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Technical Bulletin No. 101

iDM instruments

Diffuse vs. Directional Brightness Measurement

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Abstract

A description of the optical geometries of the two types of brightness testers most commonly used in the Pulp & Paper Industry is presented. An historical discussion of the development and acceptance of the two types of brightness testers, one employing directional geometry and the other employing diffuse geometry, is also presented pointing out the reasons for adoption of diffuse geometry for brightness measurement by the European and Canadian Pulp and Paper Industries and adoption of directional geometry by the American Pulp and Paper Industry. The technical and practical advantages and disadvantages of each geometry are discussed as well as their relationship to end product useage. Experimental data on several grades of paper and clay confirm the disagreement between the two standard brightness scales due to differences in illuminating and viewing geometries. The data also substantiates the capability of instruments employing diffuse geometry to average point to point variations encountered in pulp and to minimize directionality effects encountered in embossed pulps or machine made papers. Difficulties encountered in attempting to utilize diffuse brightness testers for the measurement of fluorescent papers are discussed and documented.

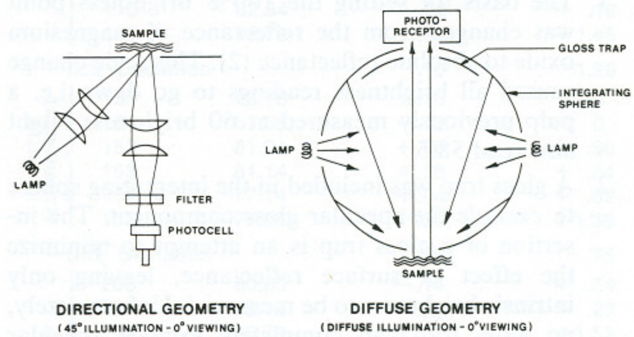
INTRODUCTION

A debate has raged for many years in the Paper Industry over the relative merits of measuring papermakers' brightness utilizing instruments employing either directional or diffuse geometry. This argument stems from the fact that brightness values are dependent upon the geometry of the testing instrument used to make the measurements. It is commonly recognized that brightness measurements made by two testers with different geometries *will not* agree (1).

The geometry of an optical instrument refers to the physical relationship of the optical components which make up the instrument such as lamps, lenses, reflectors, apertures, etc. The two geometries most commonly used in brightness testers in the pulp and paper industry are shown in Figure 1. The directional geometry referred to as 45°-0° is so called because the lamp and lens system produce a beam of light which directly strikes the sample at an angle of 45° with the perpendicular. The receiving lens system and photocell collect only the reflected light which is contained about an axis which is perpendicular to the sample (0°). This 45°-0° directional geometry is specified in TAPPI Standard T452 which further defines each geometric parameter such as size of illuminated area, viewed area, cone angle, etc.

The diffuse geometry shown in Figure 1 is referred to as diffuse-0° which means that the illumination from the lamps strikes the inner wall of a sphere, which is coated with a high reflectance white material, and multiple reflections from this surface diffuse the light before it strikes the sample. The reflected light is viewed by a photocell positioned to view the sample perpendicularly (0°). This diffuse illumination-direct viewing (0°) geometry has been specified in ISO Standards T2469 and 2470 as well as Canadian, Scandinavian and other brightness standards. The size of the sphere, area of illumination and view, and the area of openings in the sphere are geometric variables which also affect the measurement, and therefore, must be specified.

FIG.1 EXAMPLES OF DIRECTIONAL AND DIFFUSE GEOMETRIES COMMONLY EMPLOYED IN PULP AND PAPER BRIGHTNESS TESTERS



HISTORICAL DEVELOPMENT

Directional Brightness Measurement

The first paper brightness tester utilizing directional geometry as shown in Fig. 1, the GE Reflection Meter, was developed and introduced to the Pulp and Paper Industry in the early 1930's. Because of the difficulty of producing instruments which agreed with each other within the limits of visual discrimination, the Institute of Paper Chemistry established a "Brightness Standardization System" whereby all newly manufactured brightness testers were matched geometrically photometrically and spectrally to a master instrument. In addition, calibrated opal glass and paper standards were issued on a monthly subscription basis to allow brightness tester users to maintain close agreement with the IPC master. TAPPI Standard T452, which was based on the GE Reflection Meter, was adopted by TAPPI in 1948. Subsequently, brightness testers conforming to TAPPI T452 have been manufactured by Martin Sweets Company, Diano Corporation and Technidyne Corporation.

