Designation: E96/E96M – 16

Standard Test Methods for
Water Vapor Transmission of Materials[1]

This standard is issued under the fixed designation E96/E96M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 These test methods cover the determination of water vapor transmission (WVT) of materials through which the passage of water vapor may be of importance, such as paper, plastic films, other sheet materials, fiberboards, gypsum and plaster products, wood products, and plastics. The test methods are limited to specimens not over 1¼ in. [32 mm] in thickness except as provided in Section 9. Two basic methods, the Desiccant Method and the Water Method, are provided for the measurement of permeance, and two variations include service conditions with one side wetted and service conditions with low humidity on one side and high humidity on the other. Agreement should not be expected between results obtained by different methods. The method should be selected that more nearly approaches the conditions of use.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. However, derived results can be converted from one system to the other using appropriate conversion factors (see Table 1).

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation
C1809 Practice for Preparation of Specimens and Reporting of Results for Permeance Testing of Pressure Sensitive Adhesive Sealed Joints in Insulation Vapor Retarders
D449/D449M Specification for Asphalt Used in Dampproofing and Waterproofing
D2301 Specification for Vinyl Chloride Plastic Pressure-Sensitive Electrical Insulating Tape
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 Definitions of terms used in this standard will be found in Terminology C168, from which the following is quoted:

"*water vapor permeability*—the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

Discussion—Permeability is a property of a material, but the permeability of a body that performs like a material may be used. Permeability is the arithmetic product of permeance and thickness.

water vapor permeance—the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

Discussion—Permeance is a performance evaluation and not a property of a material.

3.2 *water vapor transmission rate*—the steady water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface."

4. Summary of Test Methods

4.1 In the Desiccant Method the test specimen is sealed to the open mouth of a test dish containing a desiccant, and the assembly placed in a controlled atmosphere. Periodic weighings determine the rate of water vapor movement through the specimen into the desiccant.

4.2 In the Water Method, the dish contains distilled water, and the weighings determine the rate of vapor movement

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[1] These test methods are under the jurisdiction of ASTM Committee C16 on Thermal Insulation and are the direct responsibility of Subcommittee C16.33 on Insulation Finishes and Moisture.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Metric Units and Conversion Factors[A,B]

Multiply	by	To Obtain (for the same test condition)
	WVT	
g/h·m^2	1.43	grains/h·ft^2
grains/h·ft^2	0.697	g/h·m^2
	Permeance	
g/Pa·s·m^2	1.75 × 10^7	1 Perm (inch-pound)
1 Perm (inch-pound)	5.72 × 10^{-8}	g/Pa·s·m^2
	Permeability	
g/Pa·s·m	6.88 × 10^8	1 Perm inch
1 Perm inch	1.45 × 10^{-9}	g/Pa·s·m

[A] These units are used in the construction trade. Other units may be used in other standards.

[B] All conversions of mm Hg to Pa are made at a temperature of 0°C.

through the specimen from the water to the controlled atmosphere. The vapor pressure difference is nominally the same in both methods except in the variation, with extremes of humidity on opposite sides.

5. Significance and Use

5.1 The purpose of these tests is to obtain, by means of simple apparatus, reliable values of water vapor transfer through permeable and semipermeable materials, expressed in suitable units. These values are for use in design, manufacture, and marketing. A permeance value obtained under one set of test conditions may not indicate the value under a different set of conditions. For this reason, the test conditions should be selected that most closely approach the conditions of use. While any set of conditions may be used and those conditions reported, standard conditions that have been useful are shown in Appendix X1.

6. Apparatus

6.1 *Test Dish*—The test dish shall be of any noncorroding material, impermeable to water or water vapor. It may be of any shape. Light weight is desirable. A large, shallow dish is preferred, but its size and weight are limited when an analytical balance is chosen to detect small weight changes. The mouth of the dish shall be as large as practical and at least 4.65 in.^{2} [3000 mm^2]. The desiccant or water area shall be not less than the mouth area except if a grid is used, as provided in 12.1, its effective area shall not exceed 10 % of the mouth area. An external flange or ledge around the mouth, to which the specimen may be attached, is useful when shrinking or warping occurs. When the specimen area is larger than the mouth area, this overlay upon the ledge is a source of error, particularly for thick specimens. This overlay material should be masked as described in 10.1 so that the mouth area defines the test area. The overlay material results in a positive error, indicating excessive water vapor transmission. The magnitude of the error is a complex function of the thickness, ledge width, mouth area, and possibly the permeability. This error is discussed by Joy and Wilson (**1**)[3] (see 13.4.3). This type of error should be limited to about 10 to 12 %. For a thick specimen the ledge should not exceed ¾ in. [19 mm] for a 10-in. [254-mm] or larger mouth (square or circular) or ⅛ in. [3 mm] for a 5-in. [127-mm] mouth (square or circular). For a 3-in. [76-mm] mouth (square or circular) the ledge should not exceed 0.11 in. [2.8 mm] wide. An allowable ledge may be interpolated for intermediate sizes or calculated according to Joy and Wilson.(**1**) A rim around the ledge (Fig. X2.1) may be useful. If a rim is provided, it shall be not more than ¼ in. [6 mm] higher than the specimen as attached. Different depths may be used for the Desiccant Method and Water Method, but a ¾-in. [19-mm] depth (below the mouth) is satisfactory for either method.

6.2 *Test Chamber*—The room or cabinet where the assembled test dishes are to be placed shall have a controlled temperature (see Note 1) and relative humidity. Some standard test conditions that have been useful are given in Appendix X1. The temperature chosen shall be determined according to the desired application of the material to be tested (see Appendix X1). The relative humidity shall be maintained at 50 ± 2 %, except where extremes of humidities are desired, when the conditions shall be 100 ± 1.8°F [38 ± 1°C] and 90 ± 2 % relative humidity. Both temperature and relative humidity shall be measured frequently[4] or preferably recorded continuously. Air shall be continuously circulated throughout the chamber, with a velocity sufficient to maintain uniform conditions at all test locations. The air velocity over the specimen shall be between 0.066 and 1 ft/s [0.02 and 0.3 m·s^{-1}]. Suitable racks shall be provided on which to place the test dishes within the test chamber.

NOTE 1—Simple temperature control by heating alone is usually made possible at 90°F [32°C]. However, it is very desirable to enter the controlled space, and a comfortable temperature is more satisfactory for that arrangement. Temperatures of 73.4°F [23°C] and 80°F [26.7°C] are in use and are satisfactory for this purpose. With cyclic control, the average test temperature may be obtained from a sensitive thermometer in a mass of dry sand. The temperature of the chamber walls facing a specimen over water should not be cooler than the water to avoid condensation on the test specimen.

6.3 *Balance and Weights*—The balance shall be sensitive to a change smaller than 1 % of the weight change during the period when a steady state is considered to exist. The weights used shall be accurate to 1 % of the weight change during the steady-state period (Note 2). A light wire sling may be substituted for the usual pan to accommodate a larger and heavier load.

6.4 *Thickness-Measuring Gage*—The nominal thickness of the specimen shall be determined using a thickness-measuring gage with an accuracy of ±1 % of the reading or 0.0001 in. [0.0025 mm], whichever is greater.

NOTE 2—For example: 1-perm [57 ng·Pa^{-1}·s^{-1}·m^{-2}] specimen 10 in. [254 mm] square at 80°F [26.7°C] passes 8.6 grains or 0.56 g/day. In 18 days of steady state, the transfer is 10 g. For this usage, the balance must have a sensitivity of 1 % of 10 g or 0.1 g and the weights must be accurate to 0.1 g. If, however, the balance has a sensitivity of 0.2 g or the weights are no better than 0.2 g, the requirements of this paragraph can be met by continuing the steady state for 36 days. An analytical balance that is much more sensitive will permit more rapid results on specimens below 1 perm [57 ng·Pa^{-1}·s^{-1}·m^{-2}] when the assembled dish is not excessively heavy.

