Determination of Lovibond Color by Tristimulus Colorimetry

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Introduction

At such time as expanded control laboratory facilities were installed at the Belleville, New Jersey, branch plant of The Andrew Jergens Company, Lovibond glasses were not available. However, specifications of various fatty, oily, and waxy raw materials referred to Lovibond color values of a 5¼-inch sample column, and color was so determined by the Cincinnati control laboratory. Although much had been written regarding the deficiencies of the Lovibond Color system (1) and the need for a more objective method of color description, our problem was to determine Lovibond color values indirectly by correlating that color system to transmission values obtained by spectrophotometry or photoelectric colorimetry.

The International Commission on Illumination (I.C.I.) system of color designation has received international recognition and acceptance. The method requires that a complete spectral transmission curve be made, and tristimulus color values calculated by using either the weighted ordinate or selected ordinate method (2). Although a most accurate and precise method for determining color, the time required for each sample would prohibit its use for routine control.

Photoelectric tristimulus colorimetry using three filters was then considered. Using this method, samples are measured with source-filter-photocell combinations which spectrally duplicate, as nearly as possible, the three distribution functions characterizing the standard observer combined with a standard illuminant. This direct and rapid method permits determination of approximate tristimulus values by measuring transmission of the sample using three filters of suitable spectral transmission. The Amber-Blue-Green transmission values thus obtained are then used to compute trichromatic coefficients. This three-filter method was originally described in 1940 by Richard S. Hunter in National Bureau of Standards Circular C-429, titled "Photoelectric Tristimulus Colorimetry with Three Filters." The circular states that photoelectric devices, other than the multipurpose reflectometer referred to, may be used if they utilize the source-filter-photocell combinations described, and if they are of suitable precision. Since publication of N.B.S. Circular C-429, a number of photoelectric instruments have been used successfully for tristimulus colorimetry.

Scope

It is the intention of this paper to outline a method whereby photoelectric tristimulus transmission values may be used to determine Lovibond red-yellow color of various materials, with specific reference to a set of Lovibond color glasses used by the Cincinnati, Ohio, control laboratory of The Andrew Jergens Company.

Only red and yellow glasses were used and therefore the chromaticity diagram obtained (Fig. 3) may be applied to those materials possessing only red and/or yellow color characteristics.

Apparatus

a. Lovibond Color Glasses: a set of red and yellow glasses used by the Cincinnati, Ohio, control laboratory of The Andrew Jergens Company.

b. Lumetron Model 402-E[3]: a photoelectric colorimeter using two photocells connected in a current bridge circuit: balance is indicated as a zero response on a taut-wire, single reflecting mirror type galvanometer of low (90 ohms) coil resistance: the light source is a rheostat controlled 100 candlepower projection type tungsten lamp; current is supplied through a constant voltage regulator.

c. Adapter: a specially constructed metal plate which is positioned parallel to, and directly in front of, the measuring photocell: locating pins and a U-shaped Spring hold the glass plates in front of a ½-inch diameter hole in the center of the plate (refer to Fig. 1).

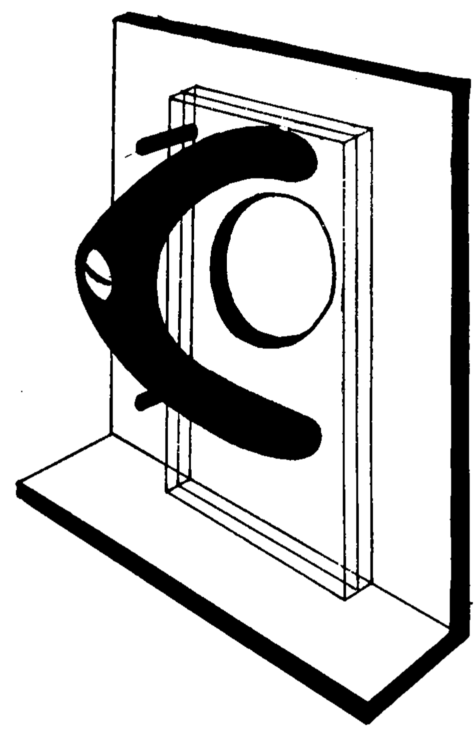

FIG. 1.

d. Tristimulus Filters: Amber, Blue, and Green glass filters designed to duplicate, in combination with the light source and photocells of the Lumetron Model 402-E, the I.C.I. Standard Observer and Illuminant C. It will be seen from Fig. 2 that the three filters have relative spectral transmission curves similar to those of the three filters referred to by N.B.S. Circular C-429, differing only in magnitude of transmission. These filters therefore permit closely approximate tristimulus values to be obtained by direct measurement of sample transmittancy.

e. Sample Cells: cylindrical shape: fused Pyrex glass body and windows with windows optically flat and parallel: 150.0 ± 0.1 mm. inside length between windows was used for the lighter samples, and 50.0 ± 0.1 mm. for the darker samples.

