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Standard Guide for Determining The Transmission of Gases Through Geomembranes[1]

This standard is issued under the fixed designation D7407; 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.

1. Scope

1.1 This guide is used as a discussion of the relevancy of several methods to obtain the vapor transmission of geomembranes.

1.2 This guide discusses applicable test methods, test materials and conditions.

1.3 The guide assumes the material being measured exhibits Fickian behavior.

1.4 This guide does not purport to critique barrier system permeability,

1.5 The guide does not address transmission through seams,

1.6 *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]

D1434 Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting

D3985 Test Method for Oxygen Gas Transmission Rate Through Plastic Film and Sheeting Using a Coulometric Sensor

D4439 Terminology for Geosynthetics

E96/E96M Test Methods for Water Vapor Transmission of Materials

F1249 Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor

F1769 Test Method for Measurement of Diffusivity, Solubility, and Permeability of Organic Vapor Barriers Using a Flame Ionization Detector (Withdrawn 2004)[3]

F1927 Test Method for Determination of Oxygen Gas Transmission Rate, Permeability and Permeance at Controlled Relative Humidity Through Barrier Materials Using a Coulometric Detector

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms applying to this test method appear in Terminology D4439

3.1.2 *atmosphere for testing geosynthetics, n*—air maintained at a relative humidity between 50 to 70 % and a temperature of 21 ± 2°C (70 ± 4°F).

4. Summary of Guide

4.1 This guide gives commentary as to the relevancy of several methods to obtain Fickian diffusion through a geomembrane. The tests evaluate gas and vapor transfer through semi-permeable and permeable geomembranes. The data is important for design of containment systems.

5. D1434 Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting

5.1 This test method covers the estimation of the steady-state rate of transmission of a gas through plastics in the form of film, sheeting, laminates, and plastic-coated papers or fabrics. This test method provides for the determination of (*1*) gas transmission rate (GTR), (*2*) permeance, and, in the case of homogeneous materials, (*3*) permeability.

5.2 Two procedures are provided: M Manometric and V Volumetric.

5.3 This is an old test which relies of the physical measurement of gas through a geomembrane with respect to log time. This test has poor accuracy and takes a very long time.

6. D3985 Test Method for Oxygen Gas Transmission Rate Through Plastic Film and Sheeting Using a Coulometric Sensor

6.1 This test method covers a procedure for determination of the steady-state rate of transmission of oxygen gas through

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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] The last approved version of this historical standard is referenced on www.astm.org.

plastics in the form of film, sheeting, laminates, coextrusions, or plastic-coated papers or fabrics. It provides for the determination of (1) oxygen gas transmission rate (O2GTR), (2) the permeance of the film to oxygen gas (PO2), and (3) oxygen permeability coefficient (P'O2) in the case of homogeneous materials. 7.2 7.3

6.2 This test method does not purport to be the only method for measurement of O2GTR. There may be other methods of O2GTR determination that use other oxygen sensors and procedures.

6.3 This method is used in the food packaging industry were plastic films rather than sheet are used. The method looks at oxygen transmission exclusively. Although interesting for food applications, results from this method may not correlate well to geomembrane performance in other non-food containment applications.

7. E96/E96M Standard Test Methods for Water Vapor Transmission of Materials

7.1 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 1.25 in. (32 mm) in thickness. 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.

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

7.3 A cup is filled with distilled water leaving a small gap (0.75″ to 0.25″) of air space between the specimen and the water. The cup is then sealed to prevent vapor loss except through the test sample. An initial weight is taken of the apparatus and then periodically weighed over time until results become linear. Caution must be used to assure that all weight loss is due to water vapor transmission through the specimen.

7.4 For geomembrane: inverted cup technique is generally conducted with water. Standard conditions are 50 % relative humidity and 23 deg Celsius. The problem with the test is two fold, a) the mass loss is very small over time compared to the mass of the apparatus being measured and b) the seal of the apparatus to the geomembrane needs to be less permeable than the geomembrane itself. This second point is difficult to accomplish for geomembranes greater than 20 mil thickness.

8. F1249 Standard Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor

8.1 This test method covers a procedure for determining the rate of water vapor transmission through flexible barrier materials. The method is applicable to sheets and films up to 3 mm (0.1 in.) in thickness, consisting of single or multilayer synthetic or natural polymers and foils, including coated materials. It provides for the determination of (1) water vapor transmission rate (WVTR), (2) the permeance of the film to water vapor, and (3) for homogeneous materials, water vapor permeability coefficient.

