OPERATING INSTRUCTIONS

08.03 PRESSURE MEMBRANE APPARATUS

Contents

1. Introduction

The 08.03 Pressure Membrane Apparatus can be used for the determination of pF values between 3.0 and 4.2. If higher pF-values are required, then the Eijkelkamp Membrane Press is required. When lower pF values need to be applied to samples, then the 08.01 Sandbox (pF 0 – pF 2), or the 08.02 Sand/Kaolin box (pF 2.0 - pF 2.7), can be used. This manual describes how to prepare the equipment for measurements, measure soil water content, and calculate and interpret the retention characteristic and pF-curves.

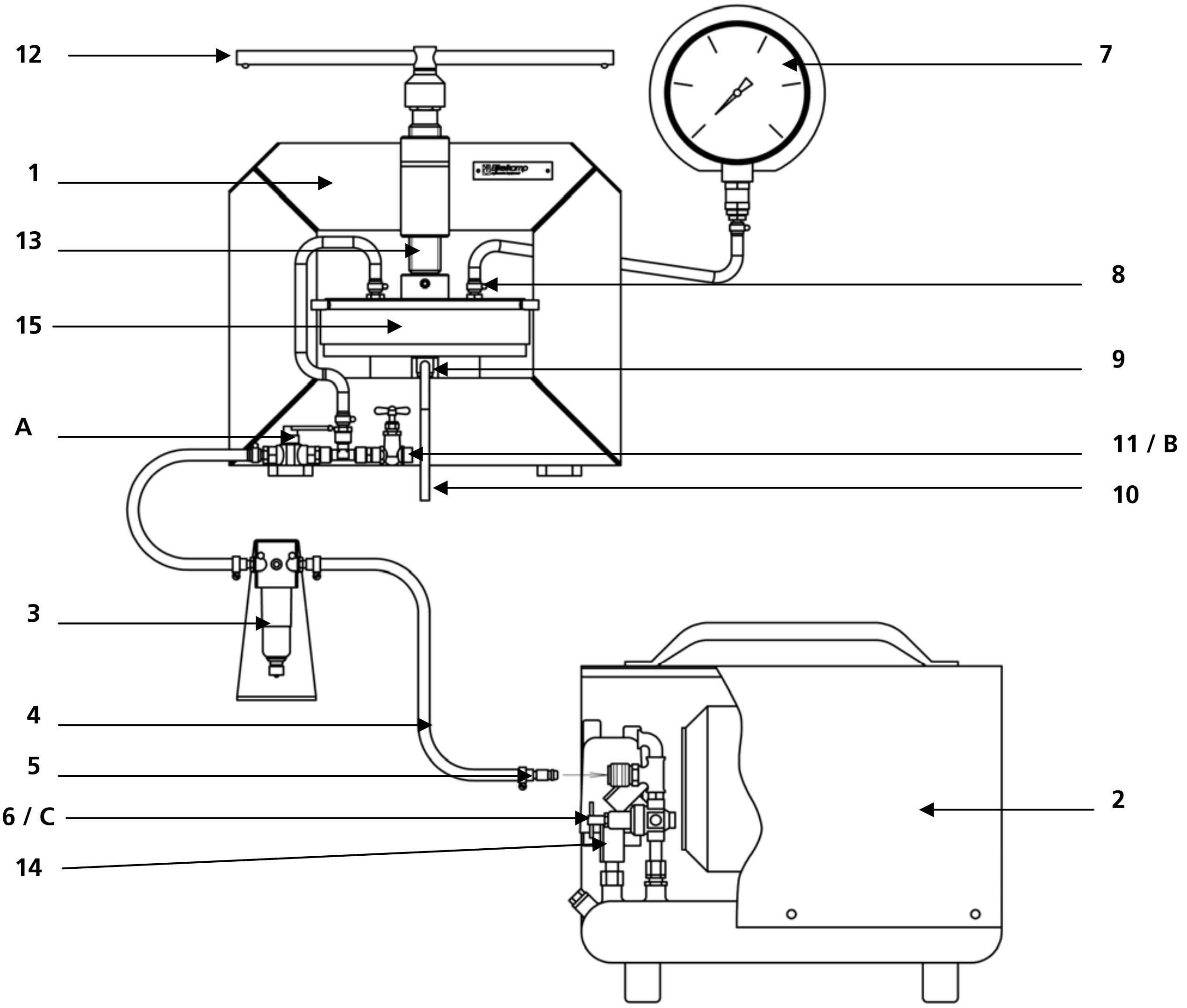
Results of measurements taken with this instrument are points on the drying curves of the relevant samples; associated with *decreasing* pressure. These pressure values are usually standard water potential increments. The wetting curve, on the other hand, is determined by graphing the water content against *increasing* pressure values. This curve is not identical to the drying curve, because the water content does not respond instantaneously to changes pressure (Hysteresis). PF-curves can be plotted - based on the results of measurements taken with this instrument.

