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Spectrophotometric Analysis

# Quantifying Color of Colored Glass Plates and Liquids Utilizing CIELAB and HunterLab Color Analysis Software

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## ■ Introduction

Applicable to many industries including but not limited to pharmaceuticals, foods, and textiles, the identification of "color" is utilized in a variety of areas. The specific coloration of a sample during experimentation can become pivotal in later application. Unfortunately, the subjective nature of color can impact the analysis of an item. Human perception of color can be unreliable, many factors affecting the analysis of perceived color including the environment in which a color is analysis and the individual's quality of sight. For this reason, the standardization of color analysis addresses the factors which impact an item's perceived color. The standardization of color analysis has been achieved through color scales such as CIELAB and HunterLab, which become useful analytical tools when paired with Shimadzu UV-Vis spectroscopic instrumentation.

The quantitation of color can be reached through color space analysis, a method which addresses many factors which can impact color including the illuminant's spectral irradiance and position. Regarding spectroscopic color analysis, color spaces express the colors of human vision—red, green, blue, and yellow—with scales representative of the illumination of the sample. When a spectral scan is performed on a sample, the color analysis typically prompts either coordinates/parameters within a color space (similarly formed in an X, Y, and Z plane fashion) or is given a value corresponding to the scale's specific values of measurement. The benefit of this spectroscopic measurement technique is that it simplifies the understood color value, facilitating the communication and representation of color data in a manageable and widely understood format.

## ■ CIELAB and HunterLab Color Spaces

CIELAB and HunterLab color spaces similarly derive from the Opponent-Color Theories with the Hunter L, a, b[1] scale (1966) preceding the CIELAB color scale (1976). The color is thus represented in three values comparable to a coordinate plane, with both scales assigning the following color spectra to variables:

- "L" representing lightness, typically on a scale of white (assigned to 100) to black (assigned to 0),
- "a" representing colors red (positive) to green (negative),
- And "b" representing the colors yellow (positive) to blue (negative).

CIELAB values are calculated using the cubed root values of the XYZ color scale whereas Hunter color scale utilizes the square roots of the CIE XYZ color scale. The Hunter L, a, b color scale has become a preferred option as compared to CIE XYZ for its uniformity, yet CIELAB has gained widespread popularity in many industries currently. The main difference found between these two-color scales is within the uniformity of colors. The CIELAB scale expands in the yellow region and contracts in blue. Conversely occurs in the Hunter L, a, b scale with the scale contract the yellowing region and expanding the blue region. Other differences are in these two scales including the derivations of the values formulaically and approximations. Additionally, the parameters are presented in different forms although the scales pertaining to the respective parameter stay the same. In specific, L*, a*, and b* are the presentation of the CIELAB parameters, whereas Hunter color scale takes on L, a, and b parameter format.

The L*a*b* color space, or CIELAB, was used for the purposes of color analysis in the color measurement discussed due to it widespread popularity across most to all industries. Hunter L, a, b, was also a color space worth including for its instrumental purpose including the pharmaceutical and food industries.

## ■ Experimentation and Representation of Data

To demonstrate the measurement of color in both CIELAB and HunterLab color spaces, both glass filters and colored liquids underwent analysis with Shimadzu instruments. For the experiment, the UV-1900i spectrophotometer and UV-2600i spectrophotometer were used to perform spectral scans of the samples. A third run of the samples was performed on the UV-2600i spectrophotometer with the ISR-2600Plus Integrating Sphere Attachment.

All the spectral scans were acquired as transmission scans, between spectrum scans ranging between 300 nm and 800 nm. Scans of the samples were analyzed using Shimadzu Color Analysis Software. This included CIELAB and HunterLab color space identification. Within the CIELAB and HunterLab parameters for color identification, the illuminant D65 (midday lighting) was utilized for the CIELAB color space and illuminant C (average noon daylight) for the HunterLab color space—comparable illuminants in industry standards.

The colored glass plate samples were from an assortment of seven distinct colors, each with own color code as follows: R-60, O-56, Y-46, Y-50, B-340, B-390, L-42. The colored liquids utilized as samples in color measurement were a mixture of colored food dye and deionized water to create eight distinct shades corresponding to the following colors: red, orange, yellow, green, light blue, dark blue, purple. An additional sample of deionized water without color treatment was utilized as a baseline in the data comparison of the liquid solution of water and food dye.

**Table 1**: Parameters for the 1900i spectrophotometer.

| Parameter | Value |
|---|---|
| Wavelength Start (λ) | 800 nm |
| Wavelength End (λ) | 300 nm |
| Data Interval | 2.0 nm |
| Scan Speed | High Speed |
| Spectrum Type | Transmittance |
| Slit Width | 1.0 nm |
| Light Source Switch Wavelength | 323.0 nm |
| S/R Switch | Standard |

**Table 2**: Parameters for the UV-2600i spectrophotometer.

| Parameter | Value |
|---|---|
| Wavelength Start (λ) | 800 nm |
| Wavelength End (λ) | 300 nm |
| Data Interval | 0.5 nm |
| Scan Speed | High Speed |
| Spectrum Type | Transmittance |
| Slit Width | 2.0 nm |
| Detector Unit | Direct Receiving of Light |
| Light Source Switch Wavelength | 323.0 nm |
| S/R Switch | Standard |

**Table 3**: Parameters for the UV-2600i with ISR-2600Plus Integrating Sphere Attachment.

| Parameter | Value |
|---|---|
| Wavelength Start (λ) | 800 nm |
| Wavelength End (λ) | 300 nm |
| Data Interval | 0.5 nm |
| Scan Speed | High Speed |
| Spectrum Type | Transmittance |
| Slit Width | 5.0 nm |
| Detector Unit | External (2 Detector) |
| Light Source Switch Wavelength | 323.0 nm |
| Detector Switch Wavelength | 830.0 nm |
| S/R Switch | Standard |

