

Evaluation Procedure for Instrumental Color Measurement

1. General Description of Instrumental Color Measurement

1.1 Purpose

1.1.1 This evaluation procedure is a reference document to support the proper measurement of the color stimulus of specimens by instrumental means as required in many of the current AATCC test methods. The document contains three major subsections covering *reflectance measurement, transmittance measurement and related calculations*. In addition, an appendix is supplied which details specific techniques and specimen handling procedures.

1.2 Terminology

1.2.1 **area-of-view**, n.—*of color measuring instrument*, the dimensions of the surface area that a color measuring instrument is capable of covering in a single color measurement.

1.2.2 **color measurement**, n.—a numerical representation of the color stimulus of an object obtained by use of a color measuring instrument. A single measurement may represent an average of multiple readings of a specimen.

1.2.3 **color measuring instrument**, n.—any device, such as a colorimeter or spectrophotometer, used to measure the relative amounts of energy reflected from (or transmitted through) a specimen in the visible region of the energy spectrum (comprising the wavelengths from 360 to 780 nm, and including as a minimum the region from 400 to 700 nm).

1.2.4 **fluorescence**, n.—a phenomenon in which radiant flux of certain wavelengths is absorbed and re-emitted at other visible, usually longer, wavelengths.

1.2.5 **geometry**, n.—*of a color measuring instrument*, one of the following terms (diffuse/8, 8/diffuse, 0/45 or 45/0) which describe the angle or manner in which a color measuring instrument:

(1) illuminates the specimen (diffuse, 8°, 45°).

(2) views the resulting reflected light (8°, diffuse, 45°, 0°).

Diffuse/8 (written as d:8°) and 8/diffuse (written as 8°:d) geometry instruments contain a sphere used to diffuse the light illuminating [or reflected from] the specimen, while 0/45 (written as 0°:45°) and 45/0 (written as 45°:0°) geometry instruments generally use mirrors or fiber optics to direct the illumination [or viewing] at a 45° angle to/from the specimen.

NOTE: Instruments of different geometries may produce different colorimetric results on most textile materials.

1.2.6 **reflectance**, n.—the ratio of the reflected radiant or luminous energy (light) to the incident energy in the given conditions.

1.2.7 **reflectance factor**, n.—the ratio of the light reflected from the specimen to the light reflected from the perfect reflecting diffuser under the same geometric and spectral conditions of measurement.

1.2.8 **specular reflection**, n.—the reflection without diffusion, in accordance with the laws of optical reflection, as in a mirror.

1.2.9 **standardization**, n.—*of color measuring instrument*, the act of measuring one or more standard materials with a color measuring instrument for the purpose of calculating a set of correction factors to be applied to all subsequent measurements.

1.2.10 **transmittance**, n.—the ratio of transmitted light to incident light under specified geometric and spectral conditions.

NOTE: Regular transmittance (of transparent materials) is the ratio of undiffused transmitted light to incident light.

1.2.11 **transmittance factor**, n.—the ratio of the light measured after being transmitted through a transparent or translucent specimen to that measured in the absence of the specimen. In case of liquid samples, the test measurement is usually that of the colored solution in a cuvette and the reference measurement is that of the identical cuvette filled with the solvent used for dissolution (usually distilled water).

1.2.12 **verification standard**, n.—*in color measurement*, any stable material which is used for the purpose of confirming (or verifying) the validity of an instrument standardization. Color measurements, which are made immediately following a standardization, are compared to original measurements of the standard to detect improper standardization.

1.3 Safety Precautions

1.3.1 These safety precautions are for information purposes only. The precautions are ancillary to the testing procedures and are not intended to be all inclusive. It is the user's responsibility to use safe and proper techniques in handling materials in this test procedure. Manufacturers MUST be consulted for specific details such as safety data sheets and other manufacturer's recommendations. All OSHA standards are rules must

also be consulted and followed.

1.3.2 Good laboratory practices should be followed. Wear eye protection in all laboratory areas.

1.3.3 The manufacturer's safety recommendations should be followed when operating laboratory testing equipment.

1.4 General Guidelines

1.4.1 In general, instrumental color measurement procedures are dictated by the type of specimen to be measured and the instrument with which it will be measured. Many types of color measuring instruments are available, differing in such features as area-of-view, illumination method and geometry. The user is cautioned that conflicting results may be obtained by comparing data acquired on instruments of different designs.

1.5 Procedure

1.5.1 Operators who utilize AATCC EP6 as a reference for color measurement should generally conduct such measurements as follows:

1.5.2 Refer to the appropriate section (Reflectance or Transmittance) for specimen to be measured.

1.5.3 Standardize instrument (see 2.4). Maintain a record of the procedure and of the results for any verification standards measured.

