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Soil quality — Determination of the water-retention characteristic — Laboratory methods

Qualité du sol — Détermination de la caractéristique de la rétention en eau — Méthodes de laboratoire

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 11274 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 5, *Physical methods*.

Annexes A and B of this International Standard are for information only.

Introduction

Soil water content and matric pressure are related to each other and determine the water-retention characteristics of a soil. Soil water which is in equilibrium with free water is at zero matric pressure (or suction) and the soil is saturated. As the soil dries, matric pressure decreases (i.e. becomes more negative), and the largest pores empty of water. Progressive decreases in matric pressure will continue to empty finer pores until eventually water is held in only the finest pores. Not only is water removed from soil pores, but the films of water held around soil particles are reduced in thickness. Therefore a decreasing matric pressure is associated with a decreasing soil water content [5], [6]. Laboratory or field measurements of these two parameters can be made and the relationship plotted as a curve, called the soil water-retention characteristic. The relationship extends from saturated soil (approximately 0 kPa) to oven-dry soil (about -10^6 kPa).

The soil water-retention characteristic is different for each soil type. The shape and position of the curve relative to the axes depend on soil properties such as texture, density and hysteresis associated with the wetting and drying history. Individual points on the water-retention characteristic may be determined for specific purposes.

The results obtained using these methods can be used, for example:

- to provide an assessment of the equivalent pore size distribution (e.g. identification of macro- and micropores);
- to determine indices of plant-available water in the soil and to classify soil accordingly (e.g. for irrigation purposes);
- to determine the drainable pore space (e.g. for drainage design, pollution risk assessments);
- to monitor changes in the structure of a soil (caused by e.g. tillage, compaction or addition of organic matter or synthetic soil conditioners);
- to ascertain the relationship between the negative matric pressure and other soil physical properties (e.g. hydraulic conductivity, thermal conductivity);
- to determine water content at specific negative matric pressures (e.g. for microbiological degradation studies);
- to estimate other soil physical properties (e.g. hydraulic conductivity).

Soil quality — Determination of the water-retention characteristic — Laboratory methods

1 Scope

This International Standard specifies laboratory methods for determination of the soil water-retention characteristic.

This International Standard applies only to measurements of the drying or desorption curve.

Four methods are described to cover the complete range of soil water pressures as follows:

a)   method using sand, kaolin or ceramic suction tables for determination of matric pressures from 0 kPa to − 50 kPa;

b)   method using a porous plate and burette apparatus for determination of matric pressures from 0 kPa to − 20 kPa;

c)   method using a pressurized gas and a pressure plate extractor for determination of matric pressures from − 5 kPa to − 1500 kPa;

d)   method using a pressurized gas and pressure membrane cells for determination of matric pressures from − 33 kPa to − 1500 kPa.

Guidelines are given to select the most suitable method in a particular case.

2 Definitions

For the purposes of this International Standard, the following definitions apply.

2.1
soil water-retention characteristic
relation between soil water content and soil matric head of a given soil sample

2.2
matric pressure
amount of work that must be done in order to transport, reversibly and isothermally, an infinitesimal quantity of water, identical in composition to the soil water, from a pool at the elevation and the external gas pressure of the point under consideration, to the soil water at the point under consideration, divided by the volume of water transported

2.3
water content mass ratio
w

mass of water evaporating from the soil when dried to constant mass at 105 °C, divided by the dry mass of the soil (i.e. the ratio between the masses of water and solid particles within a soil sample)

2.4
water content volume fraction
θ

volume of water evaporating from the soil when dried to constant mass at 105 °C, divided by the original bulk volume of the soil (i.e. the ratio between the volume of liquid water within a soil sample and the total volume including all pore space of that sample)

NOTE 1   The soil water-retention characteristic is identified in the scientific literature by various names including soil water release curve, soil water-retention curve, pF curve and the capillary pressure-saturation curve. Use of these terms is deprecated.

NOTE 2   The pascal is the standard unit of pressure but many other units are still in use. Table A.1 provides conversions for most units.

NOTE 3   Sometimes suction is used instead of pressure to avoid the use of negative signs (see Introduction). However, this term can cause confusion and is deprecated as an expression of the matric pressure.

NOTE 4   For swelling and shrinking soils, seek the advice of a specialist laboratory since interpretation of water-retention data will be affected by these properties.

3   Guidelines for choice of method

Guidelines are given below to help select the most suitable method in a particular case.

3.1   Sand, kaolin or ceramic suction tables for determination of pressures from 0 kPa to – 50 kPa

The sand, kaolin and ceramic suction table methods are suitable for large numbers of determinations at high pressures on cores or aggregates of different shapes and sizes. Analyses on samples of a wide range of textures and organic matter contents can be carried out simultaneously since equilibration is determined separately for each core. The suction table methods are suitable for a laboratory carrying out analyses on a routine basis and where regular equipment maintenance procedures are implemented.

3.2   Porous plate and burette apparatus for determination of pressures from 0 kPa to – 20 kPa

The porous plate and burette apparatus allows analysis of only one sample at a time, and several sets of equipment are therefore necessary to enable replication and full soil profile characterization. The method is particularly suited to soils with weak structures and sands which are susceptible to slumping or slaking, since minimal sample disturbance occurs. Capillary contact is not broken during the procedure and all samples, particularly soils with higher organic matter content or sandy textures, will equilibrate more rapidly using this technique. This is a simple technique suitable for small laboratories.

3.3   Pressure plate extractor for determination of pressures from – 5 kPa to – 1500 kPa

The pressure plate method can be used for determinations of all pressures to – 1500 kPa. However, different specifications of pressure chambers and ceramic plates are required for the range of pressures, e.g. 0 kPa to 20 kPa, 20 kPa to 100 kPa and 100 kPa to 1500 kPa. The method is, however, best suited to pressures of – 33 kPa or lower, since air entrapment at high negative pressures can occur. It is preferable that soils with similar water-release properties are analysed together to ensure equilibration times are approximately the same, though in practice it may be difficult. Sample size is usually smaller than for the previous two methods and therefore the technique is less suitable for heterogeneous soil horizons, or for those with a strong structural composition. Analysis of disturbed soils is traditionally carried out using this method.

3.4 Pressure membrane cells for determination of pressures from – 33 kPa to – 1500 kPa

The pressure membrane cell should only be used for pressures below – 33 kPa. Capillary contact at higher pressures is not satisfactory for this method. The method is appropriate for all soil types though the use of double membranes is recommended for coarse (sandy) textured soils. Sample size can be selected (according to the size of the pressure cell) to take into account soil structure. Different textures can be equilibrated separately using a suite of cells linked to one pressure source.

4 Sampling

4.1 General requirements

It is essential that undisturbed soil samples are used for measurement at the high matric pressure range 0 kPa to – 100 kPa, since soil structure has a strong influence on water-retention properties. Use either undisturbed cores or, if appropriate, individual peds for low matric pressure methods (< – 100 kPa).

Soil cores shall be taken in a metal or plastic sleeve of a height and diameter such that they are representative of the natural soil variability and structure. The dimensions of samples taken in the field are dependent on the texture and structure of the soil and the test method which is to be used. Table 1 provides guidance on suitable sample sizes for the different methods and soil structure.

