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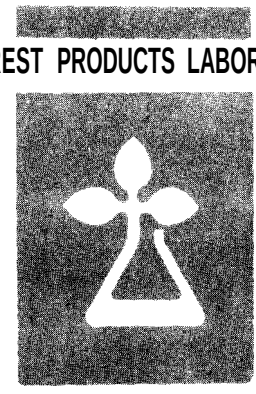

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DETERMINING SCATTERING AND ABSORPTION COEFFICIENTS BY DIFFUSE ILLUMINATION

Abstract

Opacity is a highly important use requirement of printing papers. Fundamental to the optical property of opacity are the light scattering and the absorptive powers of the paper. In this investigation, two methods for measuring these optical properties of paper and pulp were evaluated and compared. At the Forest Products Laboratory, a method using a reflectometer with filters was found to produce sufficiently accurate results in less time than a method in which a reflectometer with a monochromator was used.

DETERMINING SCATTERING AND ABSORPTION COEFFICIENTS BY DIFFUSE ILLUMINATION[1]

By

F. A. SIMMONDS, Chemist
and
C. L. COENS, Physical Science Technician

Forest Products Laboratory,[2] Forest Service
U.S. Department of Agriculture

Introduction

The opacity of paper, as well as brightness, is usually evaluated by measuring reflectance. This measurement may be made by directional or diffuse illumination. Fundamental to the optical property of opacity are the light scattering and the absorptive powers of the paper, commonly referred to as the scattering S and absorption K coefficients.

Parsons (6)[3] stated that the scattering coefficient of a pulp relates to fiber size and shape, index of refraction, and, in paper, to extent of fiber-to-fiber bonding as well. The absorption coefficient relates somewhat to index of refraction and bonding but primarily, to color. Van den Akker (10) credited Parsons for originating the optical method of estimating the relative bonded area in a pulp or a paper sheet. Van den Akker also cited using the method for determining the mechanical properties of paper.

The scattering and the absorption coefficients were dealt with by the Kubelka and Munk equations as they were applied to paper by Steele (8) and Judd (2).

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[1] Acknowledgment is made to Dale B. Bossenberry, Physical Science Technician, for assistance In the experimental work.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

Table 1.--Opacity values obtained at different wavelengths for sodium bisulfite handsheets from balsam fir

Pulp description	Opacity[1] at wavelength of:			
	540 mμ[2]	550 mμ[3]	577 mμ[2]	620 mμ[2]
	Percent	Percent	Percent	Percent
At 61 percent yield:				
Unbleached	91.7	88.3	89.0	87.0
1 percent hydrogen peroxide	84.6	81.5	82.0	78.4
1 percent hydrogen peroxide plus 1 percent sodium hydrosulfite	82.0	79.2	79.4	77.7
At 81 percent yield:				
Unbleached	93.9	91.8	91.8	89.0
1 percent hydrogen peroxide	88.5	86.7	86.1	82.0
1 percent hydrogen peroxide plus 1 percent sodium hydrosulfite	84.5	81.9	82.3	78.0
At 94 percent yield:				
Unbleached	89.7	87.3	87.5	85.7
1 percent hydrogen peroxide	89.3	85.4	86.5	84.1
1 percent hydrogen peroxide plus 1 percent sodium hydrosulfite	83.7	81.1	81.7	81.0

[1] Standard T 425 m-60 of the Technical Association of the Pulp and Paper Industry (TAPPI).

[2] Elrepho instrument.

[3] Bausch and Lomb opacimeter.

The interrelation of these coefficients and the reflectance R_∞ of an opaque pad of pulp or sheets of pulp or paper is expressed in the following equation of the Kubelka–Munk theory:

$$\frac{k}{s} = \frac{(1 - R_\infty)^2}{2R_\infty} \qquad (1)$$

In determining the specific coefficients, the scattering coefficient s is calculated from measurements of R_∞ and R_o, a chart relating these values to scattering power sW, and the weight of the specimen in grams per square centimeter. R_o is the reflectance of a single sheet of the specimen backed by a black body (usually felt). The value of sW/weight is s. The specific absorption coefficient k is then conveniently calculated from a table relating ratios of k/s to R_∞ (3). Van den Akker made the following significant comment on the specific scattering coefficient as a measure of the opacifying power of a pulp:

> "It might be thought that the specific scattering coefficient of a handsheet prepared for optical testing could be taken as a measure of the opacifying power of the pulp. However, the contribution of a given pulp to the specific scattering coefficient of the final paper is governed so heavily by the degree of interfiber bonding and environmental factors that this basis for estimating the opacifying power of a pulp is considered unsatisfactory" (11).

