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Standard Guide for
Selection of Test Methods to Determine Rate of Fluid Permeation Through Geomembranes for Specific Applications[1]

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1. Scope

1.1 This guide covers selecting one or more appropriate test methods to assess the permeability of all candidate geomembranes for a proposed specific application to various permeants. The widely different uses of geomembranes as barriers to the transport and migration of different gases, vapors, and liquids under different service conditions require determinations of permeability by test methods that relate to and simulate the service. Geomembranes are nonporous homogeneous materials that are permeable in varying degrees to gases, vapors, and liquids on a molecular scale in a three-step process (*1*) by dissolution in or absorption by the geomembrane on the upstream side, (*2*) diffusion through the geomembrane, and (*3*) desorption on the downstream side of the barrier.

1.2 The rate of transmission of a given chemical species, whether as a single permeant or in mixtures, is driven by its chemical potential or in practical terms by its concentration gradient across the geomembrane. Various methods to assess the permeability of geomembranes to single component permeants, such as individual gases, vapors, and liquids are referenced and briefly described.

1.3 Various test methods for the measurement of permeation and transmission through geomembranes of individual species in complex mixtures such as waste liquids are discussed.

1.4 *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:*

D 471 Test Method for Rubber Property—Effect of Liquids[2]
D 814 Test Method for Rubber Property—Vapor Transmission of Volatile Liquids[2]
D 815 Method for Testing Coated Fabrics—Hydrogen Permeability[3]
D 1434 Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting to Gases[4]
D 1653 Test Methods for Water Vapor Permeability of Organic Coating Films[5]
D 4439 Terminology for Geosynthetics[6]
D 4491 Test Methods for Water Permeability of Geotextiles by Permittivity[6]
E 96 Test Methods for Water Vapor Transmission of Materials[7]
F 372 Test Method for Water Vapor Transmission Rate of Flexible Barrier Materials Using an Infrared Detection Technique[4]
F 739 Test Method for Resistance of Protective Clothing Materials to Permeation by Liquids or Gases Under Conditions of Continuous Contact[8]

3. Terminology

3.1 *Definitions:*

3.1.1 *downstream*, *n*—the space adjacent to the geomembrane through which the permeant is flowing.

3.1.2 *geomembrane*, *n*—an essentially impermeable geosynthetic composed of one or more synthetic sheets. (See Terminology D 4439.)

3.1.2.1 *Discussion*—In geotechnical engineering, essentially impermeable means that no measurable liquid flows through a geosynthetic when tested in accordance with Terminology D 4491.

3.1.3 *geosynthetic*, *n*—a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering-related material as an integral part of a man-made project, structure, or system. (See Terminology D 4439.)

3.1.4 *permeability*, *n*—the rate of flow under a differential pressure, temperature, or concentration of a gas, liquid, or

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[2] *Annual Book of ASTM Standards*, Vol 09.01.

[3] Discontinued; see *1988 Annual Book of ASTM Standards*, Vol 09.02.

[4] *Annual Book of ASTM Standards*, Vol 15.09.

[5] *Annual Book of ASTM Standards*, Vol 06.01.

[6] *Annual Book of ASTM Standards*, Vol 04.09.

[7] *Annual Book of ASTM Standards*, Vol 04.06.

[8] *Annual Book of ASTM Standards*, Vol 11.03.

vapor through a material. (Modified from Terminology D 4491.)

3.1.5 *permeant*, *n*—a chemical species, gas, liquid, or vapor that can pass through a substance.

4. Summary of Guide

4.1 The wide range of uses of geomembranes as barriers in many different environments to many different permeating species requires different test procedures to assess the effectiveness of a given membrane for a given application. The permeating species range from a single component to highly complex mixtures such as those found in waste liquids and leachates. In specialized applications, service it may be important to measure transmission or migration of a species that would take place under specific conditions and environments including temperature, vapor pressure, and concentration gradients. Tests that would be applicable to the measurement of the permeability of a material to different permeants present in various applications are summarized in Table 1.

