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

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 milli-darcy) 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:*
D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]
D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft·lbf/ft^3 (605 kN·m/m^3))[2]
D 854 Test Method for Specific Gravity of Soils[2]
D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,750 kN-m/m^3))[2]
D 1587 Practice for Thin-Walled Tube Geotechnical Sampling of Soils[2]
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[2]
D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]
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[2]

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}

D 4220 Practices for Preserving and Transporting Soil Samples[2]
D 4525 Test Method for Permeability of Rocks by Flowing Air[2]
D 4564 Test Method for Density of Soil in Place by the Sleeve Method[2]
D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Testing Soil, Rock, and Related Construction Materials[2]
D 4767 Test Method for Consolidated-Undrained Triaxial Compression Test on Cohesive Soils[2]
D 5084 Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter[3]
D 5856 Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter[3]
E 1 Specification for ASTM Thermometers[4]
E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens[5]

2.2 *American Petroleum Institute Document:*
RP-27 Recommended Practice for Determining Permeability of Porous Media[6]

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

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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, 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, 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.

5.2 *Flow Measurement*:

5.2.1 The rate of air flowing into the specimen, Q, shall be measured to a precision better than 3 %. The preferred device is a digital electronic mass flowmeter upstream from the specimen. If such a flowmeter is not available, a bubble meter at the outlet of the permeameter may be used.

Note 8—When repetitious, rapid measurements are required, the digital electronic mass flowmeters will prove more convenient to use than a
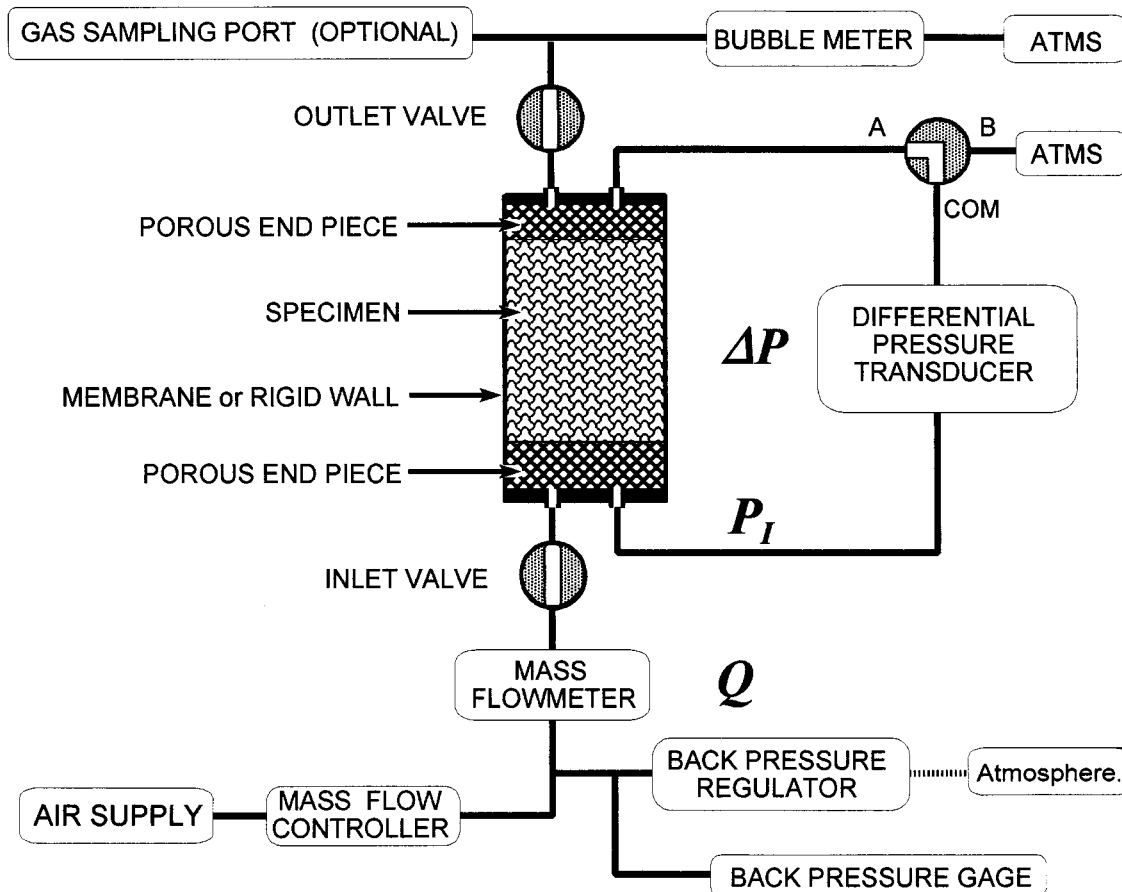
FIG. 1 Pneumatic Permeameter

