



Standard Test Methods for Water Vapor Diffusion Resistance and Air Flow Resistance of Clothing Materials Using the Dynamic Moisture Permeation Cell¹

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^{ε1} NOTE—Reapproved with editorial changes in February 2009.

1. Scope

1.1 This test method covers the measurement of the moisture vapor transport and gas flow properties of fabrics, membranes, and membrane laminates used for protective materials.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, 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

D737 Test Method for Air Permeability of Textile Fabrics

2.2 *Other Standards:*

ISO 11092 Textiles—Physiological Effects—Measurement of Thermal and Water-Vapour Resistance Under Steady-State Conditions (Sweating Guarded-Hotplate Test)³

JIS L 1099 Testing Methods for Water Vapour Permeability of Clothes³

3. Terminology

3.1 *Definitions:*

3.1.1 *water vapor diffusion, n*—the process by which water vapor molecules move from a region of high concentration to a region of low concentration.

¹ These test methods are under the jurisdiction of ASTM Committee F23 on Personal Protective Clothing and Equipment and are the direct responsibility of Subcommittee F23.60 on Human Factors.

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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.

³ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

3.1.2 *water vapor transmission rate, n*—the steady water vapor flow in unit time through unit area of a material, under specific conditions of temperature and humidity at each surface.

4. Summary of Test Methods

4.1 The testing outlined in this standard consists of measuring the amount of water vapor transport across a specimen. The water vapor transport properties can be measured in a pure diffusion mode and in a diffusion/convection mode.

4.2 Two test methods are presented in this standard:

4.2.1 *Part A (Diffusion Test)*—The test is done under the maximum difference in relative humidity and zero pressure gradient across the specimen so that only the water vapor diffusion transport through the specimen is measured (Fig. 1).

4.2.2 *Part B (Combined Convection/Diffusion Test)*—A series of pressure gradients is applied in specified increments to force air through the material (Fig. 1). Thus, the test is conducted under a combined air pressure gradient and concentration gradient that allows examination of the interaction of convective and diffusive mass transfer across the specimen. This method is designed for use on relatively air-permeable textile materials because for air-impermeable materials, the results will be the same as the diffusion test alone.

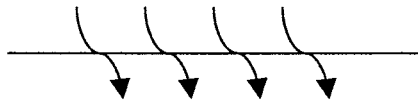
5. Significance and Use

5.1 The water vapor transport properties of textile materials are of considerable importance in determining the comfort properties of clothing systems. Water vapor transport through porous textiles may occur due to both diffusion (driven by vapor concentration differences) and convection (driven by gas pressure differences).

5.2 For air permeable porous materials, a very small pressure gradient can produce large convective flows through the pores in the structure. In many standard water vapor permeability test methods, when used for materials with high air permeability, slight variations in pressure gradient across a specimen will greatly influence the measured water vapor transport properties. Therefore, the water vapor transport

Part A: Diffusion Test – The test is done under zero pressure gradient across specimen so that only water vapor diffusion through the specimen is measured.

Top Cell: 95 % R.H.
water vapor



Higher vapor pressure

0 Air pressure gradient

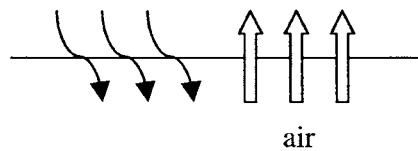
Lower vapor pressure

Bottom Cell: 5 % R.H.

Part B: Diffusion/Convection Test – A series of pressure gradients (negative – positive pressure gradients) are applied to force air through the material.

1. Negative pressure gradient – The flow of the water vapor is in the opposite direction of the air flow through the material.

Top: 95 % R.H.
water vapor



Higher vapor pressure, Lower air pressure

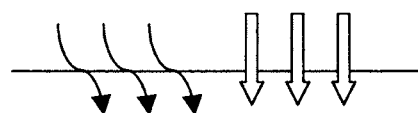
Negative air pressure gradient

Lower vapor pressure, Higher air pressure

Bottom: 5 % R.H.

2. Positive pressure gradient – The flow of the water vapor and the air flow are moving in the same direction.

Top: 95 % R.H.
water vapor



Higher vapor pressure, Higher air pressure

Positive air pressure gradient

Lower vapor pressure, Lower air pressure

Bottom: 5 % R.H.

FIG. 1 Overview of the Test Methods

properties of the porous and non-porous textile materials cannot be directly compared when the method has no provision for controlling the pressure gradient. This test method determines the diffusion and convection properties from the same

test and generates data that allows direct comparison of the results obtained between materials.

6. Sampling and Preparation of Test Specimens

6.1 Sampling:

6.1.1 *Laboratory Sample*—Take test specimens that are believed to be representative of the sample to be tested and free of abnormal distortions. The sample may be a piece of fabric or a garment.

6.1.2 If the material is of nonsymmetrical construction, the two faces shall be designated by distinguishing marks.

6.2 Sample Preparation:

6.2.1 Cut three specimens from each laboratory sample.

6.2.2 *Specimen Size*—Use specimens larger than the area of the opening in the clamping plate so that the test area is covered completely.

