Designation: D6539 – 13

Standard Test Method for Measurement of the Permeability of Unsaturated Porous Materials by Flowing Air [1]

This standard is issued under the fixed designation D6539; 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 test method covers laboratory determination of the coefficient of permeability for the flow of air through unsaturated porous materials.

1.2 This test method may be used with intact or compacted coarse grained soils, silts, or lean cohesive soils that have a low degree of saturation and that have permeability between 1.0×10^{-15} m^2 (1.01 millidarcy) and 1.0×10^{-10} m^2 (101 darcy).

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

1.3.1 By tradition in U.S. practice, the permeability of porous media is reported in units of darcy, although the SI unit for permeability is m^2.

1.4 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.4.1 For the purpose of comparing a measured or calculated value with specified limits, the measured or calculated value shall be rounded to the same precision as the specified limits.

1.4.2 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.5 *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]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4220 Practices for Preserving and Transporting Soil Samples

D4525 Test Method for Permeability of Rocks by Flowing Air

D4564 Test Method for Density and Unit Weight of Soil in Place by the Sleeve Method (Withdrawn 2013)[3]

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils

D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

D5856 Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall,

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.04 on Hydrologic Properties and Hydraulic Barriers.

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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.

Compaction-Mold Permeameter
D6026 Practice for Using Significant Digits in Geotechnical Data
E1 Specification for ASTM Liquid-in-Glass Thermometers
E145 Specification for Gravity-Convection and Forced-Ventilation Ovens
E2251 Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids

3. Terminology

3.1 *Definitions*—For definitions of technical terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *darcy*—a porous medium has a permeability of one darcy when a single-phase fluid having a viscosity of 10^{-3} Pa·s (1-cP) that completely fills the voids of the medium will flow through it under laminar (viscous) flow conditions at a rate of 1 m^3 per 1 m^2 of cross-sectional area under a pressure gradient of 1.013×10^5 Pa/m (1 atm/m). (One darcy = 9.869×10^{-13} m^2.)

3.2.2 *effective confining stress,* (Flexible Wall Method only)—the difference between the permeameter cell confining pressure and the mean specimen pore-air-water pressures.

3.2.2.1 The effective confining stress is assumed to be distributed as a radial vector exhibiting a linear gradient along the length of the specimen with a minimum at the inlet and a maximum at the outlet.

3.2.2.2 For the purposes of this test method, the effective confining stress is stated as a scalar value and calculated as the confining gage pressure minus the average of the specimen inlet and outlet gage pressures.

3.2.3 *gage pressure*—pressure measured relative to ambient atmospheric pressure.

3.2.4 *permeability*—the capacity of a porous medium to conduct gas in the presence of a gas (air) pressure gradient measured as the ratio of volumetric flow rate of air through a specimen to the resultant pressure drop across the specimen. (Also commonly known as *conductivity* or *permeability to air*.)

4. Significance and Use

4.1 This test method applies to the one-dimensional laminar (viscous) flow of air in porous materials such as soil.

NOTE 1—This test method deals with porous materials with both gaseous (air) and liquid (pore water) mobile fluids: The liquid phase is much less compressible, has a higher viscosity, and is much more tightly bound to the solid phase by chemical forces. The assumption of single-phase flow may still be presumed to be valid since the test gradient ensuring the conditions of laminar flow may be low enough that flow of the liquid phase is negligible.

4.2 The degree of saturation of the specimen shall be less than that which would produce significant internal transport of pore water or alter the continuity of air voids under the applied gradients. The maximum permissible degree of saturation must be evaluated by an experienced analyst. In no instance shall the specimen be so saturated that pore water appears at the exit of the permeameter cell during the test.

4.3 This test method is based on the assumption that the rate of mass flow through the specimen is constant with time.

NOTE 2—When a specimen contains volatile materials this assumption is violated. The mass of gas flowing out will be greater than that flowing in, the gradient cannot be determined and the test may become meaningless. Such specimens pose special problems and must be decontaminated before analysis in order to minimize health and safety concerns and to prevent contamination of the test apparatus.