bubble meter, especially at high flow rates. The need for careful hand-eye coordination technique is minimized, and the condition of constant flow is easily recognized without recording repeated measurements. Electronic flowmeters measure the mass of gas flowing through the flowmeter. The volume of the gas at any point in the system is known from Boyles Law, given the pressure and temperature at that point. Flowmeters are insensitive to temperature and pressure changes over the range of operating conditions specified by the manufacturer. Flowmeters are sensitive to the composition of the gas flowing through the flowmeters and their sensing elements are subject to long-term drift. For this reason, flowmeters must be installed upstream from the specimen where they will not be exposed to any moisture or trace volatiles that may be expelled from the specimen.

NOTE 9—The electronic flowmeter is suited for flows of 2 to 1000 cm^3/min.

5.2.2 Rates of air flow less than the range of the electronic flowmeter shall be measured with a stopwatch and a bubble meter placed downstream from the specimen where the air flow exits to the atmosphere. The bubble meter shall be used as specified by the manufacturer with due regard to ambient temperature and barometric pressure corrections. Measurements shall be repeated until a stable reading is obtained.

NOTE 10—The bubble meter is suited for low flow rates of 0.01 to 10 cm^3/min.

NOTE 11—Rotameter and orifice-type flowmeters are not acceptable substitutes for the bubble meter. Moisture in the exit air, even if transient, will cause rotameter balls to stick and flow orifices to change effective diameters.

NOTE 12—When using a soap-film bubble meter, be aware that it will generate a back pressure of 10 to 50 Pa at the specimen outlet that is easily detectable by the differential pressure transducer. This back pressure will vary as the bubbles break at the top of the meter. This variation in pressure will be minimized if there are five or more soap films ascending simultaneously.

NOTE 13—Very low-permeability specimens with low flow rates may take a long time for their pressure gradients to stabilize. Repeated bubble meter measurements are essential to ensure that an equilibrium state has been reached.

5.3 *Pressure Measuring Devices*:

5.3.1 *Specimen Pressure Drop*—The pressure drop across the specimen, ΔP, shall be measured with a digital electronic differential pressure transducer. If such a device is not available, a differential mechanical (Bourdon tube) pressure gage or liquid (water or mercury) manometer may be used. The pressure inlets shall be connected to the end pieces in the permeameter cell using static pressure lines that carry no net gas flow.

5.3.2 *Specimen Inlet Gage Pressure*—The specimen inlet pressure, P_I, shall be measured, relative to atmospheric pressure, with a digital electronic gage pressure transducer or liquid (water or mercury) manometer.

NOTE 14—The requirements of 5.3.1 and 5.3.2 may be satisfied with a single pressure measuring device if a two-way valve is installed in the specimen outlet pressure transfer line as follows: The valve common port shall be connected to the pressure measuring device port, the normally open port shall be connected to the specimen outlet port, and the normally closed port vented to atmosphere. When in the normally open position (Position A, Fig. 1), the device measures the specimen pressure drop, ΔP; when in the normally closed position (Position-B), the device measures the specimen inlet gage pressure, P_I.

5.3.3 *Back Pressure Gage*—This gage shall monitor the pressure down stream from the mass flow controller and upstream from the specimen inlet with a precision of ± 1 kPa

(0.1 psi), a range of 100 kPa (15 psi) and a precision of 5 % of full scale.

NOTE 15—The back pressure gage is essential for the flexible wall test method to facilitate the maintenance of a constant effective confining stress.

5.4 *Over-pressure Control* (Flexible wall test method only)—In addition to the requirement of 7.6.2 that the effective confining stress must remain within limits at different flow rates, the specimen inlet pressure shall not be allowed to exceed the specimen confinement pressure when a flexible wall permeameter is used.

NOTE 16—The over-pressure control test method requires close monitoring of the difference between the specimen inlet pressure and the confining pressure. The operator must ensure that the inlet pressure is never allowed to increase to about 7 kPa (1 psi) less than the confinement pressure. In the flow control test method, the back pressure regulator shall be used as a variable pressure relief valve and must be set to the confinement pressure less 7 kPa (1 psi).

NOTE 17—If the specimen inlet pressure exceeds the confining pressure, two problems will arise: (*1*) The membrane will pull away from the specimen and the air flow will divert around the specimen; and (*2*) The O-rings that seal the membrane to the permeameter base may be breached with the consequent release of air into the confinement annulus. This may drive the confining water back into the external pressurizing system with possibly damaging results. In either case, the results will be invalidated.