Lovibond Chromaticities

In view of the fact that tristimulus values were to be determined of Lovibond color glasses in various combinations, and consequently through various thicknesses of glass, the influence of type of glass,

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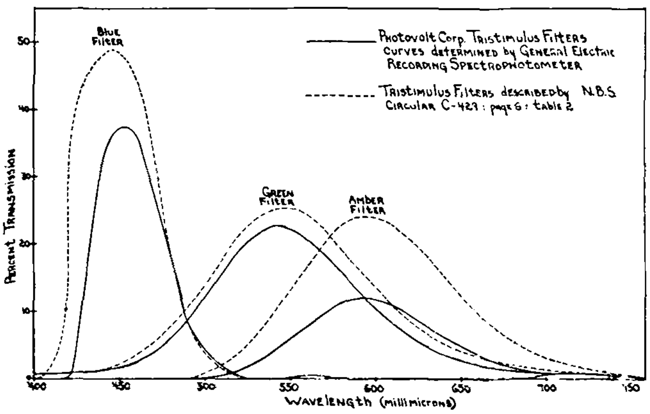

FIG. 2. Spectral transmission curves of tristimulus filters.

thickness of glass, and number of glasses, was investigated. The results obtained (refer to Table I) indicated that, whereas transmission values were not significantly affected by type of glass or thickness of glass, it was necessary to use as a color blank, an equal number of glasses to correct for reflection light losses.

TABLE I

Sample	Number of Thicknesses	Total Thickness	Per Cent Transmission
		in.	
Micro Slide Cover Glasses	1	0.0064	91.5
	2	0.0128	84.4
	3	0.0192	77.8
Microscope Slides	1	0.041	91.6
	2	0.082	84.5
	3	0.123	77.7
Plate Glass	1	0.130	91.6
	2	0.260	84.3
	3	0.390	76.0

Filter: Tristimulus Blue
Blank: Air = 100%

The following procedure was used to determine chromaticities of the Lovibond glasses:

1. Standardize the light source of the photoelectric colorimeter in accordance with the manufacturer's operating instructions, and position the adapter (refer to Fig. 1) in front of and parallel with the measuring photocell. The same light intensity and color temperature as is used to standardize the instrument, must be used when making the transmittance measurements.
2. Clean and polish the Amber-Blue-Green tristimulus filters, microscope slides, and Lovibond glasses.
3. Insert the tristimulus Amber filter into the filter holder.
4. Insert beneath the adapter spring clip, a number of microscope slides equal to the number of Lovibond glasses to be used.
5. Set the slide wire dial at 100.0% transmission and balance the instrument in accordance with the manufacturer's operating instructions.
6. Remove the microscope slides, insert the Lovibond glasses, and measure transmittance by rotating the slide wire dial to a position that produces no deflection of the galvanometer: transmittance is estimated to the nearest 0.1%.
7. Optional Check: Remove the Lovibond glasses and reinsert the microscope slides to check the instrument balance. If the transmittance varies from 100.0% by more than 0.5%, readjust the instrument balance and measure transmittance of the Lovibond glasses again.
8. Repeat steps 3-4-5-6-7 using the tristimulus Blue filter.
9. Repeat steps 3-4-5-6-7 using the tristimulus Green filter.
10. Trichromatic coefficients $\bar{x}$ and $\bar{y}$ are calculated from the A-B-G transmission readings obtained with the Amber-Blue-Green tristimulus filters, as follows:

(a)

$$X = (0.8\ A) + (0.18\ B)$$
$$Y = 1.0\ G$$
$$Z = 1.18\ B$$

(b)

$$\bar{x} = \frac{X}{X + Y + Z}$$
$$\bar{y} = \frac{Y}{X + Y + Z}$$

Tristimulus filter transmission values of 124 combinations of Lovibond red and yellow glasses were determined and computed to trichromatic coefficients $\bar{x}$ and $\bar{y}$. Table II tabulates 26 such computuations, comprising the minimum and maximum Lovibond red and yellow color intensities determined by this investigation. The chromaticity of each of the 124 combinations was indicated as a point on graph paper, and the points connected by straight lines. Line irregularities were attributed to the non-additive color variations of Lovibond glasses: these line

