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SUBJECT
CATEGORY _____ Optical Properties _____

RELATED
METHODS _____ See "Additional Information" _____

CAUTION:

This Test Method may include safety precautions which are believed to be appropriate at the time of publication of the method. The intent of these is to alert the user of the method to safety issues related to such use. The user is responsible for determining that the safety precautions are complete and are appropriate to their use of the method, and for ensuring that suitable safety practices have not changed since publication of the method. This method may require the use, disposal, or both, of chemicals which may present serious health hazards to humans. Procedures for the handling of such substances are set forth on Safety Data Sheets which must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this method, the user must determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, must follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

Diffuse brightness of paper, paperboard and pulp (d/0) (ultraviolet level D65)

Five-year review of Official Method T 579 om-18

1. Scope

1.1 This method determines the brightness of white, near-white, and naturally colored pulp, paper, and paperboard. Brightness is a commonly used industry term for the numerical value of the reflectance factor of a sample with respect to blue light of specific spectral and geometric characteristics. This method requires an instrument employing diffuse illumination and 0° viewing geometry

1.2 This method is applicable to all naturally-colored pulps, and papers and board made therefrom. The measurement is not suitable for paper or paperboard containing added coloring matter (such as yellow or green dyestuff) which appreciably absorbs light in that part of the spectrum extending from about 400 to 500 nm. This

brightness method is not applicable to colored papers.

1.3 Pulps to be tested are made into handsheets prepared according to TAPPI T 218 “Forming Handsheets for Reflectance Tests of Pulp (Büchner Funnel Procedure)” or T 272 “Forming Handsheets for Reflectance Tests of Pulp (Sheet Machine Procedure).” This method may also be used to measure the brightness of machine-dried sheets.

NOTE 1: The brightness of a handsheet will usually be 0.5 to 1.0 units higher than that of a machine-dried sheet made from the same pulp.

1.4 This method utilizes an integrating sphere to provide diffuse illumination and perpendicular (0°) observation geometry (1) designated in optical terminology as $d/0$. With this geometry, specimen surface structure and azimuthal orientation have a negligible effect on brightness.

1.5 The instrument has a relatively large specimen aperture for the purpose of averaging small area variations in reflectance, making it possible to obtain a reliable average value with only a few individual measurements.

1.6 This method is not intended for use with colored materials.

2. Summary

Diffuse reflectance is measured in the wavelength range of 400-520 nm with an effective wavelength of 457 nm by using a suitable filter set or an equivalent device for modifying the spectral response and an instrument having diffuse illumination and perpendicular observation geometry. The measurements are made in terms of absolute reflectance factors.

3. Significance

3.1 Blue-light reflectance measurements were originally designed to provide an indication of the amount of bleaching that has taken place in the manufacture of pulp. The higher the blue-light reflectance, generally the whiter the products will appear. In recent years, the method has been extended to white and near-white paper and paperboard, and is suitable for that purpose. The method provides a simple, single-number index useful for comparing similar white materials; however, colored materials are better identified by using a standardized three-dimensional color space [see TAPPI T 524 “Color of Paper and Paperboard (45/0 Geometry)” and T 527 “Color of Paper and Paperboard (d/0 Geometry)”].

3.2 Because the instrument geometry of this method is different from that of TAPPI T 452 “Brightness of Pulp, Paper and Paperboard (Directional Reflectance at 457 nm),” there is no simple relationship between the two brightness scales (2).

3.3 Specularly reflected light (gloss) is excluded from the measurement of diffuse brightness by the use of a gloss trap (specular reflectance absorber) as required in 5.1.1.3.

NOTE 2: Material containing fluorescent brightening agents will exhibit higher reflectance values to a degree which is dependent upon the ultraviolet (UV) content of the radiation incident on the specimen. Control of such UV content is essential to maintain continuity of measurement among optically brightened pulps. This method specifies that the level of UV excitation correspond to the equivalent level of CIE Illuminant D65.

NOTE 3: No known material is both perfectly reflecting and perfectly diffusing, but standards may be calibrated in terms of absolute reflectance factors (3, 4). Standards with calibrations based on this reference can be obtained from Calibration Laboratories¹, as defined in Section 5.3 of TAPPI T 1211 "Acceptance Procedures for Calibration Laboratories."