5.5 *Permeameter Cell*:

5.5.1 A permeameter cell shall be provided in which the specimen and porous end pieces are confined and subjected to a controlled flow of air. Depending upon the type of soil, the type of sampler used for recovering intact soil or the type of compaction equipment used, either a flexible wall- or rigid wall-type permeameter may be used. The flexible wall permeameter is described in Test Method D 5084. The rigid wall permeameter is similar to the description in Test Method D 5856. Soils with air permeability greater than 1 darcy may be tested in a rigid wall permeameter consisting of metal or rigid plastic liners, in thin-walled tubes or in molds, with appropriate top and bottom end attachments and connections to the pneumatic system in accordance with 5.5.2, 5.5.3, and 5.5.5.

5.5.2 The permeameter cell must be equipped with a pair of transfer lines at the inlet and a pair of transfer lines at the outlet. These lines connect the specimen and end pieces to the pneumatic system.

5.5.2.1 One line of each pair shall be reserved for the dynamic transfer of air flow to and from the specimen.

5.5.2.2 The other line shall be reserved for the static transfer of the pressures at the ends of the specimen to the differential pressure transducer.

NOTE 18—Because there is no net flow of air through the differential pressure transducer, there is no pressure drop in the static lines that can bias the measurement of the specimen pressure drop. Static pressure lines must never be directly connected to a dynamic flow line. This will introduce false readings due to venturi effects and pressure drops in the connecting tubing.

5.5.3 *Porous End Pieces*, shall be provided to serve the dual purpose of: (*1*) uniformly diffusing/collecting the flow of air across the end faces of the specimen; and (*2*) providing an efficient buffer zone between the static and flow lines.

5.5.3.1 The end pieces shall be cylindrical disks made of

any rigid material with a uniform porosity that is easily cleaned, resistant to breakage, and not chemically attacked by the specimen. Sintered silicon carbide, bronze, and aluminum oxide have proved satisfactory. Dispersion plates using radial and concentric groves are an acceptable alternative.

5.5.3.2 The thickness of the end pieces shall not be less than 6 mm (¼ in.).

5.5.3.3 The diameter of the end pieces shall be the diameter of the specimen to a tolerance of +5 % and –0 %.

5.5.3.4 The permeability of the porous end pieces shall be greater than two times the permeability of the specimen.

5.5.3.5 The end pieces shall be free of cracks, chips, and nonuniformities and shall have smooth surfaces with parallel faces.

5.5.3.6 The pneumatic permeability of the end pieces shall be periodically measured by this test method to ensure they are not clogged.

5.5.3.7 The end pieces shall be free of water or other volatile components.

5.5.4 *Head Losses*—Pressure drops across the end pieces may lead to error. To guard against such errors, the permeameter shall be assembled with end pieces but no specimen and connected to the pneumatic system. An airflow more than the test maximum airflow rate shall be applied and the resultant pneumatic permeability calculated. The permeability without a specimen shall be greater than two times the permeability when the specimen is present.

5.5.5 *Cap and Base* (Flexible Wall Method)—The cap and base shall connect the dual transfer lines to radial and concentric grooves facing the end piece to improve the uniform dispersion of the airflow.

5.6 *Permeameter Cell Pressure System (Flexible Wall Method)*—The system for pressurizing the permeameter cell shall be capable of applying and controlling the cell pressure to within 5 % in accordance with the section on Permeameter Cell Pressure Systems in Test Method D 5084. However, the effective confining stress on the test specimen shall be maintained to the target value with an accuracy of 10 % or better.

5.7 *Temperature*—The temperature of the testing environment shall not vary more than ±2°C (±4°F) over the course of test or a series of related tests. Normally, this is accomplished by performing the test method in a room with a relatively constant temperature.

5.8 *Gas Sampling Port*, may be installed at the specimen exit to facilitate the collection of specimen effluent gases for analysis. This port should be located between the outlet valve and the bubble meter.

5.9 *Sample Extruder*—The extruder must disturb the specimen as little as possible. Acceptable methods include: (*1*) sub-coring a test specimen, and (*2*) cutting the thin-walled tube or liner.

5.10 *Trimming Equipment*—Spatulas, knives, wire saw, rasp, cradle, split trimming molds, straightedge, trimming platform, and drying pans.

5.11 *Stopwatch*—A stopwatch or electronic timer accurate to 1 s for use with the bubble meter,

5.12 *Soap Solution*, for use with the bubble meter.

NOTE 19—A suitable soap solution may be made with 1 volume

glycerin, 1 volume of a concentrated liquid dishwashing detergent, and 7 to 10 volumes of particulate free deionized water.

