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SUBJECT
CATEGORY _____ Physical 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 Material 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.

Equivalent Black Area (EBA) and count of visible dirt in pulp, paper and paperboard by image analysis (Five-year review of Official Method T 563 om-15) (No changes from previous draft: Standard reaffirmed)

1. Introduction

The level of visible dirt present in pulp, paper or paperboard can impact its usefulness in a specific end use application. In such cases, the presence of visible dirt specks which are high in number, easily noticed in visual examination, or both, may detract more from the apparent usefulness of the paper material than does a lower number of specks, or specks which are less easily noticed by the eye. Both the number of dirt specks and their visual impact may be important. For someone controlling or monitoring the paper making process, the absolute physical area of dirt, or the number of dirt specks present in an inspection area may be of greatest importance. For the end user of the paper material, the overall visual impression may be the critical parameter.

2. Scope

2.1 This method uses image analysis to determine the level of dirt in pulp, paper, and paperboard in terms of Equivalent Black Area (EBA) of dirt specks within the physical area range of 0.02 to 3.0 mm² reported in parts per million as well as the number of dirt specks per square meter of sample. Using the algorithm prescribed in this method, the maximum dirt size is limited to 3.0 mm². Extension to other speck sizes (for example those greater than 3.0 mm² in physical area), may require changes in equipment, calculation procedures, or both, and is not covered in this test method. This method cannot be used for physical area measurements since it does not correctly measure the dirt specks for that mode of measurement.

2.2 The specimen to be evaluated should have a brightness, as determined by TAPPI T 452 “Brightness of Pulp, Paper, and Paperboard (Directional Reflectance at 457 nm),” of 30% or greater. It may be necessary to reform some pulp sheets into handsheets if the surface is too rough or textured.

2.3 This method is an instrumental equivalent of TAPPI T 437 “Dirt in Paper and Paperboard” and TAPPI T 213 “Dirt in Pulp,” both of which report the equivalent black area of dirt in parts per million, and TAPPI T 537 “Dirt Count in Paper and Paperboard (Optical Character Recognition -- OCR)” which reports the number of specks of 0.02 mm² or larger per square meter. This method can be implemented using any image analysis system, provided that it meets the criteria specified herein.

2.4 This method, and corresponding precision statement, was developed using laboratory analyzers and cannot be considered applicable to on-line systems.

3. Significance

3.1 The visual impact of a dark speck on a light background varies as a function of the speck size. The calculation of this visual impact is done based on Ricco’s law in this test method, and reported in terms of equivalent black area. As the dirt speck becomes sufficiently large, the equivalent black area of a black speck (a $Y_{c/2}$ value of 2.4%) on a white background (a $Y_{c/2}$ value of 81.5%) will approach the speck’s physical area. The use of the equivalent black area calculation procedure in this test method is highly significant, as it provides data continuity of dirt measurement with procedures such as TAPPI T 437 which have been in use for over 50 years (1).

NOTE 1: All $Y_{c/2}$ value (557 nm) reflectances mentioned in this method are to be measured on a diffuse reflectance instrument in accordance with T 527.

3.2 Dirt is usually found on the surface of the sheet, however dirt particles which are embedded may also be discernible by eye in papers that are transparent or translucent. The level of visible dirt present in papers used in printing, writing, and other forms of communication may be both an aesthetic and performance requirement. For example, bond and writing papers may be subjected to close visual inspection in their intended use, but may also be required to perform on scanners, bar code readers, or other automated optical recognition devices where dirt above some critical level could impact performance.

3.3 Similar considerations may be appropriate for papers used in wrapping and packaging. In addition, special considerations may be required where such materials come in contact with foodstuffs, and where visible specks may be considered unacceptable.

3.4 Dirt in the form of gritty materials embedded in the sheet is a serious defect in many printing papers used in contact printing because of the pitting and wear that they can cause in printing plates. Such dirt can also occur in paperboard such as linerboard, and when present may cause significant reduction in bursting strength. Dirt of this type is not easily detected using this procedure, because there is little color contrast between the dirt speck and the background sheet.

