Designation: D7243 – 11

Standard Guide for Measuring the Saturated Hydraulic Conductivity of Paper Industry Sludges[1]

This standard is issued under the fixed designation D7243; 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 Paper industry sludges are industrial by-products derived from wastewater treatment operations at plants associated with the manufacturing of paper. These sludges typically consist of clay and organic matter. They may also contain low levels of inorganic and organic contaminants and can be rich in microbes. Traditionally, paper industry sludges have been disposed in municipal solid waste landfills or solid waste monofills. However, in the interest of sustainability, applications are being developed where sludges can be used beneficially. One application is using sludge to construct hydraulic barriers (for example, for use in a landfill cap). Such applications generally require that the hydraulic conductivity of the sludge be measured.

1.2 Compacted paper industry sludges generally behave like soils and are amenable to geotechnical testing methods. However, several of their attributes require special attention during testing. Compacted industry sludges generally are highly compressible due to their organic component. Thus, their hydraulic conductivity can be more sensitive to the effective stress and hydraulic gradient applied during testing than most soils. The microbes in paper sludge can also produce gas during testing, confounding testing methods.

1.3 This guide is intended to supplement ASTM D5084, Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter. The purpose of the guide is to provide additional guidance on issues relevant to testing sludges using Test Methods D5084. The guide applies to specimens compacted in the laboratory using procedures such as those described in Test Methods D698 and D1557 or undisturbed specimens collected from the field using procedures such as Practice D1587 or Practice D7015.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* This standard contains a hazards section regarding the use of biocides (Section 10).

1.6 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

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

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

D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes

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

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

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
D7015 Practices for Obtaining Intact Block (Cubical and Cylindrical) Samples of Soils
D7100 Test Method for Hydraulic Conductivity Compatibility Testing of Soils with Aqueous Solutions

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of other terms in this standard, see Terminology D653.

3.1.2 *paper industry sludge*—porous solid material derived from clarification of water during wastewater treatment operations at plants producing paper and similar materials. Also referred to as paper sludge, papermill sludge, fiber clay, paper clay, or sludge.

3.1.3 *head loss,* h_L or h—the change in total head of water across a given distance.

3.1.3.1 *Discussion*—Typically the change in total head is across the influent and effluent lines connected to the permeameter, while the given distance is typically the length of the test specimen.

3.1.4 *permeameter*—the apparatus (cell) containing the test specimen in a hydraulic conductivity test.

3.1.4.1 *Discussion*—The apparatus in this case is typically a triaxial-type cell with all of its components (top and bottom specimen caps, stones, and filter paper; membrane; chamber; top and bottom plates; valves; etc.). However, the cell generally does not have a loading piston.

3.1.5 *hydraulic conductivity, k*—the rate of discharge of water under laminar flow conditions through a unit cross-sectional area of porous medium under a unit hydraulic gradient and standard temperature conditions (20°C).

3.1.5.1 *Discussion*—The term *coefficient of permeability* (or *permeability*) is often used instead of *hydraulic conductivity*, but *hydraulic conductivity* is used exclusively in this standard. These terms are synonymous.

4. Significance and Use

4.1 This guide is intended to supplement the methods and procedures described in Test Methods D5084. When following the recommendations in this guide to test paper sludges, all assumptions and limitations described in Test Methods D5084 apply.

4.2 This guide only applies to hydraulic conductivity tests on paper industry sludges where one-dimensional laminar flow of water is imposed using a flexible-wall permeameter.

4.3 The hydraulic conductivity of sludges, and other porous materials, generally decreases as the degree of water saturation decreases. This guide applies only to water-saturated sludge containing negligible amounts of gas.

4.4 This guide applies only to permeation of paper industry sludges with water. Information on testing porous materials with liquids other than water can be found in Test Method D7100.

4.5 The hydraulic conductivity of paper sludge measured in the laboratory following Test Methods D5084 and the recommendations in this guide may or may not be comparable to the hydraulic conductivity of in-place sludge. The issue has not been fully investigated. Therefore, the results should be applied to field situations with caution and by qualified personnel.

NOTE 1—The quality of the result produced when using the recommendations in this guide depends on the competence of the personnel performing the testing and the suitability of the equipment and facilities that are employed. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing, sampling, inspection, etc. Users of this guide are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Reagents

5.1 *Permeant Water:*

5.1.1 Selection of the permeant water should follow the instructions in Section 6 of Test Methods D5084. Comparative testing has been conducted to assess whether the hydraulic conductivity of sludge is sensitive to the type of water used for testing. Tests conducted by Nelson and Benson[3] indicate that essentially the same hydraulic conductivity is obtained if hydraulic conductivity tests on paper sludge are conducted with tap water, deionized water, 0.005 M $CaCl_2$, 0.01 M $CaCl_2$, or 0.01 M $CaSO_4$. These permeant waters should be considered equivalent when testing paper sludge.

5.1.2 In some cases, a biocide may be added to the permeant water to prevent generation of gases associated with microbial activity. Testing conducted previously[3] suggests that biocides do not alter the hydraulic conductivity of paper sludges when used at concentrations recommended by the manufacturer. However, comprehensive testing has not been conducted to assess how all biocides affect the hydraulic conductivity of paper sludges (for example, through chemical interactions with the solid phase). If chemical interactions are a concern, an assessment can be made with side-by-side testing using an alternative method to prevent gas generation.

