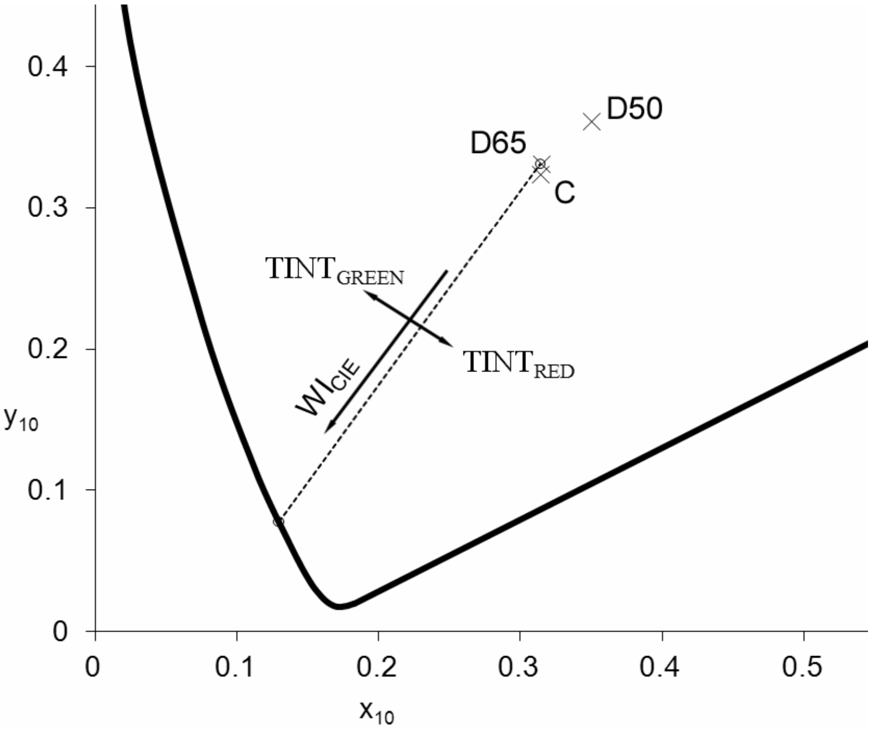

Figure 2. Chromaticity coordinates of hypothetical fluorescent sample under three illuminants

When comparing the W_{10} and $T_{W,10}$ values of three specimens under these illuminants we find that the order of the whiteness indices is according to expectations (C – D50 – D65) as shown in *Table 2.*

Table 2. W_{10} and $T_{W,10}$ indices of textile substrate treated with FWA and different tinting dyes

	W_{10}			$T_{w,10}$		
	Std1	Std2	Std3	Std1	Std2	Std3
C	64.1	70.4	71.6	-0.4	-0.4	0.5
D50	75.0	78.1	77.0	-1.2	-1.1	-0.4
D65	80.9	83.9	81.6	-0.8	-0.8	0.3

It is interesting to note, however, that the order of the W_{10} values may change with the change of illuminant (as previously remarked). Under illuminant C Std3 has a higher W_{10} value than Std 2, but under illuminant D65 this order is reversed.

There is also a serious technical problem in measuring fluorescent specimens under illuminations other than D65. For non-fluorescent reflecting specimens the calculation of the XYZ tristimulus values (and all other quantities derived from them) for any illuminant is simply a matter of using the right data: it's all just calculation. For the measurement of fluorescent specimens, however, the light source (simulating the desired illuminant) has to be installed in the instrument, to provide the correct spectral power distribution in the UV and visible range. Colour measuring spectrophotometers used in the textile industry have only D65 simulators, for the measurement under any other illuminant another type of measurement setup is needed. The best solution is to use the same light source as that used for the visual assessment (typically a colour matching booth), and measure the irradiance of the light reflected from the fluorescent specimen with a spectroradiometer.