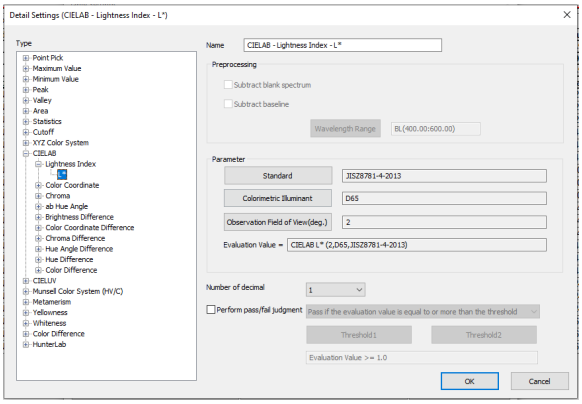


**Figure 1**: CIELAB color processing specifications for the L* lightness index parameter.

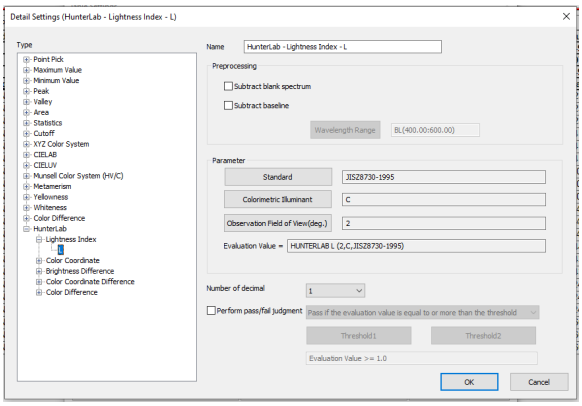


**Figure 2**: HunterLab color processing specifications for the L lightness index parameter.

**Figure 3**: Filter samples used for testing. Shimadzu PN: 204-04691-00

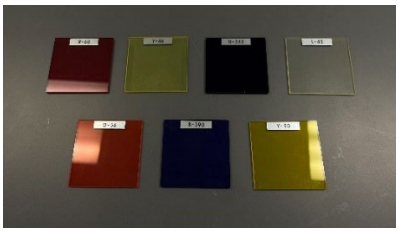

**Figure 4**: Seven individual colored glass plates utilized in the demonstration of CIELAB and HunterLab color space capabilities.

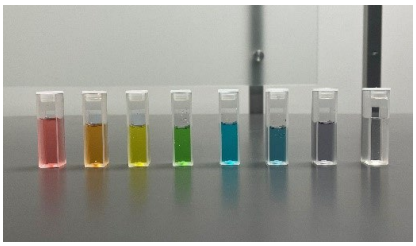

**Figure 5**: Eight individual-colored liquids were utilized in the demonstration of CIELAB and HunterLab color space capabilities.

## ■ UV-1900i Spectrophotometer for Colored Liquids

Figure 6 details transmission spectral scans of the seven colored liquids and one baseline water sample taken on the UV-1900i spectrophotometer. The color within the adjoined chart corresponds to the colors within the transmission scans graph and the colored liquids scanned.

The baseline shows the water's nature when scanned for light transmission, to help define trends which can be differentiated from that of the colored dye.

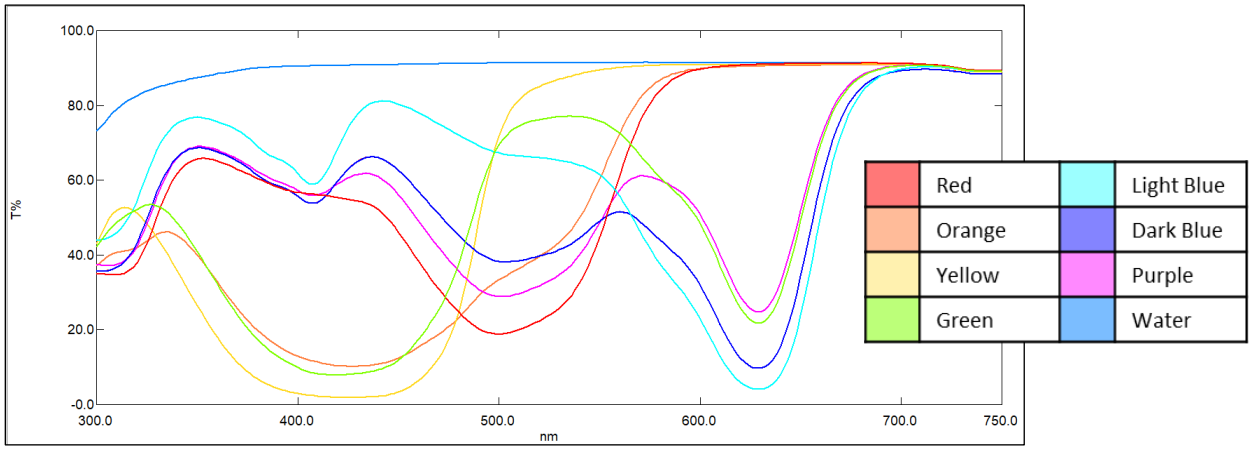


**Figure 6**: Transmission spectral scans of seven colored liquid samples and one water sample taken between 300 nm and 750 nm.

The colored liquid samples are plotted in Figure 7 and 8 within CIELAB's color space. The orientation of the data can be defined in one focused in the L* lightness index, whereas the a*b* graph represents the samples' color properties. Figure 7 plots the samples, oriented with distinct sample numbers in the X-axis and L* from a scale of 0 to 100 as the Y-axis. Figure 7 presented the black to white spectrum from 0 to 100 respectively. The L* lightness index simply defines the samples "depth" of hue. In a differing manner, the a*b* graph plots the samples, worrying for color properties, with the a* coordinate of red (100) to green (-100) pertaining to the X-axis and the b* coordinate of yellow (100) to blue (-100) pertaining to the Y-axis.