6. Procedures to Minimize Gas Generation

6.1 Gases generated by microbial activity can confound hydraulic conductivity testing of paper sludges. Indications of gas generation include: *(1)* inability to meet the termination criteria in Test Methods D5084 for steady hydraulic conductivity and continuity (section 9.5 in Test Methods D5084), *(2)* flow in the influent system in the opposite direction of the applied hydraulic gradient, and *(3)* outflow much greater than inflow. This section describes how to deal with gas generation.

[3] Nelson, M., and Benson, C., "Laboratory Hydraulic Conductivity Testing Protocols for Paper Sludges Used for Hydraulic Barriers," *Technical Bulletin No. 848*, National Council for Air and Stream Improvement, Research Triangle Park, NC, 2002.

6.2 Gas generation can be minimized or eliminated by preventing or minimizing microbial activity or by applying elevated backpressure.

6.2.1 Microbial activity can be minimized by temperature control or through the use of biocides.

6.2.1.1 Temperature control consists of placing the permeameter containing the test specimen in a chamber where the temperature is greater than 0°C and no more than 4°C. A kitchen refrigerator works well for this purpose. The temperature of the chamber should be controlled to within ±1°C and must be maintained above 0°C at all times. At lower temperatures, the effects of temperature on the viscosity and density of water reduce the hydraulic conductivity. Thus, when temperature is used to control microbial activity, the hydraulic conductivity must be adjusted to standard conditions (20°C) using the method described in section 10.3 of Test Methods D5084. Temperature control is the preferred method for minimizing gas generation.

6.2.1.2 Biocides that can be dissolved in water can be used to control gas generation. DOWICIL (2,2-dibromo-3-nitrilopropionamide) has been found effective at preventing gas generation when mixed with the permeant water at concentrations between 1000–2000 ppm.[3] When used at these concentrations, testing has also shown that the hydraulic conductivity is comparable to that obtained when testing with tap water alone under cool conditions that limit microbial activity (as described in section 6.2.1.1). When using biocides, care should be used to ensure that the biocide is well mixed with the permeant water following instructions provided by the manufacturer.

6.2.2 Gas generated by microbial activity can be suppressed using elevated backpressure. The backpressure required to suppress gas generation can be determined by incrementally increasing the backpressure as described in section 9.3 of Test Methods D5084 followed by observation of the inflow and outflow for two or more days. The backpressure is sufficient when the adverse affects caused by gas generation (described in section 6.1) are no longer present. In most cases, the backpressure will need to exceed 330 kPa to be effective in minimizing gas generation.

7. Selection of Effective Stress and Hydraulic Gradient

7.1 Because paper industry sludges are compressible, their hydraulic conductivity is sensitive to the effective stress and hydraulic gradient applied during the test. Thus, the effective stress and gradient should be set so that field conditions are simulated as closely as possible. These conditions should be specified by the requestor. If no specification is required, the test shall be conducted at an average effective confining stress in the range of 15–35 kPa and a hydraulic gradient in the range of 10–20.

7.2 If the effective stress or hydraulic gradient in the field is too low to be replicated in a flexible-wall permeameter, then tests should be conducted at a series of three or more effective stresses (or hydraulic gradients). Data from these tests are then used to extrapolate back to the effective stress (σ'_f) or hydraulic gradient (i_f) corresponding to the field condition. This procedure is illustrated in Fig. 1. Graphs such as those made in Fig. 1 are most effective when the effective stresses or hydraulic gradients are set as follows, where σ'_o (or i_o) is the lowest practical effective stress (or hydraulic gradient): σ'_o, $3 \times \sigma'_o$, $10 \times \sigma'_o$ (or i_o, $3 \times i_o$, $10 \times i_o$).

8. Termination

8.1 The termination criteria described in section 9.5 of Test Methods D5084 can be too stringent for hydraulic conductivity testing of paper mill sludges.[3] The termination criteria described in the following can be used when testing paper sludges. The method designations in this section are from Test Methods D5084.

8.1.1 *Open System (D5084 Methods A, B, C, and D)*—Continue permeation until at least four values of hydraulic conductivity are obtained over an interval of time in which: *(1)* the ratio of incremental outflow to incremental inflow is between 0.7 and 1.3, and *(2)* the hydraulic conductivity is steady. The hydraulic conductivity can be considered steady if four or more consecutive hydraulic conductivity determinations fall within ±25 % of the mean for $k \geq 1 \times 10^{-10}$ m/s or within ±50 % for $k < 1 \times 10^{-10}$ m/s, and a graph of hydraulic conductivity versus time shows no significant upward or downward trend.

8.1.2 *Constant Volume (D5084 Methods E, F)*—Continue permeation until at least four or more values of hydraulic conductivity (k) are steady. The hydraulic conductivity shall be considered steady if four or more consecutive k determinations fall within ±20 % of the mean for $k \geq 1 \times 10^{-10}$ m/s or within ±50 % for $k < 1 \times 10^{-10}$ m/s.