Take soil cores carefully to ensure minimal compaction and disturbance to structure, either by hand pressure in suitable material or by using a suitable soil corer. Take a minimum of three representative replicates for each freshly exposed soil horizon or layer; more replicates are required in stoney soils. Record the sampling date, sample grid reference, horizon and sampling depths. Dig out the sleeve carefully with a trowel, trim roughly the two faces of the cylinder with a knife and if necessary adjust the sample within the sleeve before fitting lids to each end, and label the top clearly with the sample grid reference, the direction of the sampling (horizontal or vertical), horizon number and sample depth.

Wrap the samples (e.g. in plastic bags) to prevent drying. Wrap aggregates (e.g.in aluminium foil or plastic film) to retain structure and prevent drying. Alternatively, excavate blocks measuring approximately 30 cm cube of undisturbed soil in the field, wrap in metal foil, wax (to retain structure and prevent drying) and take to the laboratory for subdivision. Store the samples at 1 °C to 2 °C to reduce water loss and suppress biological activity until they are required for analyses. Treat samples having obvious macrofaunal activity with a suitable biocide, e.g. 0,05 % copper sulfate solution.

Table 1 — Recommended sample sizes (height $\times$ diameter) **for the different test methods**

Dimensions in millimetres

Test method	Structure		
	Coarse	**Medium**	**Fine**
Suction table	50 $\times$ 100	40 $\times$ 76	24 $\times$ 50
Porous plate	50 $\times$ 76	40 $\times$ 76	20 $\times$ 36
Pressure plate		10 $\times$ 76	10 $\times$ 50
Pressure membrane		20 $\times$ 76	10 $\times$ 50

NOTE 1 The points mentioned here are specific to water-retention analyses. Reference is made to ISO 10381-1 in which general advice on sampling and problems encountered is given.

NOTE 2 In moist conditions, soil is easier to sample and in shrink/swell soils the bulk density under natural conditions is lowest. It is therefore preferable to take samples in the wet season when soil matric pressures are at or near − 5 kPa. Dry conditions should be avoided, especially for clayey soils, which are both difficult to core when dry and contract and swell with varying water content. Samples of swelling and shrinking soils can be taken in cores only under completely saturated conditions, i.e. under the water table and in the full capillary zone. In all other circumstances peds should be taken.

NOTE 3 Other relevant site information should be noted, e.g. soil water status, topsoil/surface conditions, etc. (see clause 5.6).

4.2 Sample preparation

To prepare samples for water-retention measurements at pressures greater than − 50 kPa (see clause 3), trim undisturbed cores flush with the ends of the container and replace one lid with a circle of polyamide (nylon) mesh, similar close-weave material or paper if the water-retention characteristic is known, secured with an elastic band. The mesh will retain the soil sample in the sleeve and enable direct contact with the soil and the porous contact medium. Avoid smearing the surface of clayey soils. Remove any small projecting stones to ensure maximum contact and correct the soil volume if necessary. Replace the other lid to prevent drying of the sample by evaporation. Prepare soil aggregates for high matric pressure measurements by levelling one face and wrapping other faces in aluminium foil to minimize water loss. Disturbed soils should be packed into a sleeve with a mesh attached. Firm the soil by tapping and gentle pressure to obtain a specified bulk density.

Weigh the prepared samples. Ensure that the samples are brought to a pressure of less than the first equilibration point by wetting them, if necessary, by capillary rise, mesh side or levelled face down on a sheet of foam rubber saturated with de-aerated tap water or 0,005 mol/l calcium sulfate solution. Weigh the wet sample when a thin film of water is seen on the surface. This water content represents the total or maximum water-holding capacity and is calculated according to clause 6.5.

Report the temperature at which the water-retention measurements are made.

NOTE 1 It may be necessary to discard samples with large projecting stones. The chemical composition of the wetting fluid can affect the water-retention characteristic, particularly in fine-textured soils with swelling clays. Wetting with distilled or freshly drawn tap water is not generally recommended. De-aerated 0,005 mol/l calcium sulfate solution is suggested to represent the chemical composition of the soil solution.

NOTE 2 The time required for wetting varies with initial soil water content and texture, being a day or two for sands and two weeks or more for clayey soils. Except for sands, wetting needs to be slow to prevent air entrapment in samples. Care should be taken not to leave sandy soils wetting for too long because their structure may collapse. Low-density subsoil sands without the stabilizing influence of organic matter or roots are the most susceptible. The burette method is most suitable for this type of soil and samples can be wetted using the procedure in 6.3. Soils should, ideally, be field-moist when the wetting is commenced; dried soils may cause differences in the water-retention characteristic due to hydrophobia or hysteresis.

General guidelines for wetting times are:

sand	1 to 5 days
loam	5 to 10 days
clay	5 to 14 days or longer
peat	5 to 20 days.

NOTE 3 Increasing temperature causes a decrease in water content at a given pressure. It is recommended that all water-retention measurements be made at a constant temperature of (20 ± 2) °C. Where temperature control is not available, the laboratory temperature should be monitored as the work is conducted, and reported in the test report.

NOTE 4 Very coarse pores are not water-filled when the soil sample is saturated by capillary rise.

NOTE 5 Water can be de-aerated by boiling for 5 min. It should be stored cool in a stoppered vessel.

NOTE 6 The water-retention characteristic of swelling and shrinking soils should be determined under the same load as that occurring in the field. Otherwise the laboratory data can deviate from the water-retention characteristic of the soil under natural field conditions.

5 Determination of the soil water characteristic using sand, kaolin and ceramic suction tables

5.1 Principle

A negative matric pressure is applied to coarse silt or very fine sand held in a rigid watertight non-rusting container (a ceramic sink is particularly suitable). Soil samples placed in contact with the surface of the table lose pore water until their matric pressure is equivalent to that of the suction table. Equilibrium status is determined by weighing samples on a regular basis and soil water content by weighing, oven drying and reweighing. The maximum negative pressure which can be applied before air entry occurs is related to the pore size distribution of the packed fine sand or coarse silt which is determined by the particle size distribution, the shape of the particles and their consolidation.

5.2 Apparatus

5.2.1 Large ceramic sink or other watertight, rigid, non-rusting container with outlet in base [dimensions about $(50 \times 70 \times 25)$ cm] and with close-fitting cover.

5.2.2 Tubing and connecting pieces to construct the draining system for the suction table.

5.2.3 Sand, silt or kaolin, as packing material for the suction table.

Commercially available graded and washed industrial sands with a narrow particle size distribution are most suitable. The particle size distributions of some suitable sand grades and the approximate suctions they can attain are given in table 2. It is permissible to use other packing materials, such as fine glass beads or aluminium oxide powder, if they can achieve the required air entry values.

5.2.4 Levelling bottle, stopcock and 5-litre aspirator bottle.

5.2.5 Tensiometer system (optional).

5.2.6 Drying oven, capable of maintaining a temperature of (105 ± 2) °C.

5.2.7 Balance capable of weighing with an accuracy of 0,1 % of the measured value.

NOTE   Examples of a drainage system, sand and kaolin suction tables and details of their construction are described in Annex A.