7. Test Apparatus

7.1 The procedures in these methods require measurement of the pressure gradient across the specimen and the mass flow rate. Fig. 2 is a schematic diagram of the basic system for the dynamic moisture permeation cell (DMPC). This standard is written to allow operation of the DMPC system under manual control of the test operator. However, the preferred method is to automate the data acquisition and control system of the apparatus so the entire test is performed under the control of a computer.

7.2 Control and Measuring Units:

7.2.1 *Mass Flow Rate Controller*, measures and controls the gas flows in a wide variety of applications. Either analog or electronic digital type mass flow rate controller can be used. The mass flow rate controllers maintain the correct incoming relative humidity by adjusting the ratio of the relative mass

flows of a saturated and a dry nitrogen stream. The test apparatus requires four mass flow controllers. Two controllers adjust the dry and saturated nitrogen gas streams to the top flow cell, and two controllers adjust the dry and wet nitrogen gas streams to the bottom flow cell. The mass flow controllers shall be controlled at an accuracy of $\pm 1\%$ of full scale, with a response time of less than 5 s, unless stated otherwise in the data report. Electronic mass flow controllers usually indicate flow rate in terms of volumetric flow rates at standard conditions of 0°C and atmospheric pressure. The actual volumetric flow rate at the actual test temperature can be calculated from the mass flow rate, the temperature, and the pressure of the actual flow.

7.2.2 *Channel Power Supply and Readout*, controls and displays the flow meters and controllers. The display accuracy of the channel readout shall be within $\pm 0.2\% \pm 1$ digit, unless stated otherwise in the data report.

7.2.3 *Differential Pressure Transducer*, directly measures the pressure gradient across the specimen. The differential pressure transducer can be either digital or analog type with an accuracy of within $\pm 0.2\%$ of the indicated value. The sensor requires power and signal conditioning electronics. The pressure in the flow cells is controlled by means of two automated restrictor valves (7.2.5) at the outlets of the cell.

7.2.4 *Signal Conditioner/Display Unit*, provides power and signal conditioning for the differential pressure transducer sensors.

7.2.5 *Proportioning Valve and Controller*, used to continuously control the gas flows. The restrictor valves at the exits of the cell are used to systematically vary the pressure gradient across the specimen to produce various amounts of convective

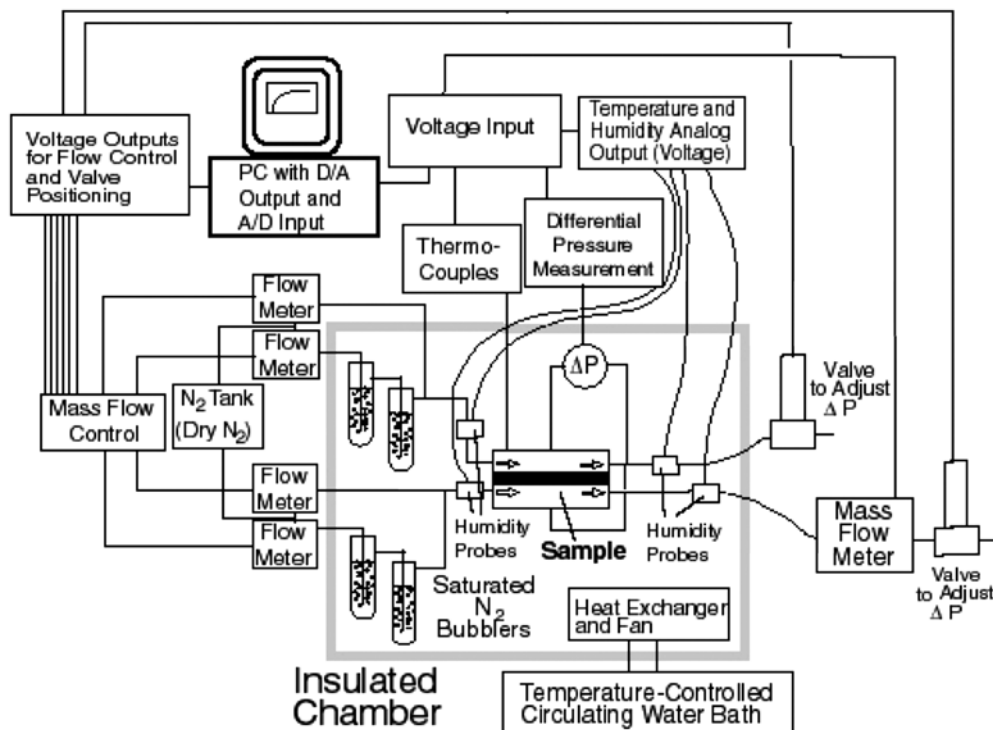


FIG. 2 Schematic of DMPC Test System

flows across the specimen. The valves shall withstand the maximum pressure in the test cell during the test. Instead of the electronic pressure gauges and automated restrictor valves, it is acceptable to use analog differential pressure gauges in a variety of different full scale ranges, and manual needle or orifice metering valves at the gas flow exit of the cells to control the pressure gradient across the test specimen.

