2120 COLOR*

2120 A. Introduction

Color in surface and ground waters results primarily from the presence of natural organic matter, particularly aquatic humic matter. Humic matter consists of humic and fulvic acids; both cause a yellow-brown color. Humic acids give a more intense color, and the presence of iron intensifies the color through the formation of soluble ferric humates. Suspended particles, especially colloidal-size particles such as clays, algae, iron and manganese oxides, give waters an appearance of color; they should be removed before measurement. Industrial wastewaters can contain lignins, tannins, dyes, and other organic and inorganic chemicals that cause color. Humic materials and the color caused by these materials are removed from potable water supplies for aesthetic reasons and for health reasons because they are precursors in the formation of disinfection by-products. Color also is removed to make water suitable for industrial applications. Colored industrial wastewaters may require color removal before discharge into watercourses.

1. Definitions

The term "color" is used here to mean true color, that is, the color of water from which turbidity has been removed. Colloidal and larger suspended particles scatter light interfering with the determination of true color measurements in Method B and in the spectrophotometric procedures of Methods C through F. The term "apparent color" includes not only color due to substances in solution, but also that due to suspended matter. Apparent color is determined on the original sample without filtration. In some waters and wastewaters, apparent color is contributed principally by colloidal or suspended material.

2. Selection of Method

Methods B and C are applicable to measurement of color caused primarily by natural organic matter. The measurements apply to all surface and ground waters; wastewaters, both domestic and industrial; and especially potable waters. While all methods (B through F) are suitable for true color measurements, for apparent color measurements use only Method B; in such cases, determine both true color and apparent color. For comparison among laboratories, calibrate Method B with Method C. Methods D through F allow color measurement for any dissolved chemical that gives the appearance of color in the visible-light wavelength range. They are especially applicable to colored waters and wastewaters having color characteristics different from, but not excluding, platinum-cobalt standards.

3. Bibliography

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CHRISTMAN, R.F. & M. GHASSEMI. 1966. Chemical nature of organic color in water. *J. Amer. Water Works Assoc.* 58:723.

THURMAN, E.M. 1985. Organic Geochemistry of Natural Waters. MartinusNijhoff/Dr. W. Junk Publishers, Dordrecht, Netherlands.

SAWYER, C.N., P.O. MCCARTY & G.F. PARKIN. 1994. Chemistry for Environmental Engineering, 4th ed. McGraw-Hill, Inc., New York, N.Y.

* Approved by Standard Methods Committee, 2001. Editorial revisions, 2011. Joint Task Group: 21st Edition—James K. Edzwald (chair), Penny J. Bristol, Brian A. Dempsey, Darren A. Lytle, David J. Pernitsky, Mike J. Sadar, Jeff Throckmorton.

2120 B. Visual Comparison Method

1. General Discussion

a. Principle: Color is determined by visual comparison of the sample with known concentrations of colored solutions. Comparison also may be made with special, properly calibrated glass color disks. The platinum-cobalt method of measuring color is the standard method, the unit of color being that produced by 1 mg platinum/L in the form of the chloroplatinate ion. The ratio of cobalt to platinum given (2120B.4) matches the color of natural waters.

b. Application: The platinum-cobalt method is applicable to natural waters, potable waters, and to wastewaters, both domestic and industrial.

c. Interference: Even a slight turbidity causes the apparent color to be noticeably higher than the true color; therefore remove turbidity by the filtration procedure described in Method C.