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[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

[4] The minimum acceptable is to perform this measurement each time the sample is weighed.

7. Materials

7.1 *Desiccant and Water:*

7.1.1 For the Desiccant Method, anhydrous calcium chloride in the form of small lumps that will pass a No. 8 [2.36-mm] sieve, and free of fines that will pass a No. 30 [600-µm] sieve, shall be used (Note 3). It shall be dried at 400°F [200°C] before use.

NOTE 3—If $CaCl_2$ will react chemically on the specimen, an adsorbing desiccant such as silica gel, activated at 400°F [200°C], may be used; but the moisture gain by this desiccant during the test must be limited to 4 %.

7.1.2 For the Water Method, distilled water shall be used in the test dish.

7.2 *Sealant*—The sealant used for attaching the specimen to the dish, in order to be suitable for this purpose, must be highly resistant to the passage of water vapor (and water). It must not lose weight to, or gain weight from, the atmosphere in an amount, over the required period of time, that would affect the test result by more than 2 %. It must not affect the vapor pressure in a water-filled dish. Molten asphalt or wax is required for permeance tests below 4 perms [230 $ng \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$]. Sealing methods are discussed in Appendix X2.

8. Sampling

8.1 The material shall be sampled in accordance with standard methods of sampling applicable to the material under test. The sample shall be of uniform thickness. If the material is of nonsymmetrical construction, the two faces shall be designated by distinguishing marks (for example, on a one-side-coated sample, "I" for the coated side and "II" for the uncoated side).

9. Test Specimens

9.1 Test specimens shall be representative of the material tested. When a product is designed for use in only one position, three specimens shall be tested by the same method with the vapor flow in the designated direction. When the sides of a product are indistinguishable, three specimens shall be tested by the same method. When the sides of a product are different and either side may face the vapor source, four specimens shall be tested by the same method, two being tested with the vapor flow in each direction and so reported.

9.2 A slab, produced and used as a laminate (such as a foamed plastic with natural "skins") may be tested in the thickness of use. Alternatively, it may be sliced into two or more sheets, each being separately tested and so reported as provided in 9.4, provided also, that the "overlay upon the cup ledge" (6.1) of any laminate shall not exceed ⅛ in. [3 mm].

9.3 When the material as used has a pitted or textured surface, the tested thickness shall be that of use. When it is homogeneous, however, a thinner slice of the slab may be tested as provided in 9.4.

9.4 In either case (9.2 or 9.3), the tested overall thickness, if less than that of use, shall be at least five times the sum of the maximum pit depths in both its faces, and its tested permeance shall be not greater than 5 perms [≈ 300 $ng \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$].

9.5 For homogeneous (not laminated) materials with thickness greater than ½ in., the overall nominal thickness of each specimen shall be measured with an accuracy of ±1 % of the reading at the center of each quadrant and the results averaged.

9.6 When testing pressure sensitive adhesive sealed joints used in insulation vapor retarder systems, prepare the specimens according to Practice C1809.

9.7 When testing any material with a permeance less than 0.05 perms [3 $ng \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$] or when testing a low permeance material that may be expected to lose or gain weight throughout the test (because of evaporation or oxidation), it is strongly recommended that an additional specimen, or "dummy," be tested exactly like the others, except that no desiccant or water is put in the dish. Failure to use this dummy specimen to establish modified dish weights may significantly increase the time required to complete the test. Because time to reach equilibrium of water permeance increases as the square of thickness, thick, particularly hygroscopic, materials may take as long as 60 days to reach equilibrium conditions.

10. Attachment of Specimen to Test Dish

10.1 Attach the specimen to the dish by sealing (and clamping if desired) in such a manner that the dish mouth defines the area of the specimen exposed to the vapor pressure in the dish. If necessary, mask the specimen top surface, exposed to conditioned air so that its exposure duplicates the mouth shape and size and is directly above it. A template is recommended for locating the mask. Thoroughly seal the edges of the specimen to prevent the passage of vapor into, or out of, or around the specimen edges or any portion thereof. The same assurance must apply to any part of the specimen faces outside their defined areas. Suggested methods of attachment are described in Appendix X2.

NOTE 4—In order to minimize the risk of condensation on the interior surface of the sample when it is placed in the chamber, the temperature of the water prior to preparation of the test specimen should be within ±2°F [±1°C] of the test condition.

11. Procedure for Desiccant Method

11.1 Fill the test dish with desiccant within ¼ in. [6 mm] of the specimen. Leave enough space so that shaking of the dish, which must be done at each weighing, will mix the desiccant.

11.2 Attach the specimen to the dish (see 10.1) and place it in the controlled chamber, specimen up, weighing it at once. (This weight may be helpful to an understanding of the initial moisture in the specimen.)

11.3 Weigh the dish assembly periodically, often enough to provide eight or ten data points during the test. A data point is the weight at a particular time. The time that the weight is made should be recorded to a precision of approximately 1 % of the time span between successive weighing. Thus, if weighings are made every hour, record the time to the nearest 30 s; if recordings are made every day, a time to the nearest 15 min would be allowed. At first the weight may change rapidly; later a steady state will be reached where the rate of change is substantially constant. Weighings should be accomplished without removal of the test dishes from the controlled atmosphere, but if removal is prescribed necessary, the time the specimens are kept at different conditions, temperature or relative humidity, or both, should be kept to a minimum. When results of water vapor transmission are expected to be less than 0.05 perm [3 $ng \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$], a dummy specimen is strongly recommended. Such a dummy specimen should be attached to an empty cup in the normal manner. The environmental effects of temperature variation and buoyancy variability due to barometric pressure fluctuation can be arithmetically tared out of the weighing values. This precaution permits earlier and more reliable achievement of equilibrium conditions. Analyze the results as prescribed in 13.1.

11.4 Terminate the test or change the desiccant before the water added to the desiccant exceeds 10 % of its starting weight. This limit cannot be exactly determined and judgement is required. The desiccant gain may be more or less than the dish weight-gain when the moisture content of the specimen has changed.

NOTE 5—The WVT of some materials (especially wood) may depend on the ambient relative humidity immediately before the test. An apparent hysteresis results in higher WVT if the prior relative humidity was above the test condition and vice versa. It is therefore recommended that specimens of wood and paper products be conditioned to constant weight in a 50 % relative humidity atmosphere before they are tested. Some specimens may be advantageously preconditioned to minimize the moisture that the specimen will give up to the desiccant. This applies when the specimen is likely to have high moisture content or when it is coated on the top (vapor source) side.

12. Procedure for Water Method

12.1 Fill the test dish with distilled water to a level ¾ ± ¼ in. [19 ± 6 mm] from the specimen. The air space thus allowed has a small vapor resistance, but it is necessary in order to reduce the risk of water touching the specimen when the dish is handled. Such contact invalidates a test on some materials such as paper, wood, or other hygroscopic materials. The water depth shall be not less than ⅛ in. [3 mm] to ensure coverage of the dish bottom throughout the test. However, if the dish is of glass, its bottom must be visibly covered at all times but no specific depth is required. Water surges may be reduced by placing a grid of light noncorroding material in the dish to break the water surface. This grid shall be at least ¼ in. [6 mm] below the specimen, and it shall not reduce the water surface by more than 10 %.

NOTE 6—For the Water Method, baking the empty dish and promptly coating its mouth with sealant before assembly is recommended. The water may be added most conveniently after the specimen is attached, through a small sealable hole in the dish above the water line.