4.1.1 In the use of geomembranes in service as barriers to the transmission of fluids, it is essential to recognize the difference between geomembranes that are nonporous homogeneous materials and other liner materials that are porous, such as soils and concretes. The transmission of permeating species through geomembranes without holes proceeds by absorption of the species in the geomembrane and diffusion through the geomembrane on a molecular basis. The driving force is chemical potential across the geomembrane. A liquid permeates porous materials in a condensed state that can carry the dissolved constituents, and the driving force for such permeation is hydraulic pressure. Due to the selective nature of geomembranes, the permeation of the dissolved constituents in liquids can vary greatly, that is, components of a mixture can permeate at different rates due to differences in solubility and diffusibility in a given geomembrane. With respect to the inorganic aqueous salt solution, the geomembranes are semipermeable, that is, the water can be transmitted through the geomembranes, but the ions are not transmitted. Thus, the water that is transmitted through a hole-free geomembrane does not carry dissolved inorganics. The direction of permeation of a component in the mixture is determined thermodynamically by its chemical potential difference or concentration gradient across the geomembrane. Thus the water in the wastewater on the upstream side is at a lower potential than the less contaminated water on the downstream side and can permeate the geomembrane into the wastewater by osmosis.

4.1.2 Although inorganic salts do not permeate geomembranes, some organic species do. The rate of permeation through a geomembrane depends on the solubility of the organic in the geomembrane and the diffusibility of the organic in the geomembrane as driven by the chemical potential gradient. Principle factors that can affect the diffusion of an organic within a geomembrane include:

4.1.2.1 The solubility of the permeant in the geomembrane,

4.1.2.2 The microstructure of the polymer, for example, percent crystallinity,

4.1.2.3 Whether the condition at which diffusion is taking place is above or below the glass transition temperature of the polymer,

4.1.2.4 The other constituents in the geomembrane compound,

4.1.2.5 Variation in manufacturing processes,

4.1.2.6 The flexibility of the polymer chains,

4.1.2.7 The size and shape of the diffusing molecules,

4.1.2.8 The temperature at which diffusion is taking place, and

4.1.2.9 The geomembrane.

4.1.3 The movement through a hole-free geomembrane of mobile species that would be encountered in service would be affected by many factors, such as:

TABLE 1 Applicable Test Method for Measuring Permeability of Geomembranes to Various Permeants

Fluid Being Contained	Example of Permeant	Example of Field Application	Applicable Test Method and Permeant Detector and Quantifier
Single-Component Fluids:			
Gas	H_2, O_2 N_2, CH_4 CO_2	Barriers, pipe, and hose liners	D 815 D 1434-V D 1434-P
Water vapor	H_2O	Moisture vapor barriers, water reservoir covers	E 96, D653
Liquid water	H_2O	Liners for reservoirs, dams, and canals	Soil-type permeameter with hydraulic pressure
Organic vapor	Organic species	Secondary containment for organic solvent and gasoline	D 814, E96, F372
Organic liquid	Organic solvents species	Containers, tank liners secondary containment	D 814, E96
Multicomponents Fluids:			
Gases	CO_2/CH_4	Barriers, separation of gases	F 372, GC, GCMS
Aqueous solutions of inorganic, for example, brines, incinerator ash leachates, leach pad leachate	Ions, salts	Pond liners	Pouch, osmotic cell, ion analysis
Mixtures of organics, spills, hydrocarbon fuels	Organic species	Liners for tanks and secondary containment	E 96 with headspace, GC
Aqueous solutions of organics	Organic species, H_2O	Liners for ponds and waste disposal	Pouch, Multi-compartment cell with analysis by GC on GCMS
Complex aqueous solutions of organics and inorganic species	H_2O, organic species, dissolved salts	Liners for waste disposal	Pouch, Multi-compartment cell, osmotic cell, analysis by head-space GC

4.1.3.1 The composition of the geomembrane with respect to the polymer and to the compound,

4.1.3.2 The thickness of the geomembrane,

4.1.3.3 The service temperature,

4.1.3.4 The temperature gradient across the geomembrane in service,

4.1.3.5 The chemical potential across the geomembrane, that includes pressure and concentration gradient,

4.1.3.6 The composition of the fluid and the mobile constituents,

4.1.3.7 The solubility of various components of an organic liquid in the particular geomembrane that increase concentration of individual components on the upstream side of the geomembrane and can cause swelling of the geomembrane resulting in increased permeability,

4.1.3.8 The ion concentration of the liquid, and

4.1.3.9 Ability of the species to move away from the surface on the downstream side.

4.1.4 Because of the great number of variables, it is important to perform permeability tests of a geomembrane under conditions that simulate as closely as possible the actual environmental conditions in which the geomembrane will be in service.

5. Significance and Uses

5.1 The principal characteristic of geomembranes is their intrinsically low permeability to a broad range of gases, vapors, and liquids, both as single-component fluids and as complex mixtures of many constituents. As low permeable materials, geomembranes are being used in a wide range of engineering applications in geotechnical, environmental, and transportation areas as barriers to control the migration of mobile fluids and their constituents. The range of potential permeants is broad and the service conditions can differ greatly. This guide shows users test methods available for determining the permeability of geomembranes to various permeants.

