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Standard Test Method for Measurement of Pneumatic Permeability of Partially Saturated Porous Materials by Flowing Air [1]

This standard is issued under the fixed designation D 6539; 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 (pneumatic permeability) through partially saturated porous materials.

1.2 This test method may be used with undisturbed or compacted coarse grained soils, silts, or lean cohesive soils that have a low degree of saturation and that have pneumatic permeability between 0.001 square micrometre (1.01 millidarcy) and 100 square micrometre (101 darcy).

1.3 The values stated in SI units are to be regarded as the standard, unless other units are specifically given. By tradition in U.S. practice, the pneumatic permeability of porous media is reported in units of darcy, although the SI unit for pneumatic permeability is square metre.

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:* [2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3(600 kN-m/m^3))

D 854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D 1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 4220 Practices for Preserving and Transporting Soil Samples

D 4525 Test Method for Permeability of Rocks by Flowing Air

D 4564 Test Method for Density of Soil in Place by the Sleeve Method

D 4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D 4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils

D 5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

D 5856 Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter

E 1 Specification for ASTM Liquid-in-Glass Thermometers

E 145 Specification for Gravity-Convection And Forced-Ventilation Ovens

TABLE 1 Viscosity of Air, μ, as a Function of Temperature

Temperature, °C	Viscosity, Pa·s
12	1.778×10^{-5}
14	1.788×10^{-5}
16	1.798×10^{-5}
18	1.808×10^{-5}
20	1.818×10^{-5}
22	1.828×10^{-5}
24	1.837×10^{-5}
26	1.847×10^{-5}
28	1.857×10^{-5}

[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 of Soil and Rocks.

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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.

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3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *darcy*—a porous medium has a permeability of one darcy when a single-phase fluid of 1-MPa·s (1-cP) viscosity that completely fills the voids of the medium will flow through it under conditions of laminar (viscous) flow at a rate of 1 $cm^3/s/cm^2$ of cross-sectional area under a pressure gradient of 1.013×10^5 Pa (1 atm)/cm. (One darcy = 0.9869 square micro metre.)

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

3.1.2.1 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.

3.1.2.2 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.

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

3.1.4 *pneumatic 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 through a specimen to the resultant pressure drop across it. Also commonly known as pneumatic conductivity or permeability to air.

3.2 For definitions of other terms used in this test method, see Terminology D 653.

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

4.5 It is assumed that Darcy's Law is valid. The validity of Darcy's law may be evaluated by plotting the volumetric flow through the specimen against the differential pressure drop across the specimen. If the individual test points lie within 25 % of a straight line passing through the origin, then Darcy's law may be taken as valid.

NOTE 3—Darcy's law is valid only when saturation does not change over time. Long measurement times associated with the use of bubble meters and manometers may indirectly be an uncontrolled source of variability when plotting flow versus pressure drop (see 8.2). 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 partially saturated 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 the electronic flowmeter is 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 wall and rigid wall, 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 D 5084, D 4525, and D 4767. This test method may be performed using a rigid wall permeameter and all reference to effective confining stress and the permeameter cell pressure system shall be disregarded.

4.8 For some specimens, the pneumatic permeability will be strongly dependent on the effective confining stress due to porosity reduction. Whenever possible, the requestor should 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 should 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, backfilling 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 moisture content

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and so forth. For this reason, laboratory test results should be applied to field situations with caution by qualified personnel.

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 D 3740 are generally considered capable of competent and objective testing.

5. Apparatus

5.1 *Pneumatic Permeameter*—The pneumatic 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 pneumatic 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 (−94°F) 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 (50 ± 1 psi).

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.

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 0.01 and 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 about 0.1 darcy) that require flows in the range from 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 downstream pressure as needed to maintain constant mass flow rate of air regardless of temperature or pressure.