2. Description of the pressure membrane apparatus

The pressure membrane apparatus operates on the basis of the principle outlined below (See Illustration 1: Assembled Sandbox with numbered components):

Saturated soil samples are placed on a semi-permeable cellophane membrane with microscopic pores. This membrane allows the passage of water from the sample, but retains the air pressure applied to the upper surface of the membrane. A casing (15) is sealed down air-tight onto a base plate by turning the handle (12) of the worm screw (13). An over pressure is realized in the pressure membrane extractor using the compressor (2). The attractive forces that soil particles exert on the soil water do not exceed the force of the applied air pressure; therefore water can drain through the membrane. Upon reaching the equilibrium the samples are removed, weighed, dried and weighed again.

Illustration 1: Assembled Pressure membrane apparatus with numbered components



1. Membrane apparatus	8. Mouth piece
2. Compressor	9. Tube tulle
3. Air filter	10. Drain tube
4. A high-pressure tube	11. T-piece
5. Mouth piece	12. Handle
6. Reduction value	13. Worm screw
7. Manometer	15. Casing

3. Technical specifications

Item	Specification
Mebrane apparatus	
Soil sample retaining rings	40 x 36 mm height 10 mm
Dimensions	45 x 24 x 53 cm (l x w x h)
Weight	34 kg
Operating range	(pF 3.0 - 4.2 1.0 - 15.5 bar)
Compressor	
Operating range (Compressor)	0 - 20 bar
Voltage	220 V
Frequency	50 Hz
Dimensions	52 x 26 x 53 cm (l x w x h)
Weight	27 kg

☞ **Select the correct voltage for the compressor.**

☞ **Reduce the overpressure before opening the casing.**

4 Preparation for use

4.1 Assembling the pressure membrane apparatus

The 08.03 Pressure Membrane Apparatus is illustrated in Figure 1, with numbered components that are referred to in the text below.

☞ **Carefully read the following instructions before preparing the pressure membrane apparatus.**

Figure 1: Secure to a table with bolts

Figure 2: Protecting mouth piece

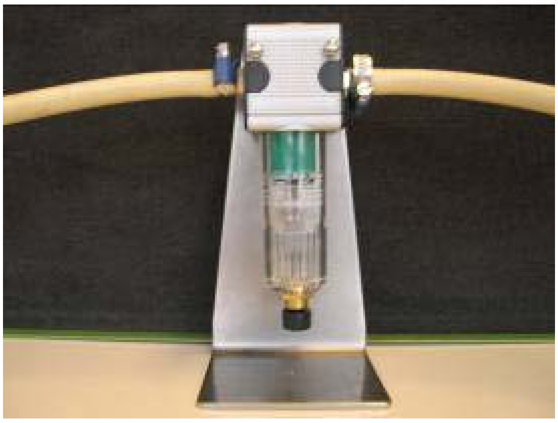


Figure 3 : Connect the air filter

4.1.1. Attach the pressure membrane apparatus (1) to a firm table, using the 4 bolts supplied with the apparatus. (Fig.1)

4.1.2. Place the air filter as close as possible to the Pressure Membrane Apparatus.

4.1.3. Connect the compressor (2) with the air filter (3), by fastening a high-pressure tube (4), to the protecting mouth piece (5) on the reduction valve (6) of the compressor.(fig2) The other end of the tube is fastened in a similar manner to the mouth piece on the air filter.

4.1.4. Connect the air filter to 'Stop Cock A' of the extractor, by using another high-pressure tube.(fig3)

4.1.5. A third high-pressure tube is connected to the manometer (7) and to a mouth piece (8) on the casing.

4.1.6. Slide the plastic drain tube (10) over the tube (9) at the bottom of the base plate.

Figure 4: A cross-shaped plate

Figure 5: Backside of the base plate

Figure 6: Ready for use

Water is drained from the membrane press through a hole in the base plate. This hole is covered with a small round plate, with a cross-shaped incision at the bottom side. (Fig. 4) Water flowing through the hole will be drained via the tube into a glass beaker or burette. (fig5)

If you intend to create a series, the second membrane apparatus may be connected to the T-piece (11). Otherwise skip to section 4.2.

