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Infrared Technique as a Research Tool for Measuring Water Vapor Transmission of Roofing Membranes

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ABSTRACT: Measurements of the permeability to water vapor of materials intended to prevent its transmission are time-consuming with the usual cup method [*1*]. Several instruments have been promoted as being capable of providing results rapidly, but doubts about their agreement with cup measurements have delayed their use for more than quality control.

One instrument with an infrared sensor was studied to investigate its accuracy and to correlate results obtained with the standard cup methods. Factors studied include those that contribute to the inconsistent performance of the instrument, especially for research work. Techniques for improving the precision and the accuracy of the instrument are discussed. The permeances of roofing papers and felts and of plastic films by both the modified IR instrument and the cup methods are reported and compared to values given in the literature.

KEYWORDS: dry cup method, electronic instrument, infrared (IR) sensor, Mylar film, permeance, roofing membranes, water vapor transmission (WVR), water vapor transmission rate (WVTR), wet cup method

Water vapor transmission (WVT) or vapor permeance is an important attribute of materials and is related to their durability and performance [*1*]. In the packaging industry, moisture equilibrium of the packaged products is considered an important factor in their shelf lives. In buildings, water in the wrong places harms materials and assemblies. In the case of roofs, properly designed and installed watertight membranes can prevent rain or liquid water penetration. However, if a membrane does not let moisture escape from underneath it, blistering or condensation can cause failure of the roof. Although high or low WVT may be needed, depending on the roof design, the WVT of a roofing membrane is an important property for roof performance.

Vapor transmission is generally measured using dry, wet, or inverted cups described in the ASTM Test Methods for Water Vapor Transmission of Materials (E 96). Although this method is a simple simulation of moisture movement through a membrane under a vapor pressure differential, it is time-consuming and requires extensive manipulation. Its reproducibility is questionable as the results are quite sensitive to the preparation of test specimens and the test conditions. Consequently, there has always been a need for a fast and precise measurement of WVT using dependable equipment.

In the late 1960s two different electronic instruments were introduced to the market. One was described in the ASTM Test Method for Water Vapor Transmission Rate of Sheet Materials Using a Rapid Technique for Dynamic Measurement (E 398). It uses a gold grid relative humidity sensor (GRHS). The other ASTM Test Method for Water Vapor Transmission of Flexible Barrier Materials Using an Infrared Detection Technique, (F 372), uses an infrared (IR) sensor. The latter apparatus has been called Mocon IRD-2. In this method (IR detection) the time to reach a certain relative humidity value is determined. The relative humidity conditions on the top and bottom sides of the material are nearly 0% and 100%, respectively, or any other desired humidity. The result obtained is water vapor transmission rate (WVTR), measured in grams per square meter per day. A second generation of this apparatus, used in the present study, includes considerable modifications and is referred to as Permatran W (PW). The instrument can be used to measure the mean permeability between 0% RH and any other value, depending on the aqueous salt solution used. Consequently, wet-cup (50 to 100%) results cannot be obtained with it.

In ASTM E 398, the apparatus is calibrated by testing materials with a range of water-vapor transport values that have been determined by either of the desiccant cup procedures, A or E, in ASTM E 96. In ASTM F 372, the instrument is calibrated gravimetrically. In ASTM Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor (F 1249) for the later infrared apparatus PW, standardization is obtained by transmission of water vapor through a 25 μm (1 mil) or 125 μm (5 mil) Mylar film.

In 1986, an interlaboratory study of the PW was completed in which thirteen laboratories tested four types of polymer films and one laboratory measured three of the materials by Procedure E of ASTM E 96. The objective was to obtain the precision of the PW and to compare the values with those from ASTM E 96. Because only six of the laboratories were able to run two samples, each in triplicate, the results were unbalanced which complicated the calculation of intra- and inter-laboratory precision. ASTM F 1249 has recently been prepared for this instrument.

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The first objective of the present study was to correlate the results from the PW with those from the ASTM E 96 cups. In preliminary testing it was found that the results obtained from the former depends on testing conditions and is only adequate for the routine or comparative testing used in quality control by industry. To obtain consistent results for research requires extensive care and manipulation. After considerable experimenting with the PW, it was found that the apparatus needed some modification to be suitable for the purpose. This paper reports the investigation of the factors that affect the results and their incorporation in the test method and in the apparatus requirements.

Theoretical Considerations

The WVT through materials is affected by various factors. The mean permeation is the WVTR corrected for vapor pressure of water, thickness of the specimen, and the relative humidity gradient. It is given by Eq 1 [2]

$$\bar{\mu} = \frac{\text{WVTR}}{P(RH_2 - RH_1)} \times L \qquad (1)$$

where $\bar{\mu}$ is the mean permeability in the relative humidity range, P is the water vapor pressure of pure water at the test temperature, L the thickness of the specimen, and RH_1 and RH_2 refer to the humidity on each side of it.

The permeability of most materials varies nonlinearly with the relative humidity whereas the "spot" permeability is the value at any given relative humidity. In Fig. 1 the values given are the means for each range studied. The dry-cup and the wet-cup values refer to the two RH regions, 0 to 50% and 50 to 100%, used in ASTM E 96.

With a solution that produces 50% RH in the PW cell, the result should be the same as with the dry cup. With water in the cell, the result is the overall mean for the entire humidity range (0 to 100%).

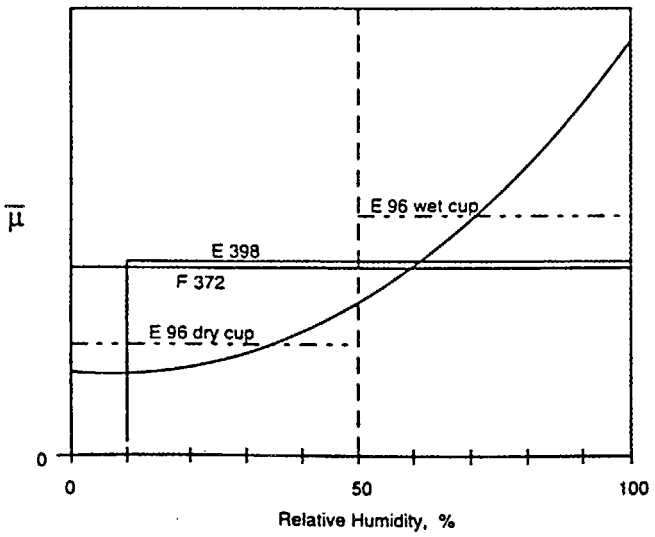

FIG. 1—*Permeability obtained by different methods.*

Permeance is usually reported on the basis of the standard cup procedures. It is given by

$$\text{Permeance} = \frac{\text{WVTR}}{P(RH_2 - RH_1)} = \frac{\bar{\mu}}{L} \qquad (2)$$