The success experienced by the U.S. Paper Industry with the use of the GE Brightness Meter and its successors is mainly attributable to the rigorous and diligent maintenance of the brightness standardization system by the Institute of Paper Chemistry. As a result, users of the system throughout the Paper Industry have developed confidence in the accuracy and reliability of their brightness measurements.

Diffuse Brightness Measurement

The most commonly used diffuse brightness tester, the Zeiss Elrepho, was introduced in the 1950's by Carl Zeiss Company of Oberkochen, West Germany. The Elrepho with its integrating sphere (diffuse) geometry was adopted by the European and Canadian Paper Industries and the International Standards Organization (ISO) as the standard instrument for measuring brightness. The Elrepho remained the only instrument manufactured in accordance with the European, Canadian and ISO standards until the recent introduction of the Technibrite Model TB-1 by Technidyne Corporation of New Albany, Indiana, U.S.A.

In contrast to the rigorously maintained directional brightness scale, which has remained relatively unchanged in over 45 years, the diffuse brightness scale has seen several major changes including:

1. The basis for setting the 100% brightness point was changed from the reflectance of magnesium oxide to absolute reflectance (2). This scale change caused all brightness readings to go down i.e. a pulp previously measured at 60 brightness might now read 58.5
2. A gloss trap was included in the integrating sphere to *exclude* the specular gloss component. The insertion of a gloss trap is an attempt to minimize the effect of surface reflectance, leaving only intrinsic brightness to be measured. Unfortunately, no gloss trap can completely exclude specular gloss from all grades of pulp and paper, therefore, the measurements are very much a function of the size and position of the trap. Brightness values may be lower by up to 2% due to the inclusion of a gloss trap (3).
3. The use of a xenon lamp has been recommended to boost the excitation of fluorescent papers. Sphere lining deterioration causes increasing absorption of ultraviolet (UV) energy as the lining ages thereby reducing the excitation of fluorescent dyes. The intended use of the xenon lamp was to boost the UV energy to a level sufficient to excite fluorescent papers and produce an appropriately higher brightness value. The use of the xenon attachment has not gained widespread acceptance due to long term stability concerns, difficulty in deciding when to use the attachment, and because of its high cost.

These changes have caused some frustration among users of the diffuse brightness method in explaining to their customers how the brightness of a pulp or paper can change 2% from one day to the next because a brightness scale change has been adopted. A 2% *increase* in brightness is never hard to explain, but a 2% *reduction* in brightness is impossible to explain to a customer.

ADVANTAGES AND DISADVANTAGES

One might reasonably ask why a part of the world (USA) would settle on the measurement of pulp and paper brightness by one geometry and another part of the world (Canada and Europe) would settle on brightness measurement by a different geometry. The reason for this disagreement is that there are valid advantages and disadvantages for both the diffuse and directional geometries of brightness measurement. The following is a synopsis of the advantages and disadvantages:

Advantages of Diffuse Geometry:

1. Averages non-uniformities — This is a very important advantage in the measurement of pulp which varies greatly in its uniformity. Far fewer measurements need to be made on an instrument which diffusely illuminates the sample than on a directional reflectance instrument in order to obtain a representative average of the overall sample reflectance.
2. Averages directionality effects — Since the diffuse brightness tester illuminates the sample from every direction, there is no change in reading associated with sample reorientation.
3. Simulates viewing condition — Some argue that the diffuse brightness tester better simulates typical viewing conditions than the directional brightness tester. This argument pertains primarily to the fact that the area of view in the standard diffuse brightness tester is larger than the area of view in the standard directional brightness tester.
4. Excludes or includes specular gloss — A gloss trap can be either included or excluded to simulate the end product viewing conditions.
5. Minimizes translucency effect — This point also pertains to the fact that the area of illumination and view is larger in the standard diffuse brightness tester than in the standard directional brightness tester.