4. *CIE whiteness limits*

The CIE recommendation [5] sets limits to the whiteness and tint indices, the values of W and T_w must lie within the following limits for the 1931 standard colorimetric observer:

$$40 < W < 5Y-280 \tag{7}$$

$$-4 < T_w < +2 \tag{8}$$

and similarly for W_{10} and $T_{W,10}$ for the 1964 standard colorimetric observer.

These limits are important, because even if a specimen has a very high whiteness value it may be too bluish (albeit within the tint limits), a light blue sample can have high CIE W index but appear to be visually blue and not white. *Figure 3.* shows the chromaticity coordinates, and *Table 3.* the W_{10} and $T_{W,10}$ indices of some optically brightened textile samples, tinted with different dyes.

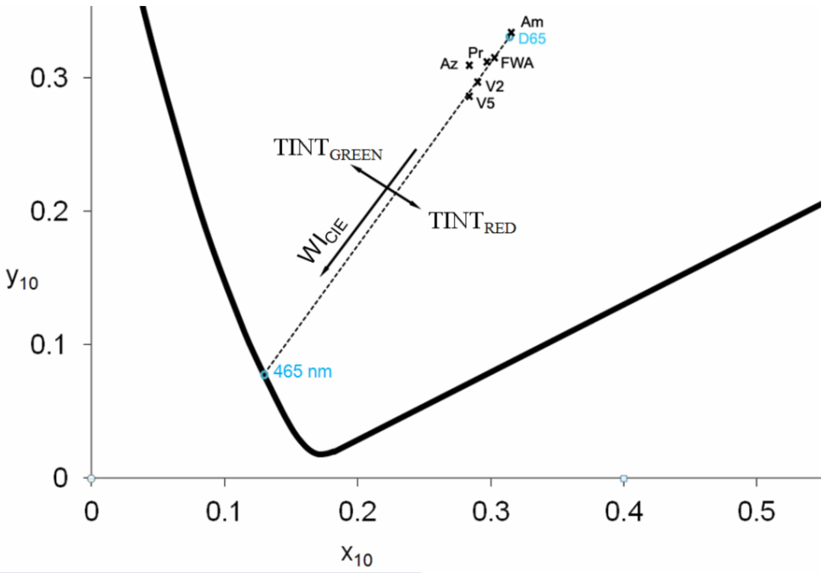

Figure 3. Chromaticity coordinates of textile substrate treated with FWA and different tinting dyes

Table 3. W_{10} and $T_{W,10}$ indices of textile substrate treated with FWA and different tinting dyes

Szinezék	W_{10}	$T_{W,10}$
BSBB2 1% (FWA)	125.73	0.39
+ Black 0.002% (Pr)	129.24	3.01**
+ Violet 0.002% (V2)	152.78*	-0.43
+ Violet 0.005% (V5)	168.07 *	-2.04
+ Yellow 0.002% (Am)	85.19	0.86
+ Blue 0.002% (Az)	143.58*	13.3**

*Outside of W_{10} limits **Outside of $T_{W,10}$ limits

On visual assessment the sample dyed with 1% of FWA appears to be white and shows a reasonably high whiteness index with neutral tint. If, however, we add even a small amount of tinting dye, the situation changes. Adding black will increase the W_{10} value, but the sample will be unacceptable, because of the strong greenish tint. Adding violet will actually increase W_{10} significantly, and the tint values remain within limits, yet visually the sample has a strong violet cast. This is explained by the fact, that the chromaticity coordinates (*Figure 3.*) stay on the whiteness line, and according to the CIE formula this means increased whiteness and no (or acceptable) tint.

Adding a yellow dye naturally decreases the whiteness, and although the sample becomes distinctly yellowish the W_{10} values are well within limits, showing that this sample is “considered commercially white”. Adding a (greenish) blue dye takes both the W_{10} and $T_{W,10}$ values outside the permissible limits.