Table 2 — Examples of sands and silica flour suitable for suction tables

Type	Coarse sand	Medium sand	Fine sand	Silica flour
Use	Base of suction tables	Surface of suction tables (5 kPa matric pressure)	Surface of suction tables (11 kPa matric pressure)	Surface of suction tables (21 kPa matric pressure)
Typical particle size distribution	**Percent content**			
> 600 µm	1	1	1	0
200 µm to 600 µm	61	8	1	0
100 µm to 200 µm	36	68	11	1
63 µm to 100 µm	1	20	30	9
20 µm to 63 µm	1	3	52	43
< 20 µm	0	0	5	47

5.3 Preparation of suction tables

Prepare suction tables using packing material that can attain the required air entry values (see table 2). In Annex A the detailed procedure for one specific type of suction table is given as an example.

5.4 Procedure

Prepare soil cores as described in 4.2. Weigh the cores and then place them on a suction table at the desired matric pressure. Leave the cores for 7 days. The sample is then weighed, and thereafter weighed as frequently as needed to verify that the daily change in mass of the core is less than 0,02 %. The sample is then regarded as equilibrated and is moved to a suction table of a lower pressure or oven dried. Samples which have not attained equilibrium should be replaced firmly onto the suction table and the table cover replaced to minimize evaporation from the table.

NOTE   The time for reaching equilibrium is proportional to the square of the height of the sample but, as a guide, cores normally require at least 7 days to equilibrate at each potential and sometimes 20 days or more. A minimum of 7 days is recommended so that samples establish good capillary connectivity, enabling an equilibrium status to be more rapidly attained.

5.5 Expression of results

5.5.1 Procedure for soils containing less than 20 % stones (diameter greater than 2 mm)

5.5.1.1 Calculate the water content mass ratio at a matric pressure p_m using the formula:

$$w\,(p_m) = \frac{m(p_m) - m_d}{m_d}$$

where

$\quad w(p_m)$ is the water content mass ratio at a matric pressure p_m, in grams;

$\quad m(p_m)$ is the mass of the soil sample at a matric pressure p_m, in grams;

$\quad m_d$ is the mass of the oven-dried soil sample, in grams.

5.5.1.2 Calculate the water content on volume basis at matric pressure p_m using the formula:

$$\theta(p_m) = \frac{m(p_m) - m_d}{V \times \rho_w}$$

where

$\quad \theta(p_m)$ is the water content volume fraction at a matric pressure p_m, in cubic centimetres water per cubic centimetre soil;

$\quad m(p_m)$ is the mass, in grams of the soil sample at a matric pressure p_m;

$\quad m_d$ is the mass of the oven-dried soil sample, in grams;

$\quad V$ is the volume of the soil sample, in cubic centimetres;

$\quad \rho_w$ is the density of water, in grams per cubic centimetre (= 1 g cm^{-3}).

NOTE 1   If a containing sleeve, mesh and elastic band are used, these should be weighed and their weights deducted from the total weight of the soil core to give $n(p_m)$.

NOTE 2   The water content volume fraction is related to the water content mass ratio as follows:

$$\theta(p_m) = w(p_m)\frac{m_d}{V \times \rho_w} = w(p_m)\frac{{}^b\rho_s}{\rho_w}$$

where

    $w(p_m)$ is the water content mass ratio at a matric pressure p_m, in grams water per gram soil;

    $^b\rho_s$ is the bulk density of the oven-dried soil, in grams per cubic centimetre.

5.5.2 Conversion of results to a fine earth basis

The stone content of a laboratory soil sample may not accurately represent the field situation and therefore conversion of data to a fine earth basis may be required for comparison of results or for correction to a field-measured stone content. If conversion of results derived from vacuum or suction methods to a fine earth basis (f) is required for soils containing stones, the following method shall be used:

$$\theta_f = \frac{\theta_t}{(1-\theta_s)}$$

where:

    θ_f is the water content of the fine earth, expressed as a fraction of volume;

    θ_s is the volume of stones, expressed as a fraction of total core volume;

    θ_t is the water content of the total earth, expressed as a fraction of total core volume.

Thus in a soil containing 0,05 total core volume fraction of nonporous stones:

$$\theta_f = \frac{\theta_t}{(1-0,05)}$$

Porous stones retain water and require a different correction: Determine the water content of porous stones at each matric pressure and correct the water content of the soil accordingly; thus in a soil containing 0,05 total core volume fraction of porous stones

$$\theta_f = \frac{\theta_t - (\theta_s \times 0,05)}{0,95}$$

where:

    θ_s is the water content of the porous stones, expressed as a fraction of the total porous stone volume in the soil sample.

NOTE 1   In soils containing many very porous stones, it is recommended that the stones be considered as part of the soil mass, and θ_f is not distinguished from θ_t.

NOTE 2   For mixtures of porous and nonporous stones, as in clay soils containing both flint and chalk fragments, correct the total soil value for both stone types.

5.6 Test report

The test report shall include the following information:

a) a reference to this International Standard;
b) a reference to the method used;
c) complete identification of the sample:

- grid reference of the sample location
- date of field sampling
- soil moisture conditions
- depth of sampling
- number of samples per determination
- size of samples
- condition of sample - undisturbed soil core/aggregate, disturbed,
  sieved, porous stone, etc.
- wetting fluid used
- temperature and range at which determinations were made;

d) the results of the determinations:
- water contents at each pressure determined as total or fine earth fraction and expressed clearly as either:
    1) volume fraction
    2) mass ratio
  or, if water contents at several pressures using the same soil sample have been determined:
    3) plot the results as a water-retention characteristic
- details of any curve-fitting method that has been applied.

e) any details not specified in this International Standard or regarded as optional, as well as any factor which may have affected the results.

6 Determination of soil water characteristic using a porous plate and burette

6.1 Principle

A negative matric pressure is applied to a glass Buchner funnel containing a porous ceramic plate by means of a hanging water column. The minimum pressure which can be applied depends on the air-entry pressure of the plate. In practice the minimum pressure applied is restricted by the distance to which the levelling burette may be lowered below the funnel, typically less than 2 m. Only one sample can be treated per Buchner funnel. The increase in volume of water in the burette is equivalent to the soil water which has drained from the soil sample. Equilibrium status is determined by observing the burette and not by weighing the sample. The soil sample is weighed and oven-dried to determine the water content at the final matric pressure.

NOTE 1   It is also possible to determine the adsorption curve as the sample is wetted.

NOTE 2   The diameter and height of the Buchner funnel should be of sufficient size to accommodate the soil core. The ceramic plate should fit the internal diameter of the Buchner funnel. A bubbling pressure of 100 kPa is suggested for all measurements carried out with this apparatus, though requirements may vary and bubbling pressures lower than this may be used.

6.2 Apparatus

6.2.1 Buchner funnel

6.2.2 Porous ceramic plate

6.2.3 Flexible watertight tubing

6.2.4 Graduated burette

NOTE   The volume of the burette and increment divisions should be chosen with due consideration of the size of the sample, the particle size distribution and density, and the negative matric pressure applied. A 50 ml burette with 0,1 ml increments is appropriate for a soil sample of 300 cm^3 volume.