7.2.6 *Electronic Mass Flow Meter and Power Supply*, connects one of the exits of the flow cells (bottom cell) and the proportioning valve. The mass flow meter directly measures and displays the mass flow rate with a response time of within 5 s.

7.2.7 *Humidity Measurement Instrument*, measures the relative humidity of the incoming and the outgoing gas flows. The relative humidity of the incoming gas flow is directly measured with the humidity sensor. Relative humidity can be measured in different ways, such as a condensation type dew point hygrometer, capacitance type relative humidity probe, or gas chromatography. Capacitance type humidity probe is recommended because it provides small size and a fast response time. The relative humidity probes shall have a measurement accuracy of $\pm 3\%$ R.H. over the range in use, unless stated in the report.

7.2.8 *Temperature Measurement Instrument*—The temperature measurement sensor shall measure the temperature within $\pm 0.1^\circ\text{C}$ with a time constant not exceeding 1 min. The temperature measurement shall be made at the same place as the humidity measurement.

7.3 *Moisture Permeation Cell:*

7.3.1 *Flow Cell Unit*, consists of two identical flow cell segments made of plastic, glass, or other materials that will not corrode and do not absorb moisture. Each cell segment consists of a flow cell and a sample clamping plate. The size of the cell can be as large as practical, so as the size of the duct. The typical size of the duct in each flow cell segment is 0.025 m wide, 0.13 m long, and 0.0050 m high. The entrance length of the nitrogen gas must be long enough to get a stable fully developed flow. At 2000 cm^3/min gas flow rate, more than 0.002 m is required for the duct length from the gas entrance to the sample, and from the specimen to the gas exit. The typical duct length is about 0.003 to 0.007 m. Each flow cell segment shall have ports for flow inlet and outlet in both ends of the flow cell segment, and a port for differential pressure measurement on the front top of the flow cell segment. A specimen is held in-between the two flow cell segments (Fig. 3).

7.3.2 *Specimen Clamping Plate*, can be made of plastic, metal, or steel, and attached to the flow cell segments by using a sealing agent or mounting bolts. The thickness of clamping plate shall be 5×10^{-5} m (0.5 mm). The hole opening in the clamping plate that determines the test area of the specimen shall have the size of 0.05 m long by 0.02 m wide (0.001 m^2). A specimen must be bigger than the hole of a clamping plate to cover the clamping plate completely.

7.3.3 *Clamping System*, prevents leakage of the nitrogen gas through the test cell unit. The sealing other than the clamping force provided by the mounting bolts is unnecessary for most thin materials such as laminated and woven textile materials. If there is any leakage from the edges of the specimen, special

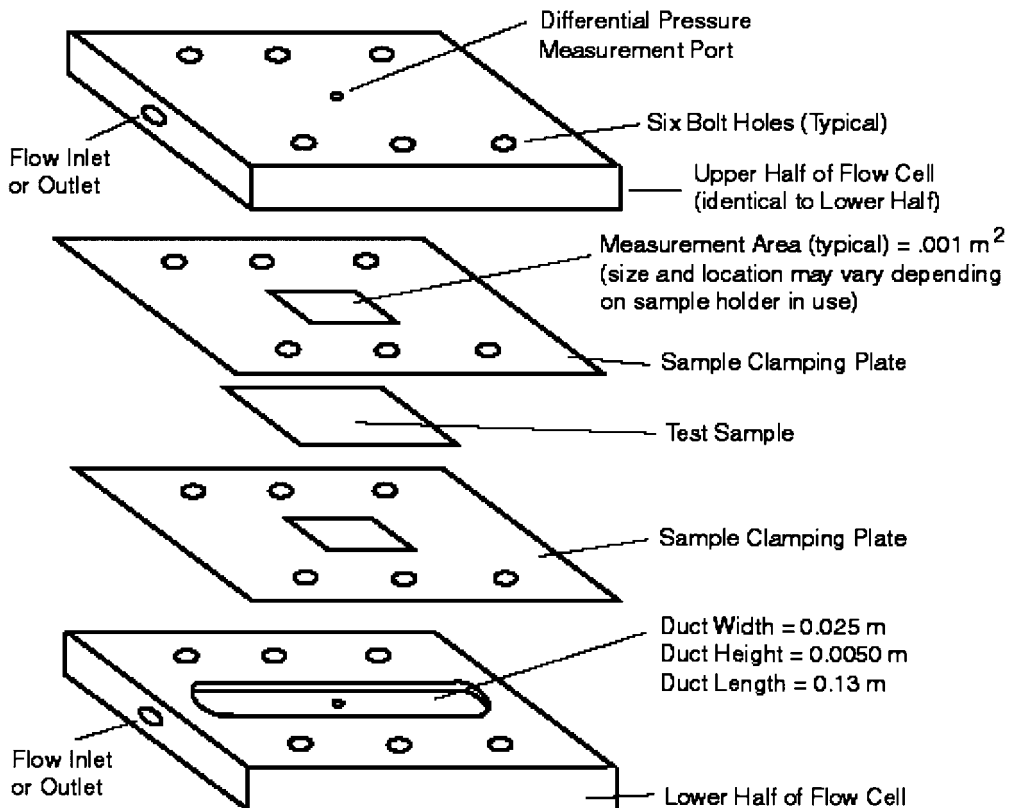


FIG. 3 Typical Dimensions of the Specimen Holder for the DMPC

sealing methods such as molten wax, curable sealant, rubber sealing gaskets may be required.