3.5 The repeatability of this method is significantly better than that of TAPPI T 437 “Dirt in Paper and Paperboard.”

4. Related documents

TAPPI T 213 “Dirt in Pulp,” TAPPI T 437 “Dirt in Paper and Paperboard,” TAPPI T 452 “Brightness of Pulp, Paper and Paperboard (Directional Reflectance at 457 nm),” TAPPI T 537 “Dirt Count in Paper (Optical Character Recognition -- OCR),” and TAPPI T 527 “Color of Paper and Paperboard ($d/0^\circ$ geometry).”

5. Definitions

5.1 *Dirt* - any foreign matter embedded in or on the sheet, which, when examined by reflected light has a contrasting, darker color to the sheet surface and has an equivalent black area of 0.02 mm² or greater as determined by this test method.

5.2 *The equivalent black area (EBA)* - the area of one of the round black spots (a $Y_{c/2}$ value of 2.4%) on the TAPPI Dirt Estimation Chart that has the same apparent area when examined visually upon its white background (a $Y_{c/2}$ value of 81.5%) as does the dirt speck when examined visually upon the particular sheet in or upon which it is embedded. A larger “gray” dirt speck has the same visual impact as a smaller “black” one when viewed on the same sheet and under the same conditions.

5.2.1 The equivalent black area (EBA) of a dirt speck determined visually is generally less than its physical area. The EBA approaches the physical area only as the speck becomes large.

5.2.2 This definition of EBA is technically identical to that found in TAPPI T 213 and TAPPI T 437, and this test method produces results that are the technical equivalent of those test methods except for the minimum dirt size.

6. Apparatus

6.1 Description of the Apparatus:

6.1.1 *Detector:* The detector is densitometric with at least 256 gray levels (G.L.) of sensitivity with the physical pixel resolution having an effective area of 0.020 mm² or less (see Note 2). The detector must view the specimen normal to its surface. The light is un-polarized and is concentrated in the visible portion of the spectrum such that 95% of the detected light reflected from a white surface will be between 380 nm and 740 nm. The illumination must be diffuse or axially symmetric with an incident angle of $45^\circ \pm 5^\circ$; the uniformity of the illumination on the specimen stage before any software corrections must be within $\pm 4\%$. The specimen stage must be shielded to prevent influence from ambient light.

NOTE 2: Precision improves with resolution. Therefore it is advisable to have as high a pixel resolution as is practical for the smallest dirt specks. However, to prevent false detections arising from sheet micro-structure, the effective minimum physical pixel resolution must not go below 0.002 mm².

6.1.2 *Analyzer:* An analyzer incorporating “Equivalent Black Area” (EBA) calculations and using a technique called the “visual impact parameter” (see (1) and Appendix A.1). This parameter permits the system to perceive dirt in the same manner as would a human judge.

6.1.3 *The certified calibration plates* must be matte and have at least one solid white area and a solid black area. There are to be two other image areas containing a minimum of 16 dots each with a $Y_{c/2}$ value difference to their background of 25% and 55%. Each set of certified calibration plates is numbered and provided with a calibration certificate containing the correction factors for the $Y_{c/2}$ reflectance of the dots. Additionally the certified calibration plates must meet the specifications in Appendix A.2. These plates are available from TAPPI.

NOTE 3: It is known that large amounts of fluorescence in paper can cause possible problems with the calibration or measurement with this method. However, that effect will be normally minimal since the reflectance values are measured at the $Y_{c/2}$ value, not at 457 nm for brightness.

6.2 *Calibration:* Turn on the light source. Allow the equipment to warm up and adjust the hardware settings according to the instructions or recommendations. If there is an adjustable focus on the detector, verify that the calibration plate image is sharply focused. The system will have reached a steady state condition when five consecutive G.L. readings are within 2% of each other.

6.2.1 *Contrast calibration:* Place the calibration plate with the greatest contrast flat on the stage. If a device is used to hold a sample flat on the stage, then this same device must be used to hold the calibration plate flat.

6.2.1.1 *Zero adjust:* With the black square in the field of view, scan the black area on the plate, adjust the instrument to report a value of not less than 9 out of 255 gray levels or 3.5% of the full gray scale (see Note 4). Successive scans of the black area must give results within $\pm 0.4\%$ G.L. values.

6.2.1.2 *Span adjust.* With the white square in the field of view, scan the white area on the plate, adjust the instrument to report a value not greater than 220 out of 255 gray levels or 86.3% of the full gray level scale (see Note 5). Successive scans of the white area must give results within $\pm 0.4\%$ G.L. values. A minimum of 200 G.L. resolution between the black and white squares is recommended and a minimum of 170 G.L. is required. The gray level scale must be precise enough that each gray level corresponds to a step of not more than 0.5% reflectance units.