Advantages of Directional Geometry:

1. Long term stability of fluorescence measurement — There is no decrease in fluorescent response due to sphere deterioration. In addition there is no change in the spectral content of the sample illumination due to spectral selectivity of the sample itself as experienced in integrating sphere instruments.
2. Simulates end use viewing conditions — Most papers which are viewed in office or home lighting are observed under predominantly directional illumination which is simulated best by the 45°-0° directional geometry. Also most viewers will intentionally tilt a glossy sheet to avoid seeing the gloss which again is simulated by the 45°-0° geometry.
3. Pinpoints directionality — In certain circumstances if the product is visually different when viewed in two orientations, the user may wish to have his brightness values corroborate those observations. In other words, if the eye sees a difference when a sheet is turned 90°, the instrument should measure that difference as is the case with 45-0° geometry.
4. Specular gloss is essentially eliminated — The directional geometry eliminates nearly all of the specular gloss component from the brightness reading, whereas, the gloss trap used with diffuse geometry can only partially eliminate the specular component.

The Relationship of Diffuse and Directional Geometries To The End Use of Brightness Measurements

If all materials to be measured with brightness testers were ideal, that is: non-directional, non-translucent, non-fluorescent, completely diffuse (non-glossy), and perfectly uniform, the results obtained with instruments employing direct and diffuse geometries would be identical. Unfortunately, in the pulp and paper industry there are few, if any, ideal surfaces to be measured, therefore, variations in brightness values must be expected when instruments employing different geometries are used. As the materials deviate further from the ideal characteristics mentioned above, one can expect larger differences between readings obtained with instruments employing direct and diffuse geometries.

The major drawback of the direct geometry as used in the brightness tester described by TAPPI Standard T452 is the small area of illumination (approximately 13mm diameter) and viewing (approximately 9mm diameter). Most grades of machine-made paper are relatively uniform and satisfactory results can be obtained by making a few measurements at various points across the sheet and averaging the results, however, significant variations in brightness readings can be expected when using the directional brightness tester to measure pulp and other non-uniform materials as shown in Table 1. Since the area of sample viewed by a standard diffuse brightness tester is 11 times the area viewed by a standard directional brightness tester, the variation from reading to reading is much smaller. In effect, a single reading on the diffuse instrument is equivalent to an average of 11 readings on the directional instrument with its much smaller measuring area. Wet pulp, because of its greater translucency, is even more difficult to measure meaningfully with the directional brightness tester.

TABLE 1.

VARIATIONS IN BRIGHTNESS VALUES AT 1 INCH INCREMENTS ACROSS PULP SAMPLES AS MEASURED BY A BRIGHTNESS TESTER EMPLOYING DIFFUSE GEOMETRY AND A BRIGHTNESS TESTER EMPLOYING DIRECTIONAL GEOMETRY.

Readings Taken on Diffuse Brightness Tester (Technibrite TB-1)

Position	Handsheet	Corrugated Pulp Lap
1	83.6	82.8
2	83.5	83.6
3	83.7	84.0
4	83.6	84.1
5	83.6	83.6
Avg. variation	0.1	0.4

Readings Taken on Directional Brightness Tester (Technidyne Model S-4)

Position	Handsheet	Corrugated Pulp Lap
1	84.2	82.8
2	84.4	84.0
3	83.4	84.6
4	84.0	83.5
5	84.7	82.8
Avg. variation	0.6	0.9

In addition to the usefulness of the averaging capabilities of the diffuse brightness tester, pulp and clay manufacturers prefer having the sample presented to the brightness tester at the bottom of the instrument which minimizes the possibility of powder or loose fibers dropping into the instrument. On the other hand, paper and board manufacturers seem to prefer the method of sample presentation employed by the standard directional brightness tester whereby multiple layers are laid flat on the top of the instrument and compressed by a standard weight. This arrangement provides less restriction for large sheets and is more convenient to the operator.

The directional geometry is generally considered to be preferable to an integrating sphere geometry for the measurement of paper containing fluorescent dyes. The brightness "boost" provided by fluorescent brighteners can be measured repeatably over long periods of time only if the ultraviolet to blue ratio of incident illumination is kept stable. If more ultraviolet light than blue light is absorbed in the optics as they age, the fluorescent response of the instrument will diminish. Since the directional geometry brightness tester has no integrating sphere, there is much less chance of UV light being absorbed, therefore, the directional instrument should provide excellent long term fluorescent response stability.

Integrating sphere instruments are also subject to changes in their response to fluorescence; a) when a gloss trap is included in the integrating sphere the sample opening becomes a larger percentage of the remaining reflective area of the sphere, causing a relatively higher degree of fluorescence excitation (see Tables 3, 4 and 5), and b) when a fluorescent paper is measured with an integrating sphere instrument, the light emitted by fluorescence is reflected by the sphere wall and reilluminates the sample adding to the original illumination. This effectively changes the spectral character of the light source each time a sample is measured (4).