6.2.5 Drying oven, capable of maintaining a temperature of (105 ± 2) °C

6.2.6 Balance, capable of weighing accurately to 0,01 g

6.2.7 Rubber stoppers and connector

6.3 Assembly of porous plate/burette apparatus

Connect the bottom of the burette to the bottom of the Buchner funnel. Connect the stopper at the top of the burette to the stopper at the top of the Buchner funnel with the flexible nylon tubing to prevent evaporation, as shown in figure 1. Fill the tubing and funnel with de-aerated water and adjust the burette until the water is level with the ceramic plate. Remove trapped air bubbles by tapping the apparatus or by applying gentle air pressure through the end of the burette, then apply a vacuum to the open end of the burette and draw de-aerated water downwards through the plate until all air bubbles are removed. Alternatively, remove air bubbles from beneath the porous plate by raising the water level to the top of the funnel, stopper the funnel and insert it.

6.4 Procedure

Place a prewetted undisturbed soil core on the water-saturated plate. Maintain the water level at the same height as the ceramic plate until the sample is saturated and then record the volume of water in the burette. Adjust the burette so that the water level in it is h cm below the middle of the sample. The negative matric pressure (p_m in kilopascals) is equivalent to $-(p_m/10)$. Adjust the burette when a reading at a defined pressure is required. Equilibrium water content is reached when the water gain in the burette is less than 0,05 % of the volume of the soil sample per day. Then read the volume in the burette and repeat the whole procedure for each desired pressure in decreasing order. The volume of water which is withdrawn from the soil sample is equal to the change in volume of water in the burette. Weigh the soil core at the final matric pressure when equilibrated, oven dry and reweigh.

6.5 Expression of results

6.5.1 Procedure for soils containing less than 20 % stones (diameter greater than 2 mm)

6.5.1.1 Calculate the water content volume fraction at the final pressure applied using the formula:

$$\theta_e = \frac{m_e - m_d}{\rho_w \times V}$$

where

θ_e is the soil water content, expressed as a volume fraction, at the final pressure applied;

m_e is the mass, in grams, of the soil sample at the final pressure applied;

m_d is the mass, in grams, of the oven-dried soil sample;

ρ_w is the density of water (= 1,00 g·cm^{-3});

V is the volume of the soil sample, in cubic centimetres.

NOTE   If a containing sleeve, mesh, etc. are used, these should be weighed and their masses deducted from the total mass of the soil core to give m_e.

6.5.1.2 Calculate the water content volume fraction at matric pressure p_m using the formula:

$$\theta_{(p_m)} = \theta_e + \frac{V_e - V_{(p_m)}}{V_{(p_m)}}$$

where

$\theta(p_m)$ is the soil water content, at matric pressure p_m, expressed as a volume fraction;

V_e is the volume of water, in cubic centimetres, in the burette at the final applied pressure;

$V(p_m)$ is the volume of water, in cubic centimetres, in the burette at matric pressure p_m.

For the conversion of results to a fine earth basis, see 5.5.2.
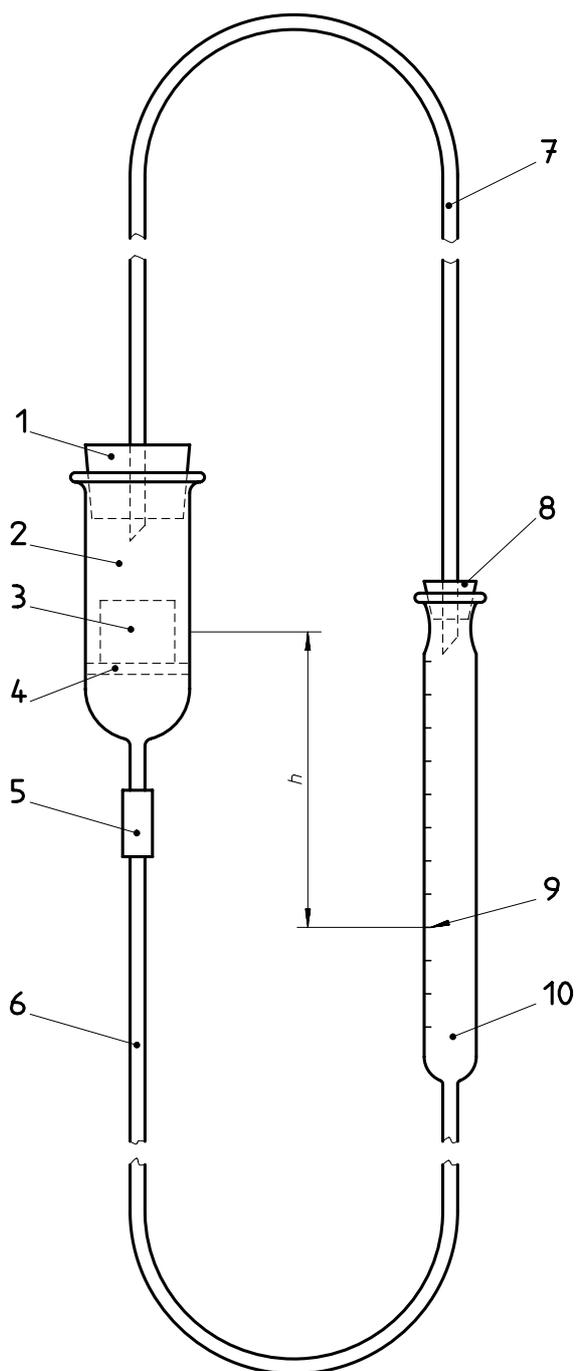
Key

1 Drilled rubber bung
2 Glass funnel
3 Soil core
4 Porous plate
5 Rubber connector
6 Flexible tubing
7 Flexible tubing
8 Drilled rubber bung
9 Constant water level for desired suction h
10 Graduated burette with adjustable support

Figure 1 — Porous plate and burette apparatus

6.6 Test report

See 5.6.

7 Determination of soil water characteristic by pressure plate extractor

7.1 Principle

Pressure plate extractors are suitable for measurement of water contents at matric pressure -5 kPa to -1500 kPa. Several small soil cores are placed in contact with a porous ceramic plate contained within a pressure chamber. A gas pressure is applied to the air space above the samples and soil water moves through the plate and is collected in a burette/measuring cylinder or similar collecting device (see figure 2). At equilibrium status, soil samples are weighed, oven-dried and reweighed to determine the water content at the predetermined pressures.

NOTE 1   It should be ensured that equipment meets the relevant health and safety standards. The high pressures used may require special precautions to be taken.

NOTE 2   It is essential that the ceramic plate has an air-entry value less than the pressure required. A range of plates is commercially available, e.g. 10 kPa, 30 kPa, 50 kPa, 1500 kPa.