The color value of water is extremely pH-dependent and invariably increases as the pH of the water is raised. When reporting a color value, specify the pH at which color is determined. For research purposes, or when color values are to be compared among laboratories, determine the color response of a given water over a wide range of pH values.[1]

d. Field method: Because the platinum-cobalt standard method is not convenient for field use, compare water color with that of glass disks held at the end of metallic tubes containing glass comparator tubes filled with sample and colorless distilled water. Match sample color with the color of the tube of clear water plus the calibrated colored glass when

viewed by looking toward a white surface. Calibrate each disk to correspond with the colors on the platinum-cobalt scale. The glass disks give results in substantial agreement with those obtained by the platinum-cobalt method and their use is recognized as a standard field procedure.

e. Nonstandard laboratory methods: Using glass disks or liquids other than water as standards for laboratory work is permissible only if these have been individually calibrated against platinum-cobalt standards. Waters of highly unusual color, such as those that may occur by mixture with certain industrial wastes, may have hues so far removed from those of the platinum-cobalt standards that comparison by the standard method is difficult or impossible. For such waters, use the methods in Sections 2120C through F. However, results so obtained are not directly comparable to those obtained with platinum-cobalt standards.

2. Apparatus

a. Nessler tubes, matched, 50-mL, tall form.

b. pH meter, for determining sample pH (see Section 4500-H^+).

c. Filter and filter assembly (for true color measurements): Use a 0.45-μm-pore-diam cellulose membrane filter of 22 or 47 mm diam. Glass fiber filters also can be used. Rinse filters before use and monitor filter blanks. Smaller-pore filters of 0.2 or 0.22 μm or even ultrafiltration may be needed to remove colloidal particles for certain samples such as Mn or Fe oxides or other colloids. Use a glass, TFE, or stainless steel assembly to hold the selected filters.

3. Reagents

a. Organic-free water: Type I reagent water (see Section 1080) or equivalent water. Use for all standard preparation and other procedures.

b. Potassium chloroplatinate, K_2PtCl_6, analytical grade.

c. Cobaltous chloride, $CoCl_2 \cdot 6H_2O$, analytical grade.

d. Hydrochloric acid, HCl, analytical grade.

e. Sodium hydroxide, NaOH, analytical grade.

4. Preparation of Standards

Dissolve 1.246 g potassium chloroplatinate and 1.00 g crystallized cobaltous chloride in water with 100 mL conc HCl and dilute to 1000 mL. This stock solution has a color of 500 color units (CU). Platinum-cobalt standards of 500 CU are available commercially, and are suitable for use as the primary standard.

Prepare standards having CU of 5, 10, 15, 20, 25, 30, 40, 50, and 100 by diluting 1.0, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, and 20.0 mL stock color standard with water in 100-mL volumetric flasks. Transfer to nessler tubes for use as standards. Protect standards against evaporation and contamination when not in use. Keep in the dark when not in use, and keep only for 1 month.

5. Procedure

a. Sample collection: Collect samples in acid-washed amber glass bottles or plastic bottles covered to keep out light. Rinse bottles once with sample before filling bottle with sample. Preferably take a sample of at least 100 mL. Analyze sample within 24 h of collection. Keep samples cold until analysis, and warm them up to room temperature before measurement.

b. Sample preparation: Check sample pH. If outside the range of 4 to 10, preferably adjust sample to pH 7 and note the adjustment.

If true color is to be measured, wash membrane filter and filter assembly by passing at least 50 mL water through filter. Filter about 25 mL sample and discard filtrate. Filter a further portion of about 50 mL through the same filter and retain for analysis.

c. Sample measurement: Observe sample color by filling a matched nessler tube to the 50-mL mark with sample and comparing it with standards. Look vertically downward through tubes toward a white or specular surface placed at such an angle that light is reflected upward through the columns of liquid. If turbidity is present and has not been removed, report as "apparent color." If the color exceeds 100 units, dilute sample in known proportions until the color is within the range of the standards.

6. Calculation

a. Calculate color units (CU) by the following equation:

$$\text{Color} = \frac{A \times 50}{B}$$

where:

A = estimated color of a diluted sample and
B = mL sample taken for dilution.

b. The correct units for true color are CU. One CU is equivalent to one Hazen unit and to one Pt-Co unit. If samples are not filtered, report data as Apparent CU. Report color results in whole numbers and record as follows:

CU	Record to Nearest
1–50	1
51–100	5
101–250	10
251–500	20

c. Report sample pH.