5.2 The transmission of various species through a geomembrane is subject to many factors that must be assessed in order to be able to predict its effectiveness for a specific service. Permeability measurements are affected by test conditions, and measurements made by one method cannot be translated from one application to another. A wide variety of permeability tests have been devised to measure the permeability of polymeric materials; however, only a limited number of these procedures have been applied to geomembranes. Test conditions and procedures should be selected to reflect actual service requirements as closely as possible. It should be noted that field conditions may be difficult to model or maintain in the laboratory. This may impact apparent performance of geomembrane samples.

5.3 This guide discusses the mechanism of permeation of mobile chemical species through geomembranes and the permeability tests that are relevant to various types of applications and permeating species. Specific tests for the permeability of geomembranes to both single-component fluids and multicomponent fluids that contain a variety of permeants are described and discussed.

6. Basis of Classification

6.1 Even though geomembranes are nonporous and cannot be permeated by liquids as such, gases and vapors of liquids can permeate a geomembrane on a molecular level. Thus, even if a geomembrane is free of macroscopic holes, some components of the contained fluid can permeate and might escape the containment unit.

6.2 The basic mechanism of permeation through geomembranes is essentially the same for all permeating species. The mechanism differs from that through porous media, such as soils and concrete, which contain voids that are connected in such a way that a fluid introduced on one side will flow from void to void and emerge on the other side; thus, a liquid can flow through the voids and carry dissolved species.

6.3 Overall rate of flow through saturated porous media follows Darcy's equation that states that the flow rate is proportional to the hydraulic gradient, as is shown in the following equation:

$$Q = kiA \tag{1}$$

where:

Q = rate of flow,

k = constant (Darcy's coefficient of permeability),

A = total inside cross-sectional area of the sample container, and

i = hydraulic gradient.

6.4 With most liquids in saturated media, the flow follows Darcy's equation; however, the flow can deviate due to interactions between the liquid and the surface of the soil particles. These interactions become important in the escape of dissolved species through a low-permeability porous liner system in a waste facility. Dissolved chemical species, either organic or inorganic, not only can permeate such a medium advectively (that is, the liquid acts as the carrier of the chemical species), but also by diffusion in accordance with Fick's two laws of diffusion.

6.5 Even though polymeric geomembranes are manufactured as solid homogeneous nonporous materials, they contain interstitial spaces between the polymer molecules through which small molecules can diffuse. Thus, all polymeric geomembranes are permeable to a degree. A permeant migrates through the geomembrane on a molecular basis by an activated diffusion process and not as a liquid. This transport process of chemical species involves three steps:

6.5.1 The solution or absorption of the permeant at the upstream surface of the geomembrane,

6.5.2 Diffusion of the dissolved species through the geomembrane, and

6.5.3 Evaporation or desorption of the permeant at the downstream surface of the geomembrane.

6.6 The driving force for this type of activated permeation process is the "activity" or chemical potential of the permeant that is analogous to mechanical potential and electrical potential in other systems. The chemical potential of the permeant decreases continuously in the direction of the permeation. Concentration is often used as a practical measure of the chemical potential.

6.7 In the transmission of a permeant through a geomembrane, Step 1 depends upon the solubility of the permeating species in the geomembrane and the relative chemical potential of the permeant on both sides of the interface. In Step 2, the diffusion through the geomembrane involves a variety of factors including size and shape of the molecules of the permeating species, and the molecular characteristics and structure of the polymeric geomembrane. A steady state of the flow of the constituents will be established when, at every point within the geomembrane, flow can be defined by Fick's first law of diffusion:

$$Qi = -Di * \frac{dc_i}{dx} \tag{2}$$

where:

Q_i = mass flow of constituent "i," g cm^2 s^{-1},
D_i = diffusivity of constituent "i," cm^2 s^{-1},
c_i = concentration of Constituent "i," g cm^3, and
x = thickness of the geomembrane, cm.

6.7.1 It should be noted that the concentration of Constituent" i" referred to in Fick's law is within the mass of the geomembrane.

6.7.2 Step 3 is similar to the first step and depends on the relative chemical potential of the permeant on both sides of the interface at the downstream geomembrane surface.

