AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428
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Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper[1]

This standard is issued under the fixed designation D 5298; 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:*

C 114 Test Methods for Chemical Analysis of Hydraulic Cement[3]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

D 1125 Test Method for Electrical Conductivity and Resistivity of Water[5]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[4]

D 2325 Test Method for Capillary-Moisture Relationships for Coarse and Medium-Textured Soils by Porous-Plate Apparatus[4]

D 3152 Test Method for Capillary-Moisture Relationships for Fine-Textured Soils by Pressure-Membrane Apparatus[4]

D 4542 Test Method for Pore-Water Extraction and Determination of the Solute Salt Content of Soils by Refractometer[4]

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Testing Soil, Rock and Related Construction Materials[3]

E 337 Test Method for Measuring Humidity With a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures[6]

E 832 Specification for Laboratory Filter Papers[7]

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology D 653 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 D 2325 and D 3152. 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 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

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

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

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 D 653.

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 E 337.

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 D 2325). Soil water content may be found from Test Method D 2216.

5.3 Measurements of soil suction may be used with other soil and environmental parameters to evaluate hydrologic processes **(1)**[8] 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 E 832; for example, Whatman No. 42, Fisherbrand 9-790A,[9] Schleicher and Schuell No. 589 White Ribbon.[9] 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 C 114 for a balance of 0.0001 g readability. In addition, balances for performance of Test Method D 2216, meeting requirements of Specification D 4753.

6.6 *Drying Oven*—Thermostatically-controlled, preferably of the forced-draft type, and capable of maintaining a uniform temperature of 110 $\pm$ 5°C throughout the drying chamber and meeting requirements of Test Method D 2216.

6.7 *Metal Block*—A metal block > 500 g mass with a flat

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

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

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 a 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:

$$h = \frac{RT}{v} \cdot \ln R_h \quad (1)$$

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.

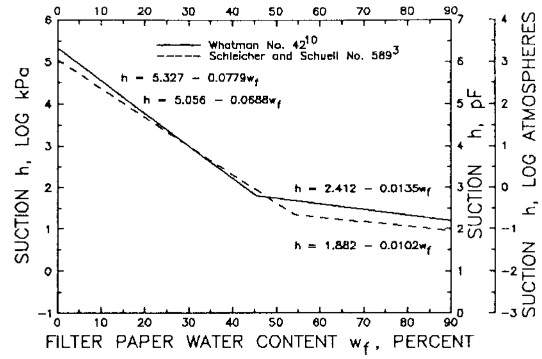
7.1.3 Standard critical tables may be used to evaluate the relative humidity of water in equilibrium with the salt solution as illustrated in Table 1. Refer to Test Method E 337 for further information on relative humidity.

7.2 Typical calibration curves for filter papers (for example, Whatman No. 42,[9] Schleicher and Schuell No. 589),[9] see Fig. 1, consists of two parts. The upper segment represents moisture 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)**[9] and w_f = 54 % for Schleicher and Schuell No. 589 **(2, 4)**.[9]

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.

TABLE 1 Salt Solution Concentrations for Evaluating Soil Suction

kPa	log kPa	pF	atm	R_h	20°C g NaCl 1000 mL water	20°C g KCl 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)

NOTE 4—Filter paper may be calibrated by using the pressure membrane, see Test Method D 3152 for the range 100 to 1500 kPa (1 to 15 atm), and the ceramic plate, see Test Method D 2325 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 D 1125) of pore-water extracted from the soil using a pore fluid squeezer **(5)** or using Test Method D 4542; 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 specimen container. The soil specimen should nearly fill the specimen container to reduce equilibration time and to minimize suction changes in the specimen.

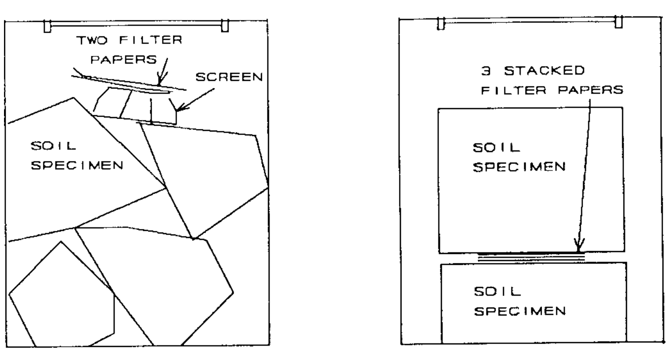
8.3.1 *Measurement of Total Suction*—Remove two filter papers from the desiccator and immediately place over the specimen, but isolate from the specimen by inserting screen wire, O-rings, or other inert item with minimal surface area between the filter papers and the soil, see Fig. 2(*a*). A filter paper edge should be bent up or offset slightly to hasten later removal of the filter paper from these large containers with tweezers, 8.6.