TABLE II

Lovibond Glasses		Tristimulus Transmissions			Trichrom. Coefficients	
Red	Yellow	Amber	Blue	Green	$\bar{x}$	$\bar{y}$
1	....	92.2	89.0	86.7	0.3190	0.3080
2	....	88.2	81.3	76.8	0.3304	0.2978
3	....	84.2	74.3	70.4	0.3379	0.2948
5	....	73.6	68.9	54.7	0.3439	0.2639
10	....	58.1	35.7	35.1	0.4066	0.2698
20	....	41.0	13.6	19.0	0.5014	0.2707
....	1	98.1	83.1	97.5	0.3232	0.3374
....	2	97.2	72.0	96.5	0.3332	0.3545
....	3	96.9	63.3	96.0	0.3424	0.3698
....	5	94.1	46.8	92.2	0.3622	0.3990
....	10	90.4	29.0	86.4	0.3912	0.4361
....	15	88.7	20.7	83.8	0.4084	0.4582
....	35	74.8	8.1	68.4	0.4400	0.4910
....	70	56.0	2.8	50.1	0.4590	0.5076
20	5	38.3	6.1	17.4	0.5630	0.3091
20	10	36.6	3.8	16.5	0.5882	0.3235
20	15	35.7	2.7	16.4	0.5967	0.3374
20	35	29.5	1.2	13.4	0.6166	0.3472
20	70	21.1	0.5	9.8	0.6204	0.3577
1	70	50.3	2.3	42.5	0.4738	0.4948
2	70	48.8	2.1	37.9	0.4937	0.4749
3	70	46.8	1.9	35.2	0.5027	0.4681
5	70	40.5	1.6	27.2	0.5291	0.4401
10	70	31.4	1.0	17.5	0.5750	0.3977
15	70	24.7	0.8	12.5	0.5976	0.3754
20	70	21.5	0.5	10.0	0.6200	0.3584

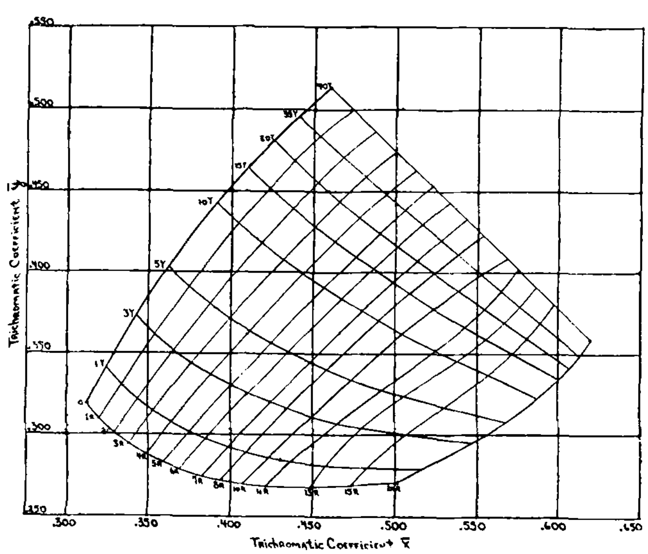

FIG. 3. Lovibond chromaticities. A. J. Cincinnati-Lovibond glasses.

irregularities did not appear to be significant, and smooth curves were drawn to produce the chromaticity diagram of Fig. 3.

Determination of Chromaticity vs. Lovibond Sample Color

The various raw materials to which the chromaticity diagram was to be applied for determination of Lovibond color, possessed indices of refraction ranging from 1.440 to 1.480. It was therefore deemed advisable to determine whether or not a difference of refractive index between the sample and the color blank would introduce significant error. Using color blanks of progressively increasing refractive index, tristimulus filter transmittancies were determined of a single sample of Sweet Almond Oil (Index of Refraction 1.468 @ 25°C.). Transmittancies were determined through 150 ± 0.1 mm. inside length sample cells and all color blanks were previously decolorized with activated carbon to a less than 10 LaMotte color value (refer to Table III). Tristimulus filter transmittancies were progressively lower as color blanks of higher refractive index were used, but this progression did not appear in the computed chromaticities, and only random variations were noted: Lovibond color equivalents ranged from 0.2 to 0.4 Red and from 21 to 24 Yellow.