7.2 Apparatus

7.2.1 Pressure chamber with porous ceramic plate.

7.2.2 Sample retaining rings/soil cores with plastic discs or lids.
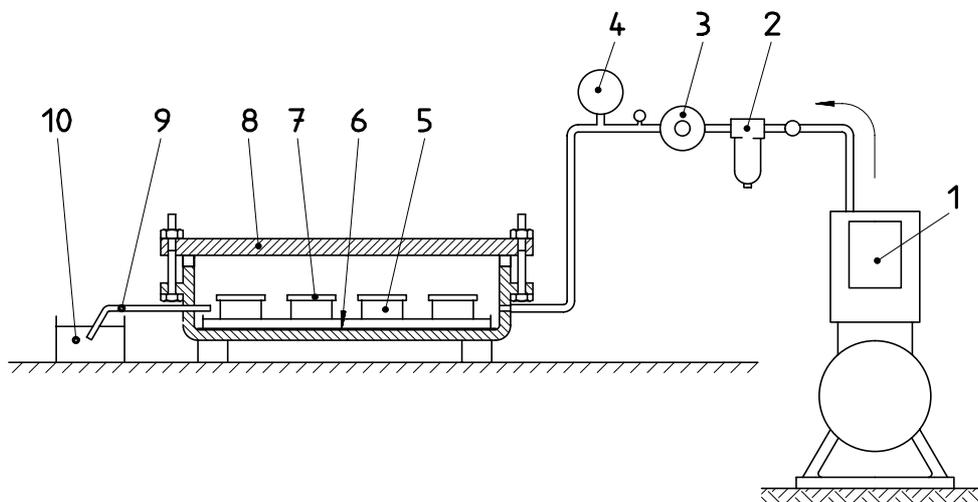
Key

1   Air compressor 2 000 kPa
2   Filter/trap
3   Pressure regulator
4   Test gauge 0 kPa to 2 000 kPa
5   Soil core
6   Ceramic plate, bubbling pressure 1 500 kPa
7   Plastic disc
8   Pressure chamber
9   Outflow tube
10 Collection vessel

Figure 2 — Pressure plate extractor system

7.2.3 Graduated burette.

7.2.4 Air compressor (1700 kPa), nitrogen cylinder or other suitable pressurized gas.

7.2.5 Pressure regulator and test gauge.

7.2.6 Drying oven capable of maintaining a temperature of (105 ± 2,0) °C.

7.2.7 Balance capable of weighing to ± 0,01 g.

7.3 Assembly of apparatus

Assemble the apparatus according to the manufacturer's instructions.

7.4 Procedure

Take small soil cores of approximately 5 cm diameter and between 5 mm and 10 mm in height *in situ* or from larger undisturbed cores. Place at least three replicate core samples on a presaturated plate of appropriate bubbling pressure. Wet the samples by immersing the plate and the samples to a level just above the base of the core until a thin film of water can be seen on the surface of the sample. Cover the bottom of the extractor with water to create a saturated atmosphere. Place a plastic disc lightly on top of each sample to prevent evaporation.

To apply the desired pressure, remove excess water from the porous plate and connect the outflow tube to the burette via the connector in the chamber wall. The pressure is supplied via regulators and gauges from a nitrogen cylinder or by a mechanical air compressor. The pressure or the compressed air source should slightly exceed the lowest matric pressure required. Apply the desired gas pressure p, check for any gas leaks and allow the samples to come to equilibrium by recording on a daily basis the volume increase in the burette. When this remains static, the samples have come to equilibrium; the matric pressure p_m of the samples equals $-p$.

To remove the samples, clamp the outflow tube to prevent a backflow of water, and release the air pressure. Weigh the samples plus sleeve immediately. Carry out sequential equilibration of the core at different pressures by removing and weighing the core at equilibrium, replacing and resetting the pressure. Moisten the ceramic plate with a fine spray of water to re-establish hydraulic contact. When the last equilibrium has taken place, dry at 105 °C and determine the oven-dry mass of the soil plus sleeve.

NOTE   Core samples of height greater than 5 cm are undesirable. It is necessary to use smaller samples for lower pressures in order to avoid prohibitively long equilibration times. At − 1500 kPa, for example, a sample height of 1 cm to 2 cm is convenient since the water in samples equilibrated at low pressures is only held in small pores and is less influenced by soil variability or structure. It is acceptable to use disturbed samples at pressures lower than − 100 kPa, providing that the disturbance consists only in breaking off small pieces of soil and not in compressing or remoulding the soil.

7.5 Calculation and expression of results

7.5.1 Procedure for stoneless soils

Calculate the water content volume fraction (θ) using the formula:

$$\theta(p_m) = \frac{m(p_m) - m_d}{\rho_w \times V}$$

where

$\theta(p_m)$ is the water content at matric pressure p_m, expressed as volume fraction;

$m(p_m)$ is the mass of wet soil, in grams;

m_d is the mass of oven-dried soil, in grams;

ρ_w is the density of water, in grams per cubic centimetre;

V is the volume of the core, in cubic centimetres.

NOTE   If a containing sleeve is used, this should be weighed and the mass deducted from the total mass of the soil core to give $m(p_m)$.

7.5.2 Procedure for stony soils

Samples containing any stones (diameter > 2 mm) shall not form part of the pressure chamber or membrane sample, since the volume of sample used is relatively small. After oven drying, determine the volume of stones in the original soil core or from a field measurement and make a correction to θ_f values convert to total soil (θ_t).

$$\theta_t = \theta_f(1 - \theta_s)$$

where

θ_f is the water content of the fine earth in the pressure vessel sample at equlibrium, expressed as a volume fraction;

θ_s is the volume of stones, expressed as a fraction of total core volume;

θ_t is the water content of the total soil, expressed as a volume fraction.

Thus in a soil containing 0,05 volume fraction of nonporous stones

$$\theta_t = \theta_f \times 0,95$$

If the stones are porous, carry out separate water-retention measurements and correct fine earth values according to their volume and retention characteristics.

7.6 Test report

See 5.6.

8 Determination of soil water characteristic using pressure membrane cells

8.1 Principle

Soils are placed on a porous cellulose acetate membrane, but they are brought into equilibrium at a given matric pressure p_m by applying a positive gas pressure p; the matric pressure of the samples equals $-p$. To maintain this pressure, the membrane and samples are contained within a pressure chamber whilst the underside of the porous medium is maintained at atmospheric pressure. Equilibrium status is attained when water outflow from the cell ceases and soil water content is determined by weighing, oven-drying and reweighing the sample. Most designs of pressure chamber can take soils in a variety of physical states, but equilibration time varies in proportion to the square of the sample height and the pressure applied. Gas pressure methods are only suited to determine matric pressures below -33 kPa.

NOTE   It should be ensured that equipment meets the relevant health and safety standards. The high pressure used may require special precautions to be taken.

8.2 Apparatus

8.2.1 Pressure cells with porous baseplates [6].

8.2.2 Air compressor (1700 kPa), nitrogen cylinder, or other suitable pressurized gas.

8.2.3 **Drying oven** capable of maintaining a temperature of $(105 \pm 2,0)$ °C

8.2.4 **Balance,** capable of weighing accurately to $\pm 0,01$ g.

8.2.5 **Cellulose acetate membrane**, dialysis membrane with an average pore radius of 240 nm (24 Å) is suitable.

**8.2.6** **Outflow bottles**, with tubes fitted to outlet of pressure cells.

8.2.7 **Liquid paraffin**.

