WI 220808.08

T 547

BALLOT NO. 3 SARG

DRAFT NO. 02

DATE 06/01/2023

WORKING GROUP
CHAIR Ben Frank

SUBJECT
CATEGORY Physical Properties

RELATED
METHODS See "Additional Information"

Air permeance of paper and paperboard (Sheffield method)

(Five-year review of Official Method T 547 om-18)

(Underscores, notes, and strikethroughs show changes from Draft 1)

1. Scope

1.1 This method is used to measure the air permeance of a circular area of paper using a pressure differential of approximately 10 kPa (1.5 psig). In order to accommodate a wide range of paper products, rubber clamping plates are available for five commonly used orifice diameters: 9.5 mm (0.375 in.), 19.1 mm (0.75 in.), 38.1 mm (1.50 in.), 57.2 mm (2.25 in.), and 76.2 mm (3.00 in.). The air flow range for this method is 0 to 3348 mL/min (0 to 400 Sheffield units). Instruments are available with either variable area flowmeters (glass tubes with internal tapers and floats) or electronic mass flowmeters.

1.2 This method measures the air that passes through the test specimen, along with any possible leakage

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of air across the surface; therefore it is unsuitable for papers with rough surfaces which cannot be securely clamped so as to avoid significant surface leakage.

1.3 For other methods of measuring the air resistance of paper using a 28.6 mm (1.125 in.) orifice diameter, refer to TAPPI T 460 "Air Resistance of Paper (Gurley Method)" or a test that operates at a pressure differential of 1.22 kPa, or TAPPI T 536 "Resistance of Paper to Passage of Air (High Pressure Method)" for 3 kPa.

2. Summary

This method measures the rate of air flow that is directed to the rubber clamping rings that hold the test specimen. Compressed air, regulated at a fixed pressure, passes through a flow measuring device just before it is directed to the paper specimen test area, which is defined by the diameter of the orifice in the rubber clamping rings. Air that passes through the paper specimen escapes to the atmosphere through holes in the downstream clamping plate.

3. Significance

The air permeance of paper may be used as an indirect indicator of variables such as: degree of beating, absorbency (penetration of oil, water, etc.), apparent specific gravity, and filtering efficiency for liquids or gases. Air permeance is influenced by the internal structure and also surface finish. Internal structure is controlled largely by the type and length of fibers, degree of hydration, orientation, and compaction of the fibers; as well as by the type and amount of fillers and sizing. The measurement of air permeance is a useful control test for machine production, but due to the number and complexity of factors outlined above, careful judgment should be used in the specification limits for air permeance.

4. Definition

4.1 Air permeance is the property of a sheet that allows the passage of air when a pressure difference exists across the boundaries of the specimen. It is quantified by measuring the rate of air flow through a specimen of given dimensions under specified experimental conditions.

4.2 Porosity is the ratio of pore volume to bulk volume. The porosity of paper is commonly evaluated by measuring its air permeance.

5. Apparatus[1]

5.1 The apparatus consists of a pressure controller for the air supply, a pressure measuring device, an air flow measuring device, a test head (rubber ring clamping assembly) which clamps the specimen and establishes the test area, connecting tubing, and calibration restrictors. The air supply must be capable of supplying the necessary flow and pressure to the system. It must be free of oil, water and other contaminants. The ideal condition for the air is to be equal to the temperature and humidity of the air in the conditioned laboratory environment.

5.1.1 A pressure controller to supply regulated air pressure to the system, upstream of the flowmeter. In the instruments that utilize variable area flowmeters with air bleeds for calibration, the pressure shall be regulated to 10.34 ± 0.2 kPa (1.50 psig). In the instruments that utilize mass flowmeters with no air bleeds, the pressure shall be regulated to 9.85 ± 0.2 kPa (1.43 psig), as this is the pressure measured downstream of the typical variable area flowmeters that have been calibrated by using air bleeds to atmosphere.

5.1.2 A pressure measuring device capable of measuring the regulated air pressure to the specified accuracy.

5.1.3 An air flowmeter having the capability to measure the range of flow required for the samples to be tested. A range of 0 to 3348 mL/min, referenced to 1 atmosphere, 21°C (0 to 400 Sheffield units) is recommended. The flow/pressure drop system response is defined in Equation 1:

$$P = 9.86 - (0.4166 \times 10^{-3})\, Q \qquad (1)$$

where:

P = specimen pressure differential, kPa
Q = airflow through the specimen (mL/min ref. @ 1 atmosphere, 21°C)

NOTE 1: Equation 1 for the system response was obtained from the traditional variable area flowmeter apparatus. This relationship is included here because systems that use electronic mass flowmeters must be "trimmed" to give a similar response, otherwise there will be significant differences in the test results *(1)*.