As found within the similar HunterLab, a sample within the spectra of color cannot a simultaneous true red and green or true yellow and blue respectively, confined to the defined scales created for each distinct coordinate.

The table 4 graph includes the eight liquid samples taken and their post spectral scan color analysis utilizing the CIELAB color space. Table 5 graph includes the eight liquid samples taken and their post spectral scan color analysis utilizing the HunterLab color space. Below each color-specified sample within the respective graphs, there are two additional scans of the same sample, which agrees with the parameters defined within the initial scan, those being the parameters defined within the L* and a*b* graphs.

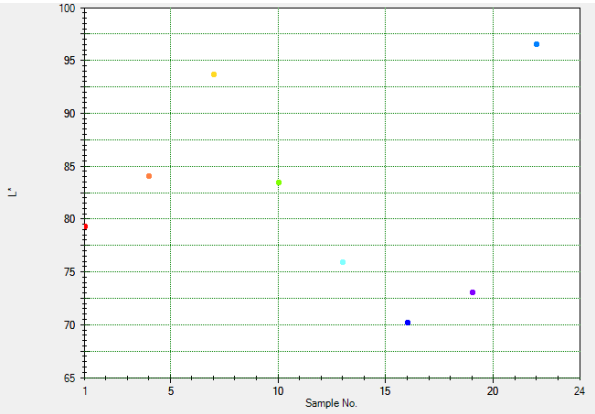


**Figure 7**: L values for the eight liquid samples in CIELAB color space.

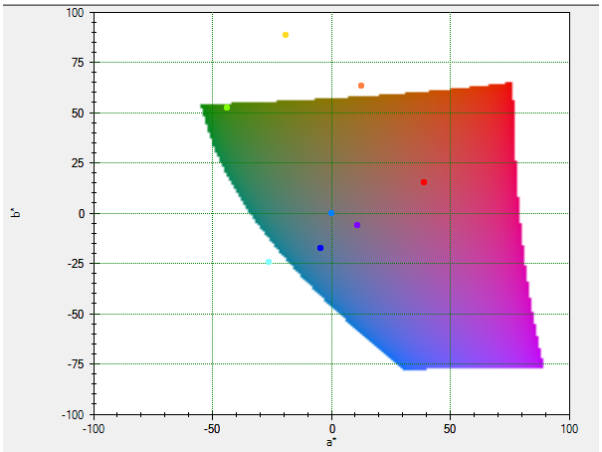


**Figure 8**: Liquid sample values plotted in a*b* plane derived from the CIELAB color space.

**Table 4**: CIELAB chart for eight liquids samples with parameter values.

| | | | | | | CIELAB - Lightness Index - L* | | CIELAB - Color Coordinate - a* | | CIELAB - Color Coordinate - b* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AV | | | | Average Value | 82.0 | | -4.2 | | 21.8 | |
| SD | | | | Standard Deviation | 8.8 | | 24.2 | | 38.9 | |
| RSD | | | | Variation Factor | 0.1 | | -5.7 | | 1.8 | |
| | Legend | | Type | File Name | General Judgment | Value | Judgment | Value | Judgment | Value | Judgment |
| 1 | ☑ | | SMP | Red_071120231.vspd | N/A | 79.3 | N/A | 38.5 | N/A | 15.6 | N/A |
| 2 | ☐ | * | SMP | Red_071120232.vspd | N/A | 79.3 | N/A | 38.5 | N/A | 15.6 | N/A |
| 3 | ☐ | * | SMP | Red_071120233.vspd | N/A | 79.3 | N/A | 38.5 | N/A | 15.6 | N/A |
| 4 | ☑ | | SMP | Orange_071120231.vspd | N/A | 84.1 | N/A | 12.4 | N/A | 63.7 | N/A |
| 5 | ☐ | * | SMP | Orange_071120232.vspd | N/A | 84.1 | N/A | 12.4 | N/A | 63.7 | N/A |
| 6 | ☐ | * | SMP | Orange_071120233.vspd | N/A | 84.1 | N/A | 12.4 | N/A | 63.7 | N/A |
| 7 | ☑ | | SMP | Yellow_071120231.vspd | N/A | 93.7 | N/A | -19.4 | N/A | 89.1 | N/A |
| 8 | ☐ | * | SMP | Yellow_071120232.vspd | N/A | 93.7 | N/A | -19.4 | N/A | 89.1 | N/A |
| 9 | ☐ | * | SMP | Yellow_071120233.vspd | N/A | 93.7 | N/A | -19.4 | N/A | 89.0 | N/A |
| 10 | ☑ | | SMP | Green_071120231.vspd | N/A | 83.5 | N/A | -44.3 | N/A | 52.9 | N/A |
| 11 | ☐ | * | SMP | Green_071120232.vspd | N/A | 83.5 | N/A | -44.3 | N/A | 52.9 | N/A |
| 12 | ☐ | * | SMP | Green_071120233.vspd | N/A | 83.5 | N/A | -44.3 | N/A | 52.9 | N/A |
| 13 | ☑ | | SMP | Light Blue_071120231.vspd | N/A | 75.9 | N/A | -26.7 | N/A | -24.1 | N/A |
| 14 | ☐ | * | SMP | Light Blue_071120232.vspd | N/A | 75.9 | N/A | -26.7 | N/A | -24.1 | N/A |
| 15 | ☐ | * | SMP | Light Blue_071120233.vspd | N/A | 75.9 | N/A | -26.7 | N/A | -24.1 | N/A |
| 16 | ☑ | | SMP | Dark Blue 1_071120231.vspd | N/A | 70.2 | N/A | -4.7 | N/A | -17.1 | N/A |
| 17 | ☐ | * | SMP | Dark Blue_071120232.vspd | N/A | 70.2 | N/A | -4.7 | N/A | -17.1 | N/A |
| 18 | ☐ | * | SMP | Dark Blue_071120233.vspd | N/A | 70.2 | N/A | -4.7 | N/A | -17.1 | N/A |
| 19 | ☑ | | SMP | Purple_071120231.vspd | N/A | 73.1 | N/A | 10.5 | N/A | -5.7 | N/A |
| 20 | ☐ | * | SMP | Purple_071120232.vspd | N/A | 73.1 | N/A | 10.5 | N/A | -5.7 | N/A |
| 21 | ☐ | * | SMP | Purple_071120233.vspd | N/A | 73.1 | N/A | 10.5 | N/A | -5.7 | N/A |
| 22 | ☑ | | SMP | Water_071120231.vspd | N/A | 96.6 | N/A | -0.1 | N/A | 0.3 | N/A |
| 23 | ☐ | * | SMP | Water_071120232.vspd | N/A | 96.5 | N/A | -0.1 | N/A | 0.3 | N/A |
| 24 | ☐ | * | SMP | Water_071120233.vspd | N/A | 96.5 | N/A | -0.1 | N/A | 0.3 | N/A |