NOTE 4: As calibration plates age, there may be a loss $Y_{c/2}$ reflectance. The $Y_{c/2}$ must be checked at least annually. If the minimum resolution falls below the required 170 G.L., then the calibration plates must be replaced.

NOTE 5: The $Y_{c/2}$ %-reflectance and G.L. are linearly related such that $1\% Y_{c/2} = 2.55$ G.L. To determine the G.L. value of the black and white calibration plates, multiply the $\% Y_{c/2}$ reported on the certificate by 2.55 provided with the set of calibration plates.

6.2.1.3 Repeat these two adjustments iteratively until both specifications are achieved.

6.2.2 *Equivalent black area calibration:* Measure each of the calibration plates. Verify that all 16 dots are detected and that the EBA results measured and reported agree within 10% of the average of all 16 dots to those determined from the data supplied with the certified calibration plates. To calculate the EBA of the dots on the plates, multiply the nominal area as stated in the specifications in Appendix A.2 by the corrected contrast difference reported on the certificates provided with the plates. If they do not match, then check the hardware and/or the condition of the calibration plates. If necessary, verify the correct operation of the equipment with the manufacturer for its adherence to this standard.

NOTE 6: Due to digitization, measurement of the smallest dots on the lowest contrast plate at the minimum resolution prescribed in this method may give variation greater than 10% from the actual EBA when individual dots are evaluated for verification. Verification should be done by using the average EBA of all 16 dots on a plate.

6.3 *Maintenance:* Follow the manufacturers' instructions regarding the equipment maintenance.

6.3.1 The calibration plates should be stored in the dark or in a black plastic envelope to prevent discoloration and loss of contrast. They should be cleaned DRY to remove dust or lint. Avoid scratching the surface as this may cause the plates to be out of specification. Periodically measure the $Y_{c/2}$ value of the white square. If the calibration plates fall outside the specifications given in Appendix A.2, then they must be replaced.

6.3.2 Unless the ambient light changes, or the hardware settings have changed, it is not necessary to recalibrate the hardware for a particular analysis. It should be noted that, with time, light sources age and hence, there may be a loss of intensity. Thus, full calibration checks and hardware adjustments must be made as frequently as specified by the manufacturer.

7. Sampling and test specimens

7.1 Sample the paper or paperboard in accordance with TAPPI T 400 “Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product.”

7.2 *Paper and paperboard:* From each test unit, select ten or more sheets having a total exposed area (both sides) of at least 10 m². Keep the specimen sheets clean between two outer extra sheets.

NOTE 7: There may be instances where less than 10 m² is examined. This may be acceptable when the quantity of dirt in the paper or paperboard exceeds the minimum required to reach a chosen level of counting precision (see section 8.3) and the sample is representative of the manufacturing process.

7.3 *Pulp.*

7.3.1 *Pulp sheets:* From each test unit, select ten or more sheets having a total exposed area (both sides) of at least 10 m² (see Note 5). Keep the specimen sheets clean between two outer extra sheets.

7.3.1.1 Some pulp sheets contain deep corrugations which may cast shadows or prevent consistent detection of the dirt specks at some locations in the sheet. Such pulp sheets must be reformed into handsheets for examination.

7.3.2 *Slush or flash dried pulp:* Take a sample and form into specimen sheets in a carefully cleaned stainless steel sheet machine according to TAPPI T 272 “Forming Handsheets for Reflectance Testing of Pulp (Sheet Machine Procedure).” Make a sufficient number of sheets so that they have a total exposed area (both sides) of at least 4000 cm². Restrain dry the sheets in rings taking care to avoid contamination and wrinkling.

NOTE 8: In thick pulp sheets, dirt specks may be embedded throughout the thickness of the sheet. When pulp is reformed into a new product, then these embedded dirt specks may have a different impact.

8. Procedure

8.1 Carefully brush away any loose surface dirt specks. If the specimen is of low basis weight, like tissue, it may be necessary to back the specimen with a clean white sheet of paper before making the measurements. Avoid measuring samples which contain smudge marks and/or wrinkles as these could dramatically affect the results.