The Kubelka–Munk equation also relates to the opacity of pulp and paper sheets. The ratio $\frac{R_o}{R_{0.89}}$ (contrast ratio) is known as TAPPI opacity. This determination is usually made with an opacimeter (Bausch and Lomb), and the value is read directly from a scale on the instrument. The effective wavelength of the opacimeter is about 550 millimicrons. Consequently, TAPPI opacity can be measured with a reflectometer with filters (Elrepho) by using the appropriate filter. At the Forest Products Laboratory, a filter having a wavelength of 577 millimicrons results in opacity values that agree closely with those obtained with the opacimeter. Typical results are shown in table 1.

Table 2.--Reflectance values for secondary standard after primary standardization of the reflectometer with filters with magnesium oxide

Filter number	Wavelength	Reflectance values		
		Manufacturer	Forest Products Laboratory	
		January 1965	April 11, 1966	August 19, 1966
	Millimicrons	Percent	Percent	Percent
1	680	82.1	82.8	82.8
2	620	84.4	84.2	84.3
3	570	85.4	85.2	85.3
4	530	86.0	85.9	86.0
5	490	85.9	85.8	85.9
6	460	85.3	85.2	85.3
7	420	84.3	84.2	84.3
8	457	85.0	84.8	85.0

Reflectometer with Filters

Description

The reflectometer with filters measures the light reflectance of surfaces. To minimize the effect of surface irregularities, the sample is illuminated diffusely by an integrating sphere. Hence, the reflectance measured by the photocells of the sample and the comparison plate is diffuse reflectance. This diffuse reflectance has the advantage of being applicable to the Kubelka–Munk theory (1). The electronic components are of sufficient quality to eliminate instrument fluctuations caused by variations in line voltage.

The instrument used at the Forest Products Laboratory is equipped with 11 pairs of narrow–band filter mounted in a rotating turret. These pairs include a blue filter for the 457–millimicron wavelength specified in the TAPPI method for measuring brightness, a set of tristimulus filters to obtain X, Y, and Z color values according to the International Chromaticity Scale, and seven other color filters (420 to 620 millimicrons) for determining color distribution.

Dearth and coworkers give a detailed description of the instrument (11).

Standardization

The procedure for standardization with magnesium oxide tablets is provided by the manufacturer and is given in SCAN Method G1:61, "Reflectance Measurement," (7). Reproducibility of standardization was reported by McLean (4, 5). Results of standardization at the Forest Products Laboratory in table 2 show the excellent stability of the instrument.

Determining Specific Scattering and Absorption Coefficients

Sample Preparation

The procedure for the determining of the specific and the scattering and the absorption coefficients is the same for handsheets and paper. The handsheets should, of course, be prepared by a standardized procedure.

TAPPI Standard 218–59, "Forming Handsheets for Optical Tests of Pulp," specifies formation of the test sheet from distilled water on a filter paper in a 16–millimeter porcelain Büchner funnel and pressing and drying the sheets between filter paper. Pressure is 50 pounds per square inch for 5 minutes.

The Forest Products Laboratory method, to be described, has been found equal, if not superior, to the TAPPI method and equal to the method used at a pulpmill research laboratory in determining TAPPI brightness. This Laboratory follows TAPPI Standard T 205 m–58, "Forming of Handsheets for Strength Testing," except that the weight used is 52 grams per meter squared. Brightness measurements are made on the smooth side of the handsheet.

At this Laboratory the weight of pulp used to form a handsheet on a 7- by 9–inch 100–mesh stainless steel wire screen is 2.1 grams on the moisture–free basis. This is equivalent to a basis weight of 52 grams per meter squared. The pulp is dispersed in deionized water and formed at a pH of 5.0, adjusted with sulfurous acid. Initial consistence is 0.07 percent, and formation time is 2 seconds. Before formation is begun the suspension is agitated mildly with air for 5 seconds. A wet sheet of unsized mimeo bond is placed on the pulp sheet, and then a wet blotter is placed on the mimeo sheet.

The couching operation consists of rolling a rubber wringer roll 2.5 inches in diameter back and forth three times using gentle pressure. The sheet composite is then lifted from the wire and placed on a platen with the handsheet uppermost. A wet mimeo sheet is placed on the handsheet and then a wet blotter. From two to four handsheets are prepared from each sample of pulp to be tested. These sheet composites are pressed at 50 pounds per square inch for 5 minutes. Not more than eight composites are pressed at one time to assure a reasonably uniform removal of water.

The blotters are removed, and the handsheets are dried between the mimeo sheets. The handsheets are restrained during drying by tacking at the corners on suitably sized wooden frames. Drying ensues under room conditions in front of an electric fan.

Each of the six specimens to be measured is 3 by 5 inches.