It should be considered that effects a) and b) described above can be taking place in combination with continuous changes in UV/blue ratio making the measurement of fluorescent materials on an integrating sphere instrument a risky proposition at best.

DISCUSSION OF EXPERIMENTAL RESULTS

The data shown in Table 1 point up the difference between brightness testers employing diffuse geometry and brightness testers employing directional geometry with regard to their ability to average non-uniformities across a sheet. Five readings were taken on a typical pulp handsheet utilizing the Technibrite Model TB-1 Brightness Tester which employs diffuse illumination-0° viewing geometry. Each reading was spaced one inch away from the previous reading. Note that the maximum variation from one position to the next is 0.2 brightness units with an average variation from one point to the next of 0.1. This same test was run utilizing a brightness tester employing 45° — 0° directional geometry (the Technidyne Model S-4 Brightness Tester). The maximum brightness variation between two points spaced one inch apart on the handsheet was 1.0 brightness units with an average variation between measurement points of 0.6. This data clearly indicates that the diffuse brightness tester, with its larger sample measurement area, provides better averaging of point to point variations within the pulp. It should be noted that the repeatability of each instrument was carefully checked and found to be within 0.1 brightness units to assure that the low point to point brightness variations measured by the diffuse brigtness tester were actually due to geometric averaging rather than lack of instrument sensitivity.

Measurements were also made at one inch increments on corrugated pulp lap which has considerably greater surface variation than a handsheet. Again, the brightness tester employing diffuse geometry and large measurement area measured substantially less point to point variation in brightness than the tester employing directional geometry.

To point up the effect of sample directionality upon brightness measurements taken with instruments employing different geometries a corrugated pulp lap, which has an exceedingly high degree of directionality, was measured in the machine and cross machine directions. The data shown in Table 2 very vividly indicate that the instrument employing diffuse geometry is much less sensitive to directionality because the sample is being illuminated from every direction. On the other hand the data obtained utilizing the directional brightness tester is very much dependent upon the orientation of the sample presented to it. When the sample is illuminated in the cross machine direction, shadowing occurs which causes a reduction in the brightness reading. Variations due to directionality in the pulp lap used in this example are far greater than those normally observed in machine made papers, however, even in paper directionality effects can be very significant.

TABLE 2.

CORRUGATED PULP LAP MEASURED IN MACHINE AND CROSS MACHINE DIRECTIONS.

TECHNIBRITE TB-1 DIFFUSE BRIGHTNESS TESTER DATA:

Sample	Mach. Direction	Cross Mach. Direction	Difference
1	82.7	82.7	0
2	83.5	83.7	.2
3	84.1	84.0	.1
4	84.2	84.2	0
5	83.7	83.8	.1

TECHNIDYNE MODEL S-4 DIRECTIONAL BRIGHTNESS TESTER DATA:

Sample	Mach. Direction	Cross Mach. Direction	Difference
1	82.3	79.6	2.7
2	84.4	81.0	3.4
3	84.3	80.2	4.1
4	84.0	81.3	2.7
5	83.1	79.7	3.4

As indicated previously, one cannot expect instruments employing different geometries to agree with one another unless the sample being measured embodies ideal optical properties. To determine the amount of disagreement to be expected in the real world of paper brightness measurement, twenty-six different grades of paper and two clays were measured with two instruments employing diffuse illumination — 0° viewing geometry as specified by ISO and one instrument employing 45° illumination — 0° viewing directional geometry as specified by TAPPI Standard T452. Table 3 shows the data obtained with specular gloss included in the diffuse geometry brightness testers. Because of its very nature, the directional geometry brightness tester excludes all specular gloss. It can be readily seen that the two instruments employing the same geometry, namely, the Elrepho brightness tester and the Technibrite Model TB-1, agree with each other quite well on all of the grades of paper and clay, however, the instrument employing directional geometry, the Technidyne Model S-4 Brightness Tester, disagrees with the diffuse brightness tester data by more than 1% for several of the samples. It is important to note the randomness of the disagreement making it impossible to derive a correction equation or table to achieve correlation between the directional and diffuse brightness values.

TABLE 3.