4.4 The permeability of porous materials may be strongly dependent on a variety of physical properties including the void ratio, the degree of saturation, and percent and direction of compaction. It is beyond the scope of this test method to elaborate upon these dependencies. Rather, this test method is intended to be a measurement technique for determining the permeability under a certain set of laboratory conditions. It is the responsibility of the test requestor to specify which soil parameters must be controlled to ensure a valid extension of the test results to field conditions.

4.5 Calculation of the permeability using Darcy's law requires laminar flow conditions through the soil specimen. The conditions for laminar flow shall be evaluated by plotting the volumetric flow rate of air through the specimen against the pressure drop across the specimen. If the individual test points lie within 25 % of a straight line passing through the origin, then laminar flow conditions are present and Darcy's law may be used to calculate the permeability.

NOTE 3—The permeability calculated using this standard is valid only when the degree of saturation does not change over time. Long measurement times associated with the use of bubble meters and manometers may indirectly lead to variability when measuring flow versus pressure drop (see 8.2) due to evaporation. The recommended use of digital electronic flow and pressure sensors leads to considerably reduced measurement times because the user can quickly determine by inspection when a steady state condition has been reached. At that point only a single reading needs to be taken for a reliable measurement. A rapid course of measurement will minimize dehydration of unsaturated specimens.

NOTE 4—Humidifying the test gas to minimize specimen dehydration is not recommended because: (*1*) there is no practical way to either measure or control the relative humidity of the test gas, either at the inlet or outlet of the specimen; (*2*) the calibration of typical digital flowmeters are generally for dry air only and would become unreliable in the presence of water vapor, especially in view of the potential for irreversible adsorption of moisture on the sensor elements; (*3*) there is a danger of permanent water condensation in the static transfer lines and other apparatus dead volumes; and (*4*) the test apparatus would become more complex and difficult to use.

4.6 This test method covers the use of two different types of permeameter cells (flexible and rigid wall permeameters) and two types of air flow regulation (mass flow control and pressure control).

4.7 A flexible wall permeameter is the preferred means for confining the test specimen in accordance with Test Methods D5084, D4525, and D4767. This test method may still be performed using a rigid wall permeameter, but all reference to effective confining stress and the permeameter cell pressure system shall then be disregarded.

4.8 For some specimens, the permeability will be strongly dependent on the effective confining stress due to porosity reduction. Whenever possible, the requestor shall specify the field overburden conditions at which this test method is to be performed. In some specimens, this stress will vary significantly with flow in an indeterminate way. All specimens shall be evaluated for this effect by performing this test method at two or more different confining stress values when a flexible wall permeameter is used.

4.9 This test method is intended to support soil remediation operations such as: soil vapor extraction, air sparging, back-filling of soils in utility trenches, and similar engineering activities.

4.10 The correlation between results obtained with this test method and in situ field measurements has only been partially established. The small laboratory specimen used in this method may not be representative of the distributed condition on-site due to vadose zone fluctuations, changes in soil stratigraphy, and so forth. For this reason, caution should be used by qualified personnel when applying laboratory test results to field situations.

NOTE 5—This test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies which meet the criterion of Practice D3740 are generally considered capable of competent and objective testing.

5. Apparatus

5.1 *Permeameter*—The permeameter shall be capable of rapidly establishing a constant flow of air through the test specimen and measuring the consequent pressure drop across it. A schematic diagram is shown in Fig. 1.

5.1.1 *Air Supply*—The compressed air supplied to the system shall:

5.1.1.1 Be pulsation-free, have sufficient volumetric capacity at all anticipated flow rates, be free of water vapor to a dew point of −70°C or less, and be free of oil,

5.1.1.2 Be free of particulate matter greater than 5 µm in diameter, and

5.1.1.3 Be provided with a monitoring gage and regulator to deliver a pressure of at least 350 ± 5 kPa.

NOTE 6—Other gases than air may be used when specified by the requestor. It is important that the electronic flowmeter is calibrated for the test gas. Nitrogen is often preferred as having more uniform viscosity and low water content. In flow meters, 1 cc equals 0.000001 m^3.