**Table 5**: HunterLab chart for eight liquids samples with parameter values.

| | | | | | HunterLab - Lightness Index - L | | HunterLab - Color Coordinate - a | | HunterLab - Color Coordinate - b | |
|---|---|---|---|---|---|---|---|---|---|---|
| AV | | | | | 78.0 | | -3.4 | | 12.4 | |
| SD | | | | | 10.4 | | 22.2 | | 28.0 | |
| RSD | | | | | 0.1 | | -6.6 | | 2.3 | |
| | Legend | | Type | File Name | Value | Judgment | Value | Judgment | Value | Judgment |
| 1 | ☑ | | SMP | Red_071120231.vspd | 75.0 | N/A | 37.9 | N/A | 13.7 | N/A |
| 2 | ☐ | * | SMP | Red_071120232.vspd | 75.0 | N/A | 37.9 | N/A | 13.7 | N/A |
| 3 | ☐ | * | SMP | Red_071120233.vspd | 75.0 | N/A | 37.9 | N/A | 13.7 | N/A |
| 4 | ☑ | | SMP | Orange_071120231.vspd | 80.4 | N/A | 9.9 | N/A | 42.5 | N/A |
| 5 | ☐ | * | SMP | Orange_071120232.vspd | 80.4 | N/A | 9.9 | N/A | 42.4 | N/A |
| 6 | ☐ | * | SMP | Orange_071120233.vspd | 80.4 | N/A | 9.9 | N/A | 42.4 | N/A |
| 7 | ☑ | | SMP | Yellow_071120231.vspd | 91.8 | N/A | -20.5 | N/A | 55.1 | N/A |
| 8 | ☐ | * | SMP | Yellow_071120232.vspd | 91.8 | N/A | -20.5 | N/A | 55.1 | N/A |
| 9 | ☐ | * | SMP | Yellow_071120233.vspd | 91.8 | N/A | -20.5 | N/A | 55.1 | N/A |
| 10 | ☑ | | SMP | Green_071120231.vspd | 79.2 | N/A | -39.1 | N/A | 37.4 | N/A |
| 11 | ☐ | * | SMP | Green_071120232.vspd | 79.2 | N/A | -39.1 | N/A | 37.4 | N/A |
| 12 | ☐ | * | SMP | Green_071120233.vspd | 79.2 | N/A | -39.1 | N/A | 37.4 | N/A |
| 13 | ☑ | | SMP | Light Blue_071120231.vspd | 70.4 | N/A | -21.3 | N/A | -26.8 | N/A |
| 14 | ☐ | * | SMP | Light Blue_071120232.vspd | 70.3 | N/A | -21.3 | N/A | -26.8 | N/A |
| 15 | ☐ | * | SMP | Light Blue_071120233.vspd | 70.3 | N/A | -21.3 | N/A | -26.8 | N/A |
| 16 | ☑ | | SMP | Dark Blue 1_071120231.vspd | 64.2 | N/A | -3.3 | N/A | -17.7 | N/A |
| 17 | ☐ | * | SMP | Dark Blue_071120232.vspd | 64.2 | N/A | -3.3 | N/A | -17.7 | N/A |
| 18 | ☐ | * | SMP | Dark Blue_071120233.vspd | 64.2 | N/A | -3.3 | N/A | -17.7 | N/A |
| 19 | ☑ | | SMP | Purple_071120231.vspd | 67.5 | N/A | 9.7 | N/A | -5.5 | N/A |
| 20 | ☐ | * | SMP | Purple_071120232.vspd | 67.5 | N/A | 9.7 | N/A | -5.5 | N/A |
| 21 | ☐ | * | SMP | Purple_071120233.vspd | 67.5 | N/A | 9.7 | N/A | -5.5 | N/A |
| 22 | ☑ | | SMP | Water_071120231.vspd | 95.6 | N/A | -0.1 | N/A | 0.2 | N/A |
| 23 | ☐ | * | SMP | Water_071120232.vspd | 95.5 | N/A | -0.1 | N/A | 0.2 | N/A |
| 24 | ☐ | * | SMP | Water_071120233.vspd | 95.5 | N/A | -0.1 | N/A | 0.2 | N/A |

*Note: Color key applicable to CIELAB and HunterLab chart sample values.*

## ■ UV-2600i Spectrophotometer Data for Colored Plates

Figure 9 details transmission spectral scans of the seven colored glass filters taken on the UV-2600i spectrophotometer with additional attachments.