5.1.2.2 *Test Method B, Pressure Control Mode*—This test method is preferred for low-permeability specimens (less than about 0.1 darcy) that require control of pressure between 5 and 35 kPa (1 and 5 psi) at low flow rates: The back pressure regulator shall act as a variable pressure relief valve that can be adjusted to produce a fixed inlet pressure. The mass flow controller is set to produce an airflow slightly in excess of the test maximum.

NOTE 7—The back pressure regulator diverts to the atmosphere a portion of the flow to maintain a constant inlet pressure to produce the required specimen flow rate.

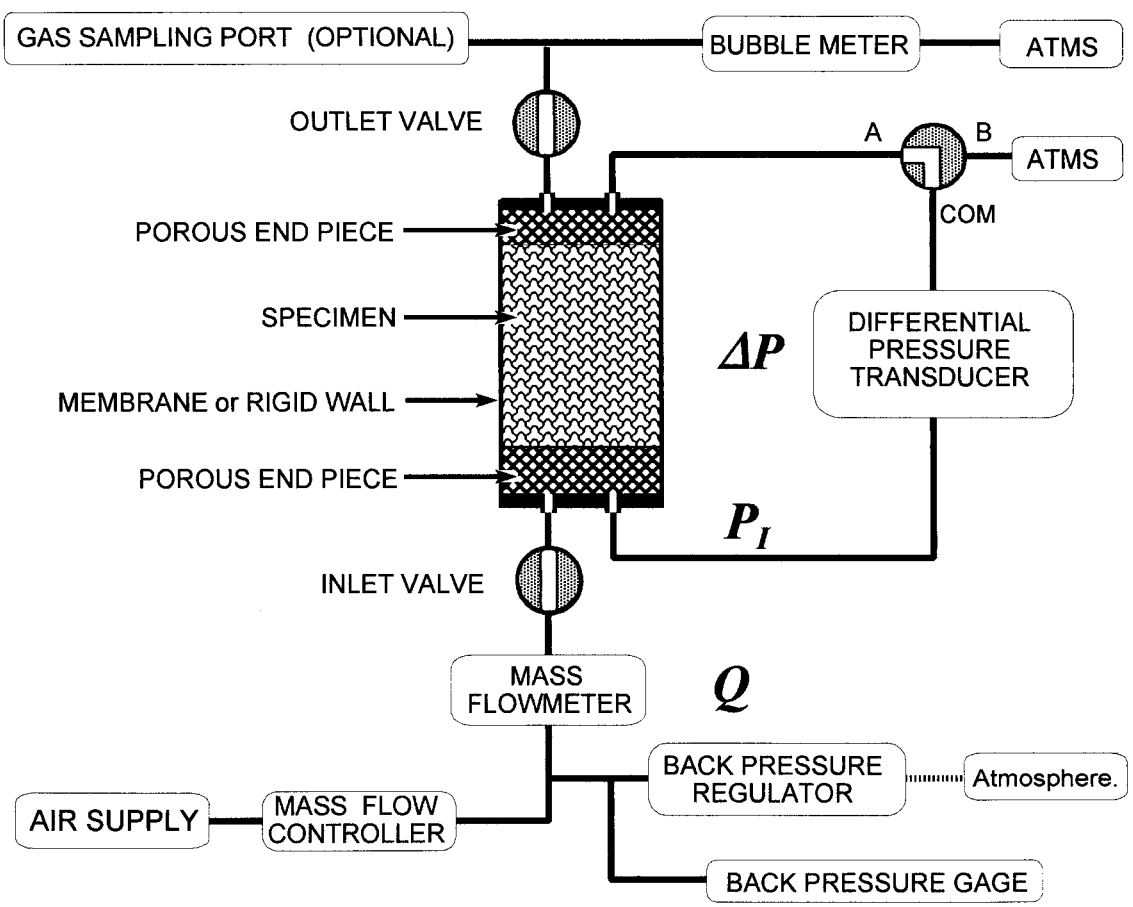

FIG. 1 Pneumatic Permeameter

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