Since WVTR is directly related to water vapor pressure (P) and the latter is very sensitive to temperature, WVTR is readily affected by temperature. Equation 1 may be rewritten to include P as a function of temperature T

$$\text{WVTR} = \bar{\mu} \times P \times (RH_2 - RH_1)/L$$
$$= \bar{\mu} \times f(T) \times (RH_2 - RH_1)/L \qquad (3)$$

The other two procedures for measuring permeance are ASTM E 398 and F 372. The first one (GRHS) for sheet material (ASTM E 398) can be compared to PW. In both cases, the wet side is 100% or other selected RH but the dry side for GRHS is not flowing air. In fact, the rate of increase in relative humidity in still air between two low values (for example 10% and 11%) is measured. The permeability result is the mean between 100% and 10%. The apparatus is calibrated with an ASTM E 96 test value, which is not really an equivalent measurement since the RH range is not the same. With a good independent calibration this method should lead to a value near but slightly higher than the PW result.

ASTM F 372 (IR detection) values should be close to those from PW (the latest version of F 372) but the exact RH value on the dry side is unknown according to the description given in the ASTM standard. These two test methods (ASTM E 398 and F 372) do not have the steady state conditions present in PW so that the results differ slightly, as shown in Fig. 1.

Experimental

Equipment

The newer infrared sensor equipment, PW (Fig. 2), is designed from a simple concept where the specimen is clamped in a measuring cell (Fig. 3). The bottom space, or the wet side of the membrane, contains a pad soaked with reagent water or an aqueous salt solution, depending on the humidity level selected for the test. The upper space is constantly flushed with dry air. As the moisture diffuses through the membrane it is collected by the flowing air and the water vapor concentration is measured in an infrared cell. Since the vapor concentration is proportional to its transmission rate, the apparatus is calibrated to give the latter directly. A metal bellows pump circulates the dry air at a flow rate that can be adjusted to any value between 0 and 100 cc/min. A four-way valve is used to purge the system. The other four-way valve can cut out the sample cell for specimen changing or zeroing the IR detector.

Materials

Various samples of asphaltic sheathing paper and felt, Mylar, and cellulose acetate sheets were used for permeation measurements by the IR detection method and the referee Cup method (ASTM E 96). Reagent water was used for both the wet cups and the inverted cups while magnesium perchlorate was used as

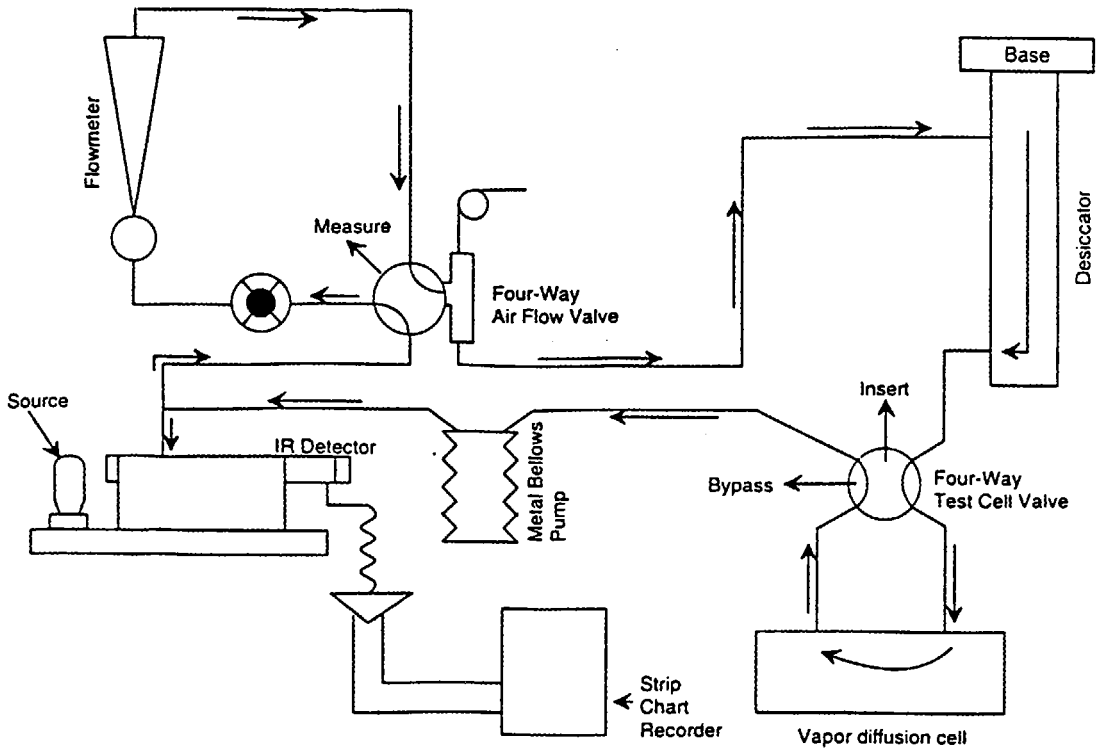

FIG. 2—*Schematic diagram of Permatran W (PW).*

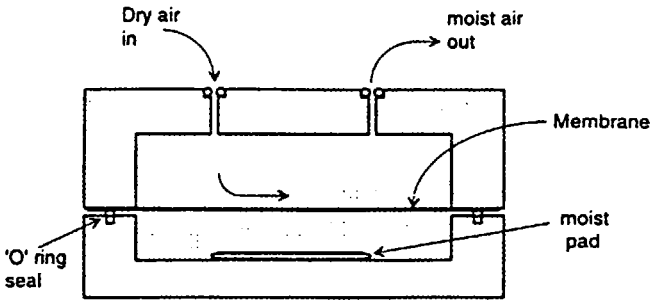

FIG. 3—*Cross-sectional view of PW's vapor diffusion cell.*

desiccant for the dry cup. Before testing, all samples were conditioned at 50% RH and 21°C until equilibrium moisture content was reached.