5.13 *Drying Oven*—The drying oven shall be thermostatically regulated at 110 ± 5°C. The drying oven shall be in accordance with Specification E 145.

5.14 *Measuring Devices*—Devices for measuring the length and diameter of the test specimen, permeameter caps, and porous end pieces shall be capable of measuring to the nearest 0.3 mm (0.01 in.) and shall be constructed such that their use will not disturb the specimen.

5.15 *Balance*—The balance shall be in accordance with Specification D 4753. Specimen mass shall be determined to an accuracy of 0.1 g for specimens up to 1000 g and 1 g for specimens greater than 1000 g.

5.16 *Thermometer*—The thermometer shall have a range from –10 to 50°C (10 to 120°F), an accuracy to 0.5°C (1°F), and be in accordance with Specification E 1 for Thermometer 58C (or 58F).

5.17 *Barometer*—Any device for measuring atmospheric pressure to an accuracy of 50 Pa (0.1 in. Hg) may be used. If an aneroid instrument is used, it shall be calibrated yearly.

5.18 *Equipment for Mounting the Specimen*:

5.18.1 *(Flexible Wall Method Only)*—The equipment shall include a membrane stretcher, and O-ring expander for placing O-rings on the base and top cap to seal the membrane.

5.18.2 *(Flexible Wall Method Only) Membranes*—The membrane used to encase the specimen shall provide reliable protection against leakage, abrasion, and chemical attack. The membrane shall be carefully inspected before use. If any flaws or pinholes are evident, the membrane shall be discarded. To minimize strain on the specimen, the diameter or width of the unstretched membrane shall be between 90 and 95 % of the specimen. The O-rings used to seal the membrane shall have an unstretched inside diameter less than 90 % of the base and cap diameters.

5.19 *Compaction Equipment*—Compaction equipment, when used, shall be suitable for the method of compaction specified by the requester.

5.20 *Humidity Chamber*, to prevent desiccation of specimens with more than 10 % clay content.

6. Test Specimen

6.1 The test specimen shall be a right circular cylinder with the following dimensions:

6.1.1 *Test Specimen Diameter*—Recommended to be at least 51 mm (2.0 in.).

6.1.2 *Test Specimen Length*—Recommended to be as follows:

6.1.2.1 Greater than 1.3 times the diameter of the test specimen,

6.1.2.2 Greater than five times the combined thickness of the porous end pieces, and

6.1.2.3 Greater than six times the largest particle size within the test specimen. Oversized particles must be indicated on the report.

6.1.3 A minimum of three diameter and three height measurements shall be made. The surface of the specimen may be uneven but the height and diameter of any indentation or

protrusion must not result in the length or diameter varying by more than ±5 %.

6.2 *Undisturbed Test Specimens*—Test specimens shall be prepared from a representative portion of undisturbed samples obtained in accordance with Practice D 1587, Practice D 3550, or Test Method D 4564 and preserved and transported in accordance with the requirements for Group C materials in Practices D 4220. The horizontal and vertical planes of layered test specimens may be identified, prepared, and tested separately as requested. Specimens are trimmed to the desired height by cutting the end surfaces plane and perpendicular to the longitudinal axis. The ends of the test specimen shall be cut and not troweled, to prevent smearing and sealing off cracks, slicken sides, or seams of more pervious intrusions. Specimens shall be trimmed, whenever possible, in an environment where changes in water content are minimized. Determine the dimensions and mass of the test specimen to the tolerances given in 5.14 and 5.15.

6.3 *Laboratory-Compacted Specimens*—The soil shall be prepared and compacted inside a mold in a manner specified by the requester. If the test specimen is placed and compacted in layers, the surface of each layer previously compacted shall be lightly scarified (roughened) with a fork, serrated knife, or similar tool. Test Methods D 698 and D 1557 describe two methods of compaction, but any other test method specified may be used, provided it is described in the report. If the test specimen contains clods of soil, the clods shall be reduced to less than 1/6 of the height of the test specimen. After compaction, the test specimen shall be removed from the mold for a flexible wall-type test. The ends shall be scarified. Determine the dimensions and mass of the test specimen to the tolerances given in 5.14 and 5.15.

6.4 *In-tube, In-liner, and In-mold Test Specimens*—Measure the mass of the container. Measure the inside diameter of the container directly, or measure the outside diameter and subtract twice the container wall thickness. Measure the height of the container. For test specimens inset into the container, measure the length of recess or measure the height of the test specimen directly and determine the total mass of the assembly.