Optical Measurements

Using a sufficient number of the 3– by 5–inch sheet specimens to provide a completely opaque pad, the reflectivity R_∞ is measured at a wavelength

of 620 millimicrons when scattering and absorption coefficients are sought. For TAPPI brightness, however, R_∞ is measured at a wavelength of 457 millimicrons.

R_o is measured with a single specimen sheet backed by a black background the reflectance of which is considered to be negligible.

The R_∞ and R_o values are multiplied by 99.5 to convert them to absolute values as established by magnesium oxide.

The scattering power sW is then read from the opacity chart in TAPPI Standard T 425 m–60. This value is divided by the basis weight in grams per square centimeters to obtain the specific scattering coefficient s. The specific absorption coefficient is then calculated from the table mentioned previously (3). Van den Akker has stated that the units of s and k are reciprocal basis weight units (9).

Reliability of Results

The reliability of the results with the method using the reflectometer with filters was determined by comparing the coefficients s and k with those determined by the method using a reflectometer with a monochromator (General Electric recording spectrophotometer) at another research laboratory.

Handsheets tested included those formed in both 100- and 270–mesh wire screens from unbeaten and variously beaten samples of a commercial softwood bleached sulfite pulp.

The results of comparing these handsheets show, in table 3, the determinations at the Forest Products Laboratory using the reflectometer with filters are sufficiently accurate. The working standards of the Elrepho milk glass were also checked for accuracy and found to be correct.

It is apparent that several differences between values for specific absorption coefficients in table 3 are large when expressed as percentages. This is because of the relations shown in equation 1.

Results of Application

Although the data in table 4 are self–explanatory, attention is called to the consistency of the results. Decreases in opacity are noted to relate to decreases in scattering coefficient because the decrease in absorption coefficient is negligible.

Table 3. --Optical data for budsheets determined by two methods[1]

Beating time	Basis weight	Reflectometer with monochromator[2]				Reflectometer with filters[3]			
		Absolute total transmittance (T)	Absolute reflectivity (R_∞)	Specific scattering coefficient (s)	Specific absorption coefficient (k)	Absolute reflectance (R_o)	Absolute reflectivity (R_∞)	Specific scattering coefficient (s)	Specific absorption coefficient (k)
Min.	G./sq. cm.								
HANDSHEETS MADE ON 100-MESH WIRE SCREEN									
0	0.00547	0.331	0.926	362	1.06	0.660	0.926	361	1.06
5	.00539	.380	.927	299	.850	.618	.928	311	.867
10	.00515	.417	.925	268	.812	.570	.913	264	1.095
15	.00523	.453	.908	228	1.06	.543	.917	228	.857
20	.00531	.476	.916	203	.783	.530	.910	212	.943
HANDSHEETS MADE ON 270-MESH WIRE SCREEN									
0	.00480	.364	.918	360	1.32	.653	.925	355	1.079
5	.00555	.371	.922	303	.998	.630	.925	307	.933
10	.00542	.404	.921	268	.910	.591	.921	270	.915
15	.00536	.437	.912	237	1.00	.559	.914	232	.939
20	.00555	.491	.907	205	.971	.541	.908	211	.983

[1] Handsheets were made from a commercial softwood bleached sulfite pulp.

[2] Effective wavelength of 650 millimicrons. Data from Laboratory A.

[3] Effective wavelength of 620 millimicrons. Data from Forest Products Laboratory.

Table 4.--Optical properties of papers with and without starch surface sizing and made from differently refined furnishes[1]

Treatment	Density	Basis weight	Brightness[2]	Opacity[3]	Absolute reflectance (R_o)[4]	Absolute reflectivity (R_∞)[4]	Scattering power (sW)	Specific scattering coefficient (s)	Specific absorption coefficient (k)	Ash
	G./cc.	G./sq. cm.	Pct.	Pct.						Pct.
Claflin refined only	0.90	0.00678	77.8	82.3	0.735	0.902	2.89	426	2.27	8.4
Claflin refined and sized	.99	.00747	74.5	77.1	.681	.888	2.23	299	2.11	7.2
Chemifined and Claflin refined	.92	.00746	75.9	82.3	.740	.896	3.02	405	2.45	8.8
Chemifined and Claflin refined and sized	1.03	.00745	72.1	74.5	.646	.875	1.90	255	2.27	8.7
Chemifined and Claflin refined and sized	1.04	.00861	70.7	76.3	.677	.872	2.23	259	2.42	7.7
Commercial sized	.87	.00742	63.6	89.9	.781	.871	4.05	456	4.35	16.9

[1] A low-viscosity ethylated starch having a low degree of substitution.

[2] Measured with an Elrepho reflectance meter using a wavelength of 457 millimicrons.

[3] Measured with Bausch and Lomb opacimeter.

[4] Measured with an Elrepho reflectance meter using a wavelength of 620 millimicrons.

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