8.2 Follow the measurement procedure outlined in the instruction manual provided by the instrument manufacturer. Care should be taken to ensure that the specimen is held flat enough so that all dirt specks in the field of view are in focus (See 7.3.1.1).

8.3 Choose a consistent target of counting precision (% uncertainty) and measure enough paper surface to reach that precision. By the nature of the sampling of randomly distributed dirt, if one sheet of paper is found to contain N dirt specks, then replicate sheets of paper from the same lot should be found to contain $N \pm \sqrt{N}$ dirt specks two times out of three. For example, if a certain area of paper is found to contain 100 dirt specks, another region with the same area should have 100 ± 10 dirt specks, or a counting precision of 10%. If another specimen only

contains 25 dirt specks, then replicate areas should contain 25 ± 5 dirt specks for a counting precision of 20%. Therefore, to reach a consistent target of 10% uncertainty in the dirt count, one measures as much paper surface as needed to reach a minimum count of 100 dirt specks.

8.4 The precision of EBA parts per million (PPM) is more complicated to estimate than the counting precision of the dirt count, because the total count is inflated by many small dirt specks that contribute relatively little to the total EBA PPM. To reach a target precision on EBA PPM one should count at least twice as many dirt specks as would be needed to reach the same precision in the particle count. For example, one would count 200 dirt specks to reach a 10% precision on EBA PPM.

9. Report

9.1 Report the total equivalent black area as parts per million.

9.2 Report the total dirt count per square meter.

9.3 Report the % uncertainty, P , given by:

$$P(\%) = 100 / \sqrt{N}$$

Where: N is the total accumulated dirt count.

9.4 If the samples are pulp, report if the test was made on pulp sheets or handsheets.

9.5 Report any deviations from this method.

9.6 If a minimum size other than 0.02 mm^2 has been used it must be reported.

NOTE 9: The average EBA should be calculated from the equivalent black areas of the individual dirt specks. In the visual technique (T 437), it was necessary to sort the dirt into size categories and to calculate the average from the nominal size associated with each category. If the size categories are too coarse, or if the dirt distribution is highly skewed, then the calculation of the mean from the size histogram may overestimate the average by several percent.

10. Precision

10.1 The following estimate of precision is based on data from an interlaboratory trial conducted in 2002. Trial sample materials consisted of Newsprint and Paperboard. The nominal brightness (Tappi Standard Method T 525) was about 57% percent for the Newsprint and about 16% for the Paperboard.

NOTE 10: The scope specifies that this method is applicable to materials that have a brightness of at least 30%. However, the Paperboard used in the precision study was outside the scope of the method but was included because lower brightness materials are frequently tested using this method. Consequently, the precision statement with the Newsprint is most representative of this method.

10.2 The repeatability and reproducibility estimates were derived from four (4) laboratories for each sample and each test result was the mean of five (5) determinations. In all cases a sufficient number of particles were counted to keep % uncertainty of counting, P, to under 7%

Material	PPM (mm ² / m ²)			Dirt Count (specks/ m ²)		
	Grand Mean	Repeatability r and (%r)	Reproducibility R and (%R)	Grand Mean	Repeatability r and (%r)	Reproducibility R and (%R)
Newsprint	31.9	5.8 (18)	15.6 (49)	873	148 (17)	479 (55)
Paperboard	107	16.0 (15)	114 (107)	2567	489 (19)	2565 (100)

10.3 Repeatability and reproducibility are estimates of the maximum difference (at 95% confidence) which should be expected when comparing two test results for materials similar to those used in the trial under similar test conditions. These estimates may not be valid for different materials or testing conditions.

11. Keywords

Brightness, Dirt, Dirt count, Image analysis, Paper, Paperboard, Pulp, Equivalent Black Area (EBA), Y reflectance.

12. Additional information

12.1 Effective date of issue: To be assigned.

12.2 The method was modified in October 1997 to correct portions to agree with the modified calibration standard. The 2008 revision added the related methods in section 12.3. The 2015 edition included a note regarding regularly checking and possible replacing the calibration plates.