The colors defined within the adjoined chart correspond to the spectral scan within the chart and are representative of the colored glass filters found in Figure 4.

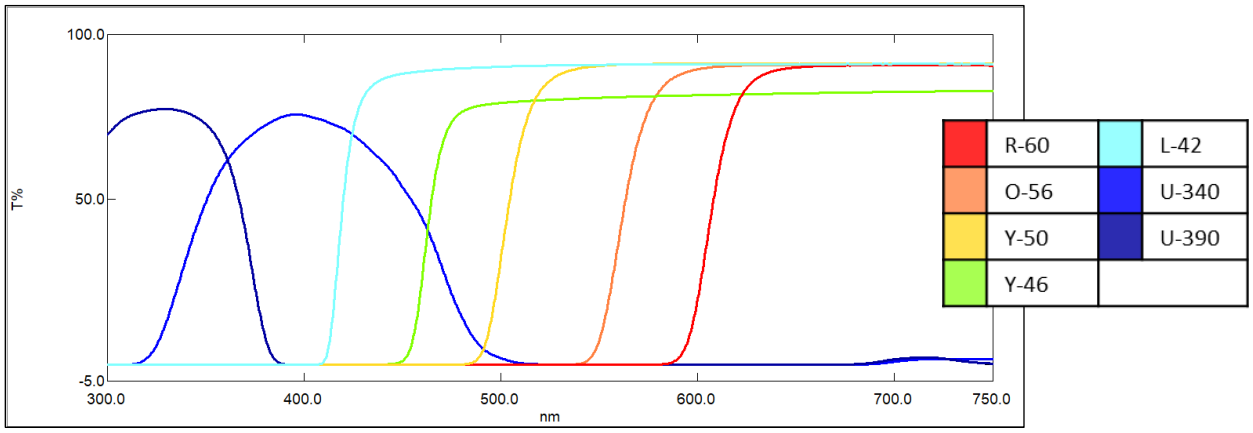


**Figure 9**: Transmission spectral scans of seven colored glass filter plates taken between 300 nm and 750 nm.

The seven colored glass filters are plotted in CIELAB color space in a similar fashion as to the data collected of the colored liquids on the UV-1900i spectrophotometer with Figure 10 being the L* lightness index or "depth" of color graphed and Figure 11 being the a*b* chart portraying the color properties of the colored glass filter samples.

Table 6 includes the CIELAB parameters for the seven colored glass filter samples, inclusive of two additional scans per sample for integrity of experimentation.

Table 7 includes the HunterLab parameters for the seven colored glass filter samples, inclusive of two additional scans per sample for integrity of experimentation. The parameters within the respective color spaces agreed well, with only small deviations which can be a result of the testing environment.