12.2 Attach the specimen to the dish (see 10.1). Some specimens are likely to warp and break the seal during the test. The risk is reduced by preconditioning the specimen, and by clamping it to the dish ledge (if one is provided).

12.3 Weigh the dish assembly and place it in the controlled chamber on a true horizontal surface. Follow the procedure given in 11.3. If the test specimen cannot tolerate condensation on the surface, the dish assembly shall not be exposed to a temperature that differs by more than 5°F [3°C] from the control atmosphere to minimize the risk of condensation on the specimen. When results of water vapor transmission are expected to be less than 0.05 perm [3 $ng \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$], a dummy specimen is strongly recommended. Such a dummy specimen should be attached to an empty cup in the normal manner. The environment effects of temperature variation and buoyancy variability due to barometric pressure fluctuation can be arithmetically tared out of the weighing values. This precaution permits earlier and more reliable achievement of equilibrium conditions. Analyze the results as prescribed in 13.1.

12.4 Where water is expected to be in contact with the barrier in service, proceed as in 11.3 except place the dish in an inverted position. The dish must be sufficiently level so that water covers the inner surface of the specimen despite any distortion of the specimen due to the weight of the water. With highly permeable specimens it is especially important to locate the test dish so that air circulates over the exposed surface at the specified velocity. The test dishes may be placed on the balance in the upright position for weighing, but the period during which the wetted surface of the specimen is not covered with water must be kept to a minimum.

13. Calculation and Analysis of Results

13.1 The results of the rate of water vapor transmission may be determined either graphically or numerically.

13.1.1 *Dummy Specimen*—If a dummy specimen has been used to compensate for variability in test conditions, due to temperature or barometric pressure, or both, the daily recorded weights can be adjusted by calculating the weight change from initial to time of weighing. This adjustment is made by reversing the direction of the dummy's weight change, relative to its initial weight, and modifying all the appropriate specimen weight(s) recorded at this time. This permits earlier achievement of equilibrium conditions. An alternate procedure, particular for tests of long duration and more than six weighings, is to subtract the arithmetic mean slope of the rate of weight change of the dummy specimen from the arithmetic mean slope of each similar specimen to get an effective rate of weight change. These procedures are also desirable if the specimen is changing weight due to a curing process while under test.

13.1.2 *Graphic Analysis*—Plot the weight, modified by the dummy specimen when used, against elapsed time, and inscribe a curve that tends to become straight. Judgment here is required and numerous points are helpful. When a straight line adequately fits the plot of at least six properly spaced points (periodic weight changes matching, or exceeding 20 % of the multiple of 100 times the scale sensitivity), a nominally steady state is assumed, and the slope of the straight line is the rate of water vapor transmission.

13.1.3 *Numerical Analysis*—A mathematical least squares regression analysis of the weight, modified by the dummy specimen when used, as a function of time will give the rate of water vapor transmission. An uncertainty, or standard deviation of this rate, can also be calculated to define the confidence band. For very low permeability materials, this method can be used to determine the results after 30 to 60 days when using an analytical balance, with a sensitivity of ≈1 mg, even if the weight change does not meet the 100 times the sensitivity requirement of 6.3. These specimens must be clearly identified in the report.

13.2 Calculate the water vapor transmission, WVT, and permeance as follows:

13.2.1 *Water Vapor Transmission:*

$$WVT = G/tA = (G/t)/A \tag{1}$$

where:

In inch-pound units:

G = weight change, grains (from the straight line),
t = time during which G occurred, h,
G/t = slope of the straight line, grains/h,
A = test area (cup mouth area), ft^2, and
WVT = rate of water vapor transmission, grains/h·ft^2.

In metric units:

G = weight change (from the straight line), g,
t = time, h,
G/t = slope of the straight line, g/h,
A = test area (cup mouth area), m^2, and
WVT = rate of water vapor transmission, g/h·m^2.

13.2.2 *Permeance:*

$$\text{Permeance} = \text{WVT}/\Delta p = \text{WVT}/S(R_1 - R_2) \tag{2}$$

where:

In inch-pound units:

Δp = vapor pressure difference, in. Hg,
S = saturation vapor pressure at test temperature, in. Hg,
R_1 = relative humidity at the source expressed as a fraction (the test chamber for desiccant method; in the dish for water method), and
R_2 = relative humidity at the vapor sink expressed as a fraction.

In metric units:

Δp = vapor pressure difference, mm Hg (1.333×10^2 Pa),
S = saturation vapor pressure at test temperature, mm Hg (1.333×10^2 Pa),
R_1 = relative humidity at the source expressed as a fraction (the test chamber for desiccant method; in the dish for water method), and
R_2 = relative humidity at the vapor sink expressed as a fraction.

13.2.3 In the controlled chamber the relative humidity and temperature are the average values actually measured during the test and (unless continuously recorded) these measurements shall be made as frequently as the weight measurements. In the dish the relative humidity is nominally 0 % for the desiccant and 100 % for the water. These values are usually within 3 % relative humidity of the actual relative humidity for specimens below 4 perms [230 ng·Pa^{-1}·s^{-1}·m^{-2}] when the required conditions are maintained (no more than 10 % moisture in $CaCl_2$ and no more than 1 in. [25 mm] air space above water).

13.3 The calculation of permeability is optional and can be done only when the test specimen is homogeneous (not laminated) and not less than ½ in. [12.5 mm] thick, calculate its average permeability as follows:

$$\text{Average permeability} = \text{Permeance} \times \text{Thickness} \tag{3}$$

13.4 *Corrections*—It is important that all applicable corrections be made to all measurements that result in permeance value more than 2-perm [114 ng·Pa^{-1}·s^{-1}·m^{-2}]. Corrections for materials with permeance value below 2-perm [114 ng·Pa^{-1}·s^{-1}·m^{-2}] are insignificant and need not be done **(2)**. The procedures for making various corrections, as summarized below, are found in the literature. **(2, 3, 4, 5, 6)**

13.4.1 *Buoyancy Correction*—The duration for one set of measurements can be many days or weeks. The atmospheric pressure may significantly change during such periods. If the test specimen is highly vapor resistant, the changes in mass due to vapor transport may be overshadowed by the apparent gravimetric changes observed. In such cases, all gravimetric data should be corrected to vacuum or any base line pressure. The following equation **(3)** can be used for buoyancy correction.

$$\frac{m_2}{m_1} = 1 + \frac{\rho_a(\rho_1 - \rho_2)}{\rho_1(\rho_2 - \rho_a)} \tag{4}$$

where:

m_1 = mass recorded by balance, kg,
m_2 = mass after buoyancy correction, kg,
ρ_a = density of air, kg m^{-3},
ρ_1 = density of material of balance weights, kg m^{-3}, and
ρ_2 = bulk density of test assembly, kg m^{-3}.

13.4.1.1 The density of air can be calculated using the ideal gas law for the measured atmospheric pressure and ambient temperature.

13.4.1.2 The buoyancy correction is important **(7)** when measured mass changes are in the range of 0 to 100 mg.

13.4.2 *Corrections for Resistance due to Still Air and Specimen Surface*—In general, if the material is highly permeable, these corrections are more significant. With known thickness of the still air layer in the cup, the corresponding vapor resistance can be calculated using the following equation**(4)** for permeability.

$$\delta_a = \frac{2.306 \times 10^{-5} P_o}{R_v T P} \left(\frac{T}{273.15}\right)^{1.81} \tag{5}$$

where:

δ_a = permeability of still air, kg·m^{-1}·s^{-1}·Pa^{-1},
T = temperature, K,
P = ambient pressure, Pa,
P_o = standard atmospheric pressure, that is, 101325 Pa, and
R_v = ideal gas constant for water, that is, 461.5 J·K^{-1}·kg^{-1}.