DATA COMPARING TWO BRIGHTNESS TESTERS EMPLOYING DIFFUSE GEOMETRY WITH ONE BRIGHTNESS TESTER EMPLOYING DIRECTIONAL GEOMETRY

SPECULAR GLOSS INCLUDED*

		DIFFUSE GEOMETRY Elrepho Brightness	DIFFUSE GEOMETRY TB-1 Comparison	DIRECTIONAL GEOMETRY S-4 Comparison
NON-FLUORESCENT	101	70.92	−.60	+ .34
	102	50.46	−.26	− .48
	103*	80.78	+.30	+ .80
	104*	80.46	+.20	+1.08
	105*	81.36	+.22	+1.08
	106	57.48	−.38	− .48
	107	48.58	−.36	+ .72
	108	81.72	+.10	− .34
	109	82.30	+.26	− .76
	110	82.80	+.28	+ .14
	111	16.24	+.02	+ .84
Std. Deviation			.30	.71
SLIGHTLY FLUORESCENT	150	73.86	+.08	− .10
	151	61.66	−.34	+ .02
	152	81.30	+.32	− .56
	153	81.18	+.16	+ .80
	154	77.08	−.02	+ .88
	155	78.46	+.28	+ .88
Std. Deviation			.24	.65
HIGHLY FLUORESCENT	200	80.56	+.32	+ .88
	201	77.90	+.16	− .06
	202	80.74	+.36	+1.60
	203	81.98	+.10	− .14
	204	85.42	+.02	− .02
	205	82.46	−.20	− .28
	206	82.48	−.24	− .12
	207	84.70	0	+1.18
	208	92.36	−.18	+ .02
Std. Deviation			.21	.73
CLAY	A	89.7	0	+ .4
	B	84.5	+.1	− .3

*Specular gloss is included in both diffuse geometry brightness testers but the directional brightness tester always **excludes** specular gloss.

All three of the brightness testers used in this study were checked and found to be in a good state of calibration with regard to photometry and spectral response. Each data point shown in Tables 3 and 4 is an average of five brightness determinations on an optically infinite pad made up in accordance with the sampling procedures described in TAPPI T400 and T452. The grades of paper used in this study are described in Table 5. The fluorescence rankings i.e., highly fluorescent, slightly fluorescent, or non-fluorescent, were determined by measuring the fluorescent component on a Technidyne Model S-4 Brightness Tester utilizing TAPPI Useful Method #548 with verification by visual observation under controlled conditions. All three instruments were calibrated based on absolute reflectance utilizing a paper transfer standard of approximately 90% brightness.

The measurements made and reported in Table 3 were repeated after insertion of gloss traps in the Elrepho and Technibrite TB-1 Brightness Testers. The data thus obtained with specular gloss excluded is reported in Table 4 along with the data obtained on the S-4 Brightness Tester which always excludes gloss. Again the disagreement due to geometric difference is apparent and defies any attempt at mathematical correlation for the wide range of brightness values and grades utilized in this study.

CHANGE IN GEOMETRY WITHIN A GIVEN INSTRUMENT

Thus far we have concerned ourselves with disagreement between instruments which have been designed to employ different illuminating and viewing geometries. Now let us consider the effect of change in geometry within a given instrument. When a black gloss trap is inserted in the integrating sphere of a diffuse brightness tester, the sample is no longer illuminated from every direction as the illuminating rays surrounding a perpendicular axis to the sample have been eliminated. This change in geometry can provide some interesting results as shown in Table 5.

Referring to the coated grades #103, 104, and 105, which are also non-fluorescent, we can see that the differences between brightness readings including gloss and excluding gloss are positive numbers approaching 1%. This indicates that the surface reflectance from the coated sheet (specular gloss) is contributing an addi-

TABLE 4.

DATA COMPARING TWO BRIGHTNESS TESTERS EMPLOYING DIFFUSE GEOMETRY WITH ONE BRIGHTNESS TESTER EMPLOYING DIRECTIONAL GEOMETRY.