5.1.4 A test head which securely clamps the specimen between pairs of rubber plates that limit the flow of air to the area of the specimen exposed by the orifice. Rubber clamping plates are available for the five commonly used orifice diameters: 9.5 mm (0.375 in.), 19.1 mm (0.75 in.), 38.1 mm (1.50 in.), 57.2 mm (2.25 in.), and 76.2 mm (3.00 in.). The pressurized side of the test head is located downstream from the flowmeter, and the air that discharges from the test specimen is free to exhaust to atmosphere.

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[1] Names of suppliers of testing equipment and materials for this method may be found on the Test Equipment Suppliers list, available as part of the CD or printed set of Standards, or on the TAPPI website general Standards page.

5.1.5 Connecting tubing, of the proper length and diameter, as specified by the manufacturer.

5.1.6 Calibration restrictors, to be used as standards for checking or setting the calibration of the air flow measuring device.

6. Calibration

6.1 The flow measuring device can be calibrated using electronic mass flowmeters that have "NIST"-traceable calibration curves. The relationship between the traditional "Sheffield unit" and engineering units (mL/min) is shown in Table 1 (*2*). When using calibration restrictors, follow the manufacturer's instructions.

Table 1. Conversion of traditional Sheffield units to engineering units

Tube #3 (SU)	*Flow (mL/min)*	*Tube #2 (SU)*	*Flow (mL/min)*	*Tube #1 (SU)*	*Flow (mL/min)*
0	0	50	313	160	1342
5	35	60	404	180	1509
10	70	70	495	200	1676
15	104	80	585	220	1843
20	139	90	676	240	2010
25	174	100	767	260	2178
30	209	110	858	280	2345
35	244	120	949	300	2512
40	278	130	1039	320	2679
45	313	140	1130	340	2846
50	348	150	1221	360	3014
55	383	160	1312	380	3181
60	418	170	1403	400	3348
		180	1493		
		190	1584		

Sheffield Tube #	Recommended range Sheffield units (SU)	Conversion to engineering units (mL/minute)
3	0 - 56	mL/min = 6.96 (SU)
2	56 - 170	mL/min = 9.08 (SU) - 141
1	170 - 400	mL/min = 8.36 (SU) + 4

mL/min = milliliters per minute referenced to 760 mm Hg and 21 °C

6.2 Air pressure calibration can be performed with instruments traceable to the "NIST." A pneumatic dead-weight tester is typically used.

7. Sampling

To determine conformance to product specifications, select a sample of paper in accordance with TAPPI T 400 "Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product."

8. Test specimens

Cut 10 test specimens from each test unit of the sample. A 125-mm (5-in.) square, or larger size is adequate. Each measured area should be free of thin or thick areas atypical of the sheet sample formation, and free of watermarks.

9. Conditioning

Precondition, condition and test the specimens in an atmosphere in accordance with TAPPI T 402 "Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets, and Related Products."

10. Procedure

10.1 Calibrate the air flowmeter system in accordance with the manufacturer's instructions.

10.2 Select the appropriate size rubber orifice plates. If using the type where various size inserts fit a master test head assembly, make sure that the gasket plate cavities and rubber plate surfaces are clean. Insert the upper and lower rubber orifice plates into the holders.

10.3 Insert the test specimen in the test head, between the rubber plates. Generally, if the smoother side of the specimen is facing downwards (towards the pressurized side), there will be less surface leakage.

10.4 Clamp the specimen between the rubber plates. Follow the manufacturer's recommendation for the clamping pressure. Some test heads are pneumatically loaded, and some are mechanically loaded using a toggle-clamp.

10.5 If using variable area flowmeter tubes, insert the plug that is connected to the flexible tubing (from the test head) into the quick coupling of the appropriate flowmeter tube. For other types of equipment, follow the manufacturer's recommendations for connecting the test air.

10.6 Apply test air pressure to the specimen after it is securely clamped. Some instruments are equipped with a toggle shut-off valve on the side of the test head base, while others have electrical controls.

NOTE 2: It is desirable to clamp the specimen with no air flow passing through the orifice, as air flow can cause the specimen to deflect. This may result in a creased sample, particularly when testing thin papers using the largest orifice size.