7. Quality Control

The QC practices considered to be an integral part of each method are summarized in Tables 2020:I and II.

a. Replicate measurements: Use at least two portions of filtered sample.

b. Duplicate analyses: Analyze every tenth sample in duplicate (i.e., duplicating the entire procedure) to assess method precision.

c. Pre-programmed spectrophotometers: For spectrophotometers with pre-programmed calibration curves, verify calibration curve regularly with the platinum-cobalt standards prepared under 2120C.4, and adjust pre-programmed curves as needed.

8. Reference

1. Black, A.P. & R.F. Christman. 1963. Characteristics of colored surface waters. *J. Amer. Water Works Assoc.* 55:753.

9. Bibliography

CHRISTMAN, R.F. & M. GHASSEMI. 1966. Chemical nature of organic color in water. *J. Amer. Water Works Assoc.* 58:723.

SAWYER, C.N., P.L. MCCARTY & G.F. PARKIN. 1994. Color. *In* Chemistry for Environmental Engineering, 4th ed., Chap. 14. McGraw Hill, New York, N.Y.

2120 C. Spectrophotometric—Single-Wavelength Method (PROPOSED)

1. General Discussion

a. Principle: Color is determined spectrophotometrically at a wavelength between 450 and 465 nm, with platinum-cobalt solutions as standards.[1–3] True color of real samples and platinum-cobalt standards follows Beer's Law.

b. Application: The spectrophotometric platinum-cobalt method is applicable to natural waters, potable waters, and wastewaters, both domestic and industrial.

c. Interference: The primary interference is from the presence of colloidal and suspended particles that absorb or scatter light at the wavelength of the spectrophotometric method. While in Section 2120B color measurements can be made without removal of particulate matter as long as they are reported as "Apparent CU", Method C requires removal of particulate matter before color determination.

Light absorbance of organic matter depends on pH; however, the variation in absorbance is small for the pH range of most waters. Because color measurements are made for aesthetic reasons, preferably do not adjust sample pH as long as it is between 4 and 10. If pH is adjusted, adjust to 7, and note. Further, pH can affect the solubility of substances, which can then interfere with the color measurement if particulate matter is formed.

d. Method detection level: The minimum detectable color depends on the cell path length. Choose a cell size that provides an absorbance within the range that results in good accuracy and linearity of response. This range depends on the quality of the spectrophotometer. If a 50-mm cell is used in the wavelength range of 450 to 465 nm, then an absorbance of 0.005 yields a minimum detectable color of 1 CU. With newer spectrophotometers, a method detection level of 2 CU can be obtained with a path length of 25 mm. Dilute samples with high color to fall within the range of the standard curve. Absorbance readings should fall within the range of 0.005 to 0.8.

2. Apparatus

a. Spectrophotometer: Choose a wavelength between 450 and 465 nm. Use matched glass cells providing a light path of at least 25 mm. Cells with path lengths of 40, 50, or 100 mm may be used. Beer's Law allows flexibility in selecting the cell path length.

b. Filter and filter assembly: See 2120B.2*c*.

3. Reagents

See 2120B.3.

4. Preparation of Standards

Prepare stock color solution of 500 CU according to 2120B.4.

Prepare standards having CU of 5, 10, 15, 20, 30, 40, 50, and 100 by diluting 1.0, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, and 20.0 mL stock color standard with water in 100-mL volumetric flasks. Protect standards against evaporation and contamination when not in use. Keep in the dark when not in use, and keep for only 1 month.

5. Spectrophotometric Standard Curve

Let spectrophotometer warm up according to manufacturer's instructions. Choose a wavelength between 450 and 465 nm to develop the standard curve; a good choice is 456 nm. The absorbance of Pt-Co has a broad maximum absorbance within this wavelength range. Use matched spectrophotometer cells. Fill one cell with water to zero the instrument. Read absorbance for each color standard, and prepare a standard curve of CU versus absorbance.