7.3.4 *Bubblers*, used to saturate nitrogen gas in water. Bubblers of 500 mL or 1000 mL are appropriate for this test. The first bubbler completes the primary saturation of the gas stream. The second bubbler ensures full saturation, and brings the gas stream back to deviation from the test temperature that may have occurred due to evaporative cooling in the first bubbler. The saturated and the dry nitrogen gas controlled by separate mass flow meters shall merge into one gas tube and enter to the top flow cell. The ratio of dry and saturated nitrogen gas determines the relative humidity in the flow cell. An identical set of two flow controllers and bubblers are needed to control the relative humidity of the bottom flow cell.

7.3.5 *Data Acquisition System*—It is possible to conduct the tests manually by reading the outputs from the relative humidity measurement devices, flow meters, and pressure transducers and performing the necessary calculations. However, it is recommended to conduct the tests under the control of a computer to automate the tasks of data collection and control of the mass flow controllers and valves.

7.4 *Materials:*

7.4.1 *Reference Material*,⁴ required for the calibration to check the instrument before testing. Use microporous expanded polytetrafluorethylene (ePTFE) membrane as a reference material.

7.4.2 *Nitrogen Gas*, pure nitrogen gas with technical grade of 99 % is used.

8. Calibration Procedures

8.1 Three calibration procedures may be necessary. The first two procedures (flow and humidity calibration) may not be required for all systems, depending on the accuracy and stability of the specific instrumentation incorporated into the particular DMPC design used.

8.2 *Flow Controller Calibration and Check*—It is important to ensure that the flow controllers are all checked and adjusted to give the same flow. For high accuracy electronic mass flow controllers, this step may be unnecessary since there is very little drift of high quality stable controllers. The flow controller check is carried out using only dry nitrogen. Any method of verifying that the flows at a specific indicated flow rate of the four controllers are equal is acceptable.

8.2.1 Test each flow controller individually by connecting it to a flow measurement device. The mass flow meter required for the diffusion/convection test is sufficient for this purpose. Adjust each mass flow controller to the mass flow rate to be used in the actual test. They should all give the same flow to within the control and measurement accuracy specifications of the mass flow controllers. If there are deviations, the full range output for electronic mass flow controllers can be manually or electronically adjusted so that each flow controller gives the same flow rate as all the other mass flow controllers. An alternate flow rate measurement method is to use a needle

valve or orifice, with a differential pressure sensor connected across the valve or orifice, which is connected to the output of a mass flow controller. Appropriate sizing of the needle valve or orifice opening, and the pressure transducer range, will give a measured pressure gradient across the valve or orifice which is indicative of whether each mass flow controller set at a particular flow is actually delivering identical gas flow rates.

8.3 *Humidity Calibration*—Requirements for humidity calibration will also depend on the humidity measurement system selected for the test. Humidity calibration procedures may be supplied by the manufacturer for the specific instrument, or may not be necessary for a high-accuracy system such as a gas chromatograph, infrared diode laser sensor, or a chilled-mirror dew point hygrometer.

8.4 *Reference Material Calibration*—Before starting test with a specimen, conduct a test with a reference material under the condition specified in 9.2. An expanded polytetrafluorethylene (ePTFE) film is used as a reference material for the system. The ePTFE membranes are microporous and hydrophobic, thus vapor transport takes place only through the interconnected air spaces of the membrane. They do not change the transport properties as a function of membrane water content or test conditions.

8.4.1 *Test Conditions*—Use the test conditions directed in 9.1.

8.4.2 Place an ePTFE film in between the top and the bottom flow cell segments.

8.4.3 Follow the same procedures in 9.2.2-9.2.4.

8.4.4 Calculate total water vapor diffusion resistance R_{dtot} described in 9.3.

8.4.5 The water vapor diffusion resistance of the reference material shall be 170 ± 10 %.

8.4.6 If the data obtained are close to the reference data, start the test. Otherwise, calibrate the instrument as described in 8.1-8.3.

PART A—DIFFUSION TEST

9. Procedure

9.1 *Test Conditions:*

9.1.1 *Temperature of Air*—Maintain the air temperature of the test chamber at $20 \pm 1^\circ\text{C}$ without fluctuating more than $\pm 0.1^\circ\text{C}$ during the test. The test can be done either in a lab or a test chamber as long as the condition is controlled. For tests not done in a temperature-controlled chamber, report the test temperature of the laboratory air and typical deviation during the course of testing.

9.1.2 *Volumetric Flow Rate*—Maintain the volumetric flow rate (at standard temperature and pressure, STP of 1 atm, 0°C) in each side of the flow cell at $2000 \text{ cm}^3/\text{min}$ ($3.33 \text{ by } 10^{-5} \text{ m}^3/\text{s}$).