8.3 Assembly of apparatus

Cut a circular disc of membrane to fit the pressure cell; soak it in water for 5 min and place it in the cell. Using a wet knife, thin saw, cheese wire or other appropriate method, cut a slice of soil about 1 cm thick across the core sample and place centrally on the membrane. The flat side of soil aggregates should be placed onto the membrane. For noncohesive sandy soils it is possible to transfer a disturbed sample to the cell using a spatula.

NOTE 1   A cross-section through a pressure membrane is shown in figure 3.

NOTE 2   It is advisable to use two discs of membrane if the soil type is liable to pierce the membrane, e.g. gritty or sandy soils, or if pressures lower than − 200 kPa are used.

Dimensions in millimetres
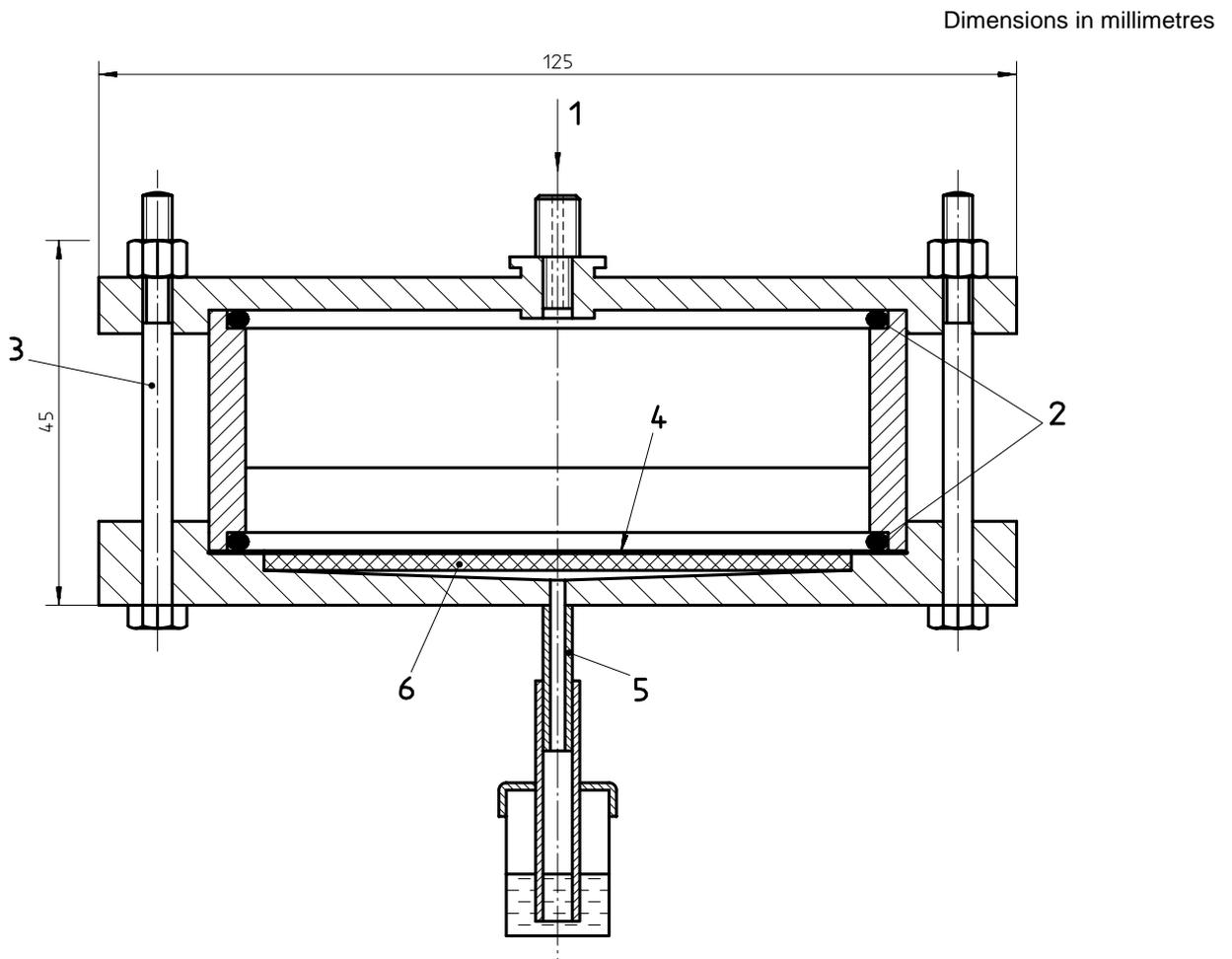
Key

1 Air from compressor
2 O-rings
3 Bolts
4 Visking membrane
5 Outflow pipe
6 Sintered bronze plate

Figure 3 — Pressure membrane cell

8.4 Procedure

Assemble the pressure cell with the soil sample; raise the pressure as required and check for leaks using detergent foam. The pressure is supplied via regulators and gauges, from a nitrogen cylinder or by a mechanical air compressor. The pressure should slightly exceed the lowest matric pressure required. Separate subsamples are required for equilibration at different pressures from each core. Weigh the outflow bottle daily to the nearest 0,01 g. A few drops of liquid paraffin in the outflow bottle will minimize evaporative losses. When no further gain or loss in outflow mass occurs on two successive days, the sample is considered to be equilibrated. Remove the soil sample from the cell, weigh it, $m_w(p_m)$, dry it in the oven and reweigh it, m_d.

NOTE   Core samples higher than 5 cm are undesirable. It is necessary to use smaller samples for lower pressures in order to avoid prohibitively long equilibration times. At − 1500 kPa, for example, a sample height of 1 cm to 2 cm is convenient since the water in samples equilibrated at low pressures is only held in small pores and is less influenced by soil variability or structure. It is acceptable to use disturbed samples at pressures lower than − 100 kPa providing that the disturbance consists only in breaking off small pieces of soil and not in compressing or remoulding the soil.

8.5 Expression of results

Record all measurements in terms of the mass of oven-dry soil and convert them to a volume basis using bulk density values for the whole core according to 5.5.2.

8.6 Test report

See 5.6.

9 Precision

Precision of results for all methods depends on several factors:

a) the condition of the soil, compared to its *in situ* state and its representativeness of the soil layer;

b) fluctuations in temperature change the viscosity of water and hence the water-retention characteristic. Also temperature changes can cause condensation and re-absorption making the determination of equilibrium state difficult to identify;

c) osmotic pressure is not normally considered separately when determining the water-retention characteristic. Soils which have a significant salt or free acid content may have a soil water pressure much lower than it would be if the soil solution consisted of pure water. Consideration to the salt content of the wetting fluid used should be given in these cases;

d) good capillary contact must be maintained at all times with the suction table, ceramic plate or membrane. Poor contact results in water contents higher than expected for a given matric pressure;

e) air may become entrapped when wetting a sample resulting in a lower water content at a given pressure, but vacuum or saturation wetting methods are not recommended to avoid this problem as sample deterioration can occur. Some air entrapment is representative of a field situation.

Precision of results is difficult to quantify, since the natural soil variability found in replicate cores can be high. The correct performance of equipment can be checked using a reference material, e.g. washed silt, on a continuous basis.