4. Definitions

4.1 *Diffuse reflectance factor*, the ratio of the radiance factor of a specimen to that of a perfectly reflecting diffuser, each being irradiated and viewed identically (4).

4.2 *Absolute brightness*, the diffuse reflectance factor for blue light in terms of a perfectly reflecting, perfectly diffusing specimen as determined on an instrument as described in section 5.

4.3 *Perfect reflecting diffuser*, the ideal reflecting surface that neither absorbs nor transmits light, but reflects diffusely, with the radiance of the reflecting surface being the same for all reflecting angles, regardless of the angular distribution of the incident light.

5. Apparatus

5.1 *Reflectometer*¹, an instrument designed for the measurement of diffuse reflectance which employs the following geometric, photometric, and spectral characteristics:

5.1.1 *Geometric characteristics (same as TAPPI T 525 "Diffuse brightness of paper, paperboard and pulp (d/0) -- ultraviolet level C")*

5.1.1.1 One or more light sources direct light into an integrating sphere which provides diffuse illumination of the specimen. The integrating sphere has an inside diameter of 150 mm ± 3 mm and is coated with a matte white paint with absolute reflectance of 96 or greater from the light source. The sphere shall be equipped with screens to eliminate direct illumination of the specimen.

5.1.1.2 The sum total of the areas of the apertures and other non-reflecting areas in the sphere does not exceed 13% of the area of the inner surface of the sphere.

5.1.1.3 The receptor aperture is surrounded by a gloss trap (black circular area) of external diameter subtending a half-angle of 15.8 ± 0.8° at the center of the specimen aperture.

5.1.1.4 No light reflected from the rim of the specimen aperture shall reach the receptor.

5.1.1.5 The measured test area on the specimen is circular with a diameter of 28 mm ± 3 ± 2 mm.

5.1.1.6 The specimen aperture diameter shall be 34 mm ± 0.5 mm and the edge thickness shall not exceed 1.5 mm.

¹ Names of suppliers of testing equipment and materials for this method may be found on the Test Equipment Suppliers list in the set of TAPPI Test Methods, or may be available from the TAPPI Quality and Standards Department.

5.1.1.7 The specimen is viewed perpendicularly (0°). Only reflected rays within a solid cone, whose vertex is in the center of the specimen aperture and of half-angle not greater than 4° , shall fall on the receptor.

5.1.1.8 Stray light from all sources shall not exceed 0.5%.

5.1.2 *Photometric characteristics.* The accuracy of the photometer, whether mechanical or electronic, is such that the departure from photometric linearity after calibration does not exceed 0.3% reflectance factor.

5.1.3 *Spectral characteristics.* The spectral distribution of the brightness function is shown in Table 1. This function has an effective wavelength of 457.0 nanometers \pm 0.5 nanometers with a bandpass at half peak height of 44 nanometers. In a filter-based reflectometer this spectral distribution is the product of the following variables:

- a) the relative spectral distribution of the reflectance of the integrating sphere,
- b) the spectral transmittance of the glass optics,
- c) the spectral transmittance of the filters, and
- d) the spectral response of the photoelectric cell(s).

For a spectrophotometer or abridged spectrophotometer the spectral reflectance data obtained between 400 and 510 nanometers is to be integrated using the weighting function indicated in Table 1.

Table 1. The relative spectral distribution function $F(\lambda)$ of a reflectometer equipment for measuring diffuse brightness

Wavelength, nm	$F(\lambda)$, arbitrary units	5 nm weights		Wavelength, nm	$F(\lambda)$, arbitrary units	5 nm weights
400	1.0	0.107		460	100.0	10.668
405	2.9	0.309		465	99.3	10.593
410	6.7	0.715		470	88.7	9.462
415	12.1	1.291		475	72.5	7.734
420	18.2	1.942		480	53.1	5.665
425	25.8	2.752		485	34.0	3.627
430	34.5	3.680		490	20.3	2.166
435	44.9	4.790		495	11.1	1.184
440	57.6	6.145		500	5.6	0.597
445	70.0	7.467		505	2.2	0.235
450	82.5	8.801		510	0.3	0.032
455	94.1	10.038		Sum	937.4	100.000
Furthermore, the area under the curve of $F(\lambda)$ for wavelengths exceeding 700 nm should be small enough for the measurement not to be affected by any infrared fluorescent radiation generated in the sample.						