NOTE 1—The speed of the gas flow depends on the volumetric flow rate and the size of the duct. When a typical sized duct (7.2.1) is used, the speed of the nitrogen gas stream will be 0.286 m/s at $2000 \text{ cm}^3/\text{min}$ ($3.33 \text{ by } 10^{-5} \text{ m}^3/\text{s}$) volumetric flow rate and 0.072 m/s at $500 \text{ cm}^3/\text{min}$ ($8.33 \text{ by } 10^{-6} \text{ m}^3/\text{s}$) volumetric flow rate (Eq 1). When a different sized duct is being used, the volumetric flow rate needs to be changed to keep the speed constant (Eq 1).

⁴ Information on the reference material of the DMPC test method can be obtained from GE Energy, Kansas City, MO 64133. (Tel: 816-356-8400)

$$V = \frac{Q}{(H \cdot W)} = \frac{Q_s \cdot 293.15}{(H \cdot W \cdot 273.15)} \quad (1)$$

where:

- V = speed of the nitrogen gas streams (m/s),
- Q = volumetric flow rate through top or bottom portion of the cell (m³/s) at the actual test temperature, T , (9.3.1.1),
- Q_s = indicated volumetric flow rate from the mass flow meter (m³/s),
- H = test cell height (m), and
- W = test cell width (m).

9.1.3 *Pressure Gradient*—Keep the pressure gradient across the specimen to 0 ± 5 Pa so that the transport takes place only by pure diffusion. This is accomplished by adjusting the valves at the outlets of the cell.

9.1.4 *Relative Humidity*—Maintain the incoming relative humidity in the top cell at $95 \% \pm 0.5 \%$ R.H. and the bottom cell at $5 \% \pm 0.5 \%$ R.H. without fluctuating more than $\pm 0.5 \%$ R.H. over the duration of the test measurement.

9.2 Test Procedures:

9.2.1 Select a specimen and place it in between the top and bottom flow cell with the side normally facing the human body towards the cell with higher relative humidity. Clamp two flow cells with sufficient force with mounting bolts to prevent gas leakage.

9.2.2 Connect all the parts together: Connect the flow inlet ports of the top and bottom cell with the gas tubes. Connect the humidity sensors to the outlet ports of the cell. The sensors are connected to the temperature and humidity readout. Connect the ports for pressure measurement with the differential pressure transducer.

9.2.3 Run the tests with specified conditions of gas flow rates, pressure gradients, temperature, and humidity in top and bottom cell segment.

9.2.4 After the specimen reaches steady-state conditions, collect a minimum of 10 data points on the mass flow rate, pressure gradient, temperature, and relative humidity in the top and bottom cell segments to determine the water vapor diffusion resistance. Steady-state shall be a rate of change of less than $\pm 1 \%$ of the calculated water vapor diffusion resistance over a period not less than 10 min. In case of a computer operation, the results may be sent to a printer or to a data file on a disk.

9.3 Calculations:

9.3.1 Calculate the total water vapor diffusion resistance (R_{dtot}) using Eq 2.

$$R_{dtot} = \frac{A(\Delta\phi)}{Q(\delta\phi)} = \frac{\Delta C}{\dot{m}} \quad (2)$$

where:

- R_{dtot} = total water vapor diffusion resistance (s/m),
- A = area of test specimen (m²),
- $\Delta\phi$ = relative humidity difference ($\phi_{top} - \phi_{bottom}$) between top and bottom incoming gas streams, expressed in decimal format (for example, 90 % = 0.90),

Q = volumetric flow rate through top or bottom portion of the cell (m³/s) at the actual test temperature, T , (9.3.1.1),

$\delta\phi$ = relative humidity difference ($\phi_{in} - \phi_{out}$) between incoming stream and outgoing stream in bottom portion of the moisture permeation cell segment, expressed in decimal format (for example, 90 % = 0.90),

\dot{m} = mass flux of water vapor across the specimen (kg/m²/s) (Eq 5), and

ΔC = log mean concentration difference between top and bottom nitrogen streams (kg/m³).

$$\Delta C = \frac{\Delta C_a - \Delta C_b}{\ln(\Delta C_a / \Delta C_b)} \quad (3)$$

where:

ΔC_a = concentration difference between the two gas streams at the incoming end of the flow cell, and

ΔC_b = concentration difference between the two gas streams at the outgoing end of the flow cell.

9.3.1.1 The actual volumetric flow rate is calculated by using Eq 3. For many mass flow rate controllers, the indicated volumetric flow rate Q_s on the digital readout is not the actual volumetric flow rate at the test conditions, but is referenced to STP, Standard Temperature (T_s) and Pressure (P_s) of 0°C and 1 atm pressure. The actual volumetric flow rate at a given temperature may be found from the volumetric flow rate indicated by the electronic mass flow meter (Q_s), the ambient temperature (T_a), and the ambient pressure of the actual flow (P_a). The pressure correction is usually negligible ($P_s / P_a \approx 1$), so only the temperature correction needs to be made. These reference conditions may vary for different mass flow controllers and the manufacturer's specifications should be consulted for the references conditions used for different flow controllers. The correction to obtain the actual volumetric flow rate (Q) from the indicated mass flow rate (Q_s) from the mass flow meter is:

$$Q = Q_s \left(\frac{T_a}{T_s} \right) \left(\frac{P_s}{P_a} \right) \cong Q_s \left(\frac{T_a}{T_s} \right) \quad (4)$$

where:

Q = actual volumetric flow rate measured by mass flow meter connected to bottom outlet of the cell (m³/s),

Q_s = indicated volumetric flow rate from the mass flow meter (m³/s),

T_a = ambient temperature (K),

T_s = reference temperature used by the mass flow meter (K), (obtained from manufacturer's specifications),

P_a = ambient pressure of the gas flow (Pa), and

P_s = reference pressure used by the mass flow meter (Pa), (obtained from manufacturer's specifications).