4.1.7. Remove the plug from the T-piece and a mouth piece (provided)

4.1.8. Bind the thread of the mouth piece with tape or smear it with a jointing compound.

4.1.9. Connect the second membrane apparatus to the T-piece, by screwing on the connecting tube.

4.1.10. Make sure the tubes are firmly fixed and free of leaks, since the working pressure rises to 15.5 bar.

☞ **The pressure membrane apparatus is now ready for use (fig. 6).**

4.2 Preparing the Pressure Membrane for use

Figure 7: Calculate the length of the plate

4.2.1 Cut two pieces of nylon filter cloth, large enough to cover the O-ring in the casing. If washed after use, the cloth may be re-used (fig 7).

☞ **The filter cloth must stay within the O-ring**

4.2.2 Cut two pieces of cellophane (membrane) foil 2 or 3 cm larger than the base plate.

Figure 8: Wash and ready for use

☞ **This membrane may not be re-used**.

4.2.3 Saturate the cellophane with water for a period of 1 to 3 hours.(fig. 8)

Figure 9: Clean the base plate with alcohol

4.2.4 Clean the base plate with (50%) alcohol (especially where the sealing ring will contact the base plate) to ensure proper, air tight, sealing.(fig. 9)

4.2.5 Saturate the filter cloths.

4.2.6 Place the filter cloths (on top of each other) on the base plate.

Figure 10: Smoothen the two cellophane sheets, and remove any air bubbles

4.2.7 Smoothen the cloths and make sure all traces of air are removed.

4.2.8 Smoothen the two cellophane sheets together, beginning by holding one straight edge. (Fig.10)

☞ **Any air or impurities between these sheets may give false readings.**

4.2.9 Place the cellophane membrane over the filter cloth and remove any air bubbles present. (Fig. 11)

Figure11: No air bubble exist

4.3 Preparing samples

Undisturbed soil samples are usually used for determining pF-curves, because of the major influences of both pore size distribution and soil structure on moisture retention. However, in the range of pF 3.0 - 4.2 (equivalent to pressures of 1.0 - 15.5 bar) soil water is primarily retained in very small pores, so soil water retention is dominantly influenced by soil texture. Disturbed soil samples are thus acceptable for analyses with the pressure membrane analyses - provided that the soil is not compressed or deformed.

4.3.1 To sample the soil, put about 1 kg of soil into a plastic bag.

At least one undisturbed core sample needs to be taken (per soil unit), because the bulk density of each soil needs to be known to calculate volumetric water content.

Figure 12: Saturate the soil

4.3.2 Moisten the soil samples.(fig.12) With sandy samples, fill a glass beaker with approximately 100 grams of soil and carefully add water until the soil will almost be saturated. With clayey or loamy clods, care should be taken to prevent air entrapment within the aggregates. Therefore, the clods are slightly flattened at the bottom side, and put on a piece of cloth, placed in a thin layer of water, so the clods are gradually saturated while air will escape.

Figure 13: Leave the sample for 3 days

4.3.3 Leave sand and loamy samples for 3 days and other textured samples for at least 7 days to saturate.(fig. 13)

4.3.4 A sufficient number of samples for each soil type should be prepared so that three to six (depending on soil variability in the field) replicates will be available at each suction level.

☞ **Only use a sample for the determination of one pF-value. (For example, pF 3.4)**

5 Procedure for determination of pF-values

Figure 14: Number the soil samples

5.1. Number the soil retaining rings and arrange them on the WET nylon membrane. If the membrane is not wet then follow the steps in section 4.3.(Fig. 14)

☞ **To prevent excessive time periods, required for reaching equilibrium conditions, do not use clods with a height of more than 1 cm .**

Figure 15: Use the spoon to fill the rings with soil

5.2. Fill the rings with saturated soil or clods using a spoon, without disturbing the soil. (Fig. 15)

5.3. Record ring numbers and the corresponding soil sample.

5.4. Place an extra ring containing a homogeneous soil or other material with a known moisture retention characteristic, corresponding to that of the soil to be analysed, in the pressure membrane apparatus to check the determination. If the moisture percentage of the reference sample differs by more than 5% at the test pressure than is expected, the test must be repeated.