TABLE III

Blanks			Tristimulus Values			Trichrom. Coeff.	
Refractive Index 25°C.	Composition		Amber	Blue	Green	$\bar{x}$	$\bar{y}$
1.333	Distilled Water		98.8	14.6	89.1	0.4344	0.4739
1.421	Dioxane		91.3	13.8	83.0	0.4320	0.4748
	Benzene	$CHCl_3$					
	pct.	pct.					
1.453	16	84	89.9	13.5	81.2	0.4335	0.4736
1.460	32	68	89.5	13.5	81.0	0.4330	0.4738
1.473	50	50	88.7	13.7	80.8	0.4309	0.4742
1.481	68	32	88.4	12.9	79.7	0.4349	0.4745
1.490	84	16	88.3	12.8	79.5	0.4353	0.4745
1.499	100	0	87.2	12.7	78.8	0.4344	0.4751

Carbon Tetrachloride A.C.S. reagent grade was chosen as the color blank because of its consistent purity, stability, negligible color, and refractive index 1.463, which approximated that of many of the materials of which Lovibond color was to be determined.

Dilution by solution of the sample in a suitable solvent, and the possibility of using shorter cells, were considered for the darker colored materials. Investigation, however, revealed that Lovibond determined color was not proportionate to dilution, nor to the length of sample column measured (4).

To determine the possible effect of haze in the sample upon chromaticity Lovibond equivalents, a progressive and cumulative 0.5% reduced tristimulus filter transmittancy was assumed and chromaticities computed therefrom (refer to Table IV). Whereas a 1.5% reduction of transmitted light, due to haze diffusion, did not significantly change the Lovibond color equivalent of a light colored material, the same transmission reduction, when applied to a darker material, resulted in a darkening effect error of 15 Lovibond yellow color units.

The following procedure was used to determine chromaticity Lovibond equivalents of various materials:

1. Standardize the light source of the photoelectric colorimeter in accordance with the manufacturer's operating instructions. The same light intensity and color temperature as is used to standardize the instrument must be used when making the transmittance measurements.
2. Clean the sample cell interiors with chromic acid cleaning solution, rinsing with distilled water and acetone, and apply suction to one filler neck to dry. Polish the tristimulus filters and the outside surface of the sample cell windows with a clean lint-free cloth.
3. Prepare the color blank by filling one of the sample cells with Carbon Tetrachloride A.C.S. reagent grade, that has a less than 10 LaMotte color value.
4. Prepare the sample by filling the other cell with the sample, permitting entrained air bubbles to rise into the filler necks.
   a. Samples that contain haze or turbidity must be previously clarified by a suitable filtration procedure.
   b. Samples that require heating to eliminate haze or to melt to a liquid state, should be heated to not more than 15° Centigrade above the melting point of the sample, and transmittancies determined as rapidly as possible. Heated samples should be visually examined after each transmittancy reading to make certain that there is no haze or opacity.
5. Insert the tristimulus Amber filter into the filter holder, place the Carbon Tetrachloride containing cell into the colorimeter, set the slide wire dial at 100.0% transmission, and balance the instrument in accordance with the manufacturer's operating instructions.
6. Remove the color blank, place the sample containing cell into the colorimeter, and measure transmittance by rotating the slide wire dial to a position that produces no deflection of the galvanometer: estimate transmittance to the nearest 0.1%.
7. Optional Check: Remove the sample containing cell and reinsert the color blank containing cell to check the instrument balance. If the transmittance differs from 100.0% by more than 0.5%, readjust the colorimeter and measure transmittance of the sample again.
8. Repeat steps 5-6-7 using the tristimulus Blue filter.
9. Repeat steps 5-6-7 using the tristimulus Green filter.
10. Calculate trichromatic coefficients $\bar{x}$ and $\bar{y}$ from the A-B-G transmission readings obtained with the Amber-Blue-Green tristimulus filters.

(a)

$$X = (0.8\ A) + (0.18\ B)$$
$$Y = 1.0\ G$$
$$Z = 1.18\ B$$

(b)

$$\bar{x} = \frac{X}{X + Y + Z}$$
$$\bar{y} = \frac{Y}{X + Y + Z}$$

TABLE IV

Material and Specification	Tristim. Filter Values			Trichrom. Coeff.		Lovibond Equivalent	
	Amber	Blue	Green	$\bar{x}$	$\bar{y}$	Red	Yellow
Cetyl Alcohol	82.0	36.6	70.0	0.3894	0.3776	2.1	5.0
	81.5	36.1	69.5	0.3901	0.3781	|	|
5¼" Column	81.0	35.6	69.0	0.3908	0.3786	↓	↓
Lovibond Color—2 Red, 5 Yellow	80.5	35.1	68.5	0.3915	0.3792	2.1	5.2
Beeswax—U. S. P. White	57.6	4.7	42.1	0.4960	0.4450	4.0	35
	57.1	4.2	41.6	0.4993	0.4473	|	|
5¼" Column	56.6	3.7	41.1	0.5026	0.4496	↓	↓
Lovibond Color— 4 Red, 35 Yellow	56.1	3.2	40.6	0.5060	0.4519	4.0	50

