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Standard Guide for Pore-Liquid Sampling from the Vadose Zone¹

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1. Scope*

1.1 This guide covers the equipment and procedures used for sampling pore-liquid from the vadose zone (unsaturated zone). The guide is limited to in situ techniques and does not include soil core collection and extraction methods for obtaining samples.

1.2 The term “pore-liquid” is applicable for liquids from aqueous pore-liquid to oil. However, the samplers described in this guide were designed, and are used to sample aqueous pore-liquids only. The abilities of these samplers to collect other pore-liquids may be quite different than those described.

1.3 Some of the samplers described in this guide are not currently commercially available. These samplers are presented because they may have been available in the past, and may be encountered at sites with established vadose zone monitoring programs. In addition, some of these designs are particularly suited to specific situations. If needed, these samplers could be fabricated.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

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*

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unique aspects. The word “Standard” in the title of this document means only that the document has been approved through the ASTM consensus process.

1.7 *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 Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

3. Terminology

3.1 Definitions—

3.1.1 For common definitions of terms in this standard, refer to Terminology D653.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *air entry value, n —in vadose zone*, the applied suction at which water menisci of the porous segment of a suction sampler break down, and air enters.

3.2.2 *bubbling pressure, n —in vadose zone*, the applied air pressure at which water menisci of the porous segment of a suction sampler break down, and air exits.

3.2.3 *cascading water, n —in groundwater*, perched groundwater that enters a well casing via cracks or uncovered perforations, trickling, or pouring down the inside of the casing.

3.2.4 *hydrophobicity, n —in vadose zone*, the property that defines a material as being water repellent. Water exhibits an obtuse contact angle with hydrophobic materials.

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

3.2.5 *matric potential, n —in vadose zone*, the energy needed to extract water from a soil against the capillary and adsorptive forces of the soil matrix.

3.2.6 *pore-liquid, n —in vadose zone*, liquid that occupies an open space between solid soil particles. Within this guide, pore-liquid is limited to aqueous pore-liquid; that includes water and its solutes.

3.2.7 *pore-liquid tension*—see *soil-water pressure*.

3.2.8 *soil-water pressure, n —in vadose zone*, the pressure on the water in a soil-water system, as measured by a piezometer for a saturated soil, or by a tensiometer for an unsaturated soil.

3.2.9 *tensiometer, n —in vadose zone*, a device for measuring soil-water matric potential (or tension or suction) of water in soil in situ; a porous, permeable ceramic cup connected through a water filled tube to a pressure measuring device.

3.2.10 *tremie, n —in groundwater*, the method whereby materials are emplaced in the bottom of a borehole with a small diameter pipe.

3.3 Terminology from D653:

3.3.1 The following terms are found in D653 and are presented here as a convenience to users.

3.3.1.1 *cation exchange capacity, CEC, n —in soils*, is a pH dependent measure of the negative electrical charge present on the surfaces of soil minerals, particularly clay minerals, and on soil organic materials, especially humic compounds, capable of dynamically adsorbing positively charged ions (cations) and polar compounds.

3.3.1.1.1 *Discussion*—The units for CEC are typically in milliequivalents per 100 grams of oven-dry soil (meq/100 g). The SI units for CEC are centimoles of charge per kilogram of oven-dry soil (cmolc/kg).

3.3.1.2 *exchange capacity*—the capacity to exchange ions as measured by the quantity of exchangeable ions in a soil or rock.

3.3.1.2.1 *Discussion*—Exchange capacity is only significant in materials having high specific surface area, such as clay minerals.

3.3.1.3 *hydraulic gradient, i [D], n —in hydraulics*, the change in total head (head loss, Δh) per unit distance (L) in the direction of fluid flow, in which $i = \Delta h/L$.

3.3.1.3.1 *Discussion*—In most cases, the application of hydraulic gradient applies to flowing water in a saturated test specimen or aquifer consisting of soil or rock, or both. The literature typically does not use $\Delta h/L$ to indicate head loss; however, there is a need to emphasize that head loss is a change (delta), Δ , in total head.