9.3.2 Calculate the water vapor flux of the specimen using Eq 5. The mass flux of water vapor across the specimen is calculated from the relative humidity difference between the flow coming into and the flow leaving the bottom portion of the flow cell.

$$\dot{m} = \frac{\delta\phi P_{sat} \cdot M_w \cdot Q_s}{ART_s} \quad (5)$$

where:

- \dot{m} = mass flux of water vapor across the specimen (kg/m²/s),
- A = area of test specimen (m²),
- $\delta\phi$ = relative humidity difference between incoming stream and outgoing stream in bottom portion of the moisture permeation cell (fractional),
- P_{sat} = water vapor saturation vapor pressure at the test temperature (N/m²),
- M_w = molecular weight of water vapor (18.015 kg/kgmole),
- Q_s = indicated volumetric flow rate from the mass flow meter (m³/s),
- R = universal gas constant (8314.5 N·m/kgmole·K), and
- T_s = reference temperature used by the mass flow meter (K), (obtained from manufacturer's specifications).

Eq 5 is derived from:

$$\dot{m} = \frac{\delta\phi Q(C_{sat})}{A} \quad (6)$$

$$C_{sat} = \frac{P_{sat} M_w}{RT} \quad (7)$$

where:

- C_{sat} = saturation water vapor concentration at the test temperature (kg/m³).

9.3.2.1 Convert the mass flux of water vapor to the water vapor transmission rate to units of g/m²/day using Eq 8.

$$\dot{m}(\text{g/m}^2/\text{day}) = 1000 \cdot 24 \cdot 60 \cdot 60 \cdot \dot{m}(\text{kg/m}^2/\text{s}) \quad (8)$$

PART B—DIFFUSION/CONVECTION TEST

10. Procedure

10.1 Test Conditions:

10.1.1 *Temperature of Air*—Maintain the air temperature of the test chamber at 20 ± 1°C without fluctuating more than ± 0.1°C during the test. The test can be done either in a lab or a test chamber as long as the condition is controlled. For tests not done in a temperature-controlled chamber, report the test temperature of the laboratory air, and typical deviation during the course of testing, shall be reported.

10.1.2 *Volumetric Flow Rate*—Set the input volumetric flow rates at 2000 cm³/min (STP) (3.33 × 10⁻⁵ m³/s; 0.286 m/s) through duct on both sides of the flow cell.

10.1.3 *Pressure Gradient*—Conduct at least 7 equally spaced test points between maximum and minimum pressure gradient possible for the particular flow rate of 2000 cm³/min flow (Table 1). The maximum and minimum pressure gradients vary depending on the air permeability of the specimen. A negative pressure gradient means that the water vapor diffusion and the convection take place in the opposite direction (the air pressure is higher in the bottom portion of the cell when the relative humidity is higher in the top portion of the cell). A positive pressure gradient means that they are in the same direction (the air pressure is higher in the top portion of the cell). (See Fig. 1.)

10.1.4 *Relative Humidity in the Flow Cells*—Maintain the incoming relative humidity in the top cell at 95 % ± 0.5 % R.H. and bottom cell at 5 % ± 0.5 % R.H.

10.1.5 *Test Duration*—Before changing the pressure gradient, make sure the specimen is in equilibrium at the test condition. Once the specimen reaches the steady-state, there is no need to change the humidity in the cell. Change the pressure gradients as specified in 10.1.3. Collect at least 5 data points for averaging when they come into equilibrium conditions at each pressure gradient.

10.2 Test Procedures:

10.2.1 Select a specimen and place it in between the top and bottom flow cell with the side normally facing the human body towards the cell with higher relative humidity. Clamp together two flow cell segments with sufficient force with mounting bolts to prevent gas leakage.

10.2.2 Connect all the parts together: Connect the flow inlet ports of the top and bottom cell with the gas tubes. Connect the humidity sensors to the outlet ports of the cell. The sensors are connected to the temperature and humidity readout. Connect the ports for pressure measurement with the differential pressure transducer. Connect the mass flow meter to the bottom cell segment outlet after the humidity sensor. Connect the flow control valves at the final gas flow outlets of each cell segment.

10.2.3 Run the tests with specified conditions of gas flow rates, pressure gradients, temperature, and humidity in top and bottom cell segments.