Testing

The vapor permeation was measured in the same conditioned room using the cups and PW with the machine temperature controller off and at a flow rate of 65 cc/min unless otherwise specified.

Great care was taken to keep the PW system air tight and dry, as small leaks can saturate the desiccant rapidly leading to unstable values. In order to get a more rapid indication of desiccant saturation, the "Drierite" indicator was placed at the bottom of the drying column near the air inlet. This manner of preparing the columns is not only more sensitive but also more convenient than placing the indicator in the middle of the column as proposed by the manufacturer [*3*].

Because it takes a few days to dry out the tubing system, an empty cell was kept in the test chamber and the pump was run all the time, even when the machine was not in use, to ensure constant dryness of the tubing. This procedure reduces the starting time of the system to only warming up the chart recorder or the data logger. Although this precaution saves time, it reduces the lifetime of the IR lamp.

The zero calibration was done on the empty cell to ensure the same conditions for the measurements as for calibration. This technique leads to a consistent value equal to that measured on the bypass. Calibration on the bypass without any protection of the test chamber gives inconsistent results for an empty cell, until it is completely dry.

The specimens were conditioned at 50% RH and 21°C for one day and then placed in the conditioning rack of the machine for at least 3 h. All measurements in the test chamber were recorded after the values had been stable within 1% for 10 min.

Results and Discussion

Comparison of the Cup and Other Methods

The permeance of Mylar films measured by the dry- and wet-cup and PW methods and shown in Fig. 4 increases linearly with the inverse of the thickness of the film. The literature shows that many materials have a greater permeance with the wet cup than with the dry cup. However, Mylar is reported to be relatively unaffected by RH so that both cups should yield the same value within the accuracy of the test method. In this study the small

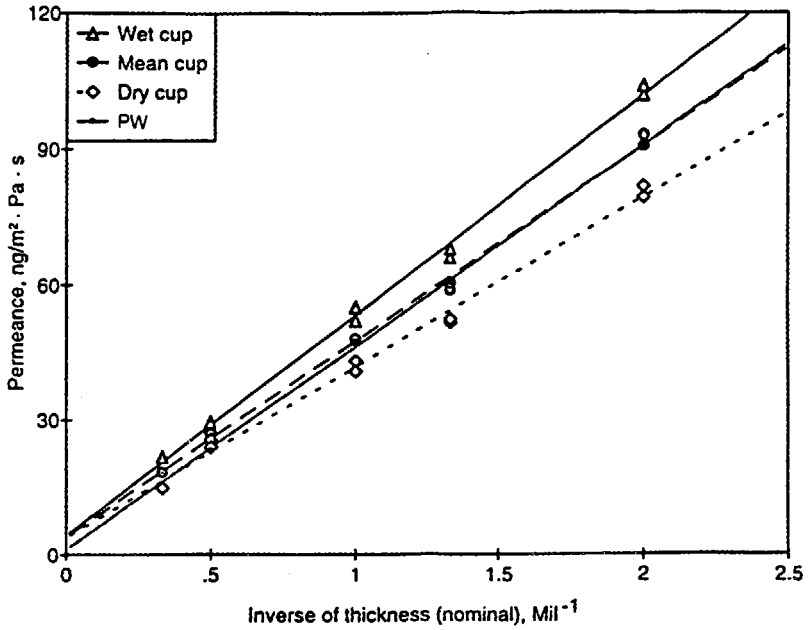

FIG. 4—*Effect of thickness and test method on Mylar permeance.*

difference, which is not significant, can be attributed to the too low room relative humidity. This can be compensated for by using the mean value from both cup procedures. Since relative humidity has no influence on the closed system of the PW, the values obtained with it are the same as the mean cup results. The small differences observed are due to temperature, as will be discussed later.

Joy and Wilson found [*4*] that the wet cup does not always give a higher value than the dry cup, as shown in Table 1. For example, foamed polyurethane, polyethylene, and Mylar show nearly the same permeance value for both wet and dry cup, but generally the wet-cup value is higher.

When cellulose acetate, which is more sensitive to relative humidity and temperature, was tested in this study the PW value was found to be higher than both cup values given in Table 2. This can be attributed to poor temperature control and an overall lack of permeability precision or to the material's sensitivity to water. There is also a considerable difference in the wet cup result from that reported by Joy and Wilson in Table 1, probably caused by differences in the cellulose acetate itself since properties will depend on the cellulose source and production process. These aspects will be further discussed in relevant sections.

In the round robin test on PW [*5*], thirteen labs, six of which ran two samples while seven ran one sample all with three replicates per sample, measured the WVTR of four materials. The results were compared with tests on three of the materials in one lab using Procedure E of ASTM E 96 but with a relative humidity range of 0 to 90% at 37.8°C. The mean values, ranges, and standard deviations are reported in Table 3.

The agreement among the PW results is quite good except for the first sample in the table. Statistically, the results from the last six materials could be pooled to obtain the precision for low permeability membranes. Because only one laboratory measured ASTM E 96 dry-cup permeance of three of the samples, it is not possible to obtain a good estimate of the agreement between the two procedures.

TABLE 1—*Wet- and dry-cup permeance values at 73°F (23°C).*

Sample Description	Permeance (ng/m².Pa.s) Dry Cup 0–50%	Wet Cup 100%–50%	Mean	Diff.*
Foamed Polyurethane Insulation, 28 kg/m³ (1.75 lb/cu. ft.), 25 mm (1 in.)	75	75	75	0
Extruded Polystyrene Insulation, 29.2 kg/m³ (1.82 lb/cu. ft.), 25 mm (1 in.)	92	92	92	0
Polyethylene Film, 0.05 mm (2 mil)	9.2	8.0	8.6	−1.2
Mylar Film, 0.025 mm (1 mil)	39	41	40	+2
Vinyl Film, 0.5 mm (20 mil)	20	20	20	0
Cellulose Acetate Film, 0.25 mm (10 mil)	270	649	460	+379

NOTE 1: The values in the referenced table [*4*] have been converted to SI units.
NOTE 2: All results were obtained from triplicate tests.
*Difference between wet- and dry-cup results.