10.7 Record the flow measurement value after 4 ± 1 second.

10.7.1 For instruments with variable area flowmeter tubes, the reading should be between the high and low calibration rings. Record the scale reading using the top of the float as soon as it is steady. If the reading is higher or lower than the calibration range, take a reading on the adjacent tube that would be in the proper range. If the reading is too high for the highest range flow tube, then select a smaller orifice plate and return to step 10.2. If the reading is too low for the lowest range flow tube, then select a larger orifice plate and return to step 10.2. After testing the specimen, close the air shut-off valve and release the specimen.

NOTE 3: To minimize errors, the largest possible orifice size should be used. Small orifice plates that keep the air flow readings below 30 Sheffield units may exhibit significant errors with only a small amount of air leakage in the instrument.

10.7.2 For instruments that use electronic air flowmeters with digital readout, follow the manufacturer's recommendations.

10.8 Make a total of ten (10) readings, each on a separate test specimen (or an area of a larger sheet that has not been previously clamped).

10.9 When comparing several samples, maintain a consistent orifice size. In practice, it is possible to measure using different orifice sizes and to normalize readings to one size. Refer to the formulas in Appendix A.2 for detailed air permeance calculations.

11. Report

11.1 Report the average of ten (10) readings in Sheffield Units, specifying the orifice diameter; or alternately in ISO Air Permeance Units (micrometer/Pascal-second). Also record the highest and lowest observed values, plus any values rejected in accordance with TAPPI T 1205 "Dealing with Suspect (Outlying) Test Determinations."

11.2 Report the orifice diameter of the rubber plate used.

11.3 Report the flow tube number when using the variable area flowmeter type of instrument.

11.4 Report the identification of the specimen side placed downwards in the measuring head.

12. Precision

12.1 The following estimates of repeatability and reproducibility are based on data from the CTS-TAPPI Interlaboratory Program from 1997 through 2001. The materials on which these data are based were various grades and weights of printing and writing papers. Only participants that were judged as acceptable by the interlaboratory analysis were included. The precision estimates are based on 10 determinations per test result and one test result per lab, per material. A more detailed chart of example results is included below.

12.2 Repeatability (within a laboratory) = 8.3%.

12.3 Reproducibility (between laboratories) = 17.5%.

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

Data Table of porosity results (Sheffield Units)

Grand Mean	*Stnd Dev Between Labs*	*Repeatability r and %r*		*Reproducibility R and %R*		*Labs Included*
279	16	17	6.1%	44	15.9%	58
181	13	11	6.2%	35	19.4%	55
103	8	9	8.9%	22	21.2%	60
87.2	5.1	9.5	10.9%	14.1	16.2%	53

13. Additional Information

13.1 Effective date of issue: To Be Assigned

13.2 Related methods: TAPPI Useful Method 524; ISO 5636-4.

13.3 The following changes have been made upon review of this method:

13.3.1 In 2022, the keyword was changed from Air permeability to Air permeance to bring it into alignment with the method overall, and this section was updated.

13.3.2 In 2018 the title of this method was changed from "Air Permeability of Paper and Paperboard (Sheffield Method)" to "Air Permeance of Paper and Paperboard (Sheffield Method)" in order to better identify the property being tested. Air permeability is a property of the material and independent of the thickness, whereas air permeance is a better term for a specimen of paper of a given thickness. Air permeability is air permeance per unit thickness. The precision data was also updated.

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13.4 The permeance equations in Appendix A.2 are calculated using Equation 1, which defines the decrease in test specimen differential pressure as a function of increasing flow. The flow restrictions in the apparatus result in a 14% loss in test specimen differential pressure within the working range from 0 to 3348 mL/minute air flow.

Deleted: 13.5 Precision data was updated in this version.

14. Keywords

Paper, Paperboard, Air permeance, Porosity

Deleted: permeability

Appendix A. Conversion of Sheffield units to Gurley Hill s/100 mL

A.1 *Estimating equation for Gurley Hill units vs. Sheffield units using plates with 19.0 mm (0.75 in.) orifice.* This is based on approximately 300 tests (T 460).