1.5.4 Obtain and prepare specimen, noting any special sampling and/or conditioning procedures that may be required (see Appendix A.1.2).

1.5.5 Present specimen to color measuring instrument, again following any special techniques required for the type of material being measured (see Appendix A).

1.5.6 Measure the color of the specimen, obtaining the appropriate spectral reflectance or transmittance factors or colorimetric values.

1.5.7 Perform any appropriate numerical calculations as specified in Section 4 or as is required by the specific test method.

2. Measurement of Color by Reflectance Methods

2.1 Principle

2.1.1 Materials of an opaque or nearly opaque nature (but not translucent) are measured by reflectance methods to obtain a numerical representation of the color of the specimen. Proper equipment setup, standardization of the color measuring instrument, and proper presentation of the test specimens to the instrument are required to achieve consistent

reliable, and meaningful reflectance measurement results. In addition, calculation of the colorimetric values required for evaluating the results must be performed in the prescribed manner.

2.2 Uses and Limitations

2.2.1 This section is restricted to the measurement of the color of opaque and nearly opaque specimens by reflectance spectrophotometers or reflectance colorimeters. The use of special procedures and/or aids to the presentation of specimens is covered in the appendix.

2.3 Apparatus and Materials

2.3.1 Reflectance color measuring instrumentation illuminates a specimen and measures the amount of light which is reflected from the surface of the specimen. Illumination is normally done in a polychromatic manner (white light), however monochromatic mode is acceptable for nonfluorescent specimens. Reflectance color measuring instruments may be broadly divided between two groups: Spectrophotometers and Colorimeters.

2.3.2 Spectrophotometers (typically $d:8^\circ$, using polychromatic illumination) separate and measure the spectrum of light reflected from the specimen, relative to a reference, white at regular intervals (wavelength intervals of 5 nm, 10 nm, and 20 nm are most common). This data may be used to calculate the needed tristimulus values (X,Y,Z) for the selected illuminant/observer combination. Some spectrophotometers (typically $8^\circ:d$) illuminate the sample with monochromatic light, and measure the amount of light reflected from the surface as the sample is illuminated at regular wavelength intervals.

2.3.3 Colorimeters measure the tristimulus values (X,Y,Z) directly through broadband filters which are designed to produce colorimetric values for one illuminant and observer (typically $C/2^\circ$). Measurement of reflectance factors at specific wavelengths is not possible with a colorimeter.

2.3.4 Within these two categories, the instruments are further defined by their geometry. Two types of geometries are prevalent: Sphere (also referred to as $d:8^\circ$ or $8^\circ:d$ and $45/0$ or $0/45$). The first term in each geometry type refers to the method (or angle) by which the sample is illuminated (ex: 45° in a $45/0$ instrument). The second term refers to the angle at which the instrument views the illuminated specimen (ex: 0° in a $45/0$ instrument).

2.3.5 Sphere ($d:8^\circ$) instruments illuminate the specimen indirectly when the specimen is placed against a port opening into a diffusely illuminated sphere, and view the specimen at an angle between 0° and 10° from the perpendicular. This arrangement is designed to capture all light reflected from the specimen. Some sphere instruments with a viewing angle

greater than 0° include a *specular port* which allows for the inclusion or exclusion of the *specular reflectance*. The majority of spectrophotometers in use in the textile industry use $d:8^\circ$, where the actual viewing angle is 8° . Measurements made on other geometries will likely produce different spectral or colorimetric results.

2.3.6 Sphere ($8^\circ:d$) instruments are similar, but the path of illumination and viewing are reversed. This method illuminates the sample at an angle between 0° and 10° , and measures the amount of light reflected from the surface into the sphere.

2.3.7 Instruments with $45^\circ:0^\circ$ or ($0^\circ:45^\circ$) geometry illuminate the specimen at the first angle and view the specimen at the second. These two geometries can be either circumferential (viewing or illuminating at 45° to the specimen in a complete circle) or directional. For most textile samples, either $45^\circ:0^\circ$ or $0^\circ:45^\circ$ yield equivalent results.

2.3.8 All color measuring instruments require a white calibrated standard with which to standardize the instrument. The colorimetric values for this calibration standard are stored in the instrument or the software and require only that a specific standard be used to standardize the instrument. The correct white standard is usually identified with a serial number.

2.4 Standardization

2.4.1 Proper standardization of any color measuring instrument is absolutely necessary to achieve uniform, accurate results. While different types of instruments require varying methods of standardization, there are common principles which must be observed.