7. Procedure

7.1 *Specimen Setup*:

7.1.1 *Flexible Wall Method*:

7.1.1.1 Place the membrane onto the membrane stretcher. Place one porous end piece on the base followed by the specimen. Place the second porous end piece on top of the specimen, followed by the top cap. Place the membrane around the specimen and, using the O-ring expander, place one or more O-rings to seal the membrane to the base and one or more additional O-rings to seal the membrane to the top cap.

7.1.1.2 Attach the tubing to the top cap, assemble the permeameter cell, and fill the confinement annulus with water.

7.1.1.3 Permit the specimen to adjust under the effective confinement. When low effective confining pressures (less than 14 kPa (2 psi)) are applied to somewhat dense or stiff specimens, the recompression or primary compression phase will be nearly instantaneous and insignificant. For loose or soft specimens and for higher effective confining pressures, volume change readings shall be taken in the annular confinement space with a burette or other measuring device to determine when primary compression has been achieved.

7.1.1.4 If simulation of effective overburden is requested, adjust the cell pressure to the desired effective confinement. For high confining pressure, it may be necessary to increase the pressure in increments and to measure the volume change of the specimen through the cell in accordance with Test Methods D 4767 or D 5084.

7.1.2 *Rigid Wall Method*:

7.1.2.1 The specimen shall be confined in a tube, liner, or mold consistent with the rigid wall assembly or in accordance with Test Method D 5856.

7.2 *Apparatus Setup*:

7.2.1 The permeameter transfer lines, valves, end pieces, and fittings shall be dry and free of foreign matter.

7.2.2 Attach the permeameter cell transfer lines to the pneumatic system.

7.2.3 If an electronic flowmeter is used, perform a one-point (minimum) calibration check as follows:

7.2.3.1 Connect the four permeameter cell transfer lines together using a four-way union.

7.2.3.2 Using the flow control mode, establish an airflow at 50 % of the flowmeter full-scale range.

7.2.3.3 Attach a suitable bubble meter to the exit of the outlet valve.

7.2.3.4 Measure the actual flow until a steady reading is obtained with both the flowmeter and bubble meter.

7.2.3.5 If the flowmeter reading and the bubble meter reading (corrected for ambient temperature and barometric pressure in accordance with the manufacturer's instructions) agree within ±5 %, the flowmeter may be regarded as accurate. If the flowmeter proves inaccurate, do not proceed until the problem is corrected and the flowmeter recalibrated.

7.3 *Perform a Leak Check*:

7.3.1 Set the back pressure to 0 Pa (0 psi).

7.3.2 Set the mass flow controller for about 10 cm^3/min.

7.3.3 Close the outlet valve.

7.3.4 Increase the back pressure to about 7 kPa (1 psi).

7.3.5 Observe the transient flow and pressure changes as the system pressurizes. The mass flowmeter and differential pressure readings should return to their initial readings; otherwise, there is leakage that must be corrected before starting the test.

7.3.6 Return the back pressure to zero.

7.3.7 Open the outlet valve.

7.4 Record the ambient temperature, T, to the nearest 0.5°C (1°F) and the barometric pressure, P_B, to the nearest 50 Pa (0.1 in. Hg).

7.5 Record initial values under conditions of zero-flow:

7.5.1 (Flexible Wall Method Only)—Record the initial confining pressure, $P°_c$.

7.5.2 Set the back pressure to zero.

7.5.3 Close the inlet valve and wait for the flowmeter and differential pressure transducer readings to stabilize under no flow conditions.

7.5.4 Record the no-flow transducer readings for the mass flow, $Q°_s$, the specimen pressure drop, $\Delta P°$, and the specimen inlet pressure $P°_1$.

NOTE 20—These initial (tare) values, signified by the superscript zero

($X°$), typically are not equal to zero and vary slightly with time and temperature. They shall be subtracted from all subsequent specimen measurements.

7.5.5 Open the inlet valve.

7.6 *Test Method A: Mass Flow Control*:

7.6.1 Set the back pressure regulator to operate as a relief valve to open to about 7 kPa (1 psi) greater than maximum expected specimen inlet pressure.

7.6.1.1 Close the inlet valve.

7.6.1.2 Temporarily disconnect the inlet flow transfer line.

7.6.1.3 Temporarily set the mass flow control to about 50 cm³/min.

7.6.1.4 Adjust the back pressure regulator to the target pressure.

7.6.1.5 Return the mass flow control to its minimum value.

7.6.1.6 Open the inlet valve and release the built-up back pressure.

7.6.1.7 Reconnect the inlet flow transfer line.

7.6.2 *(Flexible Wall Method Only)*—Adjust the confining pressure as needed to maintain the desired effective confining stress to within 10 %. Record the confining pressure, P_c.