TABLE 2—*Permeance of some plastic films (tested in triplicate at 23°C and 50% RH).*

Sample	Permeance, ng/m².Pa.s				
	Dry Cup	Wet Cup	Mean	PW	Diff.*
Mylar, 0.025 mm (1 mil)	41.8	53.5	47.7	47.2	−0.5
Cellulose Acetate, 0.25 mm (10 mil)	238	492	365	625	+260
Poly(Vinyl Chloride), 0.25 mm (10 mil)	5.5	5.5	5.5	8.7	+3.2

*Difference between mean cup and PW results.

TABLE 3—*Interlaboratory test results[a] for PW and ASTM E 96 Modified Procedure E (all values in g/m².d).*

Sample		PW (g/m².d)						
Designation	Thickness, mm (mil)	Mean WVTR	Min. Value	Max. Value	Range	Std. Dev.	E 96	Diff.[b]
Barex[c] 1	.025 (1)	76.3	56	88	32	8.4	—	
Barex 2	.025 (1)	75.6	74	79	5	3.4	—	
PET 1	.075 (3)	17.6	16.2	20.3	4.1	1.3	17.97	+0.37
PET 2	.075 (3)	17.4	16.5	18.1	1.6	0.64	—	
LDPE 1	.10 (4)	2.7	2.5	3.2	0.7	0.24	2.80	+0.1
LDPE 2	.10 (4)	2.8	2.6	3.2	0.6	0.24	—	
Comp 1	.38 (15)	1.0	0.73	1.35	0.62	0.18	0.97	−0.03
Comp 2	.38 (15)	1.03	0.73	1.35	0.62	0.18	—	

[a]The values in the reference have been modified.
[b]Difference between mean PW and modified E of ASTM E 96 results.
[c]Barex is a tradename of B.P. America's product: Acrylonitrile Methyl Acrylate Copolymer.

Effect of Air Flow Rate

Great care is needed to maintain the cleanliness of tubing. Dirt or dust in the tubing affects the reading as it can clog the flowmeter and cause erratic variations in the flow rate.

The flow rate of 65 cc/min proposed by the manufacturer is considered to be high enough to get a constant value but low enough to get a high water vapor concentration. The apparatus was calibrated at a flow rate of 65 cc/min and the apparent WVTR of 1 mil Mylar determined at various flow rates. The values plotted against the inverse of the flow rate in Fig. 5 show that apparent WVTR increases linearly with the inverse of the flow rate. In the working range of 50 to 75 cc/min, a variation of 5 cc/min (corresponding to the flowmeter precision), induces a 7 to 10% variation in WVTR. For this reason, any change or fluctuation in flow rate should be avoided after calibration. Unfortunately, the desiccant contains a high amount of dust that could affect the flowmeter. Addition of an air filter at the outlet of the column would be desirable.

Effect of Temperature

Temperature influences relative humidity obtained from salt solutions. The phenomenon might induce some systematic error in the measurements. In order to avoid any effect of this type of error, only pure water was used in the experimental work in this section.

The temperature does not only affect the relative humidity on the testing cell but also influences the mechanism of water vapor transmission. Accordingly, this aspect was studied using values of the vapor pressure of pure water [6] and the WVTR of 1 mil Mylar [3] at different temperatures. It is evident in Fig. 6 that the shape of the two curves is almost the same. The small gap between them is not due to the different scales (exact ratio of 2), indicating absence of a direct relation between WVTR and P, since Eq 3 is approximate because it involves $\bar{\mu}$, the mean permeability. There is a 5% difference between the two curves in the 35°C region. This difference reflects the increase in the kinetics of the diffusion process related to the temperature. The importance of this difference may change from one material to another. Comparison of measurements at different temperatures can lead to erroneous conclusions.

The relation between WVTR and temperature for elastomers and plastics [7] may be written as

$$\text{WVTR} = \frac{P \cdot \Delta RH \cdot \mu_o \, e^{-(E/RT)}}{L} \tag{4}$$

where:

P = the pressure of pure water at T,
ΔRH = the RH difference between the two sides of the material.
μ_o = the material permeability at time, $t = 0$
L = the thickness of the specimen,
e = natural logarithm base, 2.718,
E = activation energy of diffusion,
R = gas constant, and
T = absolute temperature, K.

Except for P, ΔRH, and T, all the terms in this equation are constant for a given material. From this equation, if E is large, the exponential term is almost equal to one and WVTR is pro-

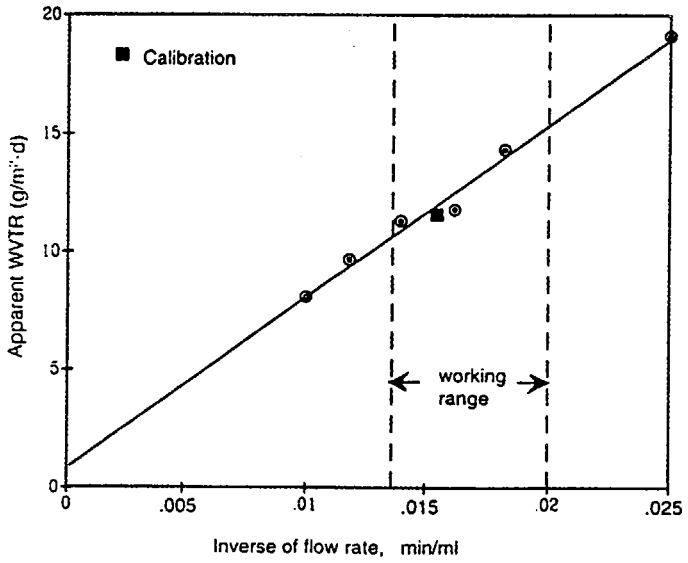

FIG. 5—*Change in apparent WVTR with airflow rate in PW.*

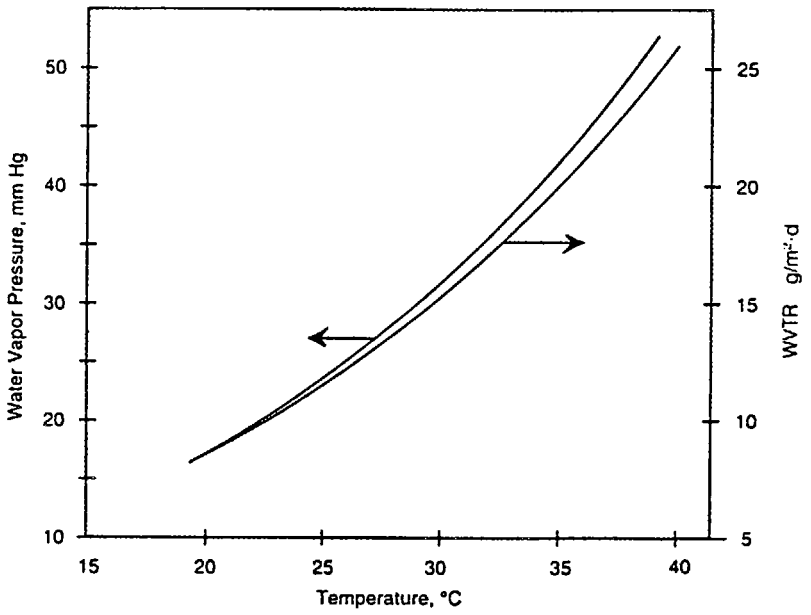

FIG. 6—*WVTR of 1 mil Mylar and water vapor pressure at different temperatures (see ASTM F 372 and Ref 6).*