13.4.2.1 In the absence of any measured data, the surface resistances (that is, inside and outside surfaces of the specimen) may be approximated using Lewis' relation.**(5)** For cup methods that follow this standard, the total surface resistance (Hansen and Lund **(6)**) should be ≈ 4×10^7 Pa·s·m^2·kg^{-1}.

13.4.3 *Edge Mask Correction*—The following equation (Joy and Wilson**(1)**) is to be used to correct the excess WVT effect due to edge masking:

$$\text{Percent excess WVT} = \frac{400t}{\pi S_1} \log_e\left(\frac{2}{1 + e^{-(2\pi b/t)}}\right) \tag{6}$$

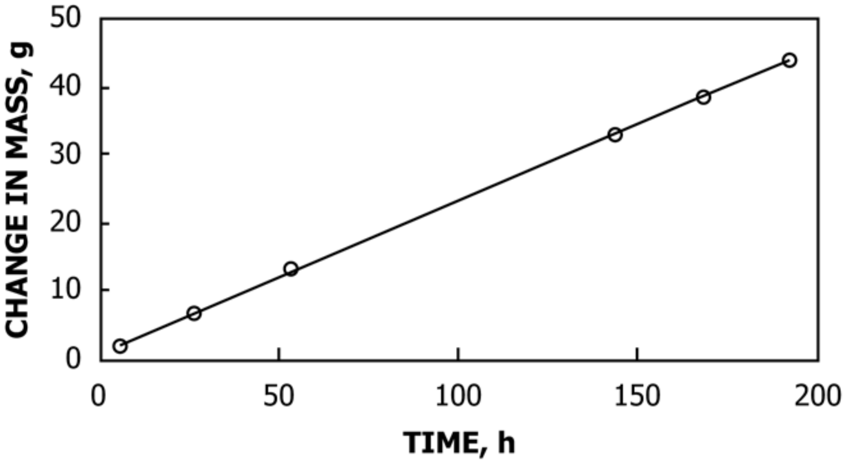

FIG. 1 Graphic Analysis

where:

t = specimen thickness, m,
b = width of masked edge, m, and
S_1 = four times the test area divided by the perimeter, m.

13.4.3.1 If the cup assembly includes any edge masking this correction shall be made.

13.5 Metric units and conversion factor are given in Table 1.

13.6 *Example (in SI unit)*—In a desiccant test on a sample of medium density glass fiber insulation the following results were recorded.

Thickness of the specimen = 25.81 mm
Test area = 0.01642 m^2
Mass of the test specimen = 20.44 g
Mass of the desiccant = 554.8 g
Initial mass of the test assembly = 1.257810 kg
Thickness of air layer in the cup = 15 mm

Elapsed Time (h)	Mass of the Test Assembly (g)	Change in Mass (g)	Chamber Temperature (°C)	Chamber RH (%)	Barometric Pressure mm Hg (kPa)
0.000	1257.810	0.000	22.83	52.60	744.7 (99.27)
6.067	1259.469	1.659	22.84	52.6	741.11 (98.79)
26.633	1264.609	6.799	22.78	52.2	744.41 (99.23)
53.150	1271.062	13.252	22.82	52.1	743.21 (99.07)
143.767	1290.773	32.963	22.74	52.2	757.69 (101.00)
168.283	1296.389	38.579	22.78	52.1	749.81 (99.95)
192.883	1301.953	44.143	22.78	52.1	758.44 (101.10)

13.6.1 *Buoyancy Correction*—As mentioned in 13.4.1, the buoyancy effect will be insignificant for this set of readings as recorded changes of mass are all above 100 mg. However, for example, the corrected mass of the test assembly weight 1257.810 g (1st reading) can be calculated using Eq 4.

m_1 = mass recorded by balance, kg = 1257.810 × 10^{-3} kg
P = Barometric pressure, Pa = 99.27 × 10^3 Pa
R = Gas constant for dry air = 287.055 J / (kg·K)
T = Chamber temperature = 22.83 + 273.15 = 295.98 K
ρ_a = density of air, kg m^{-3} = P / (RT) = 1.1684 kg m^{-3}
ρ_1 = density of material of balance weights, kg m^{-3} = 8000 kg m^{-3}
h_1 = height of the test assembly, m = 44.7 × 10^{-3} m
d_1 = diameter of the test assembly, m = 168.0 × 10^{-3} m
ρ_2 = bulk density of test assembly, kg m^{-3}

$$=\frac{4\times m_1}{\pi\times d_1^2\times h_1}=1269.4\text{ kg m}^{-3}$$

m_2 = mass after buoyancy correction = 1258.78 × 10^{-3} kg

13.6.2 A graphic analysis of the data, according to 13.1.2 is shown in Fig. 1.

13.6.3 A linear least-squares analysis of the data according to 13.1.3 gives the slope of the straight line as 0.225 ± 0.002 $g \cdot h^{-1}$, with a linear regression coefficient > 0.998.

WVT = 0.225 $g \cdot h^{-1}$ / 0.01642 m^2
= 19.595 grains·h^{-1}·ft^{-2} (≈ 3.81 × 10^6 ng·m^{-2}·s^{-1})
S = 2775.6 Pa
R_1 = 0.523
R_2 = 0
Permeance = 3.81 × 10^6 ng·m^{-2}·s^{-1} / (2775.6 Pa × 0.523)
= 2630 ng·m^{-2}·s^{-1}·Pa^{-1}

13.6.4 *Corrections for Resistance due to Still Air and Specimen Surface:*

Permeability of still air layer (Eq 5)

$$=\delta_a=\frac{2.306\times10^{-5}\times101325}{461.5\times(22.79+273.15)\times99860}\left(\frac{22.79+273.15}{273.15}\right)^{1.81}$$

= 198 ng·m^{-1}·s^{-1}·Pa^{-1}
Permeance of 15 mm still air layer
= (198) / (0.015) ng·m^{-2}·s^{-1}·Pa^{-1}
= 13200 ng·m^{-2}·s^{-1}·Pa^{-1}
Hence, the 15 mm air layer offers a vapor resistance
= 1 / (13200) m^2·s·Pa·ng^{-1} ≈ 7.6 × 10^7 m^2·s·Pa·kg^{-1}
Surface resistances (see 13.4.2)
≈ 4.0 × 10^7 m^2·s·Pa·kg^{-1}
Total corrections for resistance due to still air and specimen surface
= (7.6 × 10^7 + 4.0 × 10^7) m^2·s·Pa·kg^{-1}

13.6.5 *Edge Mask Correction*—The test assembly used does not include any edge masking. However, for example, if it includes an edge mask of width 5 mm then the following correction is to be made (see 13.4.3).