Pre-programmed color curves are available with some spectrophotometers. The curves can be verified by use of the standards prepared in 2120C.4.

6. Procedure

a. Sample collection: See 2120B.5*a*.

b. Sample preparation: See 2120B.5*b*. Always filter sample.

c. Spectrophotometric measurement: Let spectrophotometer warm up according to manufacturer's instructions. Set wavelength at same setting used to develop the standard curve; be sure that the cell path length is the same as that used for the standard curve. Fill one spectrophotometer cell with water and zero the instrument. Rinse the other cell with sample and then refill. Place cell in spectrophotometer and read absorbance. Repeat for remaining samples. Determine sample color using absorbance readings and standard curve relating absorbance and CU. For spectrophotometers with pre-programmed calibration curves for color, zero instrument and take sample measurements according to manufacturer's instructions.

7. Quality Control

See 2120B.7.

8. References

1. CROWTHER, J. & J. EVANS. 1981. Estimating color in Hazen units by spectrophotometry. *J. Amer. Water Works Assoc.* 73:265.
2. BENNETT, L. & M. DRIKAS. 1993. The evaluation of color in natural waters. *Water Res.* 27:1209.
3. HONGVE, D. & G. ÅKESSON. 1996. Spectrophotometric determination of water colour in Hazen units. *Water Res.* 30:2771.

2120 D. Spectrophotometric—Multi-Wavelength Method

1. General Discussion

a. Principle: The color of a filtered sample is expressed in terms that describe the sensation realized when viewing the sample. The hue (red, green, yellow, etc.) is designated by the term "dominant wavelength," the degree of brightness by "luminance," and the saturation (pale, pastel, etc.) by "purity." These values are best determined from the light transmission characteristics of the filtered sample by means of a spectrophotometer.

b. Application: This method is applicable to potable and surface waters and to wastewaters, both domestic and industrial.

TABLE 2120:I. SELECTED ORDINATES FOR SPECTROPHOTOMETRIC COLOR DETERMINATIONS*

	X	*Y*	*Z*
Ordinate No.		Wavelength *nm*	
1	424.4	465.9	414.1
2	435.5*	489.5*	422.2*
3	443.9	500.4	426.3
4	452.1	508.7	429.4
5*	461.2*	515.2*	432.0*
6	474.0	520.6	434.3
7	531.2	525.4	436.5
8*	544.3*	529.8*	438.6*
9	552.4	533.9	440.6
10	558.7	537.7	442.5
11*	564.1*	541.4*	444.41
12	568.9	544.9	446.3
13	573.2	548.4	448.2
14*	577.4*	551.8*	450.1
15	581.3	555.1	452.1
16	585.0	558.5	454.0
17*	588.7*	561.9*	455.9*
18	592.4	565.3	457.9
19	596.0	568.9	459.9
20*	599.6*	572.5*	462.0*
21	603.3	576.4	464.1
22	607.0	580.4	466.3
23*	610.9*	584.8*	468.7*
24	615.0	589.6	471.4
25	619.4	594.8	474.3
26*	624.2*	600.8*	477.7*
27	629.8	607.7	481.8
28	636.6	616.1	487.2
29*	645.9*	627.3*	495.2*
30	663.0	647.4	511.2
Factors when 30 Ordinates Used			
	0.032 69	0.033 33	0.039 38
Factors when 10 Ordinates Used			
	0.098 06	0.100 00	0.118 14

* Insert in each column the transmittance value (%) corresponding to the wavelength shown. Where limited accuracy is sufficient, use only the ordinates marked with an asterisk.

c. Interference: The primary interference is from the presence of colloidal and suspended particles that absorb or scatter light.

d. Quality control (QC): The QC practices considered to be an integral part of each method are summarized in Tables 2020:I and II.

