



Designation: D4404 – 18

Standard Test Method for Determination of Pore Volume and Pore Volume Distribution of Soil and Rock by Mercury Intrusion Porosimetry¹

This standard is issued under the fixed designation D4404; 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 the determination of the pore volume and the pore volume distributions of soil and rock by the mercury intrusion porosimetry method. The range of apparent diameters of pores for which this test method is applicable is fixed by the operating pressure range of the testing instrument. This range is typically between apparent pore entrance diameters of about 400 μm and 2.5 nm (0.0025 μm). Larger pores must be measured by another method.

1.2 Mercury intrusion porosimetry is useful only for measuring pores open to the outside of a soil or rock fragment; mercury intrusion porosimetry will not give the volume of any pores completely enclosed by surrounding solids. This test method will give only the volume of intrudable pores that have an apparent diameter corresponding to a pressure within the pressurizing range of the testing instrument.

1.3 Mercury intrusion may involve the application of high pressures to the specimen. This may result in a temporary or permanent alteration or both in the pore geometry. Generally, soils and rocks are composed of comparatively strong solids and are less subject to these alterations than certain other materials. However, the possibility remains that the use of this test method may alter the natural pore volume distribution that is being measured.

1.4 **Warning**—Mercury has been designated by EPA and many state agencies as a hazardous material that can cause central nervous system, kidney and liver damage. Mercury, or its vapor, may be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury-containing products. See the applicable product Material Safety Data Sheet (MSDS) for details and EPA's website (<http://www.epa.gov/mercury/faq.htm>) for additional information. Users should be aware that selling mercury or mercury-containing products or both into your state may be prohibited by state law.

1.5 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. Reporting of test results in units other than SI, such as cgs, shall not be regarded as nonconformance with this test method.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice [D6026](#).

1.6.1 The procedures used to specify how data are collected/recorded and 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 these test methods to consider significant digits used in analysis methods for engineering data.

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use. For specific precaution statements, see Section 8.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*²

[D653 Terminology Relating to Soil, Rock, and Contained Fluids](#)
[D3740 Practice for Minimum Requirements for Agencies](#)

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.06 on Physical-Chemical Interactions of Soil and Rock.

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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.

*A Summary of Changes section appears at the end of this standard

Engaged in Testing and/or Inspection of Soil and Rock as
Used in Engineering Design and Construction
**D6026 Practice for Using Significant Digits in Geotechnical
Data**

3. Terminology

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

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *apparent pore diameter*—the diameter of a pore that is assumed to be cylindrical and that is intruded at a pressure, P , given by the equation in **13.1**.

3.2.2 *inter-specimen pores*—those pores between particles when they are packed together and that are intruded during the test.

3.2.3 *intra-specimen pores*—those pores lying within the exterior outlines of the individual soil and rock fragments.

3.2.4 *intruded pore volume*—the corrected volume of mercury intruded during the test.

4. Summary of Test Method

4.1 When a liquid does not wet a porous solid, it will not enter the pores in the solid by capillary action. The non-wetting liquid (mercury in this test method) can be forced into the pores by the application of external pressure. The size of the pores that are intruded is inversely proportional to the applied pressure. The diameter of the pores filled can be calculated from this applied pressure as described in Section 13, Calculations.

4.2 The volume of the intruded pores is determined by measuring the volume of mercury forced into them at various pressures. A single determination involves increasing the pressure, either continuously or step-wise, and recording the measured intruded volume at various pressures.

4.2.1 The sample is contained in a sample cell frequently called a penetrometer. The sample is contained within a sealed bowl to which a small capillary is attached. The space in the penetrometer not occupied by the sample is first evacuated and then filled with mercury. One end of the penetrometer is open and sealed to the pressure system of the instrument. Pressure applied to the open end of the penetrometer capillary is then used to force the mercury into the pores, with larger pores filling at lower applied pressures, and smaller pores filling at higher applied pressures.

4.3 Additional information about the pore structure of the material may be determined by recording of the extrusion profile for the sample. This is performed by recording the cumulative quantity of mercury contained within the sample as pressure is reduced, again either continuously or step-wise.

4.4 Commercially available instruments include software for controlling sample evacuation, filling of sample penetrometer with mercury, pressurization of the sample according to a programmed scheme, allowance for equilibration of the pressure, recording of the pressure and amount of mercury intruded into the sample, and calculation of summary results.