t = specimen thickness, m =25.81 × 10^{-3} m
b = width of masked edge, m = 5 × 10^{-3} m
Test area = 0.01642 m^2
Perimeter = 0.4541 m
S_1 = four times the test area divided by the perimeter

$$=\frac{4\times0.01642}{0.4541}=0.1446\text{ m}$$

Percent excess WVT

TABLE 2 Results on Precision from Interlaboratory Testing

For Desiccant Method at 23°C			Repeatability			Reproducibility		
Material	Thickness (mm)^A	Mean Permeance (ng·m^{-2}·s^{-1}·Pa^{-1})^B	s (ng·m^{-2}·s^{-1}·Pa^{-1})^B	CV (%)	LSD (ng·m^{-2}·s^{-1}·Pa^{-1})^B	s (ng·m^{-2}·s^{-1}·Pa^{-1})^B	CV (%)	LSD (ng·m^{-2}·s^{-1}·Pa^{-1})^B
A	0.0254	34.7	0.95	2.7	2.7	5.6	16.2	15.9
B	0.1397	0.74	0.16	21.7	0.46	0.31	42.6	0.92
C	12.7	3.51	0.25	7.2	0.69	1.06	30.2	2.8
D	25.4	44.8	1.5	3.3	4.2	3.5	7.8	10.0
E	0.3556	2.64	0.13	5.0	0.40	0.31	11.7	0.86
For Water Method at 23°C			Repeatability			Reproducibility		
Material	Thickness (mm)^A	Mean Permeance (ng·m^{-2}·s^{-1}·Pa^{-1})^B	s (ng·m^{-2}·s^{-1}·Pa^{-1})^B	CV (%)	LSD (ng·m^{-2}·s^{-1}·Pa^{-1})^B	s (ng·m^{-2}·s^{-1}·Pa^{-1})^B	CV (%)	LSD (ng·m^{-2}·s^{-1}·Pa^{-1})^B
A	0.0254	40.91	0.77	1.9	2.2	8.9	21.8	25.2
B	0.1397	0.90	0.13	14.0	0.35	0.12	13.4	0.34
C	12.7	5.55	0.31	5.7	0.92	1.1	20.1	3.1
D	25.4	59.5	1.1	1.8	3.1	12.4	20.9	35.5
E	0.3556	3.40	0.19	5.7	0.57	0.47	13.8	1.3

^{A} 1 in. = 25.4 mm

^{B} 1 perm (inch-pound) = 57.2 ng·m^{-2}·s^{-1}·Pa^{-1}

Legend:
s = standard deviation
CV = percent coefficient of variation (s × 100/ Mean)
LSD = least significant difference between two individual test results based on a 95 % confidence level = $2\sqrt{2}s$

NOTE 1—Material B was Teflon[5] PTFE fluorocarbon resin brand of tetrafluoroethylene. It was extremely difficult to provide a seal to this sample, which accounts for the poor repeatability.

$$= \frac{400 \times 25.81 \times 10^{-3}}{\pi \times 0.1446} \log_e \left(\frac{2}{1 + e^{-(2\pi \times 5 \times 10^{-3})/(25.81 \times 10^{-3})}} \right)$$

$$= 9.86\ \%$$

13.6.6 The applicable corrections required for the analysis of the test results in this case are due to resistance of still air and specimen surface.

Water vapor resistance of the test specimen + corrections
= 1 / Permeance = (1 / 2630) m^2·s·Pa·ng^{-1}
= 3.80 × 10^8 m^2·s·Pa·kg^{-1}
The water vapor resistance of the test specimen
= (3.80 × 10^8 – (7.6 × 10^7 + 4.0 × 10^7)) m^2·s·Pa·kg^{-1}
= 2.64 × 10^8 m^2·s·Pa·kg^{-1}
Permeance of the test specimen
= 1 / (2.64 × 10^8 m^2·s·Pa·kg^{-1})
= 3.79 × 10^{-9} kg·m^{-2}·s^{-1}·Pa^{-1}
= 3790 ng·m^{-2}·s^{-1}·Pa^{-1}
Permeability
= 3790 ng·m^{-2}·s^{-1}·Pa^{-1} × 0.02581 m
= 97.8 ng·m^{-1}·s^{-1}·Pa^{-1}

14. Report

14.1 The report shall include the following:

14.1.1 Identification of the material tested, including product thickness for homogeneous materials (not laminated) greater than ½ in.,

14.1.2 Test method used (desiccant or water),

14.1.3 Test temperature,

14.1.4 Relative humidity in the test chamber,

14.1.5 Permeance of each specimen in perms (to two significant figures),

14.1.6 The side of each specimen on which the higher vapor pressure was applied. (The sides shall be distinguished as "side A" and "side B" when there is no obvious difference between them. When there is an obvious difference, this difference shall also be stated, such as "side A waxed" and "side B unwaxed."),

14.1.7 The average permeance of all specimens tested in each position,

14.1.8 The permeability of each specimen (as limited by 13.3), and the average permeability of all specimens tested,

14.1.9 Include a portion of the plot indicating the section of the curve used to calculate permeability, and

14.1.10 State design of cup and type or composition of sealant.

15. Precision and Bias

15.1 *Precision*—Table 2 is based on interlaboratory tests conducted in 1988 and 1991.[5] In 1988 four materials (A, B, C, D) were tested using the dessicant method and the water method in triplicate. Fifteen laboratories contributed data, with full results secured from four laboratories. In 1991 ten laboratories contributed data for material E, using triplicate specimens, again using both the dessicant method and the water method. Tables 3 and 4 are based on another interlaboratory test conducted in 1995–96.(**8**) One material at a nominal thickness of 1 in. (25 mm) was tested by ten participating laboratories. Results from only nine laboratories were used in the analyses because of the presence of severe outliers (see Practice E691) in the observation of tenth laboratory.

15.1.1 Test results were analyzed using Practice E691.

15.2 Additional precision data and analysis for this test method is based on an interlaboratory study (#512) conducted in 2010. Six laboratories participated in this study, analyzing four different extremely low permeance materials. Procedure A, desiccant method at 73°F/50 % RH, was used. Each "test result" reported represents an individual determination, and all participants reported three replicate test results for every material. Practice E691 was followed for the design and

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[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C16-1014. Contact ASTM Customer Service at service@astm.org.

TABLE 3 Results on Precision from Interlaboratory Testing—Dry Cup Measurements on Expanded Polystyrene

Lab	Permeability (ng·m^{-1}·s^{-1}·Pa^{-1})^A			$\bar{x}$	s	d	h	k
	Spec #1	Spec #2	Spec #3					
1	2.54	2.46	2.21	2.40	1.72E-01	-7.01E-01	-1.50	1.06
2	2.65	2.87	2.68	2.73	1.19E-01	-3.71E-01	-0.79	0.73
3	3.79	3.49	3.65	3.64	1.50E-01	5.39E-01	1.15	0.92
4	2.77	2.73	2.69	2.73	4.00E-02	-3.74E-01	-0.80	0.25
5	2.67	2.66	2.79	2.71	7.23E-02	-3.98E-01	-0.85	0.44
6	3.26	3.38	3.29	3.31	6.24E-02	2.06E-01	0.44	0.38
7	3.05	3.72	3.33	3.37	3.37E-01	2.62E-01	0.56	2.07
8	3.76	3.53	3.87	3.72	1.73E-01	6.16E-01	1.31	1.07
9	3.24	3.48	3.26	3.33	1.33E-01	2.22E-01	0.47	0.82
				$\bar{\bar{x}}$	s_r	$s_{\bar{x}}$	s_R	
				3.10	1.63E-01	4.69E-01	4.87E-01	

[A] 1 perm in. = 1.45 (ng·m^{-1}·s^{-1}·Pa^{-1})

Note 1—The average of the cell averages gives the permeability for the round robin material, according to the dry cup measurements, as 3.10 ng·m^{-1}·s^{-1}·Pa^{-1}.

Note 2—The repeatability standard deviation is 1.6 × 10^{-1} ng·m^{-1}·s^{-1}·Pa^{-1}.

Note 3—The reproducibility standard deviation is 4.9 × 10^{-1} ng·m^{-1}·s^{-1}·Pa^{-1}.