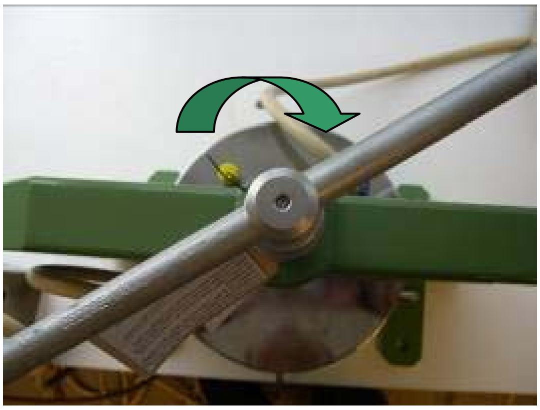


Figure16: Top view: Turning the handle clockwise

5.5. Lower the casing onto the base plate.

☞ **Ensure that there are no soil particles between the membrane and the sealing ring.**

5.6. Seal the casing firmly by turning the handle (12) of the worm screw (13) clockwise (Fig. 16)

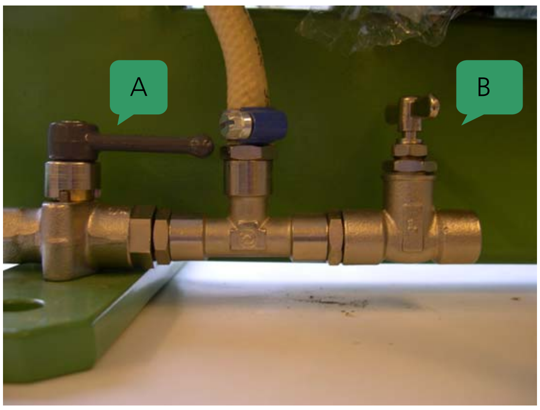


Figure17: Cock A is open, cock B is closed.

5.7. Close stop cock B and open stop cock A (make sure the compressor has built up sufficient pressure).(Fig. 17)

Figure18: Turn the control screw C

5.8. Turn the control screw C slowly open until the required pressure is shown on the manometer (14) at the reduction valve (6).(fig18) Pressures of 1.0, 2.5 bar and 15.5 bar are required for pF values of 3.0, 3.4 and 4.2 respectively. If pressure becomes too high, tighten the adjusting screw C and slowly open stop cock B until the required pressure is obtained (do not forget to close stop cock B).

5.9. Loss of pressure (leakage) can be traced by checking the required pressure on the manometer (7) of the membrane apparatus and the manometer on the compressor. (N.B. 1 kgf/cm² = 1 bar).(fig19)

5.10. The applied pressure needs to be inspected (and readjusted) once or twice a day.

Figure 19: Manometer

☞ **If the pressure indicated on the manometer is too low, immediately close stop cock A. (See Chapter 8 Troubleshooting.)**

Figure 20: Leave the samples

5.11 Leave the samples to reach equilibrium conditions. Equilibrium is reached if no more than 0.1 cm³ of water emerged through the drain tube in the preceding 24 hours. The time necessary to establish equilibrium depends on soil type: 2 to 3 days for coarse sand, and 9 or 10 days for heavy clay soils. After 10 days the experiment should be ended.(Fig. 20)

☞ **Slowly turn the worm screw until gas escapes from the pressure chamber.**

5.12 Open the pressure membrane apparatus by closing cock C on the compressor, slightly open cock B, allowing the pressure in the apparatus to fall slowly, and close B when the pressure reaches 0.5 bar (Fig. 21). Slowly turn the worm screw until gas escapes from the pressure chamber. Unscrew completely and remove the casing.

Figure 21: Close cock C and slowly open the cock B

☞ **Reduce the overpressure before opening the casing.**

Figure 22: Drying the sample

Figure 23: Weighing the sample

5.13 Remove the sample rings from the membrane and transfer the soil into numbered moisture boxes with lids, both of known weight.

5.14 Weigh the boxes with content on a balance (sensitivity of 0.01 g) and record the weight. (A copy of appendix 5 can be used for calculations)

5.15 Dry the samples in an electric drying oven at 105°C for 24 hours. If available, allow the sample boxes to cool down to room temperature in a dessicator. Weigh the boxes with lids again and record the dry weight.(Fig. 22)

5.16 Calculate gravimetric soil moisture content (w) at the corresponding pF values and convert those to gravimetric moisture (q) contents by multiplying with dry bulk density (r_d) value.(Fig. 23)

$$W = \frac{\text{Weight of soil water} * 100\%}{\text{Soil weight}}$$

$$\rho_d = \frac{\text{dry soil weight (excl. ring+cloth+elastic)}}{\text{volume of core ring}}$$

'weight of soil water'	=	weight of wet sample (incl. ring+cloth+elastic)
	-	weight of dry sample (incl. ring+cloth+elastic)
'dry soil weight'	=	weight of oven-dry sample (incl. ring+cloth+elastic)
	-	weight of dry ring+cloth+elastic

Since, with disturbed soil samples, the volume of the (filled) core ring is unknown, an undisturbed core ring is sampled to determine dry bulk density. If pF determinations using suction tables are also carried out, the bulk density, as determined from corresponding soil cores, can be used.