SPECULAR GLOSS EXCLUDED

		DIFFUSE GEOMETRY Elrepho Brightness	DIFFUSE GEOMETRY TB-1 Comparison	DIRECTIONAL GEOMETRY S-4 Comparison
NON-FLUORESCENT	101	70.20	−.18	+1.06
	102	49.98	−.02	0
	103	79.80	+.28	+1.78
	104	79.66	+.24	1.88
	105	80.56	+.14	1.88
	106	56.90	−.18	+ .10
	107	47.82	+.08	1.48
	108	81.44	−.14	− .06
	109	81.92	−.08	− .38
	110	82.84	−.02	+ .10
	111	15.78	+.24	+1.46
Std. Deviation			.16	1.26
SLIGHTLY FLUORESCENT	150	73.76	+.16	0
	151	61.68	−.12	0
	152	81.04	+.20	− .30
	153	81.14	+.28	+ .84
	154	77.14	+.04	+ .82
	155	77.96	+.30	+1.38
Std. Deviation			.28	.75
HIGHLY FLUORESCENT	200	80.80	−.14	+ .64
	201	78.12	−.26	− .28
	202	80.78	+.02	+1.56
	203	82.30	−.42	− .46
	204	85.82	−.46	− .42
	205	82.86	−.42	− .68
	206	82.86	−.48	− .50
	207	85.16	−.26	+ .72
	208	93.10	−.46	− .72
Std. Deviation			.36	.75
CLAY	A	89.7	0	+ .4
	B	84.6	−.2	− .4

TABLE 5.

SPECULAR GLOSS COMPONENT OF BRIGHTNESS (GLOSS INCLUDED — GLOSS EXCLUDED)

		Sample No.	Elrepho	Technibrite TB-1
NON-FLUORESCENT		101	+.72	+ .30
		102	+.48	+ .20
	coated	103	+.98	+1.00
	coated	104	+.80	+ .72
	coated	105	+.80	+ .88
		106	+.58	+ .38
		107	+.76	+ .32
		108	+.28	+ .52
		109	+.38	+ .72
		110	−.04	+ .22
		111	+.62	+ .24
SLIGHTLY FLUORESCENT		150	+.10	+ .02
		151	−.02	− .24
		152	+.26	+ .38
		153	+.04	− .08
		154	−.06	− .12
		155	+.52	+ .48
HIGHLY FLUORESCENT		200	−.24	+ .22
		201	−.22	+ .20
		202	−.04	+ .30
		203	−.32	+ .20
		204	−.40	+ .08
		205	−.40	− .18
		206	−.38	− .14
		207	−.46	− .20
		208	−.74	− .46

tional 1% to the brightness of the sheet. Given that positive numbers indicate the gloss contribution of the sheet, how can one explain the negative differences obtained by the Elrepho on Samples 200-208? The answer lies in the fact that the geometry of the integrating sphere was changed when the gloss trap was inserted. Inclusion of the gloss trap reduces the effective area of the sphere wall making the illuminated sample area a larger percentage of the total wall area. The resulting change in illuminating conditions causes a relatively higher excitation of the fluorescent papers yielding a higher brightness value when the gloss trap is in the instrument than when it is not.

SUMMARY

This investigation of advantages and disadvantages of diffuse and directional brightness measurement geometries leads to the conclusion that neither geometry is ideal for the measurement of all materials encountered in the pulp and paper industry. Advantages of directional geometry such as exclusion of specular gloss, long term fluorescent response stability and simulation of normal viewing conditions are important factors in the measurement of paper, particularly for grades which are coated, calendared or fluorescent. The main attribute of diffuse geometry, namely its ability to average point to point variations, lends itself well to the measurement of pulp where brightness variations within a given sample can be significant. Bearing in mind the considerations previously stated, it would appear that the choice between diffuse and directional geometry for brightness measurement must be ultimately based on the characteristics of the particular material to be measured.

TABLE 6.

DESCRIPTION OF SAMPLES TESTED

Sample No.	Description	Fluorescent Component Value
101	70# colonial white	.12
102	67# vellum bristol	.06
103	60# offset coated 2 sides	.04
104	60# offset coated 1 side	.08
105	70# coated 1 side label paper	.16
106	70# text ivory laid finish	.10
107	70# imperial ivory offset light yellow	.08
108	16# bond	.06
109	13# bond	.08
110	20# bond	0
111	unbleached kraft	.04
150	9# bond	1.08
151	20# 25% rag light gray	.94
152	110# index	.84
153	80# vellum bristol	.52
154	65# cover laid finish	.44
155	90# index	.32
200	50# offset smooth finish	2.66
201	70# offset vellum finish	2.24
202	50# offset	2.64
203	80# offset embossed finish	2.98
204	20# ledger	3.86
205	70# offset	4.16
206	9# onionskin 25% rag	4.32
207	70# pearl white offset	4.86
208	20# 25% rag	5.92

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