7.6.3 When the flow and pressure drop readings stabilize, record the mass flow, Q, the pressure drop, ΔP, and the inlet pressure, P_I.

7.6.4 Increase the flow rate by a factor of about 2.

7.6.5 Repeat 7.6.2-7.6.4 for a minimum of four data points at increasing flows.

7.6.6 Repeat 7.6.2-7.6.4, except decreasing the flow rates, for a minimum of four additional data points. It is neither necessary nor desirable to replicate the increasing and decreasing flow rates.

7.7 *Test Method B: Back Pressure Control Method*:

7.7.1 Set the back pressure to zero.

7.7.2 Set the mass flow controller to any value greater than the maximum expected flow rate.

7.7.3 *(Flexible Wall Method Only)*—Adjust the confining pressure as needed to maintain the desired effective confining stress to within 10 %. Record the confining pressure, P_c.

7.7.4 When the flow and pressure drop readings stabilize, record the mass flow, Q, the pressure drop, ΔP, and the inlet pressure, P_I.

7.7.5 Increment the back pressure to increase the air flow by a factor of about 2. For the first increment, slowly increase the back pressure just enough to produce a measurable change in the pressure drop.

7.7.6 Repeat 7.7.3-7.7.5 for a minimum of four data points at increasing flows.

7.7.7 Repeat 7.7.3-7.7.5, except decreasing the flow rates, for a minimum of four additional data points. It is neither necessary nor desirable to replicate the increasing and decreasing flow rates.

7.8 *Post Run Procedures*:

7.8.1 Record the ambient temperature, T, to the nearest 0.5°C (1°F) and the barometric pressure, P_B, to the nearest 50 Pa (0.1 in. Hg).

7.8.2 Disconnect, drain, disassemble, and clean the permeameter with minimum disturbance to the specimen.

7.8.3 Measure the dimension and mass of the specimen to the tolerance given in 5.14 and 5.15.

7.8.4 Determine the water content of the specimen in accordance with Test Method D 2216.

7.8.5 Perform other analyses specified by the requestor.

8. Calculation

8.1 Calculate, for each test point, the average volumetric flow at the center of the specimen, Q_{AV}, as follows:

8.1.1 When a flowmeter is used, calculate in accordance with Eq 1:

$$Q_{AV} = Q \cdot \frac{P_S}{\left(P_I + P_B - \frac{\Delta P}{2}\right)} \cdot \frac{T}{T_S} \tag{1}$$

where:
Q_{AV} = volumetric flow at specimen average pressure and test temperature, m³/s,
Q = flow of air into specimen at STP, m³/s,
P_B = test barometric pressure, Pa,
P_I = specimen inlet gage pressure, Pa,
P_S = pressure at STP, Pa,
ΔP = specimen pressure drop, Pa,
T_S = temperature at STP, °C, and
T = test temperature,° C.

NOTE 21—Definition of STP: The arbitrarily defined standard pressure and temperature at which the flowmeter is calibrated. Typically: 20°C (68°F) and 101.3 kPa (1 atm).

8.1.2 When a bubble meter is used, calculate in accordance with Eq 2:

$$Q_{AV} = Q \cdot \frac{P_B}{\left(P_I + P_B - \frac{\Delta P}{2}\right)} \tag{2}$$

where:
Q_{AV} = volumetric flow at specimen average pressure and test temperature, m³/s,
Q = flow of air out of specimen, m³/s,
P_B = test barometric pressure, Pa,
P_I = specimen inlet gage pressure, Pa, and
ΔP = specimen pressure drop, Pa.

8.2 Plot Q_{AV} versus ΔP for each test point. Fig. 2 shows a typical plot.

8.3 *Outliers*—Discard test points that fail Darcy's law.

8.3.1 Draw the best straight line that passes through the origin and the test points.

8.3.2 Draw an upper limit line that passes through the origin with slope 1.25 times the slope determined in 8.3.1

8.3.3 Draw a lower limit line that passes through the origin with slope 0.75 times the slope determined in 8.3.1

8.3.4 Discard all test points that lie outside the upper and lower limit lines.

8.3.5 If there are fewer than 3 or 50 % of the test points remaining, at unique flow rates, the test fails Darcy's law and shall be repeated at different conditions.