2.4.2 In general, an instrument standardization involves measuring a clean white surface of known reflectance factors (referenced to a perfect reflecting diffuser) and calculating (through software built into the instrument or computer program) a series of correction factors which will be applied to all subsequent measurements. Some instruments also require a black tile (or light trap), and possibly a gray tile. Each of these materials must be maintained in its original clean, unscratched condition. Refer to manufacturer's recommendations for cleaning instructions.

2.4.3 The frequency with which this standardization must be performed depends on many factors including the type of instrument, the environmental conditions in which the instrument operates, and the required accuracy of the results. For most applications, an interval no more than 8 hours is typical.

2.4.4 Once the standardization step has been performed, it is important to verify the success of the procedure by measuring some colored materials (**verification standards**) and comparing the resulting

colorimetric values to the original values for these materials. If the measured values do not fall within an acceptable variation from their original values, the standardization is not considered valid. The number of **verification standards** and the acceptability limits depend on user requirements, but are typically 1-3 standards and an acceptance limit of $0.20 \Delta E_{CMC}(2:1) (D_{65}/10^\circ)$ units.

2.5 Sampling

2.5.1 All measurements taken on color measuring instrumentation involve "**sampling**." The area-of-view of the instrument, the number of presentations averaged to produce a single measurement, the difficulty of presenting the specimen to the instrument, and the accuracy with which the sample represents the object of concern (garment, roll, dye lot, etc.) all play important parts in achieving meaningful and reproducible results. Refer to ASTM E1345 (see 7.1) and SAE J1545 (see 7.3) for techniques in establishing sampling procedures.

2.6 Specimen Preparation

2.6.1 The ideal specimen to measure is a rigid, non-textured, inert, opaque specimen of uniform color. Such ideal specimens do not exist in textiles, so it becomes necessary to employ techniques and practices when measuring most textile materials which eliminate or reduce the effect any objectionable characteristics have on the instrumental color measurement. Specific procedures and techniques for handling specimens which meet the following characteristics are presented in Appendix A.

2.6.2 *Fluorescence* of the specimen (from dyes or fluorescent whitening agents [FWAs]) will influence the results depending on the amount of fluorescing material present and the amount and quality of ultraviolet and visible energy in the instrument light source. Results may be particularly hard to duplicate between instruments. Example materials are white or lightly colored materials treated with FWAs (see A1.1).

2.6.3 *Moisture Content* of textile materials can affect their color and appearance characteristics. The amount of conditioning time necessary to achieve a stable moisture state varies with fiber, fabric construction, dyes and surrounding conditions. Examples of materials which are typically affected by moisture content are cotton and rayon fabrics (see A1.2).

2.6.4 *Non-Rigid* specimens tend to protrude (or "pillow") into the viewing port of instruments which contact the specimen at the measurement port. The amount of intrusion may vary depending on number of layers, softness of material and the backing pressure applied to mount the specimen. Variations in the amount of intrusion will result in significant deviations in the resulting color

measurement which are both unpredictable and non-reproducible. Examples of these materials are fiber, yarn, knits and layers of lightweight fabric (see A1.4.3).

2.6.5 *Non-Opaque* specimens allow some light to pass through the material during measurement. Most textile materials, by nature of their structure, fit this category. During measurement, any light which passes through the material to reach the backing plate (or escape from the instrument) will yield false and unpredictable results. Examples of these materials are knits, lightweight materials, and fiber (see A1.3 and A1.3.1).

2.6.6 *Sensitivity* of the specimen to light (photochromism) and/or heat (thermochromism) will result in unpredictable and nonreproducible results, depending on the degree of sensitivity and the amount of time the specimen is exposed to objectionable conditions (see A2.5).

2.6.7 *Size* of the specimen is important in obtaining a representative measurement by the instrument. When the specimen is too small for normal measurement, special techniques may be required to achieve a proper color measurement (see A1.6).

2.6.8 *Surface Texture* of the specimen (including pile lay, twill, gloss, and luster) will affect the results of the color measurement. The color measurement of specimens with such physical characteristics will be affected in different ways depending on the geometry of the instrument. Results between instruments may be non-reproducible. Examples of these specimens are carpet, corduroy and wound yarn (see A1.7).

2.6.9 *Variation in Color* (non-uniformity) within the specimen, as related to the area-of-view of the instrument can cause inaccurate and non-reproducible results. Examples are denim and heathers (see A1.8).