CAUTION: This is unreferenced data from UM 524. The conversion has not been formally investigated or reported in the literature but is apparently satisfactory for some work.

x_1 = Gurley Hill reading in s/100 mL/in^2 of air

x_2 = Sheffield units using 19.0 mm orifice

$\log x_1 = 3.70975 - 1.134 \log x_2$

For instance:

Sheffield Units	*Gurley Hill (s/100 mL)*
200	13
100	28
50	61
20	172

A.2 The relationship to air permeance (P), in micrometers per pascal second, referenced to the density of air at the test head differential pressure calculated in Equation 1, is as follows:

Orifice Diameter	Equation
9.5 mm (0.375 in.)	$P = \dfrac{Q}{42.181 - 0.00178\,Q}$
19.1 mm (0.75 in.)	$P = \dfrac{Q}{168.61 - 0.00712\,Q}$
38.1 mm (1.50 in.)	$P = \dfrac{Q}{674.42 - 0.0285\,Q}$
57.2 mm (2.25 in.)	$P = \dfrac{Q}{}$

1520.4 - 0.0642 *Q*

76.2 mm (3.00 in.) $P = \dfrac{Q}{2697.7 - 0.1140\,Q}$

P = air permeance, in micrometers per pascal second.

Q = air flow, in mL/min referenced to 21°C, 760 mm Hg (If necessary, convert Sheffield units to mL/min using the equations at the bottom of Table 1).

Appendix B. Calibration procedures for variable area flow tubes and orifices

B.1 Install and connect the instrument according to the manufacturer's instructions.

B.2 Adjust the low pressure regulator until the mercury column in the manometer indicates 10.3 ± 2 kPa (1.5 ± 0.03 psi). (Read the top of the mercury meniscus.)

B.3 Insert one plug of the plastic tubing into No. 1 coupling of the flowmeter and the other plug into No. 1 coupling of the master manifold (calibration orifice).

B.4 Close the toggle valve on the No. 1 calibration orifice and adjust the float positioning knob on the flowmeter until the top of the float is aligned with the lower red line on No. 1 scale. (Some instruments have other devices to open or close the calibration orifice, or have only an opening to be closed using the technician's finger.)

B.5 Open the toggle valve and observe where the float stops.

B.5.1 If the float position is higher than the upper red line, turn the calibrating knob counterclockwise until the float falls an approximately equal distance below the upper red line, and then use the float positioning knob to raise the float to the upper red line.

B.5.2 If the float position is lower than the upper red line, turn the calibrating knob clockwise until the float rises above the red line an approximately equal distance, and then lower the float to the red line with the float positioning knob.

B.6 Repeat steps 4 and 5 until closing the toggle valve causes the float to fall to the lower red line and opening it causes the float to rise to the upper red line.

B.7 Repeat the above procedure using the appropriate couplings and orifices for the other two columns.

B.8 After calibration, recheck the air pressure. Pressure as indicated on the mercury manometer must be 10.3 ± 0.2 kPa when no connection is made to the column couplings on the flowmeter. This pressure may drop a maximum of 0.2 kPa when the flowmeter is connected to the test head, without affecting the proper operation of the gauge.

B.9 Check the calibration each time the air supply is turned on. When the instrument is being used for long periods, the calibration must be checked at least twice during an 8-h period.

B.10 Since the three scales on the flowmeter are overlapping, the accuracy of the calibrating orifices on the gauge must be checked in the following manner:

B.10.1 The float in No. 1 column must be aligned with the lower red line when this column is connected to the No. 2 calibrating orifice and it is open. In addition, the float in No. 2 column must be aligned with the upper red line when this column is connected to the No. 1 calibrating orifice in the closed position and also when connected to the open No. 2 calibrating orifice.

B.10.2 The float in the No. 2 column must be aligned with the lower red line when this column is connected to the No. 2 calibrating orifice in the closed position and also when connected to the open No. 3 calibrating orifice. In addition, the float in the No. 3 column must be aligned with the upper red line when this column is connected to the open No. 3 calibrating orifice, and when connected to the closed No. 2 calibrating orifice.

B.10.3 When any discrepancies are found, clean the obstructed calibrating orifice by blowing it out with compressed air. If this is not sufficient, use a little solvent such as toluene or acetone before blowing it out. If the orifice cannot be cleaned adequately using solvents and compressed air, then the gauge should be returned to the manufacture for cleaning and recalibration.

Literature cited

1. Hagerty, G.A., and Walkinshaw, J.W., "Comparison of Air Permeability Measurements Among Commonly Used TAPPI Methods," *TAPPI 1992 Process and Product Quality Conference Proceedings* (October): 73.
2. Hagerty, G.A. and Walkinshaw, J.W., "The Sheffield Unit - Update to Today's Technology," *TAPPI Journal* **71**(1): 101 (1988).

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

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