10.3 Calculations:

TABLE 1 Set Points for the Diffusion/Convection Test

Test Period	Relative Humidity in the Middle Cell (%)	Relative Humidity in the Bottom Cell (%)	Middle Flow (2000 cm ³ /min)	Bottom Flow (2000 cm ³ /min)	Pressure Gradient (Pa)
1	95	5	2000	2000	-150
2	95	5	2000	2000	-100
3	95	5	2000	2000	-75
4	95	5	2000	2000	-50
5	95	5	2000	2000	-25
6	95	5	2000	2000	0
7	95	5	2000	2000	+25
8	95	5	2000	2000	+50
9	95	5	2000	2000	+75
10	95	5	2000	2000	+100
11	95	5	2000	2000	+150

10.3.1 Calculate the apparent water vapor diffusion resistance under diffusion/convection conditions using the equations in 9.3.1.

10.3.2 Plot the apparent water vapor diffusion resistance versus the air pressure gradient as shown in Figs. 4 and 5. Calculate the slope of the plot if the plot is linear. Calculate or interpolate the true water vapor diffusion resistance at zero pressure gradient. Only this interpolated value at pressure drop equal to zero is valid in defining the true water vapor diffusion resistance of the specimen.

10.3.2.1 Discussion—When a sample has some air permeability, the apparent water vapor diffusion resistance changes as the pressure gradient changes. Fig. 4 shows the plot of apparent water vapor diffusion resistance at different levels of the pressure gradient on a slightly air permeable material (#1) measured by different labs. The apparent water vapor diffusion resistance is high at the negative pressure gradient and low at the positive pressure gradient. This is because the air flowing in is the opposite direction of the water vapor (that is, negative pressure gradient), resulting in less water vapor transport (high diffusion resistance). A statistical analysis can be conducted on the slope since the plot shows a linear trend. The apparent water vapor diffusion resistance of an air impermeable material will not change when the pressure gradient changes, since there is no air flow going through the material (see sample #3 in Fig. 4). Fig. 5 shows the plot on air permeable specimen tested at different labs. The effect of the pressure gradient across a sample becomes dramatic, resulting no linear trend. It is important to note that the curve of apparent water vapor diffusion resistance versus pressure drop is only used to calculate the true water vapor diffusion resistance by interpolating or extrapolating the values at the 0 pressure drop condition. The curve can give a relative qualitative measure of the interaction of convective and diffusive transport in different samples, but only the true water vapor diffusion resistance is a quantitative value, and is the only diffusion parameter from the Diffusion/Convection test that should be used for engineering purposes.

10.3.3 Calculate the air flow resistance (m^{-1}) using Eq 9. The air flow resistance may be found from the plot of the pressure gradient versus volumetric flow rate measured by the electronic mass flow meter connected to the bottom outlet of the DMPC, using the procedure outlined below. The definition for the air flow resistance (which is the inverse of air permeability) is:

$$R_D = \left(\frac{A}{\mu} \right) \left(\frac{\Delta p}{\Delta Q_{total}} \right) \quad (9)$$

where:

- R_D = air flow resistance (m^{-1}),
- A = specimen flow area (m^2),
- Δp = pressure gradient in Pa ($kg/m/s^2$),
- μ = air viscosity (17.85×10^{-6} kg/m/s at 20°C), and
- ΔQ_{total} = total volumetric flow rate through the specimen (m^3/s).

10.3.3.1 Use Eq 10 and 11 to convert air flow resistance in units of m^{-1} to air permeability ($m^3/s \cdot m^2$, or $ft^3/min \cdot ft^2$) measured in Test Method D737, where the pressure gradient is usually 0.5 in. of water:

$$Q_{metric} (m^3/s \cdot m^2) = \frac{\Delta p}{R_D \mu} \quad (10)$$

where:

- Δp = pressure gradient in Pa (N/m^2); Frazier air permeability uses 125 Pa (0.5 in. of H_2O),
- R_D = air flow resistance (m^{-1}); value obtained from DMPC measurement, and
- μ = air viscosity (17.85×10^{-6} kg/m/s at 20°C).

$$Q_{english} (ft^3/min \cdot ft^2) = 197 Q_{metric} (m^3/s \cdot m^2) \quad (11)$$

11. Report

11.1 The report shall include the following:

11.1.1 Report the identification of the material tested (for example, fiber content, weight, thickness, etc).

11.1.2 Report the ASTM number.

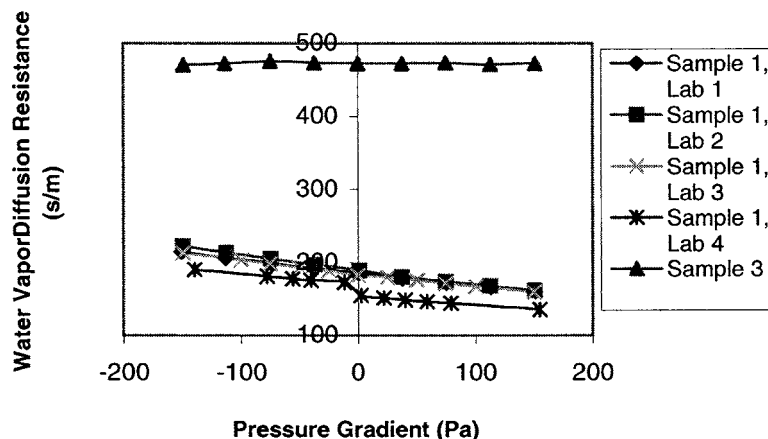


FIG. 4 Changes in Apparent Water Vapor Diffusion Resistance (R_{dtot}) as a Function of the Pressure Gradient Across a Material (Sample #1: Low Air Permeable, Sample #3: Air Impermeable)