8.2 Because paper industry sludges are compressible, the dimensions of the specimen after consolidation may be appreciably different from the dimensions measured when the test setup was originally assembled at the beginning of a test. Thus, after completing a test, reduce the applied confining, influent, and effluent pressures and disasssemble the apparatus as quickly as practical to minimize the volume change of the test specimen. Then carefully disassemble the permeameter cell and remove the specimen. Measure and record the final height, diameter, and total mass of the specimen. These dimensions shall be used when computing the hydraulic conductivity using the equations in Section 10 of Test Methods D5084. Determine the final water content of the specimen using Test Method D2216. Dimensions of the test specimen shall be measured to within 0.5 mm and masses shall be determined to the nearest 0.01 g (masses < 100 g), 0.1 g (masses < 1 kg), or the nearest 1 g (masses > 1 kg).

9. Procedure for Gradient Control in Variable Head Tests

9.1 Because paper industry sludges are compressible, variations in the hydraulic gradient during variable head tests (Methods B, C, and F in Test Methods D5084) can cause significant variations in hydraulic conductivity. Thus, when testing sludges, the head loss across the specimen shall be maintained within 85 % of the maximum head loss applied at all times during the test.

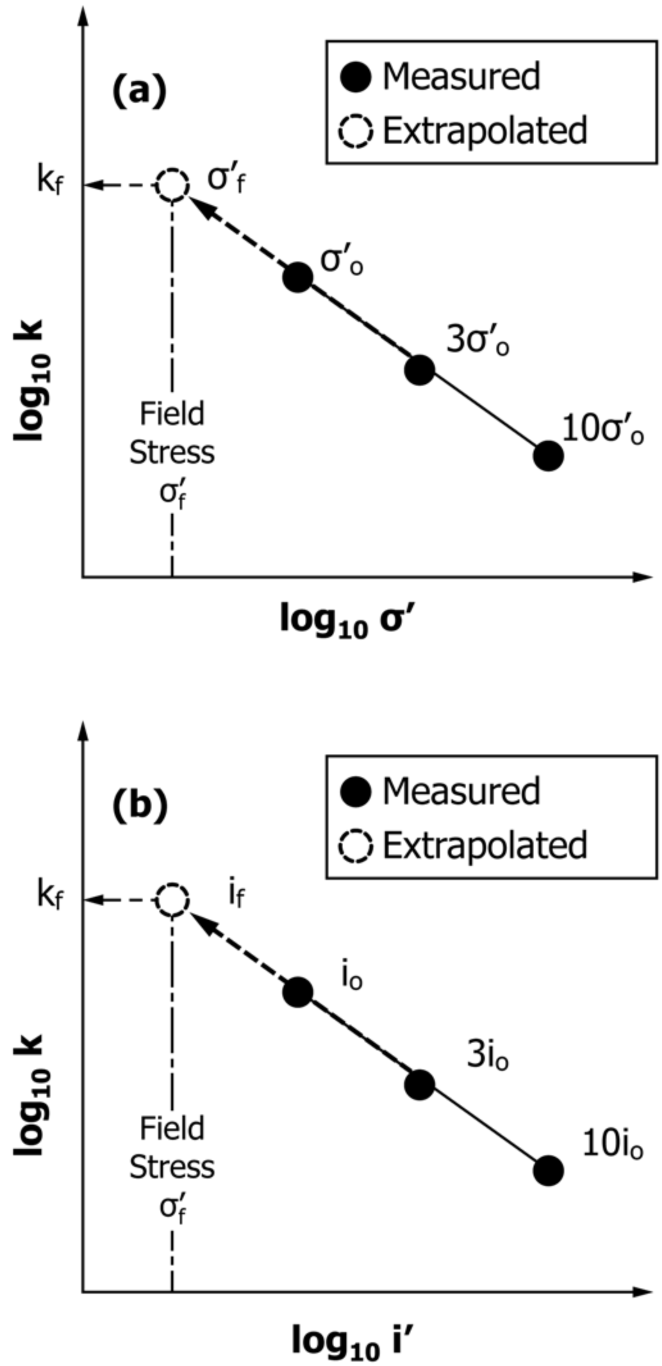

FIG. 1 Extrapolation of Test Data to (a) Effective Stress (σ'_f) or (b) Hydraulic Gradient (i_f) Existing in the Field

10. Hazards

10.1 All warnings described in Test Methods D5084 apply when following the recommendations in this guide.

10.2 Biocides are used in some cases to prevent generation of gas by microbial activity in paper sludges. Some of these biocides may be hazardous. The user must fully understand the risks associated with their use and must follow the health and safety recommendations provided by the manufacturer of the biocide.

10.3 The user is expected to clean up spills of biocide immediately using a procedure recommended by the manufacturer.

10.4 The user is expected to dispose of materials and test specimens contaminated with biocides in a safe and environmentally acceptable manner.

11. Keywords

11.1 cap; coefficient of permeability; cover; fiber clay; hydraulic barriers; hydraulic conductivity; landfill; paper clay; paper sludge; papermill sludge; permeability; permeameter