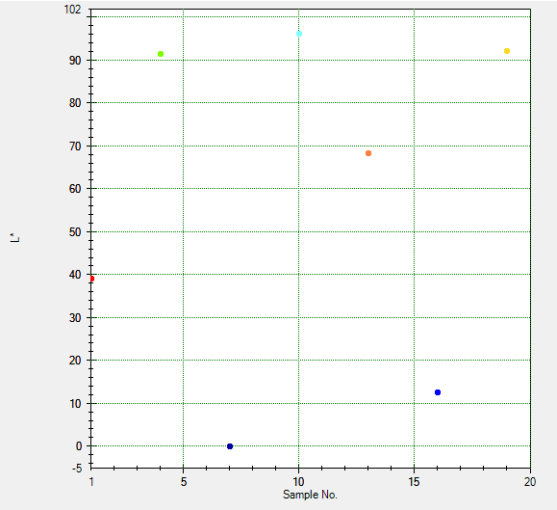


**Figure 10**: L values for the seven colored glass filter samples in CIELAB color space.

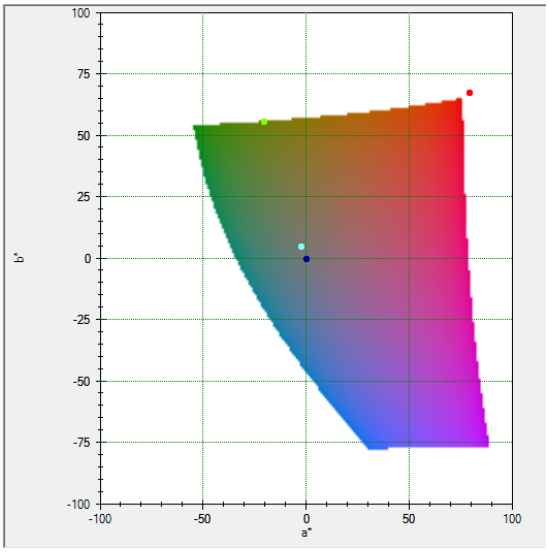


**Figure 11**: Colored glass filter sample values plotted in an ab chart derived from the CIELAB color space.

**Table 6**: CIELAB chart for seven colored glass filter samples with parameter values.

| | | | | | CIELAB - Lightness Index - L* | | CIELAB - Color Coordinate - a* | | CIELAB - Color Coordinate - b* | |
|---|---|---|---|---|---|---|---|---|---|---|
| AV | | | | Average Value | 57.2 | | 28.9 | | 37.7 | |
| SD | | | | Standard Deviation | 37.2 | | 46.9 | | 73.0 | |
| RSD | | | | Variation Factor | 0.6 | | 1.6 | | 1.9 | |
| | Legend | Type | File Name | General Judgment | Value | Judgment | Value | Judgment | Value | Judgment |
| 1 | ☑ | SMP | R60_071120231.vspd | N/A | 39.1 | N/A | 79.2 | N/A | 67.4 | N/A |
| 2 | ☐ * | SMP | R60_071120232.vspd | N/A | 39.1 | N/A | 79.2 | N/A | 67.4 | N/A |
| 3 | ☐ * | SMP | R60_071120233.vspd | N/A | 39.1 | N/A | 79.2 | N/A | 67.3 | N/A |
| 4 | ☑ | SMP | Y46_071120231.vspd | N/A | 91.5 | N/A | -20.3 | N/A | 55.5 | N/A |
| 5 | ☐ * | SMP | Y46_071120232.vspd | N/A | 91.5 | N/A | -20.3 | N/A | 55.5 | N/A |
| 6 | ☐ * | SMP | Y46_071120233.vspd | N/A | 91.6 | N/A | -20.4 | N/A | 55.5 | N/A |
| 7 | ☑ | SMP | U340_071120231.vspd | N/A | 0.0 | N/A | 0.1 | N/A | 0.0 | N/A |
| 8 | ☐ * | SMP | U340_071120232.vspd | N/A | 0.0 | N/A | 0.1 | N/A | 0.0 | N/A |
| 9 | ☐ * | SMP | U340_071120233.vspd | N/A | 0.0 | N/A | 0.1 | N/A | 0.0 | N/A |
| 10 | ☑ | SMP | L42_071120231.vspd | N/A | 96.3 | N/A | -2.5 | N/A | 5.0 | N/A |
| 11 | ☐ * | SMP | L42_071120232.vspd | N/A | 96.3 | N/A | -2.5 | N/A | 5.0 | N/A |
| 12 | ☐ * | SMP | L42_071120233.vspd | N/A | 96.3 | N/A | -2.5 | N/A | 5.0 | N/A |
| 13 | ☑ | SMP | O56_071120231.vspd | N/A | 68.5 | N/A | 54.8 | N/A | 117.1 | N/A |
| 14 | ☐ * | SMP | O56_071120232.vspd | N/A | 68.5 | N/A | 54.9 | N/A | 117.1 | N/A |
| 15 | ☐ * | SMP | O56_071120233.vspd | N/A | 68.4 | N/A | 54.9 | N/A | 117.1 | N/A |
| 16 | ☑ | SMP | B390_071120231.vspd | N/A | 12.5 | N/A | 106.4 | N/A | -103.8 | N/A |
| 17 | ☐ * | SMP | B390_071120232.vspd | N/A | 12.5 | N/A | 106.4 | N/A | -103.8 | N/A |
| 18 | ☐ * | SMP | B390_071120233.vspd | N/A | 12.5 | N/A | 106.4 | N/A | -103.8 | N/A |
| 19 | ☑ | SMP | Y50_071120231.vspd | N/A | 92.3 | N/A | -15.2 | N/A | 122.9 | N/A |
| 20 | ☐ * | SMP | Y50_071120232.vspd | N/A | 92.3 | N/A | -15.2 | N/A | 123.0 | N/A |
| 21 | ☐ * | SMP | Y50_071120233.vspd | N/A | 92.3 | N/A | -15.2 | N/A | 123.0 | N/A |

**Table 7**: HunterLab chart for seven colored glass filter samples with parameter values.

| | | | | HunterLab - Lightness Index - L | | HunterLab - Color Coordinate - a | | HunterLab - Color Coordinate - b | |
|---|---|---|---|---|---|---|---|---|---|
| AV | | | | 54.8 | | 30.0 | | -9.9 | |
| SD | | | | 36.5 | | 50.0 | | 97.4 | |
| RSD | | | | 0.7 | | 1.7 | | -9.9 | |
| | Legend | Type | File Name | Value | Judgment | Value | Judgment | Value | Judgment |
| 1 | ☑ | SMP | R60_071120231.vspd | 33.1 | N/A | 75.7 | N/A | 23.1 | N/A |
| 2 | ☐ | SMP | R60_071120232.vspd | 33.1 | N/A | 75.7 | N/A | 23.1 | N/A |
| 3 | ☐ | SMP | R60_071120233.vspd | 33.1 | N/A | 75.7 | N/A | 23.1 | N/A |
| 4 | ☑ | SMP | Y46_071120231.vspd | 89.2 | N/A | -21.1 | N/A | 41.6 | N/A |
| 5 | ☐ | SMP | Y46_071120232.vspd | 89.2 | N/A | -21.1 | N/A | 41.6 | N/A |
| 6 | ☐ | SMP | Y46_071120233.vspd | 89.3 | N/A | -21.2 | N/A | 41.6 | N/A |
| 7 | ☑ | SMP | U340_071120231.vspd | 0.4 | N/A | 1.4 | N/A | 0.1 | N/A |
| 8 | ☐ | SMP | U340_071120232.vspd | 0.4 | N/A | 1.4 | N/A | 0.1 | N/A |
| 9 | ☐ | SMP | U340_071120233.vspd | 0.4 | N/A | 1.4 | N/A | 0.1 | N/A |
| 10 | ☑ | SMP | L42_071120231.vspd | 95.2 | N/A | -2.5 | N/A | 4.7 | N/A |
| 11 | ☐ | SMP | L42_071120232.vspd | 95.2 | N/A | -2.5 | N/A | 4.7 | N/A |
| 12 | ☐ | SMP | L42_071120233.vspd | 95.2 | N/A | -2.5 | N/A | 4.7 | N/A |
| 13 | ☑ | SMP | O56_071120231.vspd | 62.9 | N/A | 52.0 | N/A | 44.0 | N/A |
| 14 | ☐ | SMP | O56_071120232.vspd | 62.9 | N/A | 52.1 | N/A | 43.9 | N/A |
| 15 | ☐ | SMP | O56_071120233.vspd | 62.9 | N/A | 52.1 | N/A | 43.9 | N/A |
| 16 | ☑ | SMP | B390_071120231.vspd | 12.6 | N/A | 121.1 | N/A | -243.4 | N/A |
| 17 | ☐ | SMP | B390_071120232.vspd | 12.6 | N/A | 121.1 | N/A | -243.4 | N/A |
| 18 | ☐ | SMP | B390_071120233.vspd | 12.6 | N/A | 121.1 | N/A | -243.4 | N/A |
| 19 | ☑ | SMP | Y50_071120231.vspd | 90.0 | N/A | -16.3 | N/A | 60.8 | N/A |
| 20 | ☐ | SMP | Y50_071120232.vspd | 90.0 | N/A | -16.3 | N/A | 60.8 | N/A |
| 21 | ☐ | SMP | Y50_071120233.vspd | 90.0 | N/A | -16.3 | N/A | 60.8 | N/A |