8.4 Calculate the coefficient of pneumatic permeability, K_P, for each valid test point in accordance with Eq 3:

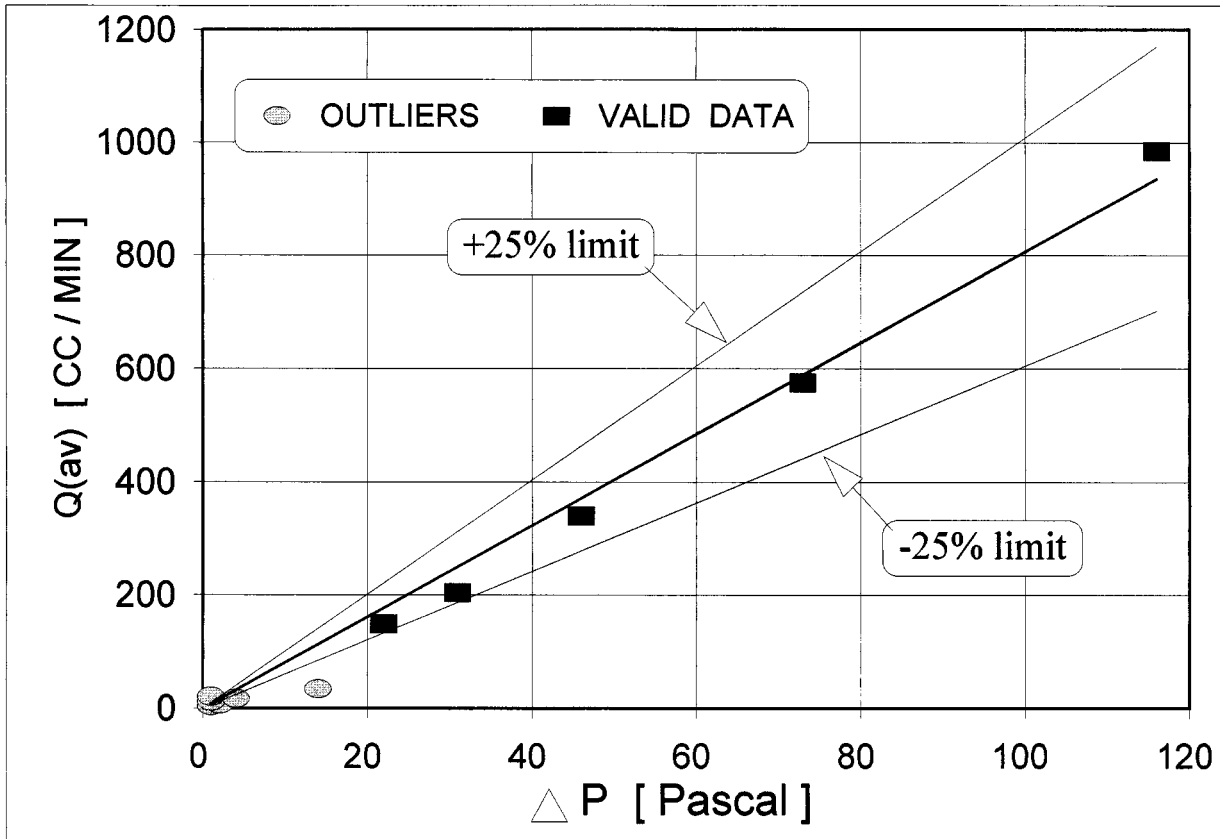$$K_P = \frac{Q_{AV}}{\Delta P} \cdot \frac{L}{A} \cdot \mu \cdot 1.013 \times 10^{12} \tag{3}$$

7

FIG. 2 Average Airflow Versus Pressure Drop

where:
K_P = pneumatic permeability, darcy,
Q_{AV} = volumetric flow of air through the specimen, m^3/s,
ΔP = specimen pressure drop, Pa,
L = specimen length, m,
A = specimen cross-sectional area, m^2, and
μ = viscosity air at the test temperature, Pa·s.

8.5 The average value of K_P for all valid test points shall be reported as the pneumatic permeability of the test specimen.

9. Report

9.1 Report the following information:

9.1.1 Specimen identifying information

9.1.2 Any special selection and preparation process including but not limited to:

9.1.2.1 A description of intrusions, such as contaminants, oversized particles (in accordance with 6.1.2.3), foreign materials, lenses, or laminations of differing composition, if present.

9.1.2.2 Whether the specimen is intact or compacted.

9.1.2.3 For layered specimens, whether the flow axis was in the horizontal or vertical plane.

9.1.2.4 The test gas, if other than air.

9.1.3 The average value of K_P at each valid test point shall be reported with no more than two significant digits and in units of darcy or millidarcy (mD). Example:" 72 millidarcy."

9.1.4 Initial and final values for the specimen length, diameter, mass, and water content.

9.1.5 A log-log graph of the specimen average volumetric air flow, Q_{AV}, versus the specimen pressure drop, ΔP, at each

test point. Valid test points shall be distinguished from outliers. Fig. 3 shows a typical plot.