5. Significance and Use

5.1 This test method is intended for use in determining the volume and the volume distribution of pores in soil and rock with respect to the apparent diameter of the entrances of the pores. In general, both the size and volume of the pores affects the performance of soil and rock. Thus, the pore volume distribution is useful in understanding soil and rock performance and in identifying a material that can be expected to perform in a particular manner (**1, 2**).³

5.2 The intrusion process to determine the volume of a pore proceeds from the outside of a specimen toward its center. Comparatively large interior pores can exist that have smaller outside openings as the only means of access. Mercury intrusion porosimetry will incorrectly register the entire volume of these “ink-bottle” pores as having the apparent diameter of the smaller access pores. In a test specimen, exterior specimen pores can exist in addition to intra-specimen pores (see **3.2** for definitions). The inter-fragment pores will vary in size and volume depending on the size and shape of the soil or rock fragments and on the manner in which the fragments are packed together. It is possible that some exterior specimen pores can have the same apparent diameter as some intra-specimen pores. When this occurs, this test method cannot distinguish between them. Thus, the test method yields an intruded pore volume distribution that is in part dependent upon the packing of multifragment specimens. However, most soils and rocks have intra-fragment pores much smaller than the inter-fragment pores. This situation leads to a bi-modal pore size distribution and the distinction between the two classes of pores can then be made (see **Figs. 1 and 2**). The intr-fragment pore concentration is shown to the left of the plot; the inter-fragment concentration is to the right.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice **D3740** are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice **D3740** does not in itself assure reliable results. Reliable results depend on many factors; Practice **D3740** provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Mercury Intrusion Porosimeter*—A device equipped with a specimen holder capable of containing one or several soil or rock fragments. This specimen holder is frequently called a penetrometer. The porosimeter shall have a means of surrounding the test specimen with mercury at a low pressure, a pressure generator to cause intrusion, pressure transducers, capable of measuring the intruding pressure with an accuracy of at least $\pm 1\%$ throughout the range of pressures over which the pores of interest are being intruded, and a means of measuring intruded mercury volumes to an accuracy of at least $\pm 1 \text{ mm}^3$.

6.2 *Analytical Balance*, with an accuracy of at least $\pm 10^{-6} \text{ kg}$ ($\pm 1 \text{ mg}$), and readable to at least $\pm 10^{-7} \text{ kg}$ ($\pm 0.1 \text{ mg}$).

³ The boldface numbers in parentheses refer to the list of references appended to this standard.