*Note: Color key applicable to CIELAB and HunterLab chart sample values.*

### ■ UV-1900i, UV-2600i, and UV-2600i with ISR-2600Plus Integrating Sphere Attachment Colored Liquids Data Comparison

Figure 12 is a culmination of the eight liquid samples scanned across three different instrument configurations: UV-1900i spectrophotometer, UV-2600i spectrophotometer, and UV-2600i spectrophotometer with ISR-2600Plus Integrating Sphere attachment.

The table to the right of the graph presents the corresponding colors from the transmission spectral scans, corresponding with the instrument the scan was taken on. The transmission spectral scans presented of each liquid sample show little deviation in scan across all instruments.

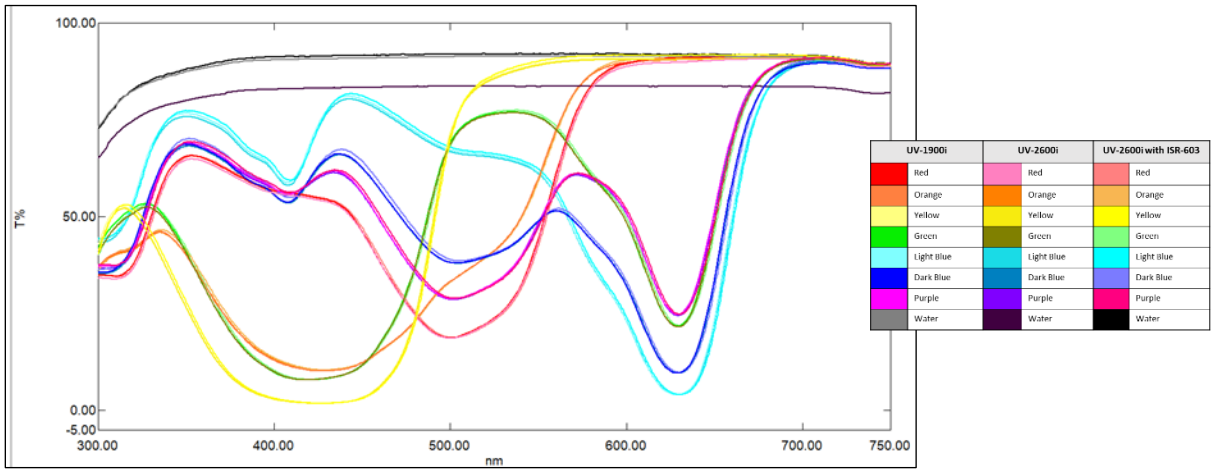


**Figure 12**: Transmission spectral scans of seven colored liquids and one sample of deionized water. Spectral scans taken from two instruments (one additional scan taken with instrument and an attachment) for each sample: UV-1900i, UV-2600i, and UV-2600i with ISR-2600Plus Integrating Sphere Attachment.

The colored liquids from the three scans from different instrument configurations were plotted with the CIELAB L* lightness index (Figure 13) and a*b* color scales (Figure 14). The colors assigned to the colored liquids' transmission scans are as well applicable to the colored points within the L* and a*b* graphs. Figure 13 begins at the value 70 as the sample surpassed this threshold of color depth. As found within the overlapping points within the a*b* graph, the scans taken across all three instrument configurations demonstrate strong agreement.

Tables 8 and 9 pertain to the comparison of the CIELAB parameters extracted from the three instrument configurations utilized during experimentation: UV-1900i spectrophotometer, UV-2600i spectrophotometer, and UV-2600i spectrophotometer with ISR-2600Plus Integrating Sphere Attachment. As determined by the averages and standard deviations found for each respective parameter across the three instruments, there was little to no deviation between the three-color analysis attempts even if the instrument configuration varied. This was conclusive in both the red colored liquid sample and the light blue colored liquid sample. There are always small deviations to be observed to the nature of the testing environment, one must account for the nature of this not being completely isolated from differences. Tables 10 and 11 provide parameters collected from the HunterLab color analysis method including within LabSolutions UV-Vis software, a software which is applicable within the three instrument configurations utilized. As determined by the averages and standard deviations found for each respective parameter across the three instruments, there was little to no deviation between the three-color analysis attempts.

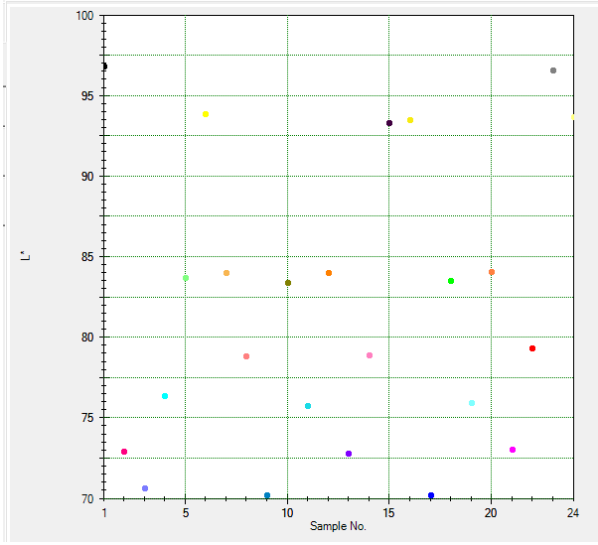


**Figure 13**: L values for the eight liquid samples in CIELAB color space from spectral scans of two instruments and an additional scan of an instrument with attachment.