5.1.4 *Spectral radiance control*: The instrument shall have some means of controlling the Ultra Violet spectral radiance of the light entering the sphere and thus irradiating the sample (see appendix A.1).

5.2 The following ancillary items must be available:

5.2.1 *Reference standards*, a non-fluorescent, white standard with a brightness calibration value with traceability to the perfect reflecting diffuser. If the instrument is to be calibrated for the measurement of fluorescent materials, a white fluorescent reference standard with traceability for CIE D65 standard illuminant conditions must be used.

5.2.2 *Instrument standard(s)*, one or more opal glass or ceramic standards.

5.2.3 *Black cavity*, for calibration of the zero point of the photometric scale. This black body shall have a reflectance factor which does not differ from its nominal value by more than 0.2% at all wavelengths. The nominal value is usually zero.

5.2.4 *Lens tissue*, non-fluorescent, non-abrasive lens paper or tissue.

6. Reagents

Cleaning solution, distilled water and detergent free from fluorescing or abrasive ingredients.

7. Calibration and standardization

7.1 *Calibration standards*

7.1.1 *Reference standard*, a non-fluorescent white standard with certified traceability to absolute reflectance. These must be obtained from Calibration Laboratories (see Note 3).

7.1.2 *Fluorescent reflectance standard*, a fluorescent reference standard with certified UV excitation traceability based upon CIE Illuminant D65, to calibrate instruments for the measurement of fluorescent materials (see Note 3).

7.1.3 *Instrument standard(s)*, one or more opal glass or ceramic instrument standards are required.

NOTE 4: A reference standard is used to transfer calibration from a Calibration Laboratory to a given instrument. Reference standards should never be cleaned as cleaning may change their value. Instrument standards should be used frequently to check the stability of a given instrument's calibration. An instrument standard evaluated on one instrument should never be used to calibrate another instrument. Instrument standards may be cleanable (consult the manufacturer's instruction manual).

7.2 *Calibration of instrument standard(s)*

7.2.1 Procedure for instruments which are not equipped with an internal instrument standard.

7.2.1.1 Turn instrument on and allow it to come to operating equilibrium. Consult instruction manual for manufacturer's recommended warm-up time.

7.2.1.2 Clean one or more opal glass or ceramic instrument standards (per manufacturer's instructions) if they have not been cleaned recently.

7.2.1.3 Select the brightness measurement (457 nm) position.

7.2.1.4 Adjust the instrument to read the black cavity value with the black cavity in the specimen position.

7.2.1.5 Place the reference standard in the specimen position. Adjust the instrument to read the assigned value.

7.2.1.6 Place an instrument standard in the specimen position and read and record the calibration value for this standard. Repeat this procedure to obtain values for additional standards if desired.

7.2.1.7 To calibrate for the measurement of fluorescent materials, use the fluorescent and non-fluorescent reference standards per the manufacturers recommended procedure to achieve calibration for both standards.

7.2.2 *Procedure for instruments equipped with an internal instrument standard.*

7.2.2.1 Turn instrument on and allow it to come to operating equilibrium. Consult the instruction manual for manufacturer's recommended warm-up time.

7.2.2.2 Use the manufacturer's recommended instruction to calibrate the instrument to the black cavity.

7.2.2.3 Place the reference standard in the specimen position. Use the manufacturer's recommended procedure to establish calibration based on this standard and to transfer calibration to the instrument's internal instrument standard.

7.2.2.4 To calibrate for the measurement of fluorescent materials, the fluorescent and non-fluorescent reference standards must be used interactively per the manufacturer's recommended procedure to achieve calibration for both standards.

NOTE 5: The reflectance of opal-glass or ceramic standards is relatively stable; however, they must be calibrated at regular intervals on the specific instrument with which they will be used by making use of reference standards and the procedures described in Section 7.

8. Use of instrument standards

If instrument standards have been evaluated in accordance with the instructions in Section 7.2, one of the instrument standards may be used on a regular basis to check and, if necessary, reestablish calibration. If a second instrument standard was evaluated, it may be stored away to periodically check the stability of the first instrument standard. For instruments which are equipped with an integral standard, an external instrument standard may be maintained, if desired, but doing so is not a requirement of this method.

NOTE 6: Reference standards should be acquired on a regular basis (not less than 4 times per year) to assure the stability of calibration.