2. Apparatus

a. Spectrophotometer, having absorption cells of a minimum of 10 mm, a narrow (10-nm or less) spectral band, and an effective operating range from 400 to 700 nm.

b. Filter: See 2120B.2*c*.

3. Procedure

a. Sample preparation: Bring two 50-mL samples to room temperature. Use one sample at the original pH; adjust pH of the other to 7.0 by using sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH) of such concentrations that the resulting volume change does not exceed 3%. A standard pH is necessary because of the variation of color with pH. Remove particulate matter from samples before color determination (see 2120B.5*b*).

b. Determination of light transmission characteristics: Thoroughly clean 1-cm absorption cells. Rinse twice with filtered sample, and fill cell with filtered sample.

Determine transmittance values (in percent) at each visible wavelength value presented in Table 2120:I, using the 10 ordinates marked with an asterisk for fairly accurate work and all 30 ordinates for increased accuracy. Set instrument to read 100% transmittance on the distilled water blank and make all determinations with a narrow spectral band.

4. Calculation

a. Tabulate transmittance values corresponding to wavelengths shown in Columns *X*, *Y*, and *Z* in Table 2120:I. Total each transmittance column and multiply totals by the appropriate factors (for 10 or 30 ordinates) shown at the bottom of the table, to obtain tristimulus values *X*, *Y*, and *Z*. The tristimulus value *Y* is percent luminance.

b. Calculate the trichromatic coefficients *x* and *y* from the tristimulus values *X*, *Y*, and *Z* by the following equations:

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

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

Locate point *(x, y)* on one of the chromaticity diagrams in Figure 2120:1 and determine the dominant wavelength (in nanometers) and the purity (in percent) directly from the diagram.