TABLE V

Material	Sample Column Length	Chromaticity Lovibond Equiv.		Lovibond Color Readings		
		Red	Yellow	Red	Yellow	Blue
	mm.					
Ceresine	150	0.2	0.8	0.4	1.0	0.5
Petrolatum—White	150	0.1	1.4	0.1	1.0	0
Cetyl Alcohol	150	0.2	1.0	0.6	1.0	1.0
Stearyl Alcohol	150	0.5	0.7	0.1	1.0	0.5
Spermaceti	150	0.4	1.6	0.2	2.0	0
Stearic Acid—T. P.	150	0.5	1.5	0.5	1.5	0.5
Triethanolamine	150	0.5	2.5	0.6	3.0	1.0
C. O. Fatty Acid	150	1.0	7.5	0.8	8.0	0
Beeswax—White	150	2.6	15.0	2.8	16.0	2.0
Mannitan Monolaurate	150	3.5	42.0	4.2	35.0	0
Mannitan Monolaurate	50	1.3	9.5	1.5	10.0	0.5
Almond Oil—Expressed	150	0.7	42.0	2.1	20.0	2.0
Almond Oil—Expressed	50	0.3	6.5	0.9	7.0	1.0
Sweet Almond Oil—USP	150	1.2	70.0	1.5	25.0	0
Sweet Almond Oil—USP	50	0.6	11.0	0.6	9.0	0.5
Mixed Fatty Acid Esters	50	9.0	70.0	7.7	70.0	0

Duplicate samples of the various materials were submitted to the A. J. Cincinnati control laboratory for direct determination of Lovibond color. Standard procedure for direct visual determination of Lovibond color specified that an arbitrary red-yellow ratio be used,

0 to 3 Red : Use 10 Yellow to 1 Red
3 to 5 Red : Use 35 Yellow
Above 5 Red : Use 70 Yellow

and that blue Lovibond glasses be used when necessary, to obtain the best possible color match: to elimimate these blue color values 0.4 Red is subtracted for every 0.5 Blue. The use of blue glasses is apparently a visual matching expediency rather than a hue modification: blue values obtained are therefore reported, but not considered pertinent to the accuracy evaluation of the chromaticity Lovibond equivalents.

Examination of Lovibond color readings and chromaticity Lovibond equivalents (Table V) revealed that results compared favorably to within a 0.5 color unit variance, when color values were less than 10 Red-10 Yellow. Greater variances observed for the darker samples were attributed to the use of an arbitrary red-yellow ratio for the visual determination of Lovibond color, and to a reduced Lovibond color sensitivity (refer to Fig. 4) as reflected in both the visual determination values and the chromaticity equivalents. To determine Lovibond color of the darker materials, it would appear advisable to use a shorter column length to secure chromaticity Lovibond equivalents less than 10 Red-10 Yellow, and to refer these values to a suitably adjusted Lovibond color specification.

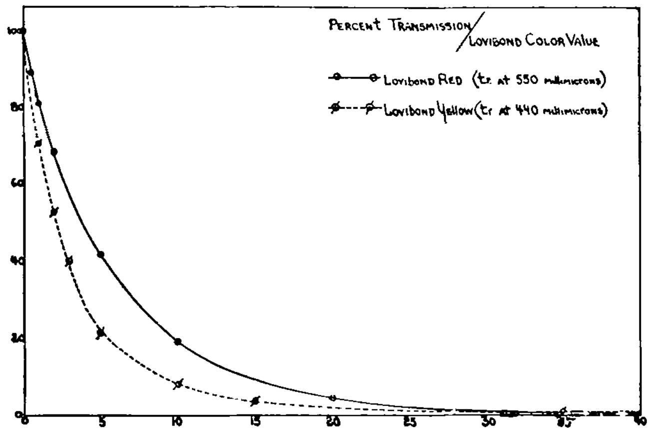

FIG. 4.

Conclusion

Subject to the cumulation of additional comparative values, it is tentatively concluded that, within the limitations specified by this paper, it is possible to obtain reasonably accurate Lovibond color values indirectly, by using the photoelectric colorimeter and tristimulus filters described.

REFERENCES

1. Gibson, K. S., and Harris, F. K.: Bur. Stds. Sci. Paper No. 547 (1927):
Walker, G. K.: Bur. Stds. Research Paper No. RP-653 (1934): etc.
2. Hardy, A. C., "Handbook of Colorimetry," Technology Press (1936).
3. Manufactured by the Photovolt Corporation, 95 Madison Avenue, N.Y.C.
4. Report of the A.O.C.S. Color Committee: Journal A.O.C.S., Aug. 1948, Curve 9 and 10.