8.3.2 *Measurement of Matric Suction*—Place three stacked filter papers in contact with the soil specimen, see Fig. 2(*b*). The outer filter papers prevent soil contamination of the center filter paper used for analysis of the matric suction. The outer filter papers should be slightly larger in diameter than the center filter paper. This can be accomplished by cutting the center paper so that the diameter is at least 3 to 4 mm smaller than the outer filter papers. This will help prevent direct soil contact with the center filter paper.

8.4 *Equilibrating Suction*—Put in place the lid of the specimen container and seal with at least one wrapping of plastic electrical tape. Then place the sealed container in an insulated chest and place in a location with temperature variations less than 3°C. A typical nominal temperature is 20°C. The suction of the filter paper and the specimen in the container should be allowed to come to equilibration for a minimum of seven days.

NOTE 6—If filter papers are placed with soil specimens while in the field, the filter papers should be oven dried overnight then stored in an airtight container over desiccant to minimize moisture in the filter paper. Moisture in the filter paper prior to testing expands the fibers and alters the filter paper void space that may lead to a change in the calibration curve of the filter paper. Keep the insulated chest while in the field in the shade during hot summer days and in a heated area during cold winter days. Place the chest with the sealed containers in a temperature controlled room at about 20°C following return from the field.

NOTE 7—Equilibration of suction between the soil, filter paper and air in the closed container is the desired result of the equilibration period. It must be recognized that the equilibration process is dependent upon the initial suction of the soil, initial relative humidity of the air, soil mass and space in the container. The seven day period is sufficient for conditions normally involved in soil mechanics; however, under many conditions equilibration will be completed more quickly. This suction measurement must avoid condensation so thermostatic control may be necessary. Sample temperature control during equilibration will ensure that condensation effects are minimized. Storing the specimen containers containing the soil specimen and filter paper in a thermostatic box (for example, ice chest) made of polystyrene insulation and packing expanded vermiculite or similar material around the box will help minimize thermal fluctuations. It is possible to limit thermal fluctuations to ± 0.01°C with such an insulation scheme.



A. Total Suction B. Matrix Suction

FIG. 2 Setup for Equilibrating Suction in Large Container

8.5 *Predetermining Mass of Filter Paper Containers*—At the end of the equilibration period, place each of the two filter papers, if total suction is to be measured, or the center filter paper of a three-layer stack, if matrix suction is to be measure in a separate filter paper container of predetermined mass. The mass is determined to the nearest 0.0001 g, designated T_c (tare-cold), before the specimen container is removed from the insulated chest. It is suggested that the mass of the filter paper container be determined immediately prior to determining the total mass of the filter paper and filter paper container.

8.6 *Transferring the Filter Papers*—Utilizing a pair of tweezers, transfer each filter paper from the specimen container into a metal container alternate or plastic bag alternate of predetermined mass (T_c). This entire process must be completed in 3 to 5 s. The key to successful measurements of filter paper water content is to minimize water loss during transfer of filter paper from the specimen container and during mass determination prior to oven drying. Observations have been made of 5 % or more mass loss due to evaporation during a 5 to 10 s exposure of the filter paper to a room with relative humidity, R_h, of 30 to 50 %.

8.6.1 *Metal Container Alternate*—Place lids loosely on metal container alternates (not ajar). Care must be taken to seal the metal container alternate after each transfer; that is, take the filter paper from the specimen container and place the filter paper into a metal container, then seal the container. Repeat this procedure for the second filter paper using the second container of predetermined mass if total suction is to be determined. Seal the containers as quickly as possible to ensure that ambient air does not alter the moisture condition of the soil specimen or filter papers.

8.6.2 *Plastic Bag Alternate*—Quickly transfer a filter paper to a plastic bag of predetermined initial mass and seal the bag. Repeat this procedure for additional filter papers.

8.7 *Determining Mass of Filter Paper and Filter Paper Containers*—Immediately determine the mass of each of the containers with the filter papers M_1 to the nearest 0.0001 g.