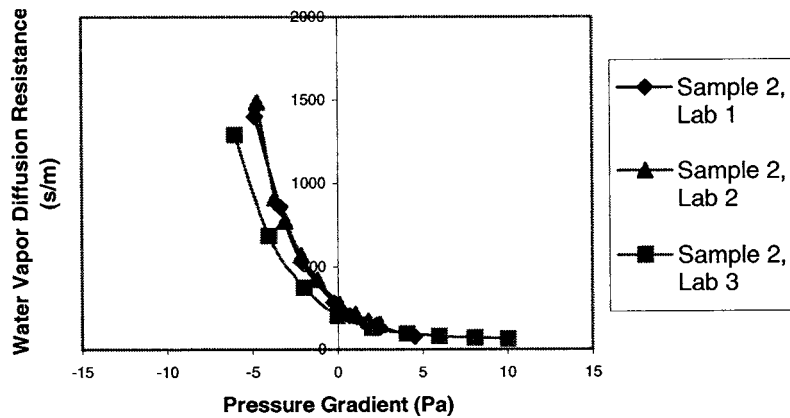


FIG. 5 Changes in Apparent Water Vapor Diffusion Resistance (s/m) as a Function of the Pressure Gradient Across a Material (Sample #2: Air Permeable)

11.1.3 Report the test method; Part A: Diffusion Test, or Part B: Diffusion/Convection Test.

11.1.4 Report the data.

11.1.4.1 *Part A*—Report the true water vapor diffusion resistance (s/m) and water vapor transmission rate (kg/m²·s or g/m²·day) at the condition of 0 pressure drop across the specimen.

11.1.4.2 *Part B*—Report a plot of apparent water vapor diffusion resistance (s/m) and apparent water vapor transmission rate (kg/m²·s or g/m²·day) versus the pressure gradient, and the true water vapor diffusion resistance and true water vapor transmission rate at the condition of zero pressure gradient. Report may include the slope of the plot if the plot is linear. Report may include the air flow resistance (m⁻¹) or air permeability.

11.1.5 Report any modification to the test.

12. Precision and Bias⁵

12.1 An interlaboratory test was conducted in 2001 in accordance with Practice E691, involving randomly drawn samples of three fabrics by five laboratories. For each material, all the specimens were prepared at one source and individual specimens were prepared and distributed by one laboratory. Each test result was the average of three individual determinations. One lab’s data were omitted from the statistical analysis on the convection test because the test was not performed in the specified direction.

12.2 The terms repeatability limit and reproducibility limit in Tables 2-4 are used as specified in Practice E177.

12.3 *Bias*—There are no recognized standards on which to base an estimate of bias for these test method.

13. Keywords

13.1 air flow resistance; dynamic moisture permeation cell; water vapor diffusion; water vapor diffusion resistance; water vapor flux; water vapor transmission rate

⁵ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:F23-1006.

TABLE 2 Water Vapor Diffusion Resistance Value Summary of Precision Parameters^A

Fabric	Mean Water Vapor Diffusion Resistance Value (s/m)	Repeatability Standard Deviation (S _r)	Reproducibility Standard Deviation (S _R)	95 % Repeatability Limit (r = 2.8 × S _r)	95 % Reproducibility Limit (R = 2.8 × S _R)
1	172.55	3.14	14.81	8.80	41.47
2	262.71	6.09	23.94	17.06	67.02
3	509.70	12.28	39.53	34.37	110.67

^A The data from 5 labs are used for the analysis.

TABLE 3 Air Permeability Value Summary of Precision Parameters^A

Fabric	Mean Air Permeability Value (cm ³ /s·cm ²)	Repeatability Standard Deviation (S _r)	Reproducibility Standard Deviation (S _R)	95 % Repeatability Limit (r = 2.8 × S _r)	95 % Reproducibility Limit (R = 2.8 × S _R)
1	0.2067 ^A	0.0258	0.0258	0.0723	0.0723
2	34.2667 ^B	1.9942	3.4076	5.5836	9.5413
3	0.0267 ^A	0.0365	0.0471	0.1022	0.1320

^A The data from 4 labs are used for the analysis.

^B The data from 3 labs are used for the analysis.

TABLE 4 Slope of the Changes in Water Vapor Diffusion Resistance Value as a Function of Pressure Gradient Summary of Precision Parameters^A

Fabric	Slope (Δ(s/m) / ΔPa)	Repeatability Standard Deviation (S _r)	Reproducibility Standard Deviation (S _R)	95 % Repeatability Limit (r = 2.8 × S _r)	95 % Reproducibility Limit (R = 2.8 × S _R)
1	0.1945	0.0252	0.0282	0.0707	0.0790

^A The data from 4 labs are used for the analysis.

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