portional to P. In most cases, however, E is unknown and no formal comparison can be made from one temperature to another. Furthermore, relative humidity is sensitive to temperature so that small temperature variations may induce large WVTR variations particularly in the low relative humidity range. This relation can be used for thermodynamic calculations. As an example, from Fig. 6 and Eq 4, E has been calculated to be about 2.7 kJ/mol for Mylar. Although this equation is not of common use for routine testing of materials, it is given here to state the importance of temperature control.

It should also be noted that, due to RH dependency, the change in WVTR with temperature is rapid, about 5% per degree. This effect may lead to large variations from one set to another and give erroneous results. Temperature variation in the room or cooling of the specimen by the flowing air can cause large variations in transmission. Even the heat produced by the PW circuits can affect the results. Hence, it is essential to have good temperature control in order to calibrate the apparatus and to measure WVTR.

An external cell was designed and built at the National Research Council of Canada (NRCC) to accommodate thick roofing membranes. At room temperature this cell leads to a decrease in WVTR of 9% compared to the same specimen at room temperature in the test chamber with the heating device off. The

difference can be attributed to a 2°C temperature variation between the two measurement conditions.

The PW contains a heating device for controlling above-room temperatures. Since the flowing air is not heated it cools the specimen locally. The exact temperatures of the film and the measuring conditions are not known at that juncture.

With a 15-mil Mylar film and various heating rates, temperatures were measured in three different locations: the thermometer slot, the bottom part of the cell, and the top part of the cell near the air inlet. The temperatures shown in Fig. 7 make the difference between the three locations obvious. With no heat there is a 2°C difference between the cell and room temperature. There is also up to 2 to 3°C of difference between the slot and the cell when heated. The flowing air is cooler than the cell and produces a local cooling effect near the inlet. Such a temperature gradient can be a driving force like an RH gradient [8] and can affect the WVTR.

Consequently, there is a need for a temperature recorder accurate to ±0.3°C inside the cell. Also, temperature control to keep the cell, the specimen, and the air at a temperature between approximately 15 and 50°C is desirable.

Equilibrium Time

Time to reach equilibrium in WVTR measurements is an important factor and needs to be defined concisely. Even when specimens have been conditioned for several days in the rack a significant time is still required to obtain a reliable reading. On this kind of apparatus, a value is usually recorded when the condition is stabilized. Depending upon how the various operators define or interpret "stabilized" or "equilibrium," different results may be obtained from one operator to another. In ASTM F 1249, "Constant value with no significant trend" is used as the definite equilibrium. Since some materials reach equilibrium faster than others, use of a specific time is not possible. Nevertheless, there is a need for a reliable standard using a realistic time scale, since the intent of an apparatus, like PW, is to reduce the testing time to a minimum.

The latter is examined in Fig. 8 where the different equilibrium times for three Mylar samples are shown. In this study all specimens were conditioned for at least three days, which was considered adequate for stability of Mylar. The values were normalized to the 50-min WVTR of each sample. As expected, the thin Mylar film reaches the steady state condition of WVTR faster than the thicker ones. In all cases, however, the time required is more than the 10 min proposed by the instrument manufacturer [3]. Only the 0.5-mil sample reached 95% of its final 50-min value within 9.5 min. The thickest sample took 19 min to reach this level. It must be understood that these values are relative and may vary from one day to another. To get these results measurements were taken over a long time (more than one hour), yet Mylar reaches equilibrium faster than most materials. This method requires extensive time and should be avoided if possible.

One way to simplify this problem is to use a slowly decreasing rate as standard. For example, repeatable results were obtained by using a minimum limit of 1% variation over 10 min. This method leads to a value that is about 99% of the 50-min. value, i.e., within the stated 2% precision of the apparatus. Very long equilibrium times, which are impossible to measure by the present method, can be obtained by taking a measurement daily. It should be recognized that equilibrium times are only relative and do not have any inherent significance. The value may change considerably from day to day and is always governed by the saturation of the desiccant columns. Nevertheless, the time to achieve the 1% variation rate was always longer than the 10 to 15 min specified by the manufacturer.

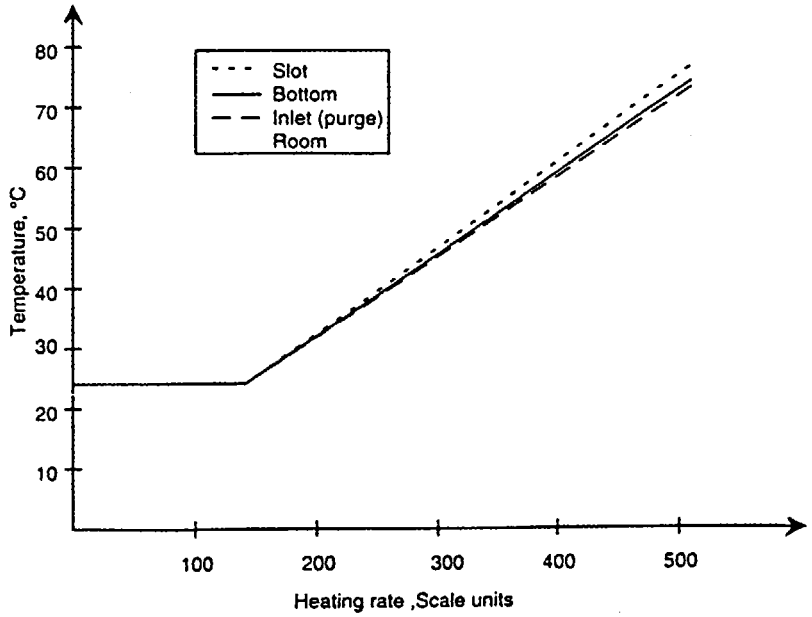

FIG. 7—*Temperature at various locations in PW apparatus at different heating rates.*