8.8 *Equilibrating Temperature*:

8.8.1 *Metal Container Alternate*—Place the metal containers with filter paper in an oven at 110 ± 5°C with the lids slightly ajar or unsealed to permit moisture to escape. The containers should remain in the oven for a minimum of 2 h. After the minimum time, seal and leave the containers in the oven for at least 15 min to allow temperature equilibration. Remove the metal container with filter paper from the oven and then determine the dry total mass M_2 to 0.0001 g. Immediately remove and discard the filter paper and redetermine the mass of the container that had contained the filter paper or hot mass T_h to 0.0001 g. Repeat this procedure for additional containers.

NOTE 8—If the containers containing filter paper are metal, they should be placed on a metal block for approximately 30 s to cool. The metal block acts as a heat sink and will reduce the temperature variation during determination of mass.

8.8.2 *Plastic Bag Alternate*—Place the filter paper in the drying oven for a minimum of 2 h, then place in a desiccant jar over silica jel or standard desiccant to cool for a minimum of 2 to 3 min. Place in the plastic bag and determine mass, M_2.

Remove the filter paper and determine the final mass of the plastic bag, T_h.

8.8.3 Once the masses M_2 and T_h have been determined, discard the filter papers. Under no circumstances shall oven-dried filter papers be re-used in conducting this standard test.

9. Calculation

9.1 Calculate for each filter paper:

$$M_f = M_2 - T_h \quad (2)$$

$$M_w = M_1 - M_2 + T_h - T_c \quad (3)$$

where:

M_f = mass of dry filter paper, g,
M_2 = dry total mass, g,
T_h = mass of the hot container, g,
M_w = mass of water in the filter paper, g, and
T_c = mass of the cold container, g.

from the measured quantities M_1, M_2, T_c, and T_h.

NOTE 9—The hot container mass T_h may be consistently less than the cold mass T_c if metal filter paper containers are used because of the loss of surface adsorbed moisture when heated. Air currents from rising of air heated by the hot metal container may also contribute to a smaller hot container mass. The average difference between hot and cold container mass for 69 measurements is 4.6 ± 0.9 % of the filter paper mass and must be considered if measurements of the filter paper mass are to have an error less than 5 %. No test results are available for plastic bags.

9.2 The water content of the filter paper w_f by mass is:

$$w_f = 100 \frac{M_w}{M_f} \quad (4)$$

where:

w_f = filter paper water content, percent.

9.3 Convert the filter paper water content, w_f, to a suction value by reference to a calibration curve or calculate the suction from

$$h = mw_f + b \quad (5)$$

where:

m = slope of filter paper calibration curve, $\log_{10}$ kPa/% water content, and
b = intercept of the filter paper calibration, $\log_{10}$ kPa.

9.3.1 A calibration curve defined by Eq 5 is unique for each type of filter paper and consists of a line with a relatively steep slope and a relatively flat slope, Fig. 1. The suction determined from the calibration curve may be taken as the average of the suctions evaluated from the water contents if two filter papers were used to determine the soil suction. The test results should be discarded if the difference in suction between the two filter papers exceeds 0.5 log kPa.

10. Report

10.1 Table 2 is an example data sheet for evaluating soil suction using filter paper.

10.2 Report the soil water content corresponding to the total soil suction, temperature of measurement and equilibration time, method of calibrating filter paper, and bulk density of soil.

10.3 Report the salinity of the pore water if determined to permit evaluation of osmotic suction and calculation of matric suction $hm = h - hs$.

11. Precision and Bias

11.1 *Precision*—Data are being evaluated to determine the precision of this test method. In addition, Subcommittee D18.04 is seeking pertinent data from users of the test method.

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

12. Keywords

12.1 filter paper; soil relative humidity; soil suction

TABLE 2 Evaluation of Soil Suction Using Filter Paper

BORING NO.:______________ DATE TESTED:____
DATE SAMPLED:______________ TESTED BY: ____
SAMPLE NO.:______________

Depth							
Moisture Tin No.							
Top Filter Paper/ Bottom Filter Paper (circle)		Top Bottom	Top Bottom	Top Bottom	Top Bottom	Top Bottom	Top Bottom
Cold Tare Mass, g	T_c						
Mass of Wet Filter Paper + Cold Tare Mass, g	M_1						
Mass of Dry Filter Paper + Hot Tare Mass, g	M_2						
Hot Tare Mass, g	T_h						
Mass of Dry Filter Paper, g ($M_2 - T_h$)	M_f						
Mass of Water in Filter Paper, g ($M_1 - M_2 - T_c + T_h$)	M_w						
Water Content of Filter Paper, g ($M_w + M_f$	W_f						
Suction, pF	h						

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