3.3.1.4 *vadose zone, n —in geohydrology/hydrogeology*, the hydrogeological region extending from the soil surface to the top of the water (groundwater) table.

3.3.1.4.1 *Discussion*—The capillary fringe is included in this zone. Overall movement of water is vertical in the vadose zone. There can be more than one vadose zone in special cases, such as when there is perched groundwater. The vadose zone is commonly referred to as the “unsaturated zone” or “zone of

aeration.” These alternate names are inadequate as they do not take into account locally saturated regions, such as perched groundwater.

4. Summary of Guide

4.1 Pores in the vadose zone can be saturated or unsaturated. Some samplers are designed to extract liquids from unsaturated pores; others are designed to obtain samples from saturated pores (for example, perched groundwater) or saturated macropores (for example, fissures, cracks, and burrows). This guide addresses these categories. The sampler types discussed are:

4.1.1 Suction samplers (unsaturated sampling), (see Section 7),

4.1.2 Free drainage samplers (saturated sampling), (see Section 8),

4.1.3 Perched groundwater samplers (saturated sampling), (see Section 9), and

4.1.4 Experimental absorption samplers (unsaturated sampling), (see Section 10).

4.2 Most samplers designed for sampling liquid from unsaturated pores may also be used to sample from saturated pores. This is useful in areas where the water table fluctuates, so that both saturated and unsaturated conditions occur at different times. However, samplers designed for sampling from saturated pores cannot be used in unsaturated conditions. This is because the liquid in unsaturated pores is held at less than atmospheric pressures. According to Richards Outflow Principle that states that pore-liquid will not generally flow into an air-filled cavity (at atmospheric pressure) in unsaturated soil.

4.3 The discussion of each sampler is divided into specific topics that include:

4.3.1 Operating principles,

4.3.2 Description,

4.3.3 Installation,

4.3.4 Operation, and

4.3.5 Limitations.

5. Significance and Use

5.1 Sampling from the vadose zone may be an important component of some groundwater monitoring strategies. It can provide information regarding contaminant transport and attenuation in the vadose zone. This information can be used for mitigating potential problems prior to degradation of a groundwater resource (1).³

5.2 The choice of appropriate sampling devices for a particular location is dependent on various criteria. Specific guidelines for designing vadose zone monitoring programs have been discussed by Morrison (1), Wilson (2), Wilson (3), Everett (4), Wilson (5), Everett, et al (6), Wilson (7), Everett, et al (8), Everett, et al (9), Robbins, et al (10), Merry and Palmer (11), U.S. EPA (12), Ball (13), and Wilson (14). In general, it is prudent to combine various unsaturated and free

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

drainage samplers into a program, so that the different flow regimes may be monitored.

5.3 This guide does not attempt to present details of installation and use of the equipment discussed. However, an effort has been made to present those references in which the specific techniques may be found.

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 facility used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/observation/ and the like. Users of this standard are cautioned that compliance with Practice D3740 does not itself guarantee reliable results. Reliable results depend on many factors; D3740 provides a means of evaluating some of those factors.

6. Criteria for Selecting Pore-Liquid Samplers

6.1 Decisions on the types of samplers to use in a monitoring program should be based on consideration of a variety of criteria that include the following:

- 6.1.1 Needed sampling depths,
- 6.1.2 Needed sample volumes,
- 6.1.3 Soil characteristics,
- 6.1.4 Chemistry and biology of the liquids to be sampled,
- 6.1.5 Moisture flow regimes,
- 6.1.6 Durability of the samplers,
- 6.1.7 Reliability of the samplers,
- 6.1.8 Climate,
- 6.1.9 Installation requirements of the samplers,
- 6.1.10 Operational requirements of the samplers,
- 6.1.11 Commercial availability, and
- 6.1.12 Costs.

6.2 Some of these criteria are discussed in this guide. However, the ability to balance many of these factors against one another can only be obtained through field experience.