Annex A

(informative)

Construction of suction tables

A.1 Sand suction table

Construct a flushable drain system from semirigid tubing, e.g. as shown in figure A.1 to fit the floor of the container, allowing a 2 cm margin from the walls. Cement all joints with waterproof adhesive. Cut slits 1 cm long in the underside of the tubing at 1 cm to 2 cm spacing. Wrap the tubes in three layers of nylon voile. Fit PVC tubing through the bung to the drain system and cement the bung into the sink outlet. Ensure that the drain system slopes upwards to a point above the outlet. Assemble glassware and external tubing as in figure A.2.

Close tap A. Flush the drain system to remove the air. Fill all tubes with deaerated water and half fill the container. Connect a 5-litre aspirator bottle and vacuum pump at point B. Pour sufficient clean coarse sand into the sink to cover the drain system to about 1 cm, ensuring that the slope towards the outlet is retained within the sand. Add about 3 cm of saturated fine sand. Open tap A, turn on the vacuum to draw off water, but continue to maintain the water level well above the sand surface. When no air bubbles are visible in the tube below the sink outlet close tap A and add a second layer of saturated fine sand. Repeatedly add fine sand and draw off included air until the sand surface is about 7 cm from the top of the sink, ensuring that at all times the surface is submerged under water. De-aerating should continue at intervals for a few days after filling is completed, until there is no evidence of air in the system. Finally, remove the vacuum system from B, set the desired pressure by adjusting the height (h) of the outflow of the levelling bottle, open tap A, and drain off surplus water. The desired pressure is $-|h|$ cmH$_2$O. Use table A.1 to convert to other pressure units. Place a sheet of nylon voile on the sand surface while it is still wet.

To test that the sand has an air-entry value in excess of the desired pressure, leave the levelling bottle at h cm for 2 days; raise the level at 10-min intervals by 20 cm until the surface is flooded, reconnect the vacuum source and check that no air appears at the outlet tube. During the later stages of filling the container, fine material may accumulate on the surface or in suspension; allow this to settle overnight and scrape off before recommencing filling.

Should air entry occur at any time, reflood the sand table with de-aerated water and allow to drain to the preset pressure. In case the sand table becomes airlocked, apply a vacuum suction at point B shown in figure A.2, but only if the surface is covered with water, otherwise air will be drawn into the system.
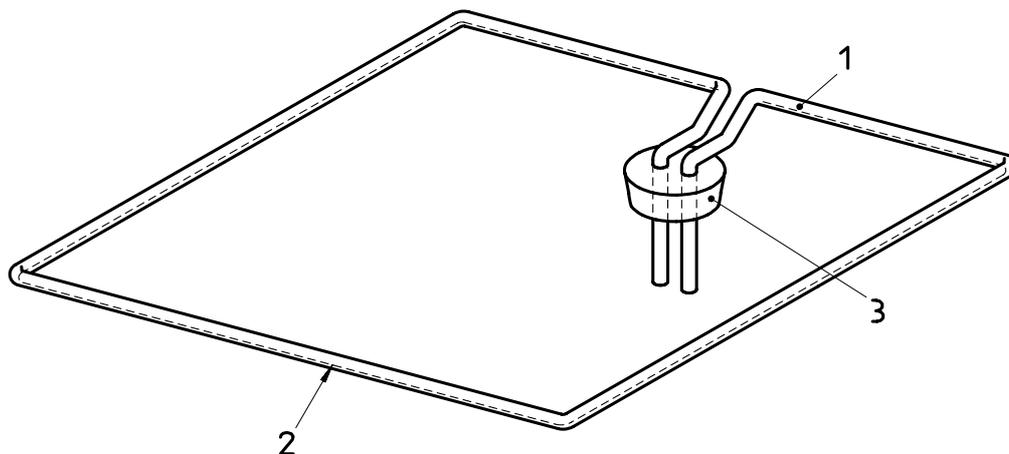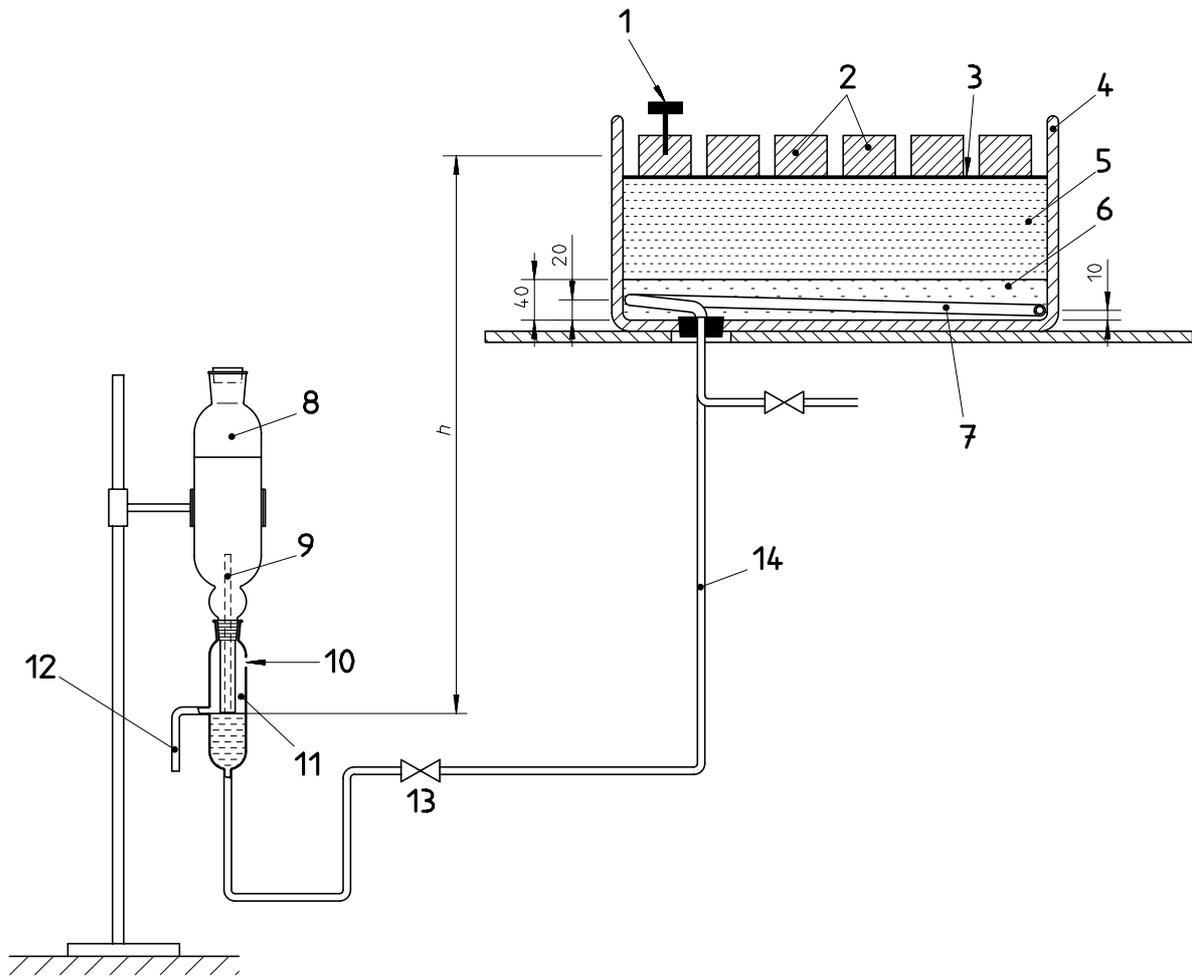