12.3 Related methods: ASTM D 6101 “Standard Test Method for Equivalent Black Area (EBA) of Dirt in Pulp, Paper and Paperboard by Image Analysis”; PAPTAC (Canada) D35P “Equivalent Black Area (EBA) of Visible Dirt in Pulp, Paper, and Paperboard by Image Analysis”; ISO 5350-4. All of these test methods are technically equivalent to this method and use the same calibration chart that was developed, calibrated, and presently sold through TAPPI PRESS.

Literature cited

1. Jordan, B. D. and Nguyen, N. G., "Emulating the TAPPI Dirt Count with a Microcomputer," JPPS, **14**(1), J16-19 (1988).

References

1. Jordan, B. D., Nguyen, N. G. and Bidmade, M., "Dirt Counting with Image Analysis," JPPS, **9**(2) TR60-64 (1983).
2. Jordan, B. D. and Nguyen, N. G., "Dirt Counting with Microcomputers," JPPS, **11**(3), J73-78 (1985).
3. Overington, I., "Vision and Acquisition," Pentech Press, p. 49, London (1976).

Appendix A.1

A.1.1 *The center-surround filter.* First, the digitized image is filtered with a "center-surround" filter. If the intensity of the picture point at each location (i, j) is called $X(i, j)$, the average background in a 1.0 mm^2 area centered on the point (i, j) is called $\langle X(i, j) \rangle$ then the filtered intensity $I(i, j) = X(i, j) - \langle X(i, j) \rangle$. There are various ways to estimate the background intensity $\langle X(i, j) \rangle$ but any picture points inside a dirt speck should be excluded from the estimate of $\langle X(i, j) \rangle$. If all the potential filter points fall within a dirt speck, then other means may be explored to sense the background immediately around the dirt speck (within 0.5 mm of the speck perimeter). For example, it may be necessary to expand the width of the background filter only at these locations where the usual filter is entirely within a very large speck.

A.1.2 *The contrast threshold.* The threshold T is the grey level increment corresponding to a difference of 10% reflectance. Each picture point (i, j) is considered "detected" as a part of a speck if $I(i, j) \geq T$.

A.1.3 *The EBA.* The EBA of a speck is proportional to the sum of the $I(i, j)$ values for all "detected" picture points:

$$EBA = k \sum_{(i,j) \Rightarrow (I(i,j) \geq T)} I(i, j)$$

The constant of proportionality is determined by the calibration procedure below. The total EBA is the sum of all the EBA values from the individual specks.

A.1.4 *The calibration plates.* The original EBA scale was established by the TAPPI Dirt Estimation Chart used in TAPPI Test Method T 437. A 1.0 mm^2 dot on that card has an EBA of 1.0 mm^2 by definition. The Ricco's law parameter I of such a dot equals the nominal area multiplied by the difference in reflectance of the white card and the black ink. This reflectance difference is 83%. The calibration plates used for the present method each have their own assigned value of reflectance difference between background and dot. For example, one of the plates may have an assigned reflectance difference of 20%, which is only one quarter as contrasty as the dots on the original dirt estimation chart and a dot on that plate with a physical area of 1.0 mm^2 would have a nominal EBA of 0.25 mm^2 .

A.1.4.1 Each calibration plate contains 16 dots with physical areas ranging from 0.04 mm² to 1.5 mm². The nominal EBA of each dot will be given by:

$$\text{EBA (nominal)} = (\text{stated physical area}) \times \frac{(\text{Background reflectance-spot reflectance})}{83\%}$$