3. Measurement of Color by Transmittance Methods

3.1 Principle

3.1.1 Materials of a transparent nature are measured by transmittance methods to obtain a numerical representation of their color and/or their relative strength (concentration) compared to that of a standard material. The most common application is the measurement of solutions of dyes in clear solvents contained in a glass cuvette or flow cell for the purposes of determining colorant identity, relative strength or color difference.

3.2 Uses and Limitations

3.2.1 This method is generally suitable for the measurement of true solutions which are transparent and void of particulate matter. Although translucent or turbid liquids are sometimes measured by transmittance methods, such methods are

beyond the scope of this evaluation procedure.

3.3 Apparatus, Reagents, and Materials

3.3.1 Transmittance instruments may be dedicated instruments (capable only of measuring transmittance specimens), or may be combined with a sphere for an instrument capable of performing both reflectance and transmittance measurements. Most transmittance instruments are spectrophotometers, although a few are colorimeters.

3.3.2 Transmittance cells or cuvettes (used to hold the solution during measurement) are typically made of glass or quartz and are designed for specific path-lengths (normally 10 mm) suitable for measurement of most textile related solutions (usually requiring some dilution steps to be taken before measurement). Flow-through cells, which allow the solution to be pumped or fed through them, are more efficient for high volume applications and usually result in better reproducibility of results.

3.3.3 When using volumetric procedures, volumetric glassware (pipettes and flasks) is **absolutely required** for proper preparation of specimens, and only glassware which is rated at *class A* should be used.

3.3.4 Balances which are capable of accurate results within 0.1% of the quantity being weighed must be used when weighing specimens used to prepare the solution for measurement.

3.4 Standardization

3.4.1 Before measuring specimen(s), the instrument must be standardized according to the manufacturer's directions. Normally this requires measuring a clear solution of the solvent used for dissolution (usually distilled water) in a clean transmittance cell to produce a 100% reference line. Some instruments require the measurement of a "blocked beam" to set a 0% reference. This procedure produces a set of correction factors which are applied to all subsequent measurements. The use of one or more colored filters as a **verification standard** to check both photometric and wavelength accuracy is recommended.

3.5 Sampling

3.5.1 Sampling procedures for transmission methods depend on the nature of the material and the type of specimen collected. Powder and paste specimens should be taken from enough locations to ensure a reproducible sample within the population being sampled and thoroughly mixed prior to proceeding with weighing and dissolving.

3.6 Specimen Preparation

3.6.1 Specimens must be prepared by prescribed laboratory procedures using analytical balances and volumetric glassware. Solutions should be prepared at a

concentration at which the percent transmittance of the solution in the transmittance cell is between 10% and 50% at the wavelength of maximum absorbance (see 7.4). Each specimen must be in true solution, not in suspension, dispersion or association. When preparing specimens where solubility is unknown, it is necessary to let the prepared solution stand for a period of time to observe any settling of contents. If such settling is observed, a true solution does not exist and other solvent systems are required. All specimens should be allowed to reach room temperature prior to presenting the specimen to the instrument.

4. Calculations

Most calculations of colorimetric nature are performed by the software being used to operate the color measuring instrument. In normal cases of reference to this Evaluation Procedure it will not be necessary for the user to perform these calculations; however they are described in this Evaluation Procedure as a means of reference and standardization for those who may need to perform such calculations.

4.1 Tristimulus Values

4.1.1 The tristimulus values (X, Y, Z) are derived from spectral data and are the basis for all colorimetric calculations. The exact X, Y, Z values derived from a set of spectral data depend on several factors including the wavelength range (and interval) of measurement and the user's choice of illuminant/observer functions used in the calculation. While most calculations of tristimulus values are performed by computer programs, interested persons should refer to ASTM E308 (see 7.1) for definitive procedures (see 7.2).

4.2 1976 CIE L^*, a^*, b^*, C^* , and hue angle (h_{ab})

4.2.1 Calculate the $L^*, a^*, b^*, C^*, h_{ab}$ values from the X, Y, Z tristimulus values for both the reference and specimen as follows:

$$L^* = 116(Y/Y_n)^{1/3} - 16$$

if $Y/Y_n > 0.008856$

but

$$L^* = 903.3 (Y/Y_n)$$

if

$$Y/Y_n \leq 0.008856$$

$$a^* = 500[f(X/X_n) - f(Y/Y_n)]$$

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)]$$

where:

$$f(X/X_n) = (X/X_n)^{1/3}$$

if

$$X/X_n > 0.008856$$

or

$$f(X/X_n) = 7.787(X/X_n) + 16/116$$

if

$$X/X_n \leq 0.008856$$

$$f(Y/Y_n) = (Y/Y_n)^{1/3}$$