The CIE whiteness limits expressed in equations (7) and (8) play an important role, but are not without problems. The case of the yellow tinting dye is less problematic, because a very low whiteness index means obviously that the specimen is not “white enough”. The problem is at the other end, where a very high whiteness index might mean commercial acceptance of an unacceptable sample. Observance of the CIE limits is therefore important, but there is an unexpected problem at the high end. Technology has advanced so far, that the paper industry can already produce samples which are visually considered really white, but are outside the equation (7) limits [3]. *Figure 4.* illustrates the current CIE limits as defined by equation (7) and new limits proposed by Coppel et al. [3].

The CIE whiteness is the white rectangular like area and is defined in the region delimited by the whiteness inequality conditions. W_{NEW} is the continuous surface, which gradually (and not abruptly) decreases as we move away from the current limits.

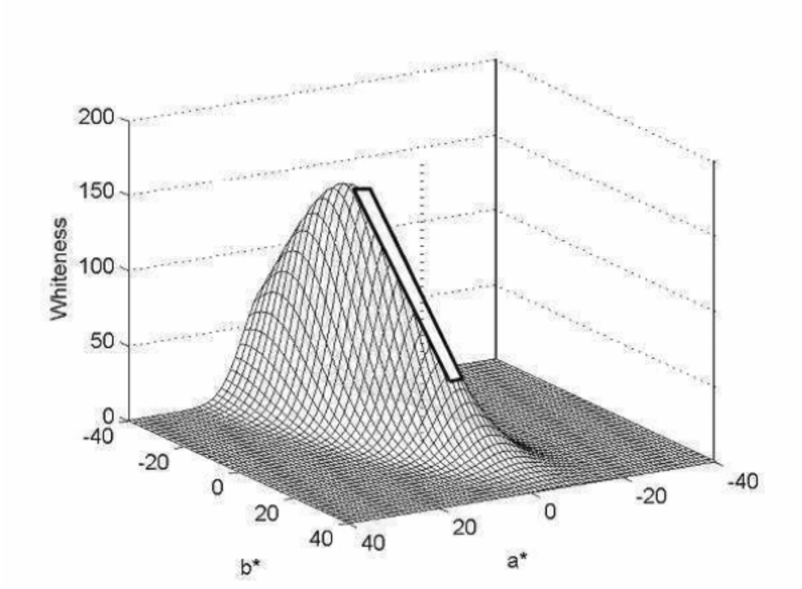

Figure 4. Comparison of the CIE whiteness to W_{NEW} for $L^* = 95$.
(Courtesy L. G. Coppel [3] Reproduced by kind permission of the Central Bureau of the CIE, Vienna))

Conclusions

- Further investigations are necessary to determine, whether the Ganz-Griesser calibration method and formula really yields much better reproducibility between industrial colour measuring instruments of the same of even different models. If it is possible to overcome the restrictions of the CIE whiteness and tint formulae by using Ganz-Griesser the latter should be adopted by CIE and turned into an international standard. Otherwise the CIE restrictions should be revised and the application of the CIE formulae be approved for common industrial situations involving different instruments.
- Preliminary data indicate that the current practice of transferring 45^o:0^o calibration data from national standardizing laboratories to sphere instruments used in industry may be acceptable even without the use of correction factors. When using diffuse white transfer standards (PTFE) the difference between different geometries may be within the acceptable practical tolerance.
- No data are available on the possibility of applying the CIE whiteness formula under illuminations other than D65. Although some standards permit the usage of the CIE

formulae for illuminant C and even D50, no published visual research supports this practice. Even less is known about the possibility of using any whiteness formula under such practically important illuminations as TL84, CWF or similar.

- The current limits for the validity of the CIE whiteness and tint formulae are important in practice, particularly the upper whiteness limit (where a high whiteness index may be misleading: the specimen may be visually distinctly non-white). Further investigations are necessary to decide on the eventual implementation of a new, improved whiteness formula.

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