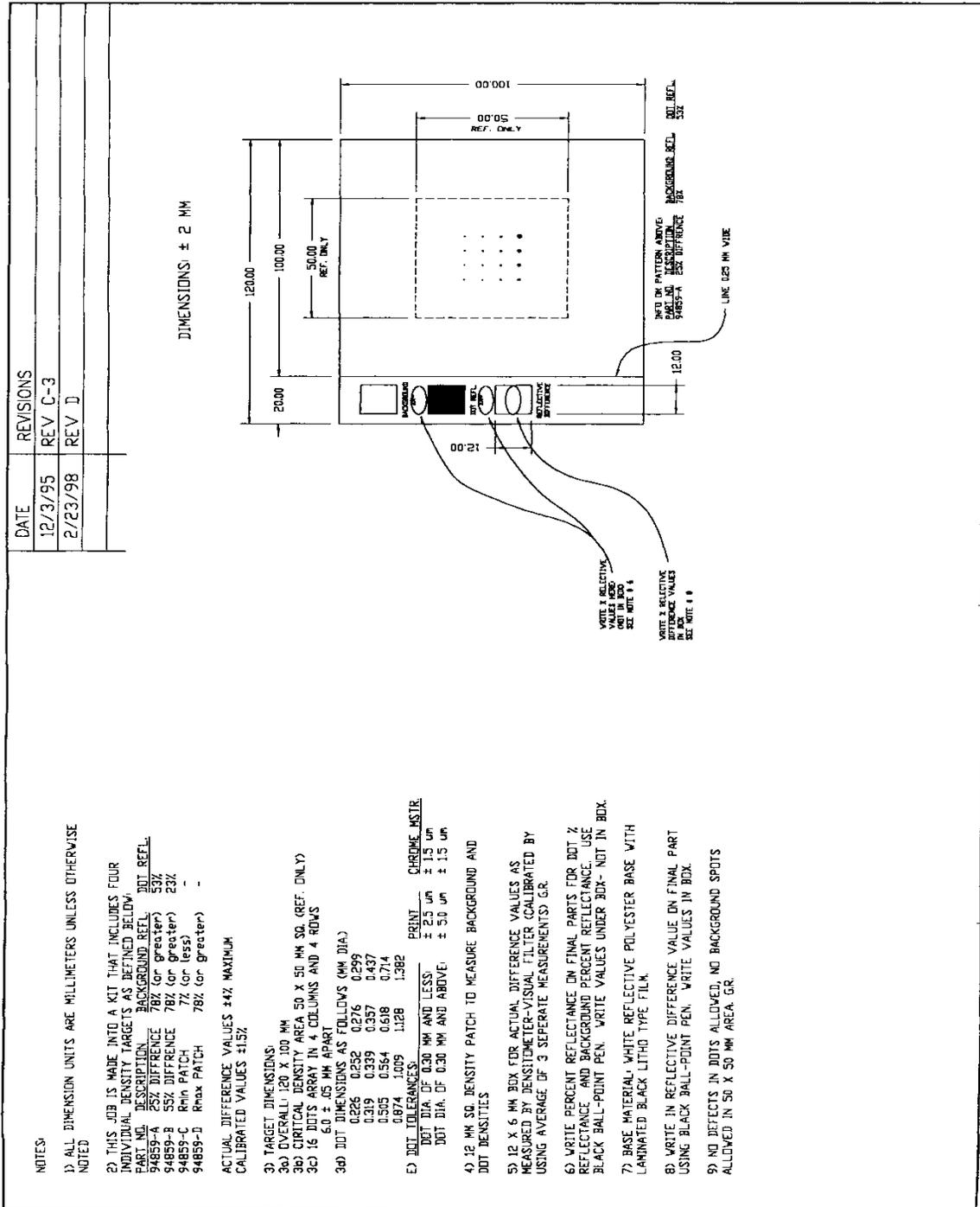


Fig. 1. Preferred calibration plate design specifications.

A.1.5 *The calibration process.* Calibration involves determining the calibration constant k in the calculation of EBA. Use the instrument to measure the EBA of the 16 dots on the calibration plate with the calibration constant k temporarily reset to 1.0. Determine the proper calibration constant k as the ratio of the nominal EBA to the measured EBA of the 16 dots on the plate.

$$k = \frac{\text{Nominal EBA}}{\text{Measured EBA}}$$

Equivalently, k is the slope of a plot of Nominal EBA versus Measured EBA for the 16 dots.

A.1.5.1 If the instrument is functioning well, such a plot should be a straight line, and the k value determined from the lighter calibration plate should agree with the k value determined by a darker plate.

Appendix A.2

A.2.1 The plates were designed assuming the reflectance contrast of each of the 16 dots in a set would equal that of the reference gray square to the side of the dots in a set. Consequently, each set of calibration plates is tested and certified by an independent accredited laboratory. The plates in a set are assigned a serial number and provided with a certificate that reports the $Y_{c/2}$ reflectances for the black and white plates as well as the $Y_{c/2}$ correction factors for the dots on the plate with the highest contrast. Only the $Y_{c/2}$ values, reported on the certificate, must be used when calibrating the apparatus.

A.2.2 Figures 1 and 2 show the recommended design specifications and drawings of the calibration plates. The design must meet the required specifications stated in Section 6.2.1.2.

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