6.8 Chemical potential is a thermodynamic concept that indicates the direction in which the permeation will go, that is, from high to low potential. To use concentration directly to replace chemical potential requires the individual molecules of the permeating species to neither interact with each other nor with the membrane they are permeating. This condition approximately exists when a permanent or a noncondensable gas, such as oxygen, nitrogen, or helium, permeates a membrane. However, the individual molecules of organic species can interact with each other and with the polymer to increase solubility of the species in the geomembrane.

7. Test Methods

7.1 *Permeability of Geomembranes to Single-Component Fluids*—Many of the applications of geomembranes are for barriers to the permeation of single-component permeants, that is, a single gas, vapor, or liquid. With respect to water, such applications include reservoir liners, moisture vapor transmission barriers, floating covers for reservoirs, canal liners, and tunnel liners; other applications involving single-component fluids would also include liners for secondary containment. Other applications might be methane barriers in tunnels, MSW landfills, and buildings built near methane and hydrocarbon sources. Various tests that are appropriate for assessing barriers to the permeation of different types of single-component fluids are discussed in the following paragraphs.

7.1.1 *Permeability of Geomembranes to Single Gases*:

7.1.1.1 For such applications as linings for waste disposal facilities and methane barriers, the permeability to gases is important in geomembrane selection. The permeability of geomembranes can be assessed by measurement of the volume of the gas passing through the geomembrane under specific conditions or by measurement of the increase in pressure on the evacuated downstream side. Both methods are described in Test Method D 1434. The apparatus used for the volumetric method is shown schematically in Fig. 1 (see Ref **(1)**).[9]

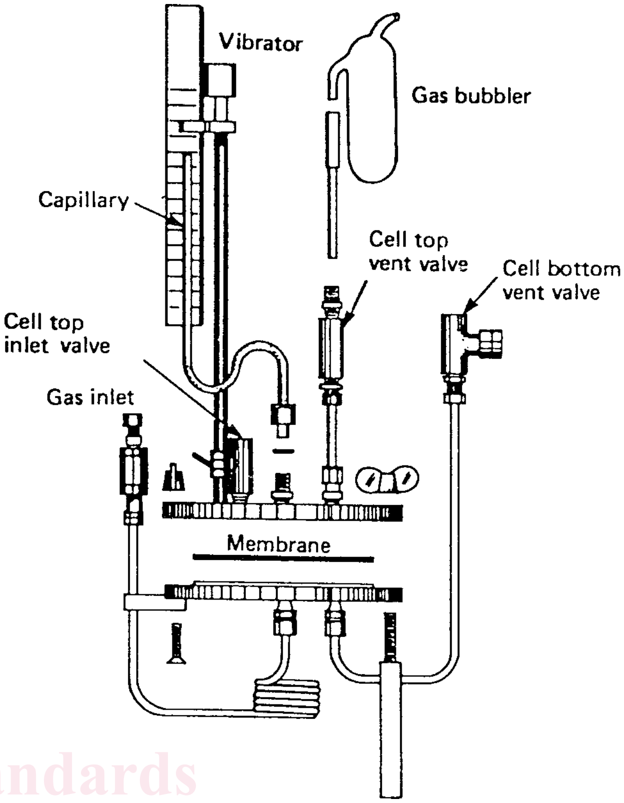

FIG. 1 Gas Permeability Apparatus in Test Method D 1434, Procedure V—Volumetric (1)

7.1.1.2 The volumetric method has been used to measure the permeability of a wide range of geomembranes to methane, carbon dioxide, and nitrogen. In this procedure, the geomembrane is in contact with the gas on both sides, that is, on the upstream side at a pressure greater than atmospheric and on the downstream side at atmospheric pressure to yield a concentration gradient and diffusion of the gas in the geomembrane. Other variables that should be considered in assessing the gas transmission rate (GTR) of a given gas include thickness and such test conditions as temperature and pressure.

7.1.2 *Permeability of Geomembranes to Water*:

7.1.2.1 *Permeability to Moisture Vapor*—For applications such as reservoir covers and moisture barriers, permeability to moisture vapor can be measured by a variety of methods that reflect the service conditions. Determinations can be made by measuring the change in weight of a small cup that contains either a small amount of distilled water or a desiccant and is sealed at the mouth with a specimen of the geomembrane, for example, Test Methods E 96. An example of the type of cup that is used in this test is shown in Fig. 2 (see Refs **(1)** and **(2)**).

7.1.2.2 *Permeability to Water*—Under a head of water comparable to that encountered in a water reservoir, the pressure on the surface of a geomembrane can cause a small transmission of water through the geomembrane. Various

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[9] The boldface numbers given in parentheses refer to a list of references at the end of the text.