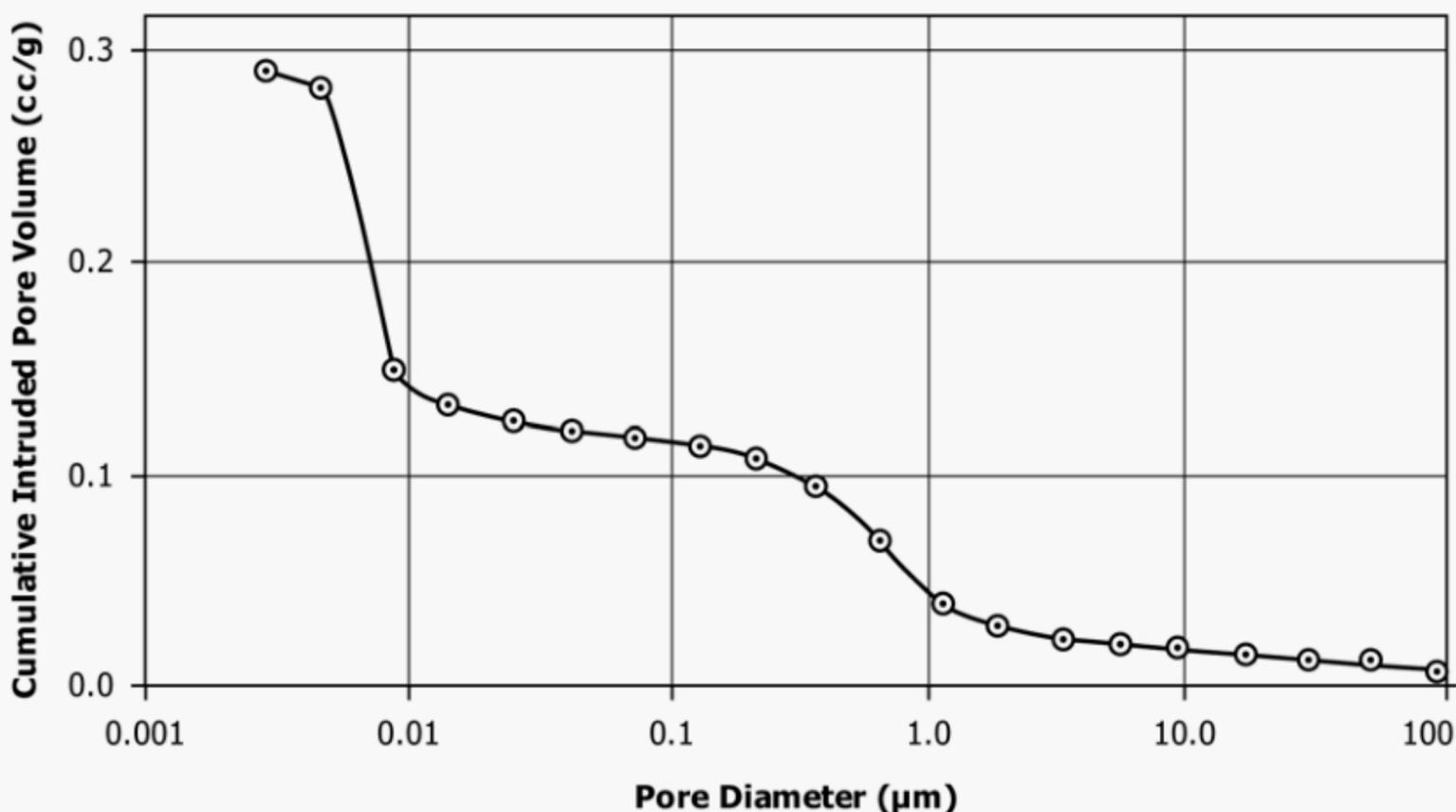


FIG. 1 Example of Cumulative Pore Volume Distribution Plot

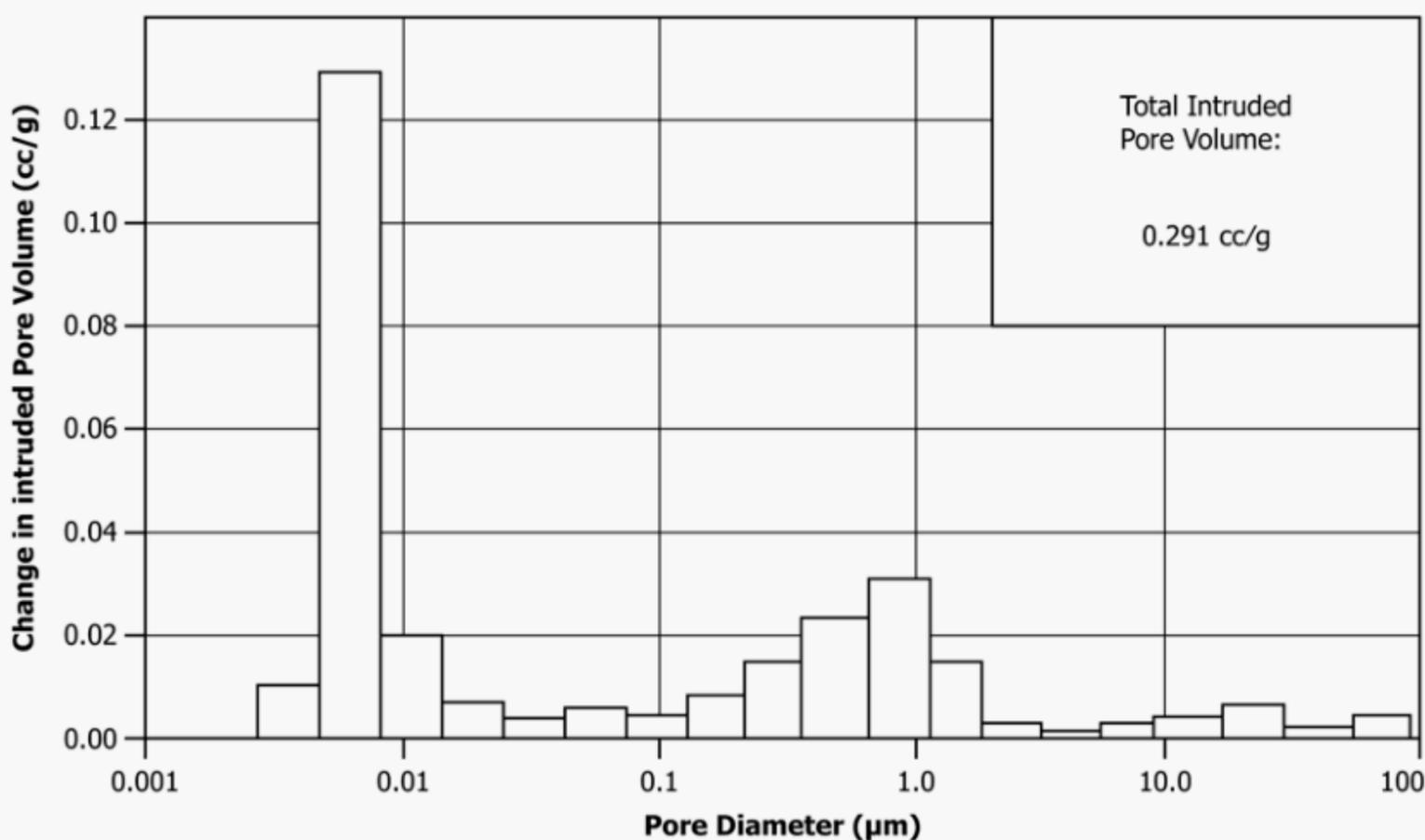


FIG. 2 Example of Differential Pore Volume Distribution Plot

6.3 *Fume Hood*—A ventilated enclosure designed to limit exposure to hazardous/toxic vapors, fumes, or dust by providing a means to move the air away from the user, preferably venting it outside.

6.4 *Thermometric Device*—A thermometric device capable of measuring the temperature range within which the test is being performed readable to 0.5°C or better and having an accuracy of at least ±1°. The thermometric device shall be standardized by comparison to a nationally or internationally traceable thermometric device and shall include at least one

temperature reading within the range of testing. The thermometric device shall be standardized at least once every twelve months.

6.5 *Drying Oven*—Controllable at or above 150 ± 10°C.

7. Reagent

7.1 *Triple-Distilled Mercury*.

7.2 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that

all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.⁴ Other grades or amalgams may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8. Safety Precautions

8.1 Warning—Mercury has been designated by many regulatory agencies as a hazardous material that can cause serious medical issues. Mercury, or its vapor, has been demonstrated to be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products. See the applicable Safety Data Sheet (SDS) for additional information. Users should be aware that selling mercury and/or mercury containing products into your state or country may be prohibited by law (see **Note 2**).

NOTE 2—Mercury is found in several chemical forms, such as: elemental, inorganic, and organic:

(A) **Elemental Mercury:** Elemental mercury, also referred to as metallic mercury, is a shiny, silver-white, odorless liquid. Elemental mercury readily evaporates at room temperature to form a colorless, odorless gas. In an enclosed space, even a relatively small amount of mercury can result in the accumulation of a very high level of mercury vapor in indoor air. Therefore, exposure via inhalation of elemental mercury is a particular concern when mercury is spilled in laboratories or in other enclosed areas. Vapor levels can be limited through temperature control of and fresh air flow through the laboratory space where the analysis is performed. Many laboratories are maintained at or below 293 K (20°C), with forced air flow through the area either through use of exhaust fans or a continuously-operating fume hood.

(B) **Inorganic Mercury:** Mercury combines with other elements, such as chlorine, sulfur, or oxygen, to form inorganic mercury compounds or “salts,” which are usually in the form of white powders or crystals. Inorganic mercury does not readily evaporate and is not easily inhaled; however inorganic mercury can be absorbed across the gastrointestinal tract and the surface of the skin. Therefore, ingestion and skin contact can result in exposure.

(C) **Organic Mercury:** Mercury also combines with carbon to make organic mercury compounds. The most common form is methyl mercury, which is produced mainly by small organisms in the water, soil, and sediment. Increasing emissions of mercury into the environment can increase the levels of methyl mercury that these small organisms make. The most significant source of human exposure to organic mercury is through diet, particularly from fish products. Since organic mercury is easily absorbed through the gastrointestinal tract and through the skin, ingestion and skin contact can result in exposure.

8.2 Store mercury in closed containers to control its evaporation and use only in conjunction with a fume hood in a well-ventilated room.

8.3 Mercury can also be absorbed through the skin, so avoid direct contact. Wash hands immediately after any operation involving mercury; the use of mercury approved gloves is advocated.

