Designation: D5298 – 03

Standard Test Method for
Measurement of Soil Potential (Suction) Using Filter Paper[1]

This standard is issued under the fixed designation D5298; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers laboratory filter papers as passive sensors to evaluate the soil matric (matrix) and total potential (suction), a measure of the free energy of the pore-water or tension stress exerted on the pore-water by the soil matrix (**1, 2**)[2]. The term potential or suction is descriptive of the energy status of soil water.

1.2 This test method controls the variables for measurement of the water content of filter paper that is in direct contact with soil or in equilibrium with the partial pressure of water vapor in the air of an airtight container enclosing a soil specimen. The filter paper is enclosed with a soil specimen in the airtight container until moisture equilibrium is established; that is, the partial pressure of water vapor in the air is in equilibrium with the vapor pressure of pore-water in the soil specimen.

1.3 This test method provides a procedure for calibrating different types of filter paper for use in evaluating soil matric and total potential.

1.4 The values stated in SI units are to be regarded as the standard. The inch-pounds units given in parentheses are approximate.

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.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

C114 Test Methods for Chemical Analysis of Hydraulic Cement [4]

D653 Terminology Relating to Soil, Rock, and Contained Fluids [5]

D1125 Test Methods for Electrical Conductivity and Resistivity of Water [4]

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass [4]

D2325 Test Method for Capillary-Moisture Relationships for Coarse- and Medium-Textured Soils by Porous-Plate Apparatus[6] [4]

D3152 Test Method for Capillary-Moisture Relationships for Fine-Textured Soils by Pressure-Membrane Apparatus[6] [4]

D4542 Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer [3]

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing [7]

E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures) [8]

E832 Specification for Laboratory Filter Papers

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology D653 for standard definitions of terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *atmosphere*—a unit of pressure equal to 76 cm Mercury or 101 kPa at 0°C.

3.2.2 *matric (matrix) suction, hm (kPa)*—the negative pressure (expressed as a positive value), relative to ambient atmospheric pressure on the soil water, to which a solution identical in composition with the soil water must be subjected in order to be in equilibrium through a porous permeable wall with the soil water; pressure equivalent to that measured by Test Methods D2325 and D3152. Matric suction is a function of the relative humidity due to the difference in air and water pressure across the water surface; the relative humidity or water vapor pressure decreases as the radius of curvature of the

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[2] The boldface numbers given in parentheses refer to a list of references at the end of the text.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

[5] *Annual Book of ASTM Standards*, Vol 11.01.

[6] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

[7] *Annual Book of ASTM Standards*, Vol 11.03.

[8] *Annual Book of ASTM Standards*, Vol 14.02.

water surface decreases. The term "matric" is grammatically correct, while matrix is commonly used in the civil engineering literature.

3.2.3 *molality, moles/1000 g*—number of moles of solute per 1000 g of solvent.

3.2.4 *mole*—molecular weight of a substance in grams.

3.2.5 *osmotic (solute) suction, hs (kPa)*—the negative pressure to which a pool of pure water must be subjected in order to be in equilibrium through a semipermeable membrane with a pool containing a solution identical in composition with the soil water; decrease in relative humidity due to the presence of dissolved salts in pore-water.

3.2.6 *pF*—a unit of negative pressure expressed as the logarithm to the base ten of the height in centimeters that a column of water will rise by capillary action or negative gage pressure (Mg/m^2) divided by the unit weight of water (Mg/m^3) times 1000. pF $\approx$ 3 + logarithm to the base ten of the negative pressure in atmospheres. Refer to capillary head or capillary rise in Terminology D653.

3.2.7 *soil relative humidity, R_h*—the ratio of the vapor pressure of pore water in the soil to the vapor pressure of free pure water. Relative humidity in the soil is defined as relative humidity measured by Test Method E337.

3.2.8 *total potential (kPa)*—the sum of gravitational, pressure, osmotic and external gas potentials. Potential may be identified with suction when gravitational and external gas potentials are neglected.

3.2.9 *total soil suction, h (kPa)*—the negative pressure, relative to the external gas pressure on the soil water, to which a pool of pure water must be subjected to be in equilibrium with the soil water through a semipermeable membrane that is permeable to water molecules only. Total soil suction (expressed as a positive value) is the sum of osmotic (solute) and matric (matrix) suctions.

3.2.10 *vapor pressure of free pure water (kPa)*—the saturation vapor pressure of free pure water at a given dry-bulb temperature.

3.2.11 *vapor pressure of pore water in soil (kPa)*—the partial pressure of water vapor that is in equilibrium with pore-water in soil at a given dry-bulb temperature.