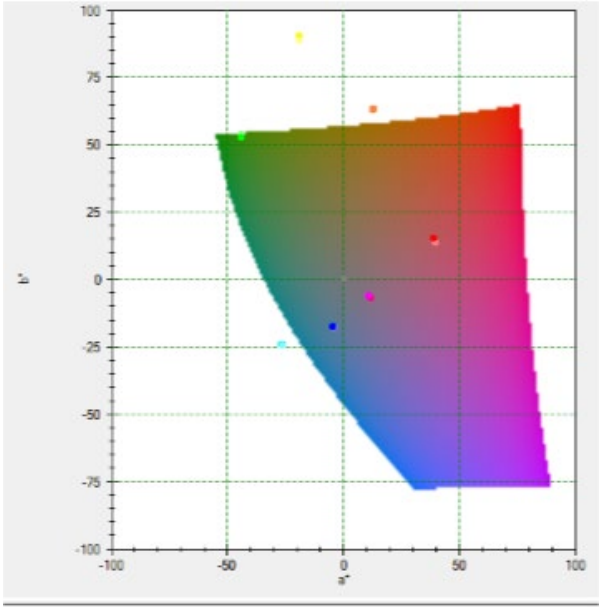


**Figure 14**: Liquid sample values plotted in an ab chart derived from the CIELAB color space inclusive of three sets of data across varying instruments and configurations.

**Table 8**: Comparison chart detailing the average and standard deviation of CIELAB coordinates for light blue liquid sample between the following instruments: UV-1900i, UV-2600i, and UV-2600i with ISR-2600Plus Integrating Sphere Attachment.

| CIELAB Light Blue Color Analysis Across Instrumentation | | | |
|---|---|---|---|
| **INSTRUMENT** | **Lightness L*** | **Coordinate a*** | **Coordinate b*** |
| UV-1900i Spectrophotometer | 75.9 | -26.7 | -24.1 |
| UV-2600i Spectrophotometer | 75.8 | -26.7 | -23.8 |
| UV-2600i with ISR-2600Plus Integrating Sphere Attachment | 76.4 | -26.9 | -23.7 |
| **AVERAGE** | **76.03** | **-26.77** | **-23.87** |
| **STANDARD DEVIATION** | **0.32** | **0.12** | **0.21** |

**Table 9**: Comparison chart detailing the average and standard deviation of CIELAB coordinates for red liquid sample between the following instruments: UV-1900i, UV-2600i, and UV-2600i with ISR-2600Plus Integrating Sphere Attachment.

| CIELAB Red Color Analysis Across Instrumentation | | | |
|---|---|---|---|
| **INSTRUMENT** | **Lightness L*** | **Coordinate a*** | **Coordinate b*** |
| UV-1900i Spectrophotometer | 79.3 | 38.5 | 15.6 |
| UV-2600i Spectrophotometer | 78.9 | 38.6 | 15.3 |
| UV-2600i with ISR-2600Plus Integrating Sphere Attachment | 78.8 | 39.6 | 14.0 |
| **AVERAGE** | **79.00** | **38.90** | **14.97** |
| **STANDARD DEVIATION** | **0.26** | **0.61** | **0.85** |

**Table 10**: Comparison chart detailing the average and standard deviation of HunterLab coordinates for light blue liquid sample between the following instruments: UV-1900i, UV-2600i, and UV-2600i with ISR-2600Plus Integrating Sphere Attachment.

| HunterLab Light Blue Color Analysis Across Instrumentation | | | |
|---|---|---|---|
| **INSTRUMENT** | **Lightness L*** | **Coordinate a*** | **Coordinate b*** |
| UV-1900i Spectrophotometer | 70.4 | -21.3 | -26.6 |
| UV-2600i Spectrophotometer | 70.2 | -21.3 | -26.4 |
| UV-2600i with ISR-2600Plus Integrating Sphere Attachment | 70.2 | -21.5 | -26.3 |
| **AVERAGE** | **70.30** | **-21.40** | **-26.55** |
| **STANDARD DEVIATION** | **0.14** | **0.14** | **0.35** |

**Table 11**: Comparison chart detailing the average and standard deviation of CIELAB coordinates for red liquid sample between the following instruments: UV-1900i, UV-2600i, and UV-2600i with ISR-2600Plus Integrating Sphere Attachment.

| HunterLab Red Color Analysis Across Instrumentation | | | |
|---|---|---|---|
| **INSTRUMENT** | **Lightness L*** | **Coordinate a*** | **Coordinate b*** |
| UV-1900i Spectrophotometer | 75.0 | 37.9 | 13.7 |
| UV-2600i Spectrophotometer | 74.5 | 37.9 | 13.4 |
| UV-2600i with ISR-2600Plus Integrating Sphere Attachment | 74.4 | 39.1 | 12.4 |
| **AVERAGE** | **74.63** | **38.30** | **13.17** |
| **STANDARD DEVIATION** | **0.32** | **0.69** | **0.68** |

## ■ Conclusion

CIELAB and HunterLab color spaces provide a simplified and efficient way in analyzing the coloration of a sample with precision and uniformity across Shimadzu UV-Vis instrumentation as determined by the experimentation completed on colored liquids and colored glass filters.

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