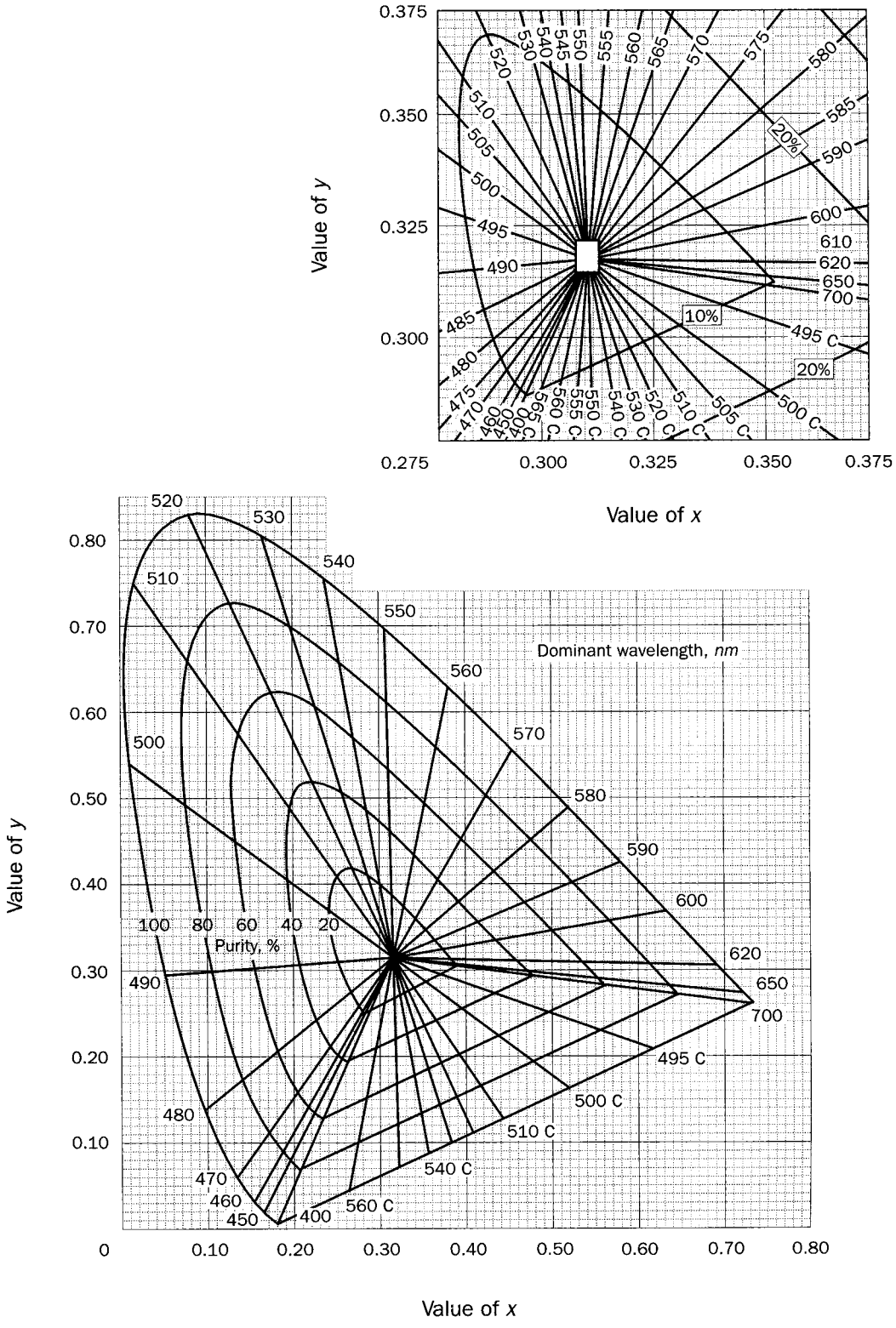


Figure 2120:1. Chromaticity diagrams.

TABLE 2120:II. COLOR HUES FOR DOMINANT WAVELENGTH RANGES

Wavelength Range *nm*	Hue
400–465	Violet
465–482	Blue
482–497	Blue-green
497–530	Green
530–575	Greenish yellow
575–580	Yellow
580–587	Yellowish orange
587–598	Orange
598–620	Orange-red
620–700	Red
400–530c*	Blue-purple
530c–700*	Red-purple

* See Figure 2120:1 for significance of "c".

Determine hue from the dominant-wavelength value, according to the ranges in Table 2120:II.

5. Expression of Results

Express color characteristics (at pH 7.0 and at the original pH) in terms of *dominant wavelength* (nanometers, to the nearest unit), *hue* (e.g., blue, blue-green, etc.), *luminance* (percent, to the nearest tenth), and *purity* (percent, to the nearest unit). Report type of instrument (i.e., spectrophotometer), number of selected ordinates (10 or 30), and the spectral band width (nanometers) used.

6. Bibliography

HARDY, A.C. 1936. Handbook of Colorimetry. Technology Press, Boston, Mass.

2120 E. Tristimulus Spectrophotometric Method

1. General Discussion

a. Principle: Tristimulus values are a set of three numbers obtained from a spectrophotometer or colorimeter that, when combined in various ways, describe how the human eye perceives a given color. Calculations using the three tristimulus values typically are used to define the color of a specimen for color matching specifications or for routine control purposes.

The percentage of tristimulus light transmitted by the solution is determined and the transmittance values are then converted to trichromatic coefficients and color characteristic values.

b. Application: This method is applicable to potable and surface waters and to domestic and industrial wastewaters.

c. Interference: See 2120C.1*c*.

2. Apparatus

a. Spectrophotometer with narrow spectral band width (10 nm or less), an effective operating range of 380 to 780 nm, and a tungsten lamp light source. Instrument must be able to obtain transmittance values at a multitude of wavelengths and calculate tristimulus values *X*, *Y*, and *Z*[1] to produce a final color result.* Calibrate calculation algorithm software against platinum-cobalt standard reference.

b. Spectrophotometer cells, 1 cm.

c. Filtering apparatus and filter: See 2120 B.2*c*.

* Hach DR/4000 Spectrophotometer, Program No. 1666, or equivalent.