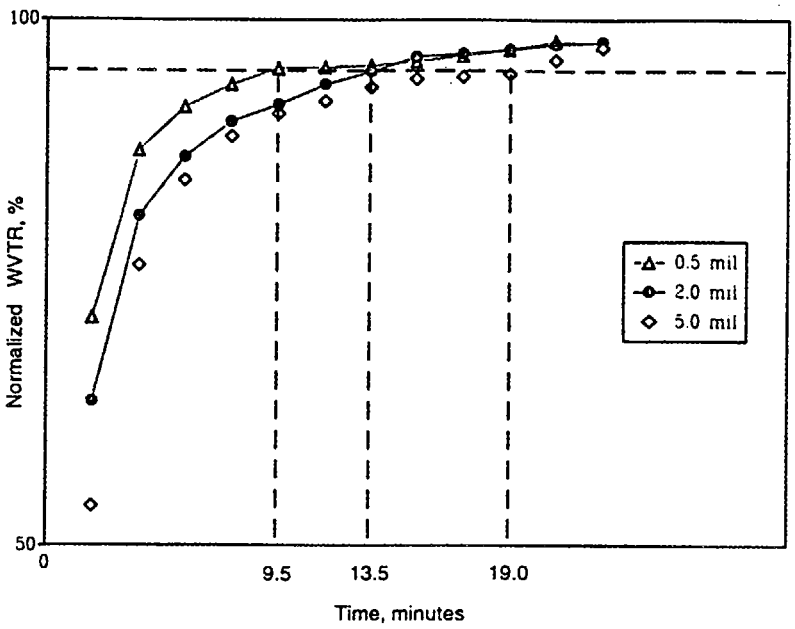

FIG. 8—*Effect of thickness and time on WVTR (normalized to 50 min value).*

Effect of Relative Humidity

In order to get a complete overview of the permeation phenomenon, various RH values must be used. Using salt solutions reduces the water vapor pressure and avoids condensation on the films. As discussed earlier, a change in relative humidity has a significant effect on permeability and, to be able to make comparisons, it is necessary to use the same specific conditions. Commonly used conditions in ASTM E 96 and D 1653 are given in Table 4. A salt solution that produces 50% RH inside a large desiccator that holds cups containing water or desiccant can be used for wet- and dry-cup procedures (Procedures A and C). A 90%-RH salt solution is used for Procedure E in ASTM E 96 and Procedure B and Condition C in D 1653. In Method A of ASTM D 1653, Condition A specifies reagent water in the cup, and desiccant in the test chamber, thus attempting to cover the entire RH range in one test. This test condition is not present in ASTM E 96. Results obtained by one procedure cannot be reliably compared to those from another procedure.

Special care must be taken in the preparation of the salt solutions. An excess of salt should be put in the cell to ensure saturation. Blends of two or more salts produce an RH value different from that from a pure salt. In fact, the RH value that a salt is supposed to produce can vary widely from one literature reference to another.

Because of its low sensitivity to relative humidity some WVTR measurements were made on Mylar film using different salt solutions taken from ASTM E 104, Recommended Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions. In Fig. 9 the results are plotted against the RH value given for those salts with the WVTR normalized to the 100% RH value. The results show that the relative WVTR of Mylar varies linearly with relative humidity implying a constant permeance over the entire RH range.

Although the transmission rates obtained by the two cup methods differ slightly (about 10%) and the values given in the literature differ from each other by 5% (Table I), all standard values given in the operating manual for Permatran W-1 correspond fairly well to a constant permeability with RH. This relates to the results obtained with various salts.

In order to completely characterize a material, sensitivity to moisture must be verified. Some materials are plasticized by

TABLE 4—*Commonly used permeability test conditions.*

ASTM Method and Procedure		Temperature		% Relative Humidity	
		°C	(°F)	Inside Cup	Outside Cup
E 96	A	23	(73)	0	50*
E 96	B	23	(73)	100	50
E 96	C	32.2	(90)	0	50*
E 96	D	32.2	(90)	100	50
E 96	E	38	(100)	0	50*
D 1653	A	23	(73)	100	near 0
D 1653	A	23	(73)	100	50
D 1653	B	23	(73)	0	50
D 1653	B	38	(100)	0	90

*ASTM E 96 permits 90% for testing at extreme humidity.

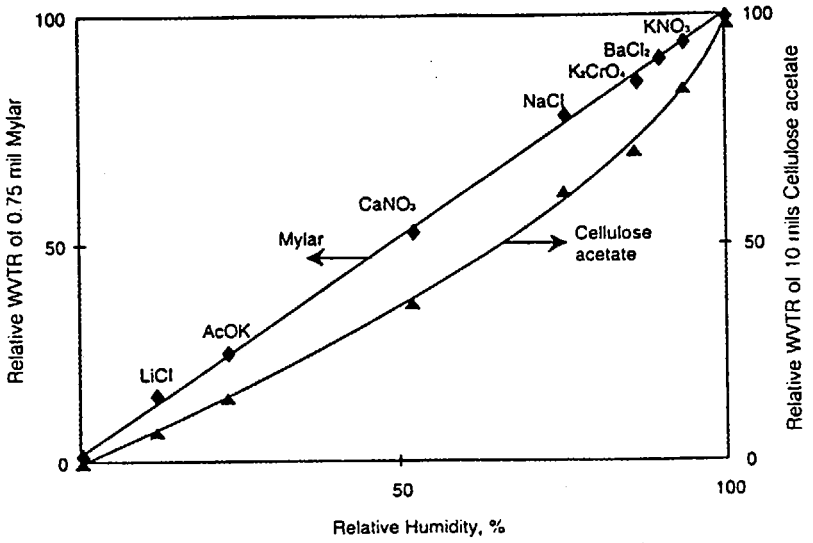

FIG. 9—*Relative WVTR of Mylar and cellulose acetate at different relative humidities.*

water and the diffusion process is affected. Such a material transmits not only as a function of ΔRH but also as a function of the RH on top and bottom of the sample.