9. Test specimens

9.1 *Sample preparation -- paper and paperboard*

9.1.1 Sample the material to be tested in accordance with TAPPI T 400 "Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product." From each test unit cut a representative portion of the paper or board into seven or more tabs at least 30 mm longer and 20 mm wider than the specimen aperture [nominally 51 mm (2 in.) by 38 mm (1½ in.) with the short dimension parallel to the machine direction]. Avoiding any water

mark, dirt, or blemish, assemble the tabs in a pad with the top sides up. Use the top tab as a cover only; mark it near one corner to identify the sample and the top side. More than seven specimen tabs may be required for thin or transparent samples to ensure that the pad is completely opaque. (Only a few tabs will be required for paperboard.) The number of tabs in the pad should be such that the measured reflectance is not changed by doubling its thickness.

9.1.2 Do not touch test areas of the specimen with the fingers. Protect the test areas from contamination, excessive heat, or intense light.

9.2 *Sample preparation -- pulp.* Prepare sheets from pulp samples in accordance with TAPPI T 218 "Forming Handsheets for Reflectance Tests of Pulp (Büchner Funnel Procedure)" or TAPPI T 272 "Forming Handsheets for Reflectance Testing of Pulp (Sheet Machine Procedure)." Remove the filter paper cover from the dried handsheets. Cut the handsheets into tabs large enough to cover the measurement aperture of the instrument. Use a pad of tabs of sufficient number that doubling it will not change the brightness reading. Six tabs may be sufficient. Sheet pulp may be tested as received if desired, but results may not agree with handsheets made from the pulp because of differences in surface characteristics. See Note 1.

10. Procedure

10.1 Select the brightness (457 nm) measurement position and calibrate the instrument.

NOTE 7: When testing handsheets of pulp, a single 150 mm diameter handsheet can be conveniently cut into six pie-shaped tabs using a paper cutter with a special template. The six tabs can be stored in the folded filter paper cover until ready to read the brightness.

10.2 Remove the top cover tab as prepared in 9.1 or 9.2 and place it on the bottom of the stack of tabs. Place the tabs, with the smooth side up, on a clean specimen holder.

10.3 Read the brightness of the first tab and record to the nearest 0.1%. Transfer the top tab to the bottom of the stack and make a brightness reading on the second tab. Repeat this procedure until five tabs have been read.

NOTE 8: Handle the specimens by the edges to avoid contamination. With many instruments, the brightness measurement must be made with reasonable speed because the reflectance may change as the moisture content of the surface of the specimen changes when heated by the instrument lamps. Color reversion is also possible with unstable material, so do not leave the stack of tabs against the specimen aperture while recording results.

NOTE 9: Temperature and moisture content of the specimen has a slight effect on brightness. The best reproducibility is obtained by conditioning and making the tests in an atmosphere of less than 60% relative humidity and a temperature of $23^{\circ}\text{C} \pm 4^{\circ}\text{C}$.

11. Report

11.1 Report a precise identification of the sample.

11.2 Reference TAPPI Official Method T 525 "Diffuse brightness of paper, paperboard and pulp (d/0) -- ultraviolet level C."

11.3 Report the ultraviolet calibration condition of the instrument during the time of this measurement.

- 11.4 Report the brightness of the sample as the average of five tab readings to the nearest 0.1%.
- 11.5 Indicate whether data were obtained from measurement of a machine sheet or handsheet.

12. Precision

12.1 Pulp

12.1.1 For the maximum expected difference between two test results, each of which is the average of five test determinations:

12.1.1 For handsheets made with Büchner Funnel Procedure (T 218)

S_r	r	S_n	R
0.053	0.146	0.412	1.14

12.1.2 For handsheets made with Sheet Mold Procedure (T 272)

S_r	r	S_n	R
0.049	0.136	0.704	1.95

12.1.3 In 12.1.1 and 12.1.2, S_r is the within lab standard deviation, r is the within lab repeatability, S_n is the between lab standard deviation, and R is the between lab reproducibility; in accordance with the definitions of these terms in TAPPI T 1200 “Interlaboratory Evaluation of Test Methods to Determine TAPPI Repeatability and Reproducibility.”

12.1.2 Data on the precision of this method when used for pulp have been obtained from an interlaboratory study conducted during February 2000 in accord with T 1200 sp-91. The study included 3 pulp samples ranging in brightness from 83 to 91. Nine laboratories participated in the study using the Büchner Funnel procedure, and eleven using the Sheet Mold procedure.