3. Procedure

a. Sample collection: See 2120B.5*a*.

b. Sample preparation: Filter turbid samples according to 2120B.5*b*.

c. Spectrophotometric measurement: Let spectrophotometer warm up in accordance with manufacturer's directions. Set instrument to pre-programmed calibration curve for tristimulus color. Zero instrument and perform measurements according to manufacturer's method directions. Express results as prescribed in 2120D.5.

Alternatively, obtain tristimulus values for color by a published computation method.[1]

4. Quality Control

See 2120B.7.

5. Reference

1. AMERICAN SOCIETY FOR TESTING AND MATERIALS. 1995. Standard practice for computing the colors of objects by using the CIE system. E308-95, ASTM Standards on Color and Appearance Measurement, 5th ed. American Soc. Testing & Materials, West Conshohocken, Pa.

6. Bibliography

HACH COMPANY. 1999. Hach DR/4000 Spectrophotometer Procedures Manual, 9th ed. Hach Co., Loveland, Colo.

2120 F. ADMI Weighted-Ordinate Spectrophotometric Method

1. General Discussion

a. Principle: Three properties describe color: hue, chroma, and value. Hue is the "color" (blue or red, for example); chroma is the intensity, brightness, or dullness of color; and value is the amount, or lightness or darkness, of color. In accordance with Adams-Nickerson chromatic value formula,[1] this method calculates single-number color difference values, i.e., uniform color differences. For example, if two colors, A and B, are judged visually to differ from colorless to the same degree, their ADMI color values will be the same.[2] Values are independent of chroma and hue. Spectrophotometrically, transmittance is measured at multiple wavelengths and converted to a set of abstract numbers, which then are converted to a single number that indicates color value. This number is expressed on a scale used by the American Dye Manufacturers Institute (ADMI).[2]

b. Applications: This method is applicable to colored waters and wastewaters having color characteristics significantly different from, but not excluding, platinum-cobalt standards.

c. Interferences: See 2120C.1*c*.

2. Apparatus

a. Spectrophotometer, with narrow spectral band width (10 nm or less), an effective operating range of 400 nm to 700 nm and a tungsten lamp light source. Instrument must be able to obtain transmittance values at a multitude of wavelengths and calculate tristimulus (ordinate) values, preferably by using the weighted-ordinate method.* Calibrate calculation algorithm software against platinum-cobalt standard reference.

* Hach DR/4000 Spectrophotometer, Program No. 1660, or equivalent.

b. Spectrophotometer cells, 1 cm.

c. Filtering apparatus and filter: See 2120B.2*c*.

3. Procedure

a. Sample collection: See 2120B.5*a*.

b. Sample preparation: Prepare two 100-mL sample portions, one at the original pH and one at pH 7.0. Filter turbid samples according to 2120B.5*b*.

c. Spectrophotometric measurement: Let spectrophotometer warm up in accordance with the manufacturer's instruction. Set instrument to pre-programmed calibration curve for ADMI Weighted Ordinate Method. Zero instrument and take measurements of original and pH-adjusted samples according to manufacturer's directions. Express results as prescribed in 2120D.5 for both original and pH-adjusted samples.

Alternatively, obtain ADMI weighted-ordinate values for color by a published computation method.[2]

4. Quality Control

See 2120B.7.

5. References

1. McLaren, K. 1970. The Adams-Nickerson colour-difference formula. *J. Soc. Dyers Colorists* 86:354.
2. Allen, W., W.B. Prescott, R.E. Derby, C.E. Garland, J.M. Peret & M. Saltzman. 1973. Determination of color of water and wastewater by means of ADMI color values. *Proc. 28th Ind. Waste Conf.*, Purdue Univ., Eng. Ext. Ser. No. 142:661.

6. Bibliography

Hach Company. 1999. Hach DR/4000 Spectrophotometer Procedures Manual, 9th ed. Hach Co., Loveland, Colo.