9.2 Suggested additional information that may be presented in the report as follows:

9.2.1 Specific Gravity in accordance with Test Method D 854.

9.2.2 Porosity.

9.2.3 Void ratio.

9.2.4 Degree of saturation.

9.2.5 Maximum and minimum effective confining stress.

9.2.6 All information specified by the requestor.

10. Precision and Bias

10.1 *Precision*—Pneumatic permeability values shall not be reported to more than two significant digits. Data are being evaluated to determine the precision of this test method and its correlation with measurements made in the field. Preliminary data indicates a wider range of permeability is found in field testing compared to laboratory testing of similar soil. Due to the nature of the soil or rock materials tested by this test method, it is either not feasible or too costly at this time to produce multiple specimens that have uniform properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation. Subcommittee D18.04 on Hydrologic Properties of Soil and Rocks welcomes proposals that would allow for development of a valid precision statement.

10.2 *Bias*—There is no accepted reference material for this test method; therefore, bias cannot be determined.
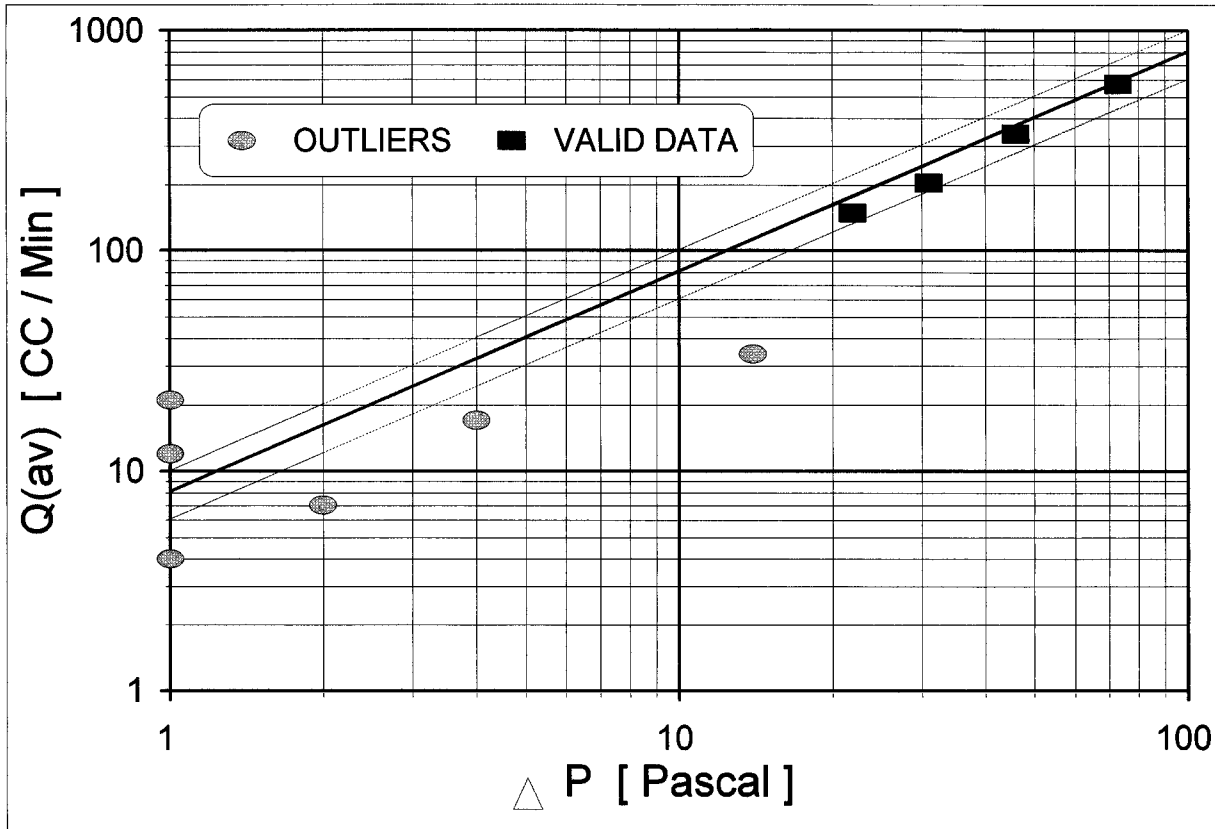
FIG. 3 Log-Log Plot of Airflow Verus Pressure Drop

11. Keywords

11.1 airflow; flexible wall permeameter; permeability; per-meameter; pneumatic permeability; rigid wall permeameter