8.4 Exercise extreme care to avoid spilling mercury. Clean up any spills immediately using procedures recommended explicitly for mercury.

8.5 Handle intruded specimens with great care and dispose of in a safe and environmentally acceptable manner immediately after completion of the test (See **Note 3**).

NOTE 3—USEPA conditionally exempts small quantity generators (CESQG). Small quantity generators generate 100 kg or less per month of hazardous waste, or 1 kg or less per month of acutely hazardous waste. See 40 CFR 261.5 for the eligibility requirements for CESQG's.

9. Sampling and Test Specimens

9.1 The sample from which the test specimen is drawn shall be representative of the soil or rock of interest. The test specimen shall be as large as practicable considering the test apparatus. Blank errors, discussed in Section 12, System Corrections, can be minimized when the volume of the sample under test occupies the majority of the sample cell space, minimizing the amount of mercury required to surround the sample. When adequate sample material is available, a minimum of 3 specimens should be run on samples from similar material. If a statistical analysis of the results is desired, a minimum of 10 specimens is necessary.

9.2 Specimen size is limited by the pore-measuring capacity of the penetrometer (see **Note 4**). The small specimen size may prevent the measurement of porosity represented by relatively large cracks and fissures in the material. Judgement is required in the application of these measurements to the characterization of the soil or rock masses.

NOTE 4—Currently the specimen size limited by the pore-measuring capacity of the penetrometer is slightly more than 16,387 mm³.

10. Preparation of Test Specimens

10.1 The ideal preconditioning for the test specimen is an outgassing or drying procedure such as freeze drying or critical region drying that removes foreign fluids from the pores and pore walls of the soil or rock and does not alter the soil or rock in any way. If possible, the appropriate combination of temperature and pressure and the necessary time of conditioning shall be experimentally determined for the specific soil or rock under test. This outgassing or drying technique shall then be the one specified and used.

10.2 Rock or coarse-grained soil without fines shall be outgassed in a vacuum at or below 1.3 Pa (10 μmHg) and at a temperature of 150 ± 10 °C for a minimum of 24 h. Soil containing plastic fines needs special drying procedures to avoid alteration of pore structure. Freeze drying has been successfully employed (**3, 4**) and is a simple procedure. Critical region drying may also be used (**5**), but is more complex and expensive than freeze drying.

10.3 After preconditioning, work quickly as the test specimen is exposed to the laboratory atmosphere where it can reabsorb vapors.

11. Procedure

11.1 Determine and record the mass of the preconditioned test specimen to the nearest 0.0001 g and then quickly place the test specimen in the penetrometer.

11.2 Place the penetrometer containing the specimen in the pressure vessel of the porosimeter and evacuate to a pressure to 1.3 Pa (10 μmHg) or below.

⁴ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For Suggestions on the testing of reagents not listed by the American Chemical Society, see *Annual Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

11.3 Fill the penetrometer with mercury by pressurizing to 1.4 KPa or more such that it will promote filling.

NOTE 5—The pressure used to fill the penetrometer with mercury is also capable of intruding sufficiently large pores of both the inter- and intra-fragment classes. Thus, the process can intrude into some pores and the volume distribution of these pores cannot subsequently be determined. This fact should be recognized, and where possible, a filling pressure should be selected that will not intrude pores in the diameter range of interest.

11.4 Place the filled penetrometer in the pressure vessel of the porosimeter if not done so in order to fill the penetrometer with mercury (commercially available instruments have different mercury filling means), then prepare the instrument for pressurization and intrusion readings. Record the initial pressure used for mercury filling and base value corresponding to initial amount of mercury in the penetrometer. Most commercially available instruments use capacitance change to monitor mercury remaining in the penetrometer and not yet filling the sample pores, and thus the initial capacitance value must be recorded. Many of these commercially available instruments record the capacitance and pressure values automatically.

11.5 Raise the pressure, either continuously or incrementally, and record both the absolute pressure and the volume of intruded mercury to the nearest 0.1 mm^3 (0.0001 cm^3) until the maximum pressure of interest is reached. When raising the pressure incrementally, the pressure shall be maintained during the pause and not allowed to decrease. When testing some materials, the time needed to achieve intrusion equilibrium will not be the same at all pressures. Often the equilibrium time is appreciably longer at pressures that cause an abrupt and large increase in intruded volume. Failure to record the equilibrium intrusion may result in some of the pore volume being incorrectly assigned to smaller pore diameters. The extent to which this may be a problem can be assessed by conducting two tests, each at a different pressure increase rate, and comparing the results.