Key

1 Nylon voile

2 Slotted underside

3 Bung

Figure A.1 — Example of a drain system for sand and kaolin suction tables

Dimensions in millimetres

Key

1 Tensiometer in "dummy sample"
2 Soil core sample
3 Nylon voile
4 Ceramic sink
5 Fine sand (60-100 μm)
6 Coarse sand
7 Drain system
8 250 cm^3 reservoir
9 Thin nylon tube
10 Air inlet
11 Levelling bottle
12 Overflow (B)
13 Tap A
14 Flexible 7 mm id nylon tubing

Figure A.2 — Example of a sand suction table

Table A.1 — Pressure equivalents

	MPa	kPa	kgf/cm^2	bar	atm	m H$_2$O	mm Hg	psi lbf/in^2
MPa	1	1000	10,197	10	9,869	102,2	7500,6	145,04
kPa	0,001	1	$1,019 \times 10^{-2}$	0,0100	$9,87 \times 10^{-3}$	0,1022	7,5006	0,14504
kgf/cm^2	$9,807 \times 10^{-2}$	98,07	1	0,9807	0,9678	10,017	735,56	14,223
bar	0,100	100	1,0197	1	0,9869	10,215	750,06	14,504
atm	0,1013	101,33	1,0332	1,0132	1	10,351	760,02	14,696
mH$_2$O	$9,788 \times 10^{-3}$	9,7885	$9,983 \times 10^{-2}$	$9,789 \times 10^{-2}$	$9,661 \times 10^{-2}$	1	73,424	1,4198
mmHg	$1,333 \times 10^{-4}$	0,1333	$1,3595 \times 10^{-3}$	$1,333 \times 10^{-3}$	$1,315 \times 10^{-3}$	$1,362 \times 10^{-2}$	1	$1,934 \times 10^{-2}$
psi lbf/in^2	$6,895 \times 10^{-3}$	6,895	$7,031 \times 10^{-2}$	$6,895 \times 10^{-2}$	$6,805 \times 10^{-2}$	0,7043	51,714	1

NOTE — To convert from the units in the first column to another unit, multiply by the factor given, e.g. 1 bar = 10^{-5} Pa = 750,06 mmHg, etc. The density of water is taken as 1,0 g·cm^{-3} at 20 °C.
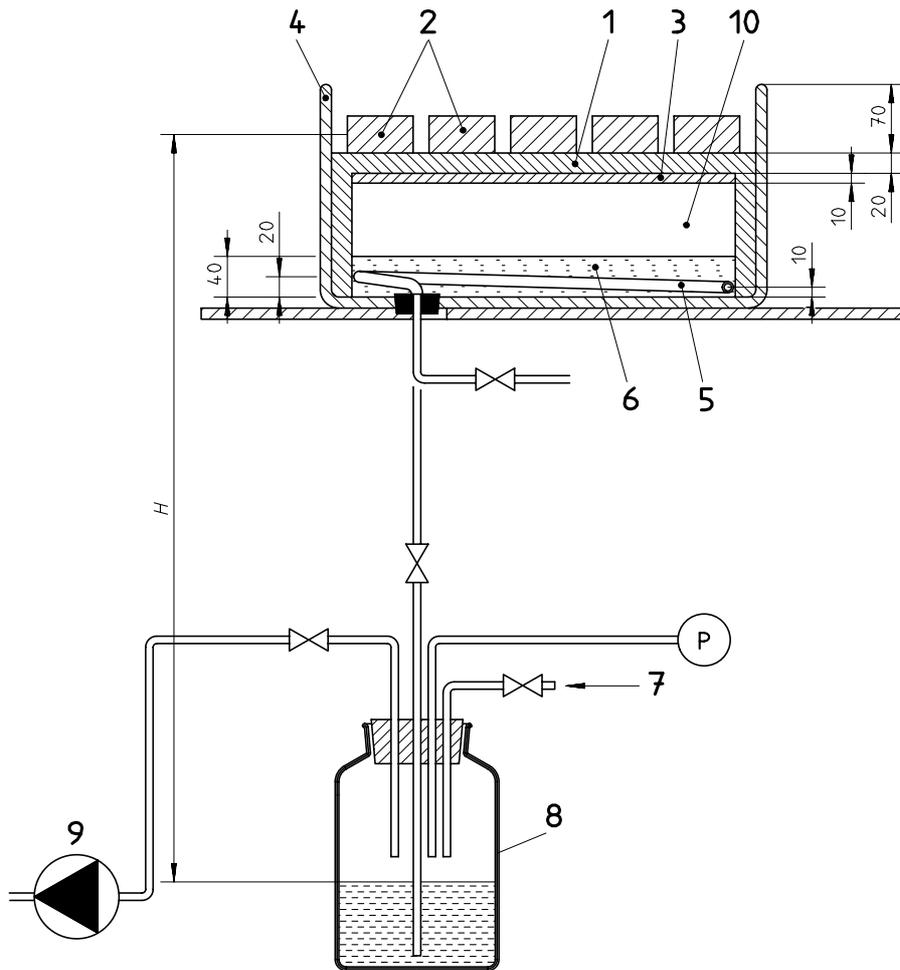
A.2 Kaolin suction table

The kaolin suction table (see figure A.3) is constructed in much the same way as the sand suction table. Line the walls of the sink with kaolin, thoroughly mixed with water, before adding the coarse sand, then add coarse silt (20 µm to 63 µm; silica flour is suitable) up to about 10 cm from the top of the sink. At this stage vigorously apply the de-aerating procedure as for sand suction tables, until no air is present in the silt. Spread a mixture of wet kaolin and silt over the whole surface about 1 cm thick, followed by a 2 cm layer of pure kaolin puddled to a stiff consistency. Lower the water level while the clay is pressed firmly onto the surface and smooth off with a trowel. Flood the surface from above, and continue de-aerating for a few days at hourly intervals. Once the system is air-free, drain off the surface by setting the desired pressure, using the vacuum pump, aspirator bottle and pressure indicator (e.g. a mercury manometer) and using the formula

$$p_{\mathrm{m}} = p - |h| \, \mathrm{cm\,H_2O} = 0{,}098(p - |h|) \, \mathrm{kPa}$$

A tensiometer system inserted into a core packed with silt (20 µm to 63 µm) can be used to maintain a constant check on the matric pressure applied to cores on both sand and kaolin baths.

Dimensions in millimetres

Key

1   Kaolin
2   Soil core sample
3   50/50 kaolin/silt
4   Ceramic sink
5   Drain system
6   Coarse sand
7   Air
8   Aspirator bottle
9   Vacuum pump
10 Coarse silt

Figure A.3 — Example of a kaolin suction table

Annex B
(informative)

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