8.2 Values for water vapor permeance and water vapor permeability must be used with caution. The inverse relationship of WVTR to thickness and the direct relationship of WVTR to the partial pressure differential of water vapor may not always apply.

8.3 This is a good test for geomembranes unfortunately the device used for the method is proprietary.

8.4 Like many of the methods critiqued, sealing issues of the device to the geomembrane exist.

8.5 This high end test is sophisticated and relinquishes results quickly.

9. F1769 Standard Test Method for Measurement of Diffusivity, Solubility, and Permeability of Organic Vapor Barriers Using a Flame Ionization Detector

9.1 This test method covers the measurement of volatile organic-vapor-barrier properties of films, plastic sheeting, coated papers, and laminates. The specific material properties measured include diffusivity, solubility, and permeability coefficients; parameter values which are required for the solution of mass transfer problems associated with nonsteady state and steady state conditions.

TABLE 1 Grouping of Test Methods for measuring Gas Transmission with Respect to Application

ASTM Method	Oxygen OTRM	Vapor MVTR	Volatile Organic OTM	Methane
D1434	yes	no	no	yes
D3985	yes	no	no	no
E96/E96M	no	yes	no	no
F1249	yes	no	no	no
F1769	no	no	yes	yes
F1927	yes	no	no	no

9.2 Applicable test vapors include volatile organic compounds which are detectable by a flame ionization detector. Examples of applicable permeation compounds include solvents, organic film additives, flavor compounds, and aroma compounds.

9.3 This test method assumes the material being measured exhibits Fickian behavior and uses the solutions to Fick's Laws for a planar surface as the data regression model.

9.4 This high end test that yields breakthrough time under steady state conditions. The accuracy of the test is an order of magnitude better than Test Method D1434. However, there is currently only one commercial manufacturer of this equipment.

10. F1927 Test Method for Determination of Oxygen Gas Transmission Rate, Permeability and Permeance at Controlled Relative Humidity Through Barrier Materials Using a Coulometric Detector

10.1 This test method covers a procedure for determination of the rate of transmission of oxygen gas, at steady-state, at a given temperature and %RH level, through film, sheeting, laminates, co-extrusions, or plastic-coated papers or fabrics. This test method extends the common practice dealing with zero humidity or, at best, an assumed humidity. Humidity plays an important role in the oxygen gas transmission rate (O2GTR) of many materials. This test method provides for the determination of oxygen gas transmission rate (O2GTR), the permeance of the film to oxygen gas (P'O2), and oxygen permeability coefficient (P''O2) in the case of homogeneous materials at given temperature and %RH levels(s).

10.2 Oxygen is held on one side of the geomembrane while Nitrogen is held on the other. Specimen is in a controlled humidity which is advantages for EVOH and Nylon.

11. Keywords

11.1 diffusion; geomembrane; film; permeability; permeance; sheet; transmission

APPENDIX

(Nonmandatory Information)

X1. Examples Showing the Conversion of Permeance to Permeability of a Geomembrane

X1.1 **Water-Vapor Transmission.** Since nothing is absolutely impermeable, the assessment of the relative impermeability of geomembranes is an often discussed issue. The discussion is placed along with physical properties for want of a better location. The test itself could use an adapted form of a geotechnical engineering test using water as the permeant; however, this would be impractical. In such a case, the hydraulic heads required are so great that leaks or failed specimens invariably result. At lower heads, long test times leading to evaporation problems become a major obstacle. Instead, a completely different approach is taken whereby water vapor is used as the permeant and diffusion is the fundamental mechanism of permeation. In the water-vapor transmission (WVT) test, a test specimen is sealed over an aluminum cup with either water or a desiccant in it and a controlled relative humidity difference across the geomembrane boundary is maintained. The ASTM test method is covered under E96. With water in the cup (i.e., 100% relative humidity) and a lower relative humidity outside of it, a weight loss over time can be monitored. The required test time varies, but it is usually from 3 to 40 days. Water vapor transmission, permeance, and (diffusion) permeability are then calculated, as shown in Example 1 and 2.

X1.2 **Example 1** Calculate the WVT, permeance, and (diffusion) permeability of a 0.75 mm thick fPP geomembrane of area 0.003 m2, and a forty day mass change of 0.216 g at an 80% relative-humidity difference while being maintained at a temperature of 30C. Solution: Calculations proceed in stages as follows.