TABLE 4 Results on Precision from Interlaboratory Testing—Wet Cup Measurements on expanded polystyrene

Lab	Permeability (ng·m^{-1}·s^{-1}·Pa^{-1})^A			$\bar{x}$	s	d	h	k
	Spec #1	Spec #2	Spec #3					
1	2.90	3.14	2.94	2.99	1.29E-01	-3.58E-01	-0.94	0.77
2	3.50	3.46	3.52	3.49	3.06E-02	1.43E-01	0.37	0.18
3	4.23	3.76	3.65	3.88	3.08E-01	5.29E-01	1.39	1.84
5	3.32	3.29	2.97	3.19	1.94E-01	-1.58E-01	-0.41	1.16
6	2.61	2.82	2.80	2.74	1.16E-01	-6.08E-01	-1.59	0.69
7	3.53	3.18	3.41	3.37	1.77E-01	1.92E-02	0.05	1.06
8	3.30	3.42	3.29	3.34	7.23E-02	-1.42E-02	-0.04	0.43
9	3.75	3.97	3.67	3.80	1.55E-01	4.46E-01	1.17	0.93
				$\bar{\bar{x}}$	s_r	$s_{\bar{x}}$	s_R	
				3.35	1.67E-01	3.82E-01	4.06E-01	

[A] 1 perm in. = 1.45 ng·m^{-1}·s^{-1}·Pa^{-1}

Legend:
$\bar{x}$ = Cell average or the average from one laboratory
s = Cell standard deviation, or the standard deviation for one laboratory
$\bar{\bar{x}}$ = Average of the Cell averages
d = Cell deviation or the difference ($\bar{x} - \bar{\bar{x}}$)
s_r = Repeatability standard deviation (within a laboratory)
s_R = Reproducibility standard deviation (between the laboratories)
h = the between-laboratory consistency statistic
k = the within-laboratory consistency statistic

Note 1—The average of the cell averages gives the permeability for the round robin material, according to the wet cup measurements, as 3.35 ng·m^{-1}·s^{-1}·Pa^{-1}.

Note 2—The repeatability standard deviation is 1.7 × 10^{-01} ng·m^{-1}·s^{-1}·Pa^{-1}.

Note 3—The reproducibility standard deviation is 4.1 × 10^{-01} ng·m^{-1}·s^{-1}·Pa^{-1}.

analysis of the data; the details are given in ASTM Research Report No. C16-1040.[6]

15.2.1 *Repeatability limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

15.2.1.1 Repeatability limits are listed in Table 5 below.

15.2.2 *Reproducibility limit (R)*—Two test results shall be judged not equivalent if they differ by more than the "*R*" value for that material; "*R*" is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

15.2.2.1 Reproducibility limits are listed in Table 5 below.

15.2.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

15.2.4 Any judgment in accordance with statements 9.1.1 and 9.1.2 would have an approximate 95% probability of being correct.

15.3 The precision statement was determined through statistical examination of 72 test results, submitted by six

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[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C16-1040. Contact ASTM Customer Service at service@astm.org.

TABLE 5 Water Vapor Transmission (perms) ILS #512

Material	Average[A]	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	s_r	s_R	r	R
A	0.00877	0.00166	0.00336	0.00465	0.00940
B	0.00843	0.01067	0.01067	0.02988	0.02988
C	0.02028	0.01698	0.01698	0.04756	0.04756
D	0.00567	0.00938	0.00967	0.02626	0.02706

[A] The average of the laboratories' calculated averages

laboratories, for four materials. The four materials were described as:
Material A: 6 mil high barrier PVdC-based film
Material B: 10 mil high barrier PVdC-based film
Material C: 15 mil high barrier HDPE-based film
Material D: PET film/1 mil aluminum foil/PET film lamination

15.4 To judge the equivalency of two test results, it is recommended to choose the material that is closest in characteristics to the test material.

15.5 Using information from this ILS, Appendix section X3 discusses the testing of extremely low permeance materials.

15.6 An additional interlaboratory study employing very low permeance materials, ILS no. 607, was conducted by committee F02 in 2012.[7]

16. Keywords

16.1 permeability; plastics (general); plastic sheet and film; sheet material; thermal-insulating materials; thermal insulation permeability films; water vapor transmission (WVT)

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[7] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C16-1045. Contact ASTM Customer Service at service@astm.org.

APPENDIXES

(Nonmandatory Information)

X1. STANDARD TEST CONDITIONS

X1.1 Standard test conditions that have been useful are:

X1.1.1 *Procedure A*—Desiccant Method at 73.4°F [23°C].

X1.1.2 *Procedure B*—Water Method at 73.4°F [23°C].

X1.1.3 *Procedure BW*—Inverted Water Method at 73.4°F [23°C].

X1.1.4 *Procedure C*—Desiccant Method at 90°F [32.2°C].

X1.1.5 *Procedure D*—Water Method at 90°F [32.2°C].

X1.1.6 *Procedure E*—Desiccant Method at 100°F [37.8°C].

X1.2 Unless otherwise prescribed by regulation, specification, ASTM standard, or other governing document, select test conditions similar to those to which the material will be exposed to actual use.

X2. CUP DESIGN AND SEALING METHODS

X2.1 An ideal sealing material has the following properties:

X2.1.1 Impermeability to water in either vapor or liquid form.

X2.1.2 No gain or loss of weight from or to the test chamber (evaporation, oxidation, hygroscopicity, and water solubility being undesirable).

X2.1.3 Good adhesion to any specimen and to the dish (even when wet).

X2.1.4 Complete conformity to a rough surface.

X2.1.5 Compatibility with the specimen and no excessive penetration into it.

X2.1.6 Strength or pliability (or both).

X2.1.7 Easy handleability (including desirable viscosity and thermal of molten sealant).

X2.1.8 Satisfactory sealants possess these properties in varying degrees and the choice is a compromise, with more tolerance in items at the beginning of this list for the sake of those at the latter part of the list when the requirements of 7.2 are met. Molten asphalt or wax is required for permeance tests below 4 perms [240 $ng \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$]. Tests to determine sealant behavior should include:

X2.1.8.1 An impervious specimen (metal) normally sealed to the dish and so tested, and

X2.1.8.2 The seal normally assembled to an empty dish with no specimen and so tested.

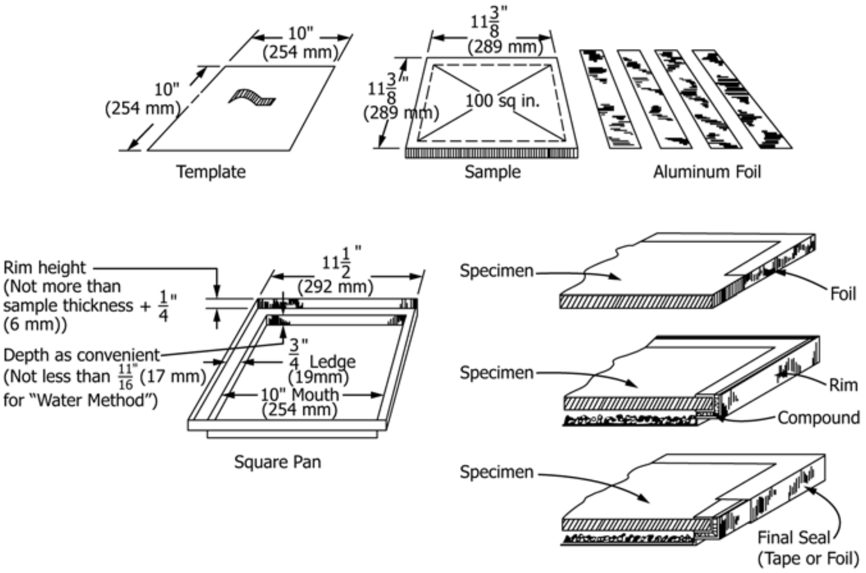

FIG. X2.1 Apparatus for Water Vapor Transmission Tests of Large Thick Specimens

X2.2 The following materials are recommended for general use when the test specimen will not be affected by the temperature of the sealant:

X2.2.1 Asphalt, 180 to 200°F [82 to 93°C] softening point, meeting the requirements of Specification D449/D449M, Type C. Apply by pouring.