12.1.3 The user of these precision data is advised that it is based on actual mill testing, laboratory testing, or both. There is no knowledge of the exact degree to which personnel skills or equipment were optimized during its generation. The precision quoted provides an estimate of typical variation in test results which may be encountered when this method is routinely used.

12.2 Paper. The following are expected differences at 95% probability between two test results, each of which is the average of five test determinations:

12.2.1 Non-Fluorescent Samples:

s_r	r	s_n	R
0.083	0.23	0.404	1.12

12.2.2 Fluorescent Samples:

s_r	r	s_n	R
0.141	0.39	1.134	3.14

12.2.3 In 12.2.1 and 12.2.2, s_r is the within lab standard deviation, r is the within lab repeatability, s_n is the between lab standard deviation, and R is the between lab reproducibility; in accordance with the definitions of these terms in TAPPI T 1200 “Interlaboratory Evaluation of Test Methods to Determine TAPPI Repeatability and Reproducibility.”

12.2.4 Data on the precision of this method have been obtained from the published reports of the CTS-TAPPI Interlaboratory Program from 1996 through 1999. The data included four non-fluorescent samples, each of which had fluorescent contribution to brightness of 0.3% or less; and three fluorescent samples having fluorescent contributions to brightness ranging from 3 to 8%.

12.2.5 The user of these precision data is advised that it is based on actual mill testing, laboratory testing, or both. There is no knowledge of the exact degree to which personnel skills or equipment were optimized during its generation. The precision quoted provides an estimate of typical variation in test results which may be encountered when this method is routinely used.

13. Keywords

Pulp, Paper, Paperboard, Brightness, Diffuse reflectance, Handsheets

14. Additional information

14.1 Effective date of issue: To be Assigned.

14.2 Related methods: ISO 2469, 2470-1, 2470-2, and 3688; PAPTAC E.1; SCAN P3; BSI 4432 Part 2470, T 218, T 218, T 272, T 1200, T 1211.

14.3 This standard combines the testing of pulp and the testing of paper and paperboard using the d/0 geometry into a single method. The separate method for paper and paperboard, T 571, is withdrawn.

Literature cited

1. Höfert, H. J., "A Filter Photometer for the Measurement of Reflectance," *Z. Inst. Kunde.* **67** (5): 115(1959).
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4. Van den Akker, J. A., "Evaluation of Absolute Reflectance for Standardization Purposes," *J. Opt. Soc. Am.* **56**: 252 (1966).
5. Popson, M. T., and Robertson, P.C., "Brightness Confusion for Paper Consumers," TAPPI Engineering, Pulping, and Environmental Conference (October 13, 2009).

Appendix A.1. Ultraviolet spectral radiance controlA.1 *UV adjustment*

A.1.1 For the measurement of materials containing fluorescent whitening agents, some means of setting the spectral power distribution of the radiation incident on the test piece to give a specified UV-content within the spectral range defined by the CIE and of maintaining this setting or of mathematically simulating such a power distribution is required. For this purpose, a filter having a half-peak cut-off wavelength of 395 nm shall be used. If the filter is movable, it shall be mounted in a device which permits its position to be identified and maintained, and reproducibly reset. In addition, a filter or other means shall be provided to reduce the impact of UV-B excitation on the measurements. For this purpose, a sharp cut-off filter with a maximum transmission of 50% at 320 nm shall be used (5).

NOTE 10 The relative spectral power distributions of the CIE illuminants C, D50, and D65 are defined only for wavelengths longer than 300 nm.

A.2 *Fluorescence elimination*

A.2.1 For the measurement of radiance factors with the fluorescence effect eliminated, the instrument shall be equipped with a sharp cut-off UV-absorbing filter having a transmittance not exceeding 5 % at and below a wavelength of 410 nm and exceeding 50 % at a wavelength of 420 nm (i.e. a half-peak cut-off wavelength of 420 nm), or shall employ an equivalent procedure. The cut-off filter shall have characteristics such that a reliable radiance factor value is obtained at 420 nm. This value shall be repeated at all lower wavelengths to provide adequate data for the colorimetric computations, provided that the International Standard for the quantity concerned does not include other instructions.

NOTE 11 This procedure is equivalent to the ASTM E308-08 instruction to add the weighting functions if data for certain wavelengths are missing.

Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Standards Department.