7. Suction Samplers

7.1 Table 1 presents the various types of suction samplers.

The range of operating depths is the major criterion by which suction samplers are differentiated. Accordingly, the categories of suction samplers are as follows:

7.1.1 Vacuum Lysimeters—These samplers are theoretically operational at depths less than about 7.5 m. The practical operational depth is 6 m under ideal conditions.

7.1.2 Pressure-Vacuum Lysimeters—These samplers are operational at depths less than about 15 m.

7.1.3 High Pressure-Vacuum Lysimeters—(also known as pressure-vacuum lysimeters with transfer vessels) These samplers are normally operational down to about 46 m, although installations as deep as 91 m have been reported (15).

7.1.4 Suction Lysimeters with Low Bubbling Pressures (Samplers With PTFE Porous Sections)—These samplers are available in numerous designs that can be used to maximum depths varying from about 7.5 to 46 m.

NOTE 2—The samplers of 7.1.1, 7.1.2, 7.1.3, and 7.1.4 are referred to collectively as suction lysimeters. Within this standard, lysimeter is defined as a device used to collect percolating water for analyses (16).

7.1.5 Filter Tip Samplers—These samplers theoretically have no maximum sampling depth.

7.1.6 Experimental Suction Samplers—The samplers have limited field applications at the present time. They include cellulose-acetate hollow-fiber samplers, membrane filter samplers, and vacuum plate samplers. They are generally limited to depths less than about 7.5 m.

7.2 Operating Principles:

7.2.1 General:

7.2.1.1 Suction lysimeters consist of a hollow, porous section attached to a sample vessel or a body tube. Samples are obtained by applying suction to the sampler and collecting pore-liquid in the body tube. Samples are retrieved by a variety of methods.

7.2.1.2 Unsaturated portions of the vadose zone consist of interconnecting soil particles, interconnecting air spaces, and interconnecting liquid films. Liquid films in the soil provide

TABLE 1 Suction Sampler Summary

Sampler Type	Porous Section Material	Maximum ^A Pore Size (µm)	Air Entry Value (cbar)	Operational Suction Range (cbar)	Maximum Operation Depth (m)
Vacuum lysimeters	Ceramic	1.2 to 3.0 (1) ^A	>100	<60 to 80	<7.5
	PTFE	15 to 30 (2) ^A	10 to 21	<10 to 21	<7.5
	Stainless steel	NA ^B	49 to 5	49 to 5	<7.5
Pressure-vacuum lysimeters	Ceramic	1.2 to 3.0 (1) ^A	>100	<60 to 80	<15
	PTFE	15 to 30 (2) ^A	10 to 21	<10 to 21	<15
High pressure-vacuum lysimeters	Ceramic	1.2 to 3.0 (1) ^A	>100	<60 to 80	<91
	PTFE	15 to 30 (2) ^A	10 to 21	<10 to 21	<91
Filter tip samplers	Polyethylene	NA ^B	NA ^B	NA ^B	None
	Ceramic	2 to 3 (1)	>100	<60 to 80	<7.5
	Stainless steel	NA ^B	NA ^B	NA ^B	none
Cellulose-acetate hollow-fiber samplers	Cellulose	<2.8	>100	<60 to 80	<7.5
	Acetate				
	Non cellulosic				
Membrane filter samplers	Polymer	<2.8	>100	<60 to 80	<7.5
	Cellulose	<2.8	>100	<60 to 80	<7.5
	Acetate				
Vacuum plate samplers	PTFE	2 to 5	NA ^B	NA ^B	<7.5
	Alundum	NA ^B	NA ^B	NA ^B	<7.5
	Ceramic	1.2 to 3.0	>100	60 to 80	<7.5
	Fritted glass	4 to 5.5	NA ^B	NA ^B	<7.5
	Stainless steel	NA ^B	49 to 5	49 to 5	<7.5

^A Pore size determined by bubbling pressure (1) or mercury intrusion (2).

^BNA = Not available.