(a) Find the water vapor transmission:

$$WVT = \frac{g \times 24}{t \times a}$$

where:

g = weight change (g),
t = time interval (h), and
a = area of specimen (m2).

$$WVT = \frac{(0.216)(24)}{(40)(24)(0.003)} = 1.80\ g/m^2 - day$$

(b) The permeance is given as:

$$permeance = \frac{WVT}{\Delta P} - \frac{WVT}{S\,(R_1 - R_2)}$$

where:

ΔP = vapor pressure difference across membrane (mm Hg),
S = saturation vapor pressure at test temperature (mm Hg),
R_1 = relative humidity within cup, and
R_2 = relative humidity outside cup (in environmental chamber).

$$permeance = \frac{180}{32(1.00 - 0.20)} = 0.0703\ metric\ perm$$

(c) (Diffusion) permeability = permeance × thickness = (0.0703)(0.75) = 0.0527 metric perm-mm

NOTE X1.1—This is a vapor-diffusion permeability following Fickian diffusion and not the customary Darcian permeability as seen in the following example. This is bad science, mixing the two theories is technically undependable however, after numerous request we have illustrated it below in Example 2.

X1.3 **Example 2** Using the information and data from Example 1, calculate an equivalent hydraulic permeability (i.e., a Darcian permeability, or hydraulic conductivity) of the geomembrane as is customarily measured in a geotechnical engineering test on clay soils.,

Solution: The parallel theories are
Darcy's formula for hydraulic permeability, q = kiA,

$$q\left(\frac{cm^3}{s}\right) = k\left(\frac{cm}{s}\right)\frac{\Delta h}{\Delta 1}\left(\frac{cm\,H_2O}{cm\ soil}\right)A\left(cm^2\right)$$

and the WVT test for Fickian diffusion permeability,

$$flow\left(\frac{cm^3}{s}\right) = k\left(\frac{cm^3}{cm^2 - s - cm - H_2O/cm\ liner}\right)$$

$$pressure\left(\frac{\Delta cm\,H_2O}{cm\ liner}\right)A\left(cm^2\right)$$

Thus we must now modify the data used in Example 5.1 into the proper units.

$$WVT = 1.80\,\frac{g}{m^2 - day}\,\frac{1}{(10^{-4})(24)(60)(60)} = 2.08 \times 10^{-9}\frac{g}{cm^2 - s}$$

$$permeance = \frac{WVT}{\Delta P} = \frac{WVT}{S(R_1 - R_2)}$$

$$= \frac{2.08 \times 10^{-9}}{32(1.00 - 0.20)}$$

$$= 0.812 \times 10^{-10}\frac{g}{cm^2 - s - mm\ Hg}$$

$$permeability = permeance \times liner\ thickness$$

$$= 0.812 \times 10^{-10}\,(0.075)$$

$$= 0.609 \times 10^{-11}\frac{g}{cm^2 - s - mm\ Hg/cm\ liner}$$

$$= 6.09 \times 10^{-11}\frac{g}{cm^2 - s - cm\ Hg/cm\ liner}$$

In terms of water pressure,

$$hydraulic\ conductivity = 6.09 \times 10^{-11}\frac{g}{cm^2 - s - \frac{cm\ Hg}{cm\ liner}\,13.6\,\frac{water}{mercury}}$$

$$= 0.448 \times 10^{-11}\frac{g}{cm^2 - s - \frac{cm\ water}{cm\ liner}\frac{g}{}}$$

Now using the density of water,

$$hydraulic\ conductivity = 0.448 \times 10^{-11}\frac{g}{cm^2 - s - \frac{cm\ water}{cm\ liner}\,1.0\,\frac{g}{cm^3}}$$

and canceling the units out, we get a comparable Darcian k-value for the geomembrane of

$$k = 0.5 \times 10^{-11}\ cm/s\ or\ 0.5 \times 10^{-13\ m/s}$$

NOTE X1.2—It should be mentioned, however, that the above described test method is extremely difficult to conduct for thick geomembranes and particularly for HDPE since its WVT values are so low. The least amount of leakage around the test specimen-to-container seal will greatly distort the resulting test results. As such the test is not recommended for general use and an entirely different configuration may be necessary, although the concept and theory will be the same.

Of particular interest is the conversion of 1.0 g/m2-day, approximately equal to 10 l/ha-day, which is the leakage sometimes associated with a flawlessly placed geomembrane. It has been referred to in various regulations as de-minimus leakage.

Bibliography

(1) R. M. Koerner, (2005), Designing with Geosynthetics, fifth edition, Pearson Prentice Hall, Upper Saddle River, NJ pp 796.