For a moisture-sensitive material such as cellulose acetate, WVTR is lower than the corresponding straight-line values between 0 to 100% RH so that a large variation in mean permeance can be observed (Fig. 9). From the mean permeability (PW) curves, the permeability curve was determined (Fig. 10), and the cup values calculated. The latter values are 40% higher than the results obtained by the cup method. Such a difference between the two methods cannot be attributed to calibration method errors that would have lead to similar results with Mylar. This difference indicates a high sensitivity of cellulose acetate to water vapor concentration.

In order to reinforce that statement, a cellulose acetate was imersed in water for 24 h. It increased about 2% in length when in contact with water so it is very sensitive to humid conditions. This phenomenon alone, however, cannot explain the large difference. Figure 10 shows that the permeability curve calculated from permeation results is similar to Fig. 3, thus indicating one of the possible uses of PW.

Effect of Condensation

As shown in the previous section, some materials are very sensitive to moisture and should not be allowed to come in con-

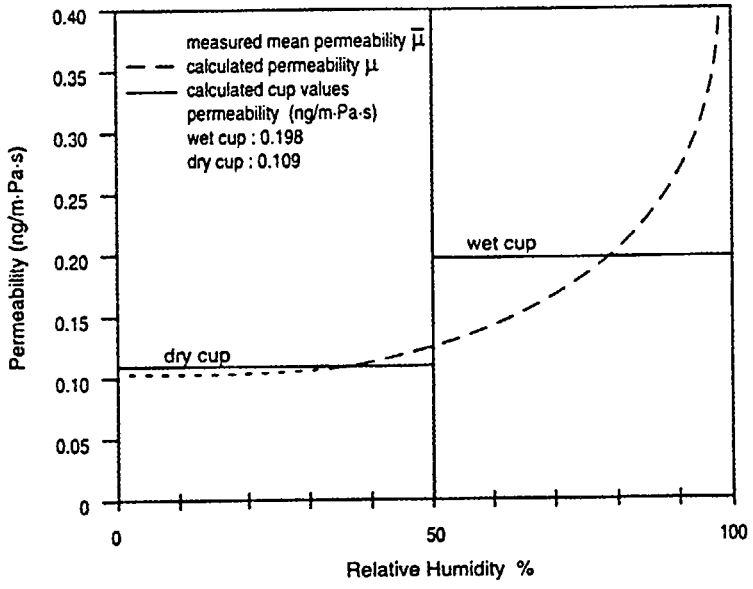

FIG. 10—*Permeability of cellulose acetate versus relative humidity.*

tact with water. The design of the PW is such that this cannot always be achieved. The air flowing over the specimen, although at the same temperature, can produce a cooling effect and create some condensation on the other side of the film. This problem is enhanced by heating the cell, since the unheated air cools the specimen faster and even a difference of one or two degrees is sufficient to cause some condensation.

Condensation does not affect many materials, as shown by Mylar and similar materials exhibiting little difference between wet-cup and inverted wet-cup tests. Hygroscopic ones, however, are readily affected as indicated by the inverted-cup measurements of [4] listed in Table 5.

In the present study, permeance of 15# asphalt-saturated felt was measured using different cups. The dry-, wet-, and inverted wet-cup results were 20, 315, and 920 ng·m^{-2}.Pa.s, respectively. Based on these values, the Permatran is expected to give 168 ng/m^2.Pa.s (Fig. 11).

In the inverted PW cell, the film is in direct contact with water so its water content increases slowly. The resulting wetting of the specimen leads to a rapid increase of vapor transmission to about 600 ng/m^2.Pa.s followed by a slow increase up to 710 in the subsequent days. The increase for the upright cell is slower but similar. Extrapolation of the latter to zero time leads to a value that is close to the mean cup value. Since it is impossible to get a constant value within one hour for this kind of material, extrapolation to zero should be done whenever possible, although such extrapolated values are not necessarily reliable.

It might have been expected that the inverted PW cell would yield the mean of the dry- and inverted-cup results. However, the difference in the thickness of the water layer in the inverted cup and the inverted cell is rather considerable. The effective RH value (the driving force) of liquid water is higher than the RH value of vapor alone, but with the much thinner layer of water in the cell the zero extrapolation is about the same as the

TABLE 5—*Comparison of wet-cup and inverted wet-cup tests at 73°F (23°C) and 50% RH.*

Samples	Permeance (ng/m^2.Pa.s)		
	Dry Cup	Wet Cup	Inverted Wet Cup
Asphalt-Coated Building Paper, Standard Weight	47.5	62.9	114.5
Asphalt-Saturated Sheathing Paper, Heavy Weight	46.9	362	503
15-lb Asphalt-Saturated Sheathing Paper	269	480.5	726
15-lb Asphalt-Saturated Roofing Felt	108.5	686	915
Asphalt-Infused Sheathing Paper	366	1087	2402
Tar-Infused Sheathing Paper	377.5	1773	4060
Perforated Asphalt-Coated Sheathing	629 paper	801	858

NOTE 1: The values from the referenced source [4] have been converted to SI units.

NOTE 2: Results in each case are the mean of six specimens. The same specimens were used for wet-cup and inverted wet-cup tests. In the inverted wet-cup tests, the water head was 12.7 mm (½ in.) Separate specimens, with vapor flow in the reverse direction, were used for the dry-cup tests.

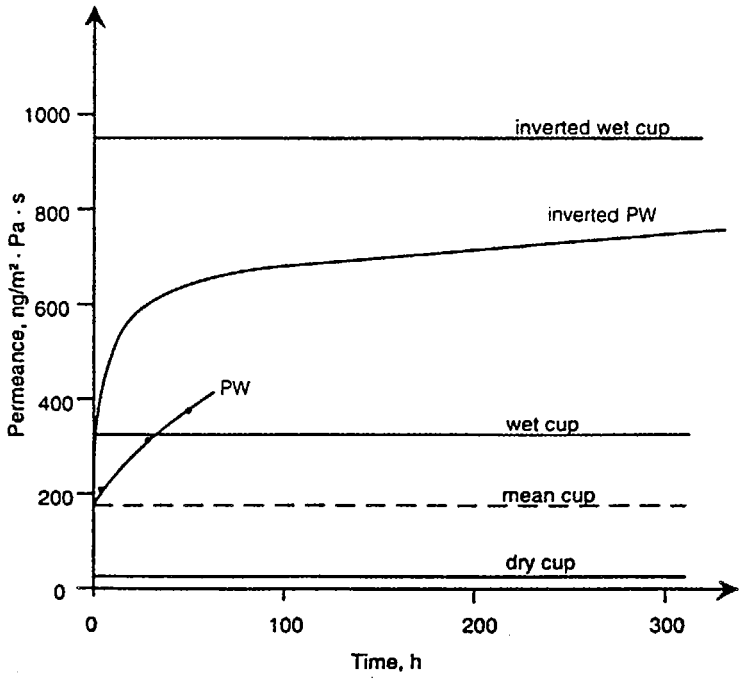

FIG. 11—*Permeance of 15# asphalt-saturated organic felt with time.*

wet-cup result. In addition, some materials swell to different extents so that the structure of their films is altered. Consequently, the transmission mechanism in both inverted situations becomes quite complex but the net result is the WVT rates are higher than in the normal cell and the wet- and dry-cups.