If the density of the soil water is assumed as 1 g/cm³, then volumetric soil water content (cm³/cm³) is determined as:

$$\theta = w * \rho d = \text{gravimetric water content} * \text{bulk density}$$

5.17 Plot the calculated volumetric soil water content on the X-axis and the corresponding pF value on the (positive) Y-axis, to plot part of the pF curve.

To plot the soil water retention characteristic, calculated volumetric soil water content is plotted on the X-axis, against soil water potential on the (negatieve) Y-axis.

A copy of Table 2, can be used to calculate gravimetric and volumetric soil water content for the different pF-values. Note that pF 7 (corresponding to a matric potential of -10,000,000 hPa, or -10,000 bar) is set to a moisture content of 0.

6 Filling in as measurements are taken (Table 2)

Sample number	Ring number	pF	Cm water column (potential in hPa)	Weight (g)					V = Volume of core ring = ...cm³		
				Wet weight (sample, ring, cloth, elastic) A	Dry weight (sample, ring, cloth, elastic) B	Weight of ring, cloth, elastic C	Weight of soil water $D = A - B$	Weight of dry soil $E = B - C$	Gravim. water content $W = D / E$	Bulk density (g / cm³) $\rho_d = E / V$	**Volum. Water content** $\theta = W * \rho_d$
		0,0	1,0								
		0,4	2,5								
		1,0	10								
		1,5	31,6								
		1,8	63,1								
		2,0	100								
		2,3	200								
		2,7	500								

7 Troubleshooting

The pressure indicated on the manometer (7) should be the same as on the compressor. If the pressure indicated on the manometer is too low, immediately close stop cock A. The leak may be caused by:

Cause	Solution
Hole in the membrane. This may be checked by immersing the drain tube under water - air bubbles will then be evident.	Fit a new membrane.
A faulty seal (leakage between casing and base plate). The leakage may be traced by applying a soapy solution to the seal.	Fix the leak.
A leak between tube and one of the mouth pieces. This may also be checked using a soapy solution.	Tighten the tube.
A leak in the sealing ring.	Replace it with an included spare sealing ring.

The samples can be re-used if the leakage is discovered in the first hour of the operation, while they are still wet. Otherwise, new samples must be used.
If the equipment is left unattended, e.g. during the weekend, it is advisable to close stop cock A. Then drying out of the samples by a continuous air flow and subsequent emptying of the air cylinder due to leakage can be prevented.

8 Maintenance

- Regularly check the pressure hoses.
- The nylon filter and the cellophane (membrane) can be re-used if cleaned thoroughly with running water.
- Regularly check the air filter.
- Regularly clean the membrame apparatus and the sealing rings.

9 General Information

The pF-curves plotted below will be used to illustrate the soil physical characteristics that can be deduced from pF-curves. The example soil contains three different soil horizons (each of which has a known pF-Curve). These curves are referred to in Table 3.