11.6 When absolute pressure cannot be recorded directly, the gauge pressure shall be recorded at each step such that the absolute pressures can be calculated.

11.7 The choice of pressure intervals at which data are to be recorded is left to the judgment of the operator. Normally, at least 10 to 15 intervals will be necessary to adequately define the pore volume distribution. In selecting these pressure intervals, a rough idea of the expected distribution is helpful, since the pressure interval can be larger in regions where little or no intrusion occurs and should be smaller in regions where a large volume of intrusion is expected. It is not necessary to continue the process up to the maximum pressurizing capability of the instrument if all of the pores of interest in a particular test specimen have been intruded at a lesser pressure.

11.8 Upon completion of the pressuring cycle, reduce the pressure and disassemble and clean the instrument in accordance with the manufacturer's instructions.

12. System Correction

12.1 An intrusion test on a nonporous specimen is necessary to obtain values to use in correcting intrusion data for apparatus

compressibilities and volume changes due to expansion/contraction because of temperature changes.

12.2 Select a nonporous material that has approximately the same compressibility and bulk volume as the soil or rock specimen that is to be tested.

12.3 Test the nonporous specimen in exactly the same manner as outlined in Section 11. Raise the pressure using the same increments used for the soil or rock tests to make sure that temperature changes due to pressuring are the same.

12.4 Test results of the nonporous material are a series of measured volume changes that are also expected to occur during an actual test. These results are then used to correct the intruded volumes as discussed in 13.3.2.

12.5 Compressibilities of the various components in the system augment the measured intrusion values while the pressure-induced heating and consequent expansion of the system reduces the measured volumes. In a particular instrument, one of these effects will be dominant. Therefore, results of the nonporous specimen test will be either an apparent intrusion (compressibility dominant), appearing as additional recorded positive intrusion, or an expulsion of mercury (heating dominant), appearing as reduction in the amount intruded, also known as negative intrusion.

13. Calculation

13.1 Intruding pressures must be expressed as absolute pressures before they can be used to compute the corresponding pore diameters. If the recorded values are gauge pressures, they should be converted to absolute pressures.

13.2 Absolute pressures (P_{ABS}) are converted to apparent intruded pore diameters using Eq 1. To calculate the apparent intruded pore diameter, the surface tension and contact angle be known. When a cylindrical pore model is assumed, the relationship between pressure and size is given as follows:

$$d = \frac{4\gamma(\cos\theta)}{P_{ABS}} \quad (1)$$

where:

- d = apparent intruded pore diameter, nearest 0.1 nm,
- γ = surface tension of the mercury, under vacuum at 20°C , 480 mN/m,
- θ = contact angle between the mercury and the pore wall, 140° (see 13.2.2),
- P_L = absolute pressure causing the intrusion, nearest 0.1 kPa,
- P_G = pressure of gas, nearest 0.1 kPa,
- $P_{ABS} = P_G - P_L$, nearest 0.1 kPa.

NOTE 6—Since the technique is usually done under vacuum, the gas pressure begins at zero. The contact angle of mercury with most solids is between 130 and 150, so an average of 140 can be taken without much error.

13.2.1 Small deviations between the reported surface tension values of mercury are not significant as the surface tension enters the equation only as a linear term.

13.2.2 The contact angle enters the equation as a cosine function, and it is important to know the value of the angle accurately for the material under test. The contact angle of

mercury has been measured on a variety of solids by several different techniques; references to some of these measurements are given in [Appendix X1](#). This appendix also lists references for several methods of contact-angle measurement that have been found useful. The ideal value for reducing the data is the one that has been determined for the material under test. If direct measurement is impractical, the use of an assumed value is customary. If mercury intrusion is being used for the comparison of similar materials for quality control purposes, then an assumed value is satisfactory; however, when different materials are being compared, the assumption of a single value for the contact angle may lead to errors.

13.3 Correct the intruded volume readings using the system corrections values as determined in Section 12 as follows.

NOTE 7—Some commercially available instruments can perform these corrections automatically once the necessary corrections have been determined.

13.3.1 Subtract the correction values from the values obtained during the test if the system correction data indicates apparent intrusion. Record the corrected intrusion volume to the nearest 0.1 mm^3 (0.0001 cm^3).

13.3.2 Add the correction values to the values obtained during the test if the system correction data indicates mercury expulsion. Record the corrected intrusion volume to the nearest 0.1 mm^3 (0.0001 cm^3).