4. Summary of Test Method

4.1 Filter papers are placed in an airtight container with a specimen for seven days to allow sufficient time for the vapor pressure of pore-water in the specimen, vapor pressure of pore water in the filter paper, and partial vapor pressure of water in the air inside the container to reach equilibrium. The mass of the filter papers is subsequently determined and the suction of the specimen is determined from a calibration relationship of the filter paper water content with suction applicable to the type of filter paper and the test procedure of this test method.

5. Significance and Use

5.1 Soil suction is a measure of the free energy of the pore-water in a soil. Soil suction in practical terms is a measure of the affinity of soil to retain water and can provide information on soil parameters that are influenced by the soil water; for example, volume change, deformation, and strength characteristics of the soil.

5.2 Soil suction is related with soil water content through water retention characteristic curves (see Test Method D2325). Soil water content may be found from Test Method D2216.

5.3 Measurements of soil suction may be used with other soil and environmental parameters to evaluate hydrologic processes (**1**)[9] and to evaluate the potential for heave or shrinkage, shear strength, modulus, in situ stress and hydraulic conductivity of unsaturated soils.

5.4 The filter paper method of evaluating suction is simple and economical with a range from 10 to 100 000 kPa (0.1 to 1000 bars).

6. Apparatus

6.1 *Filter Paper*—The paper used must be ash-free quantitative Type II filter paper, see Specification E832; for example, Whatman No. 42, Fisherbrand 9-790A,[10] Schleicher and Schuell No. 589 White Ribbon.[10] A suitable diameter is 5.5 cm (2.2 in.).

NOTE 1—Filter papers may be treated by dipping each paper in a 2 % concentration of formaldehyde prior to use to prevent organism growth on or biological decomposition of the filter paper. Biological decomposition may be significant when filter papers are subject to a moist, warm environment for more than 14 days. Appropriate precautions should be taken when preparing formaldehyde solutions and treating filter paper.

6.2 *Specimen Container*—120 to 240 mL (4 to 8 oz) capacity metal or glass (rust free) container and lid (for example, coated with zinc chromate to retard rusting) to contain the specimen and filter papers. The inside of these containers may also be coated with wax to retard rusting.

6.3 *Filter Paper Container*—This container holds filter paper following the equilibration of suction and removal from the specimen container.

6.3.1 *Metal Container Alternate*—Two nominal 70 mL (2 oz) capacity metal moisture containers (aluminum or stainless) with lids to dry the filter paper. The containers should be numbered by imprinting with a metal stamp. The containers should not be written on with any type of marker or labelled in any manner. Throw-away vinyl surgical non-powdered or similar gloves should be used anytime the small containers designated for filter paper measurements are handled to prevent body oils from influencing any mass measurements made prior to handling.

6.3.2 *Plastic Bag Alternate*—Plastic bag large enough to accommodate the filter paper disks (approximately 50 mm in dimension) capable of an airtight seal.

6.4 *Insulated Chest*—A box of approximately 0.03 m^3(1 ft^3) capacity insulated with foamed polystyrene or other material capable of maintaining temperature within $\pm$ 1°C when external temperatures vary $\pm$ 3°C.

6.5 *Balance*—A balance or scale having a minimum capacity of 20 g and meeting the requirements of 4.2.1.1 of Specification C114 for a balance of 0.0001 g readability. In addition, balances for performance of Test Method D2216, meeting requirements of Specification D4753.

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

[10] Available from Thomas Scientific Supply, P.O. Box 99, Swedesboro, NJ 08085.

6.6 *Drying Oven*—Thermostatically-controlled, preferably of the forced-draft type, and capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber and meeting requirements of Test Method D2216.

6.7 *Metal Block*—A metal block > 500 g mass with a flat surface to hasten cooling of the metal containers with filter paper.

6.8 *Thermometer*—An instrument to determine the temperature of the tested soil to an accuracy of ± 1°C.

6.9 *Miscellaneous Equipment*—Tweezers, trimming knife, flexible plastic electrical tape, O-rings, screen wire, brass discs, etc. Tweezers should be at least 110 mm (4.5 in.) in length.

6.10 *Desiccator*—A desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate.

NOTE 2—Anhydrous calcium sulfate is sold under the trade name Drierite.

NOTE 3—It is preferable to use a desiccant that changes color to indicate when it needs reconstitution.

7. Calibration

7.1 Obtain a calibration curve applicable to a specific filter paper by following the procedure in Section 8, except for replacing the soil specimen with salt solutions such as reagent grade potassium chloride or sodium chloride of known molality in distilled water.