X2.2.2 Beeswax and rosin (equal weights). A temperature of 275°F [135°C] is desirable for brush application. Pour at lower temperature.

X2.2.3 Microcrystalline wax[8] (60 %), mixed with refined crystalline paraffin wax (40 %).

X2.3 The materials listed in X2.3.1 are recommended for particular uses such as those shown in Fig. X2.1. The suggested procedure described in X2.3.2 applies to an 11⅜-in. [289-mm] square specimen if its permeance exceeds 4 perms [240 ng·m^{-2}·s^{-1}·Pa^{-1}] (limited by evaporation of sealants).

X2.3.1 *Materials:*

X2.3.1.1 Aluminum foil, 0.005 in. [0.125 mm] minimum thickness.

X2.3.1.2 Tape, meeting the requirements of Specification D2301, vinyl chloride plastic pressure-sensitive, electrical insulating tape.

X2.3.1.3 Cement, contact bond, preferably rubber base.

X2.3.2 *Procedure:*

X2.3.2.1 *Step 1*—Seal aluminum foil around edges of specimen, leaving a 100-in.^{2} [0.0654-m^2] exposed test area on each side. Use contact bond cement as directed by the manufacturer.

X2.3.2.2 *Step 2*—Spread sealant on inside of rim and ledge. Place desiccant (dry), or water and surge control material (wet) in pan. Press specimen in place. Avoid squeezing compound into the test area.

X2.3.2.3 *Step 3*—Coat outside of rim and bottom of ledge with contact bond cement, and place foil strips from edge of template, around rim, and bottom of ledge.

X2.4 A method of using hot asphalt, as applied to a 10-in. [254-mm] square-mouth dish with ledge and rim, is as follows:

X2.4.1 *Apparatus:*

X2.4.1.1 *Template*—A square frame of brass or steel, 3⁄16 in. [5 mm] thick and ¾ in. [19 mm] deep. The 3⁄16-in. [5-mm] thickness is tapered to zero at the bottom of the frame where it will touch the test specimen and maintain a 10-in. [254-mm] square test area.

X2.4.1.2 *Sealant*—Asphalt (see X2.3.1 used at the proper pouring consistency of 375 to 450°F [179 to 232°C].

X2.4.1.3 *Melting Pot,* for the asphalt, electrically heated, with one dimension greater than 11⅜ in. [289 mm].

X2.4.1.4 *Small Ladle,* for pouring.

X2.4.2 *Procedure*—Mark the 11⅜-in. [289-mm] square specimen with a line at an equal distance from each edge, so that the area enclosed by the lines is as nearly as possible a 10-in. [254-mm] square. The template may be used for marking. Dip each edge of the specimen in molten asphalt up to the line, so that the test area is defined and all edges are coated with a heavy layer of asphalt. Place the specimen over the pan containing water or desiccant. Lightly oil the template or coat with petroleum jelly on its outer side, and place on the specimen. Pour molten asphalt into the space between the template and the rim of the pan. After the asphalt has cooled for a few minutes, the template should be easily removable.

X2.5 Hot wax may be applied like asphalt. It may also be applied (freely) with a small brush. Its lower working temperature may be advantageous when a specimen contains moisture.

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[8] The sole source of supply of the microcrystalline wax known to the committee at this time is E. I. DuPont de Nemours & Co., Inc., Polymer Products Dept., Wilmington, DE 19898. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

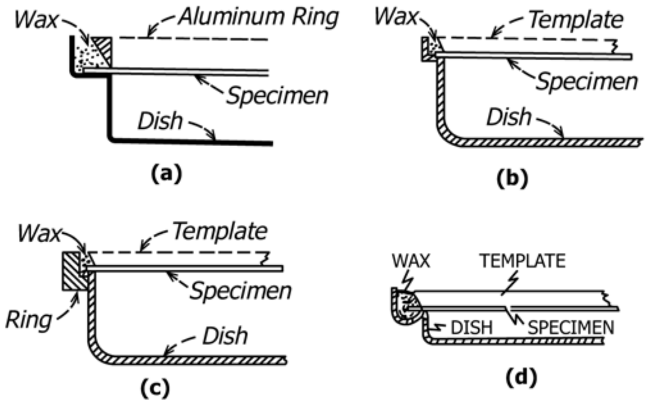

FIG. X2.2 Several Types of Dishes for Water Vapor Transmission Tests of Materials in Sheet Form

X2.6 Several designs for dishes with supporting rings and flanges are shown in Fig. X2.2. Various modifications of these designs may be made provided that the principle of prevention of edge leakage by means of a complete seal is retained. The dishes may be constructed of any rigid, impermeable, corrosion-resistant material, provided that they can be accommodated on the available analytical balance. A lightweight metal, such as aluminum or one of its alloys, is generally used for larger-size dishes. In some cases when an aluminum dish is employed and moisture is allowed to condense on its surface, there may be appreciable oxidation of the aluminum with a resulting gain in weight. Any gain in weight will ordinarily depend on the previous history of the dish and the cleanness of the surface. An empty dish carried through the test procedure as a control will help to determine whether any error may be expected from this cause. When aluminum dishes are used for the water methods, a pressure may develop inside the assembly during a test due to corrosion. This can cause seal failure or otherwise affect the result. Where this is a problem, it can be overcome by providing inside the dish a protective coating of baked-on epoxy resin or similar material. Dishes with flanges or rings that project from the inner walls of the dish are to be avoided, as such projections influence the diffusion of the water vapor. The depth of the dish for the water procedures is such that there is a 0.80 ± 0.20-in. [20 ± 5-mm] distance between the water surface and the under surface of the specimen, with a water depth of about 0.20 in. [5 mm].

X2.6.1 For the desiccant-in-dish procedures, the dishes need not be as deep as those required for the water-in-dish procedures. The desiccant is within ¼ in. [6 mm] of the under surface, and a minimum depth of only ½ in. [12 mm] of desiccant is required.

X2.6.2 The dishes shown in Fig. X2.2 require a molten seal.

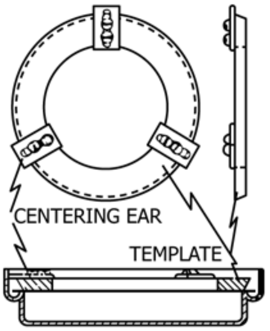

FIG. X2.3 Template Suitable for Use in Making the Wax Seals on Test Dishes

X2.6.3 A template such as is shown in Fig. X2.3 is usually used for defining the test area and effecting the wax seal. It consists of a circular metal dish ⅛ in. [3.18 mm] or more in thickness with the edge beveled to an angle of about 45°. The diameter of the bottom (smaller) face of the template is approximately equal to, but not greater than, the diameter of the effective opening of the dish in contact with the specimen. Small guides may be attached to the template to center it automatically on the test specimen. A small hole through the template to admit air, and petrolatum applied to the beveled edge of the template facilitate its removal after sealing the test specimen to the dish. In use, the template is placed over the test specimen and when it is carefully centered with the dish opening, molten wax is flowed into the annular space surrounding the beveled edge of the template. As soon as the wax has solidified, the template is removed from the sheet with a twisting motion. The outside flange of the dish should be high enough to extend over the top of the specimen, thus allowing the wax to completely envelop the edge.