13.4 Since the amount of mercury intruded is dependent upon the amount of sample under test, the volume of mercury intruded per unit mass is generally desired rather than the absolute total intrusion volume. If this is the case, convert the corrected intruded volumes to a unit mass basis. Divide each corrected intrusion value by the specimen mass and record the value to the nearest $0.1 \text{ mm}^3/\text{g}$ ($0.0001 \text{ cm}^3/\text{g}$).

NOTE 8—At low pressures, corrections account for the fact that part of the apparent intrusion recorded is actually the compression of air trapped in the penetrometer when it was filled with mercury. This correction is only important when the distribution of large pores has to be measured accurately. When large pores ($\sim 50 \mu\text{m}$ diameter) are not of interest, the low pressure corrections may be ignored.

14. Report: Test Data Sheet(s)/Form(s)

14.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in [1.5](#) and in Practice [D6026](#).

14.2 Record as a minimum the following general information (data):

14.2.1 Identification of the material being tested, such as the project identification, boring number, sample number, and depth,

14.2.2 Description, classification, or both of the sample and the test specimen(s), and

14.2.3 Describe any problems that were encountered.

14.3 Record as a minimum the following test specimen data:

14.3.1 Specimen mass,

14.3.2 Conditioning method used,

14.3.3 The contact angle and indicate if the value is assumed or measured,

14.3.4 The type of system correction, apparent intrusion or mercury expulsion,

14.3.5 A table showing the corrected cumulative intrusion volumes on a per gram basis and the corresponding absolute intruding pressure (**Note 9**), and

14.3.6 A graphical, cumulative pore volume distribution having the intruded volumes per gram on the ordinate with an arithmetic scale, and the apparent pore diameters on the abscissa with a logarithmic scale.

NOTE 9—The pore size distribution may also be expressed in terms of intruded volume per cubic centimetre of total specimen volume, if this is a more convenient form for the results.

14.3.7 *Optional*—A differential plot of the distribution. This plot may have either the slope of the cumulative plot taken at various points or the incremental increase in intrusion between various points plotted against the apparent pore diameters. The slope or change shall be on the ordinate, with an arithmetic or logarithmic scale as appropriate, and the apparent pore diameters shall be on the abscissa with a logarithmic scale.

14.3.7.1 A differential plot can lead to a distorted image of the pore size distribution unless care is exercised in the selection of the diameter points at which the slope or change in intrusion is calculated. It is recommended that pore diameters be selected that are approximately equally spaced on the logarithmic diameter axis, and that these diameters be used consistently to avoid distortions in the appearance of the differential plot.

14.3.7.2 When a differential plot is presented, there shall be on the plot itself a statement of the cumulative total intruded pore volume. Typical examples of both cumulative and differential pore volume distribution plots are shown in [Fig. 1](#) and [Fig. 2](#).

15. Precision and Bias

15.1 *Precision*—Test data on precision is not presented due to the nature of the soil and rock materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Also, it is either not feasible or too costly to produce multiple specimens that have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

15.1.1 Subcommittee D18.06 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

15.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

15.3 Appendix A of Ref ([3](#)) shows examples of single-laboratory variations for several compacted soils. No multi-laboratory comparisons are available, and statistical evaluations of variability are either not available or are incomplete.

16. Keywords

16.1 hydraulic conductivity; mercury intrusion; mercury extrusion; permeability; pore volume distribution; pore volume; pore size; porosimetry; porosity; soil; voids

APPENDIX

(Nonmandatory Information)

X1. DETERMINING CONTACT ANGLES

X1.1 The contact angle between mercury and the wall of a pore in a solid depends upon many factors. Among these are the nature of the solid, the cleanliness of the pore wall, the roughness of the pore wall, whether the mercury is advancing or retreating along the solid surface, and the purity of the mercury. For these reasons, the operant contact angle for a particular material will generally be different from that for another material. Thus, the best contact angle to use in reducing the porosimetry data is one that has been measured on the material in question with the mercury used for the porosimetry experiment. Ref (6) gives a summary of a wide variety of experimental techniques for measuring contact angles.

X1.2 Some contact angles have been reported in the references. Some examples of contact angles are given in Table X1.1.

X1.3 If a published contact angle value is to be adopted, it is recommended that the reference be carefully studied to assess the validity of its use for reducing porosimetry data.