5.1.2 *Flow Control*—The flow rate of air shall be regulated upstream from the specimen by a mass flow controller (flow control method) or a back pressure regulator (pressure control method), or both. The flow control shall be capable of regulating air flow between 1.67×10^{-10} and 1.67×10^{-5} m^3/s (0.01 to 1000 cm^3/min) to ±5 %. Two test methods of flow control are required to adapt to a wide range of specimen permeability:

5.1.2.1 *Test Method A, Flow Control Mode*—This test method is preferred for high-permeability specimens (greater than 0.1 darcy) that require flows in the range from 3.33×10^{-8} and 1.67×10^{-5} m^3/s (2 to 1000 cm^3/min) and low specimen inlet pressures. The mass flow controller is set for the desired flow through the specimen. It shall automatically adjust its

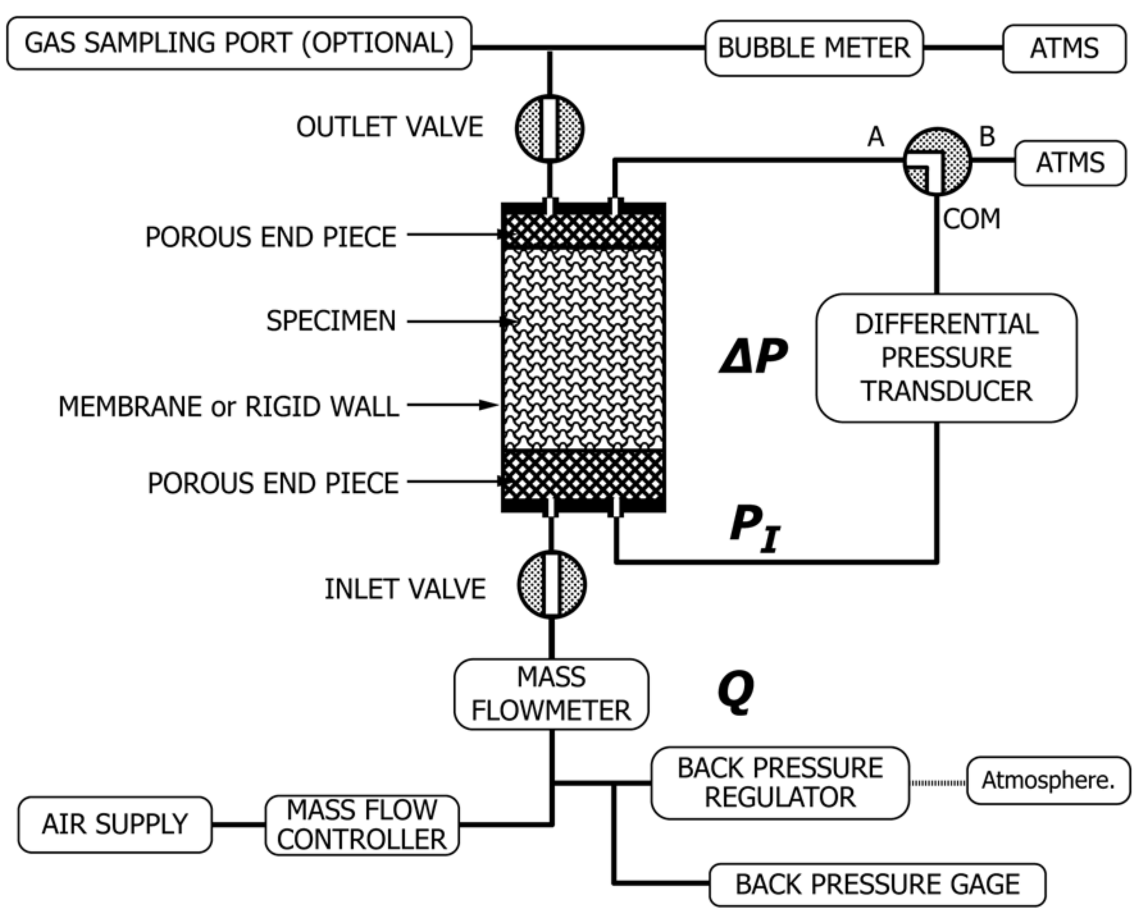

FIG. 1 Permeameter for Measurement of the Permeability of Unsaturated Materials