7.1.1 Suspend the filter paper above at least 50 cc of salt solution in the specimen container, see 6.2, by placing it on an improvised platform made of inert material such as plastic tubing or stainless steel screen.

7.1.2 Calculate the suction of the filter paper from the relative humidity of the air above the solution by:
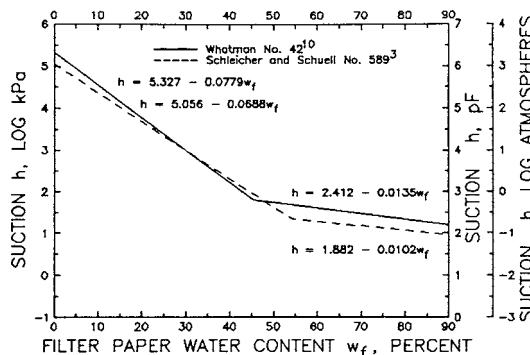
$$h = \frac{RT}{v} \cdot ln\, R_h \qquad (1)$$

where:
h = suction, kPa,
R = ideal gas constant, 8.31432 Joules/mole·K,
T = absolute temperature, degrees kelvin (K),
v = volume of 1000 moles of liquid water, 0.018 m^3, and
R_h = relative humidity, fraction.

7.1.3 Standard critical tables may be used to evaluate the relative humidity of water in equilibrium with the salt solution as illustrated in Table 1. Refer to Test Method E337 for further information on relative humidity.

7.2 Typical calibration curves for filter papers (for example, Whatman No. 42,[10] Schleicher and Schuell No. 589),[10] see Fig. 1, consists of two parts. The upper segment represents moisture

TABLE 1 Salt Solution Concentrations for Evaluating Soil Suction

| | | | | | 20°C | |
| | | | | | g NaCl | g KCl |
kPa	log kPa	pF	atm	R_h	1000 mL water	1000 mL water
−98	1.99	3.0	−0.97	0.99927	1.3	1.7
−310	2.49	3.5	−3.02	0.99774	3.8	5.3
−980	2.99	4.0	−9.68	0.99278	13.1	17.0
−3099	3.49	4.5	−30.19	0.97764	39.0	52.7
−9800	3.99	5.0	−96.77	0.93008	122.5	165.0

NOTE 1—Coefficient of determination r >0.99.
FIG. 1 Calibration Suction-Water Content Curves for Wetting of Filter Paper (4)

retained as films adsorbed to particle surfaces, while the lower segment represents moisture retained by capillary or surface tension forces between particles. The filter paper water content break point is w_f = 45.3 percent for Whatman No. 42 (**3, 4**)[10] and w_f = 54 % for Schleicher and Schuell No. 589 (**2, 4**).[10]

7.3 The calibration curves in Fig. 1 are applicable to total suction[3]. Variability in results is less than 2 % of the suction above 100 kPa. Soil disturbance has minimal influence on suction above 20 kPa. At moisture contents with suctions less than 20 kPa, sample disturbance increases variability of measurement (**2, 4**). The right vertical axis of Fig. 1 provides the suction in units pF and atmospheres pressure; for example, h = 2 log atmospheres is a suction of 100 atmospheres, while pF = 5 or 100 000 cm water.

NOTE 4—Filter paper may be calibrated by using the pressure membrane, see Test Method D3152 for the range 100 to 1500 kPa (1 to 15 atm), and the ceramic plate, see Test Method D2325 for the range 10 to 100 kPa (0.1 to 1 atm).

8. Procedure

8.1 *Filter Paper Preparation*—Dry filter papers selected for testing at least 16 h or overnight in the drying oven. Place filter papers in a desiccant jar over desiccant after drying for storage until use.

8.2 *Measurement of Suction*—Total suction will be measured if filter papers are not in contact with the soil specimen; moisture transfer will be limited to vapor transfer through the air inside the specimen container. Matric suction will be measured if the filter paper is in physical contact with the soil. Physical contact between the soil and filter paper allows fluid transfer including transfer of salts that may be dissolved in the pore water.

NOTE 5—When the soil is not sufficiently moist, adequate physical contact between the filter paper and soil may not always be possible. This can cause an inaccurate measure of matric suction. Matric suction may be inferred by subtracting the osmotic suction from the total suction. The osmotic suction may be determined by measuring the electrical conductivity (see Test Method D1125) of pore-water extracted from the soil using a pore fluid squeezer (**5**) or using Test Method D4542; a calibration curve (**6**) may be used to relate the electrical conductivity to the osmotic suction.

8.3 *Filter Paper Placement*—Place an intact soil specimen or fragments of a soil sample, 200 to 400 g mass, in the