TABLE X1.1 Examples of Contact Angles

Material	Contact Angle, °	Reference
Alkali borosilicate glass	153	(7)
Quartz	132–147	(8)
Clay minerals	139–147	(9)
Aluminum oxide	127	(10)

REFERENCES

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SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this test method since the last issue, D4404–10, that may impact the use of this test method. (February 1, 2018)

(1) Several of numbered sections have been deleted, and several have been added, as described below. Therefore, many sections of this standard have been renumbered. In addition, some notes have been removed, and others added, again as described below, resulting in new numbers for many of the notes. Note that for this summary of changes, reference is made to revised paragraph and note numbers as they existed in the previously approved version of this standard, and not to any

new paragraph and note numbers that resulted from renumbering required by this revision. On the other hand, any newly added paragraph or note is referenced by the new number assigned to it.

- (2) Expanded range of pore sizes frequently measured in 1.1.
- (3) Added new 1.6, in place of previous 1.4 expanding significant digits requirement so as to be in accordance with Practice D6026.

- (4) Revised units statement in 1.5 to allow use of cgs units without nonconformance to this standard.
- (5) Revised 3.1 *Definitions* so as to move reference to D653 to 3.1.1, and revised to add clarity to this statement.
- (6) Removed equation from 4.1 since it was duplicated in Section 13 on Calculations, and added a reference to that section for the equation used to calculate pore diameter from applied pressure.
- (7) Added 4.2.1 through 4.4 to provide more thorough description of how the method works.
- (8) Moved statement that helps to explain Figures 1 and 2 from 14.3.7.2 to 5.2 where the figures appear.
- (9) Revised Note 1 to improve clarity.
- (10) Revised 6.1 to improve clarity.
- (11) Removed 6.2 since an external vacuum pump is not generally needed.
- (12) Added balance readability requirement to 6.3.
- (13) Corrected name of the fume hood in 6.4 and expanded description.
- (14) Expanded description of thermometric device in 6.5 to add clarity.
- (15) Added description of drying oven used to prepare samples in new 6.5.
- (16) Deleted 7.2 and moved information into 7.3.
- (17) Renamed Section 8 from Safety Precautions to Hazards, and revised 8.1 to add additional information relating to the safe handling of mercury.
- (18) Revised Note 3 to remove unnecessary details, along with footnote 5.
- (19) Corrected the name of the fume hood in 8.2.
- (20) Revised title of Section 9.
- (21) Revised 9.1 and 9.2 to improve clarity and provide additional explanation.
- (22) Moved mandatory information from Note 4 to 9.1, removing Note 4.
- (23) Revised Note 5 to improve clarity.
- (24) Renamed Section 10 from Conditioning to Preparation of Test Samples.
- (25) Revised 10.1 to improve clarity.
- (26) Revised 10.2 to improve clarity and to add tolerance for sample preparation temperature.
- (27) Moved mandatory information from Note 6, along with 11.2, to new 10.3, deleting Note 6 as a result.
- (28) Removed unnecessary 11.1.
- (29) Revised 11.4, 11.5 and Note 7 to improve clarity.
- (30) Revised 11.6 to provide additional explanation and information on how analysis data are obtained and recorded.
- (31) Revised 11.7 to include the number of significant digits to record for experimental data, and precaution concerning time required for intrusion equilibration.
- (32) Moved mandatory information from Notes 8 and 9 into text of 11.7 and new 11.6, respectively. These two Notes were subsequently deleted.
- (33) Revised 11.8 to improve clarity.
- (34) Removed unnecessary Note 11.
- (35) Renamed Section 12 from Blank Test for Correction to System Corrections.
- (36) Revised 12.1, 12.3, 12.4, and 12.5 to improve clarity. Information in 12.5.1 and 12.5.2 was moved to other parts of Section 12 and thus deleted.
- (37) Revised 13.1, 13.2, 13.2.1, and Note 12 to improve clarity.
- (38) Reformatted equation in 13.2 to improve clarity.
- (39) Revised 13.3, 13.3.1, 13.3.2, and 13.4 to provide more information about how system corrections are applied to intrusion volume values. New Notes 7 and 8 were added to provide additional information about corrections.
- (40) Expanded name of Section 14.
- (41) Revised paragraphs of Section 14 to expand information to be reported and to provide additional clarity.
- (42) Revised 15.1 to correct former typographical error and to improve clarity.
- (43) Revised 15.2 to improve clarity.
- (44) Revised list of Keywords.

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