X2.6.4 Gasketed types of seals are also in use on appropriately designed dishes. These simplify the mounting of the specimen, but must be used with caution, since the possibility of edge leakage is greater with gasketed seals than with wax seals. Gasketed seals are not permitted for the measurement of permeance less than 4 perms [240 $ng \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$]. As a further precaution when gasketed seals are used instead of preferred sealants, a blank test run is suggested using glass or metal as a dummy specimen.

X2.6.5 A suitable weighing cover consists of a circular disk of aluminum 1⁄32 to 3⁄32 in. [0.8 to 2.4 mm] in thickness provided with a suitable knob in the center for lifting. The cover fits over the test specimen when assembled and makes contact with the inside beveled surface of the wax seal at, or just above, the plane of the specimen. The cover is free of sharp edges that might remove the wax and is numbered or otherwise identified to facilitate its exclusive use with the same dish.

X3. PROCEDURE TO CALCULATE DEPENDENCY OF WATER VAPOR TRANSMISSION RATE ON RELATIVE HUMIDITY

X3.1 The dependency of the water vapor transmission (WVT) rate of materials on relative humidity (RH) can be determined using a combination of desiccant and water method (**9**).

X3.2 Procedure

X3.2.1 Dry cup tests with *desiccant method* test set up but also with additional chamber RH levels other than 50% are carried out. Three chamber RH levels: 50%, 70%, and 90% shall be selected.

X3.2.2 Wet cup measurements with water method test set up but at two chamber RH levels are to be carried out. Two chamber RH levels, 70% and 90% shall be selected.

X3.3 Data Analysis

X3.3.1 From the slope of the time versus mass change data plot, for each chamber RH levels, the rate of WVT for the corresponding test specimen at a specific chamber RH level is determined according to 13.2.1.

X3.3.2 The WVT rate is plotted against the chamber RH. This results in two separate but intersecting plots.

X3.3.2.1 If the plots are linear and intersect at 50% chamber RH, it is concluded that the material under consideration is nonhygroscopic and the rate of WVT does not depend on the local chamber RH.

X3.3.2.2 For the hygroscopic material the intersection of the plots will be at a chamber RH greater than 50% and water method may yield a nonlinear dependency.

X3.3.3 For hygroscopic materials the sum of the rate of WVT from dry and wet cup measurements at the 90% chamber RH represents theoretically the dry cup measurements for WVT rate done at 100% chamber RH.

X3.3.4 Similarly for hygroscopic materials the sum of the rate of WVT from dry and wet cup measurements at the 70% chamber RH represents theoretically the dry cup measurements for WVT rate done at 100% chamber RH. If this calculated value of WVT rate at 100% chamber RH differs from the same calculated in centilitres X3.3.3 by more than 10% then the whole test procedure should be repeated.

X3.3.5 The calculated dry cup WVT rate at 100% chamber RH, as shown above, is combined with the directly measured dry cup measurements data at 50%, 70% and 90% chamber RH to generate a set of WVT rate values spanned over the entire range of chamber RH (that is, 0 to 100%). These values of WVT rate when plotted against the corresponding chamber RH would define the dependency of WVT rate on RH.

X3.3.6 The algebraic expression of the best-fitted curve that passes through the origin from the WVT rate versus chamber RH is to be used to determine the derivative of the plot at any given local RH.

X3.3.7 The water vapor permeance of the material at a specific chamber RH is derived from the following expression.

$$Water\ Vapor\ Permeance\ (WVP) = \left\{ \frac{(Magnitude\ of\ derivative) \times 100}{Saturation\ water\ vapor\ pressure\ at\ 73.4°F\ (23°C)} \right\} \quad (X3.1)$$

X3.3.8 All normal required corrections (13.4) are applicable to X3.3.7.

X4. TESTING OF EXTREMELY LOW PERMEANCE MATERIALS

X4.1 In 2010-2011 an inter-laboratory study using Procedure A was conducted using thin, extremely low permeance materials as the test specimens. The statistics from this study related to precision of the method are covered in Section 15 of these test methods.

X4.2 In addition to developing a precision statement, a number of other objectives was targeted in undertaking this round robin. Those objectives and a discussion of the findings are discussed herein:

X4.3 Provide experience testing extremely low and "zero perm" materials.

X4.3.1 Many labs that conduct the E96/E96M tests do not have occasion to test such materials. The materials tested in the study ranged from anticipated values of about 0.015 perm down to zero perm. All materials were 0.015 in. (0.38 mm) thick or less. Circumstances were such, however, that the final group of participating labs in fact did have experience testing in this range. As such, input from inexperienced labs was not available.

X4.4 Determine what difficulties are encountered in testing at these levels.

X4.4.1 With one exception, no notable difficulties were reported by the labs. One lab was consistently obtaining loss of weight during the tests. An assignable cause was not determined, and it was decided not to use their results. Otherwise, there was no feedback on problems with the test.

X4.4.2 The occurrence of outliers indicates problems that were undetected or uncorrected by the operators, or both. The outliers are always high results. Absent the presence of obvious defects in the test specimens, which would be visible under normal lighting or over a light box, the cause for outliers is invariably inadequate sealing to the dish. It would appear that operators were not recognizing outliers appearing early in the test, or were not taking action to correct faulty seals or otherwise determine a cause.

X4.4.3 The types of materials tested can be expected to be very consistent. One exception could be foil or foil laminations, which can contain pinholes of a size or number that can produce apparently outlying results. These will be detectable over a light box. The foil lamination samples in this study were pre-screened for presence of pinholes, and only pinhole-free specimens were used.

X4.4.4 The primary problem encountered in testing extremely low permeance materials then would appear to be inadequate or failing seals. It is critical that operators monitor data early on for apparent outliers. When one is suspected, whether or not a breach in the seal is visible in the test dish, the seal should be "re-flowed", the specimen taken out of the test, or a replacement replicate started.

X4.4.5 It is strongly recommended that a program be set up to provide either water vapor transmission rate or permeance, and correlation coefficient computation, real time at each weighing. This way outliers can be spotted immediately and checked for cause.

X4.5 *Application of correlation coefficient:*

X4.5.1 The correlation coefficient indicates if a strong linear relationship in the coordinate data points exists.

X4.5.2 Very high correlation indicates a very straight line slope for the weight gain per unit time, which in turn can be used as an indication of steady state.

X4.5.3 High correlation is not necessarily expected when testing materials of extremely low permeance, since the slope of the weight gain per unit time is approaching zero, and any variation in the test conditions has a greater impact on individual weighings. Zero or near-zero permeance tests may never show good correlation.

X4.6 *Time required to reach steady state:*

X4.6.1 It is generally thought that extremely low permeance materials require many weeks or months to reach a true steady state and to provide a reliable result.

X4.6.2 A graph of perm vs. time at steady state should show a flat line.

X4.6.3 Using the data from one lab that obtained the most consistent expected results, the approximately first one third of the test duration (18 days) showed perm results that indicated a condition that was not steady-state.

X4.6.4 The second third (19-36 days) graph showed a much straighter line, but one not totally flat.

X4.6.5 The last third (37-54 days) showed the straightest you line of perm results; given the range of the data, steady state is well indicated.

X4.6.6 While the above findings would indicate that two months or more may be needed to reach steady state, the change in results after the first two or three weeks was very small, less than would impact a result rounded to two significant figures. The purpose of the test might dictate the duration required; that is, screening or QC tests might be run for shorter durations than R&D tests where a high degree of accuracy is desired, which might be run for more than two months .

X4.6.7 It is known that thicker materials and moisture-retaining materials need upwards of two months or longer to reach steady-state. Evidence shows that very thin materials such as those tested in this ILS, even if of extremely low permeance, may not need such a long test duration to reach steady state.

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