As an example, asphalt glass felt with small pin holes should show the effect of inversion without the effect of swelling. As shown in Fig. 12 there is still a difference between the wet and inverted cups, but it is proportionally smaller than the difference obtained with asphalt organic felt (Fig. 13). In the latter case, there are also no apparent leaks and the exterior surface stays dry. This shows that even pin holes do not allow water to flow through but still lead to a higher permeation value. It also shows the multiple origins of inverted cup values. Consequently, it is impossible to correlate inverted-cup and PW inverted-cell measurements. It is apparent from these results that condensation can have a strong effect on the WVTR value.

Conclusions

The Permatran W is an efficient apparatus and can be easily used for quality control and routine testing. Some of the findings of this study could readily be incorporated to improve its use in quality control. To get the accurate and precise measurements necessary for research and development, the apparatus needs several modifications and the technique for using it could be improved. For improved repeatability of results from different specimens of the same sample (or the same specimen at different

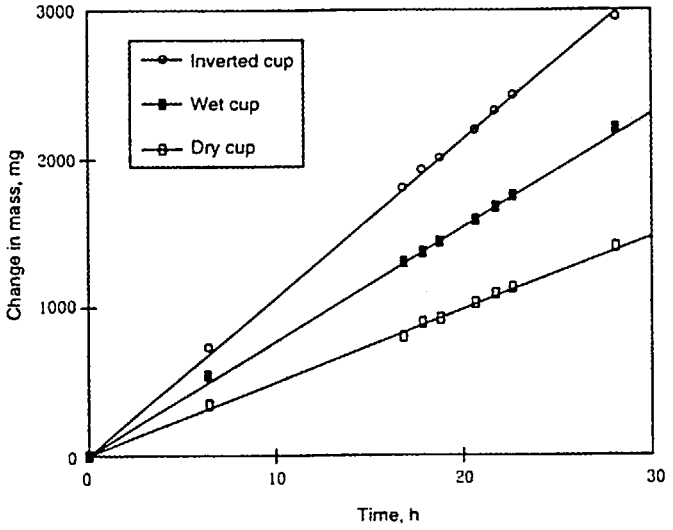

FIG. 12—*Mass change of asphalt-impregnated glass felt using different methods.*

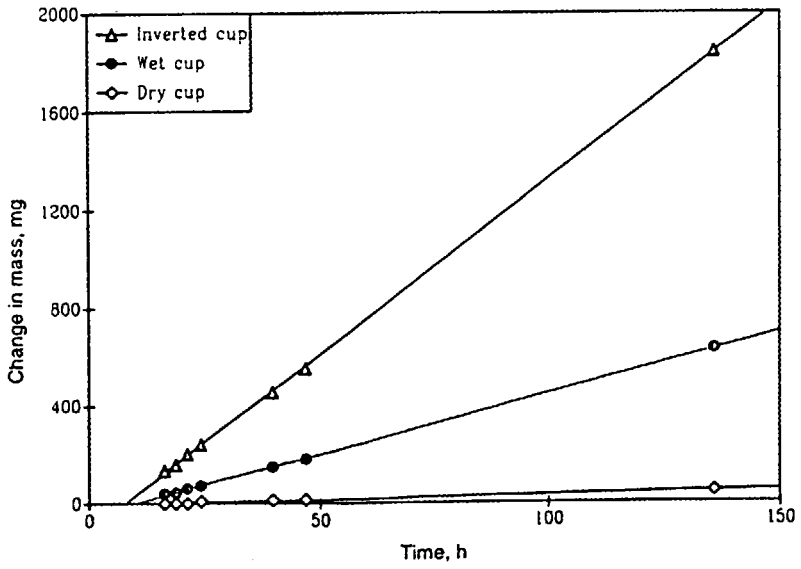

FIG. 13—*Mass change of 15# asphalt-saturated organic felt using different methods.*

times) and the reproducibility with more than one instrument, a standard measurement procedure should be developed.

The apparatus is highly sensitive to the air flow rate. Although the flowmeter is not very accurate, when the system is at the optimum conditions the needle value maintains sufficiently stable conditions to provide reliable measurements. Cleanliness and dryness of the air flow path are crucial.

Condensation should be avoided in testing hygroscopic materials. For this purpose, and to establish the RH value in the cell, an accurate temperature monitoring device should be added to the system. Temperature should be plotted at the same time as WVTR. Heating the flowing air avoids condensation and ensures better temperature stability. Care must then be taken to avoid condensation in the tubing and in the IR detector. A small change in the cell design could also be made to avoid direct air flow on the specimen.

It is important to do the zero calibration with an empty cell rather than bypassing the flow. This technique ensures similar conditions for calibration and measurement and also keeps the tubing between the valve and the cell dry.

Since Mylar is not stable over several years its use as a standard is questionable. There is a need for a standard material that is not affected by time, mechanical stress, or by chemicals such as silicone grease or organic dirt, etc. As an example, calibration with 19 μm (0.75 mil) Mylar using the method described in Ref 5 leads to a 15% difference from that with the 25-μm (1 mil) film supplied.

A standard procedure to ensure the reliability of the measured values is proposed. A change in the apparent WVTR of less than 1% within a 10-min period was selected because that seems to correspond to the plateau in the WVTR versus time curve. The use of this limit leads to more repeatable results than a standard equilibrium time, which is not applicable to all materials.

These proposed changes should improve the accuracy and precision of the PW and make it a reliable apparatus for research and development.

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