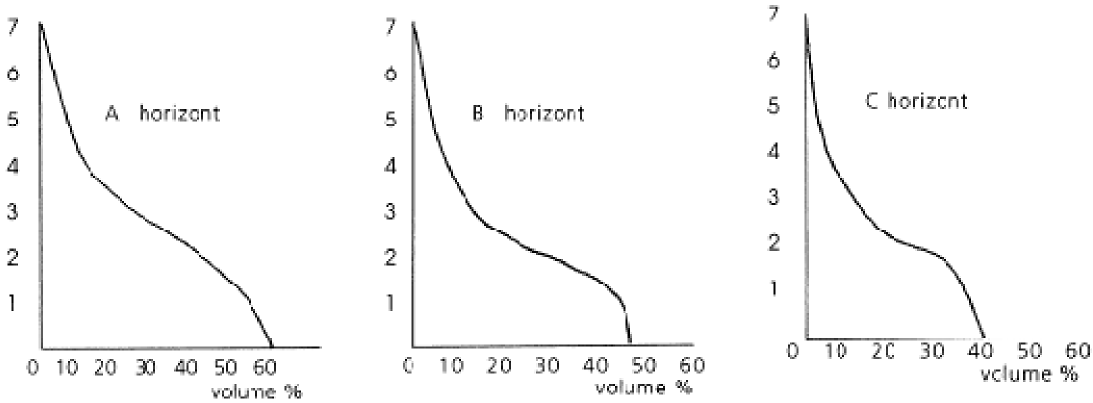


Table 3: Determining soil characteristics from pF-Curves

Physical Characteristic	**Definition and how to determine**
Moisture content	Volume fraction of water filled pores at a certain matric potential. For example, at a matric potential of 1000 hPa (1 bar, pF 3.0), the A horizon has a volumetric moisture content of 20 %.
Field capacity (FC)	Moisture content at pF 2 The A horizon has a moisture content of 35 % at FC and the C horizon 24 %.
Permanent wilting point (PWP)	Moisture content at pF 4.2 The A horizon has a moisture content of 8 % at PWP and the C horizon 4 %.
Porosity	In a sandy soil, all pores are filled with water at saturation (pF0),and empty when oven-dry (pF 7). Therefore, the volume percentage between pF 0 and pF 7 is equal to the porosity in a sandy soil. In a clay soil porosity, or total pore volume, depends upon moisture content, due to swelling and shrinking. Therefore, for clay soil porosity cannot be determined from the pF -curve. The example soil is a loamy sand soil, and allows estimating porosity: At saturation, the A horizon has a volumetric moisture content of 50 %, when the soil is oven dry the moisture content is 0 %, therefore, 50 % of the soil volume is pore space, filled with water and air, and porosity is 50 %.

Volume fraction solid matter	Total volume fraction minus porosity. Since porosity of the A horizon is 50 %, the volume fraction of pores is 0.5 and volume fraction of solid matter in the A horizon is 1 - 0.5 = 0.5
Aeration status	Volume of available air: porosity minus moisture content. Depending on crop type, a certain ratio between water and air supply is required for optimal crop growth. In the example soil, (A horizon) at a moisture potential of 1000 hPa (pF 3), moisture content is 20%, total pore space is 50 %, so the volume of available air is 30 %.
Pore size distribution	Shape of pF curve: Pores of similar size will be emptied at the same matric potential. The more homogenous the pore size distribution, the faster the drop in soil moisture content upon a small decrease in matric potential, and the flatter the slope of the pF curve. The steeper the slope, the more gradual the emptying of soil pores, the more heterogeneous the pore size distribution. In general, a heterogeneous pore size distribution is preferable for agricultural applications, since these soils have a higher water holding capacity. The example soil illustrates the effect of organic matter presence and biological activity in the A horizon. In the A horizon, the slope of the pF-curve is more gradual than in the C horizon, meaning that pores are emptied more gradually in the A horizon, corresponding to a heterogeneous pore size distribution. The C horizon contains a relatively large amount of pores of similar size, which are all drained around a matric potential of - 100 hPa (pF 2). A slight increase in the suction will lead to a change in moisture content of almost 10 %.
Capillary conductivity	The rate of capillary conductivity depends upon the amount and size of water filled pores involved in water flow. This depends upon the moisture potential of the soil. A decrease of the water potential (an increase in suction level) corresponds with a decrease in moisture content. Because water is forced to flow through narrow pores with a high friction, this consequently leads to a reduction in the capillary motion. Permeability rate depends on the distribution and amount of macro-pores.

Storage capacity	Storage capacity of a soil at a specific ground water level corresponds to the air volume present. Storage capability is expressed in mm water per decimetre of soil (1 mm water per 10 cm °1 volume percent). For the example soil, the storage capacity of the C horizon at a moisture tension of 100 hPa (pF2) is calculated as total pore space (40 %) - moisture content (25 %) = volume of air (15 %). A volumetric air content of 15 % corresponds to a storage capacity of 15 mm of water per decimetre of C horizon.
Plant available soil water	The amount of water between FC and PWP in volume percentage. This value should be used with caution. First, plants will start wilting with subsequent yield losses well before the permanent wilting point. Secondly, plant available soil water is replenished by capillary rise, rainfall and irrigation water. Eg: A fine sandy soil, rich in loam has a rooting depth of about 40 cm. • The A horizon has a depth of 20 cm. • The B horizon has a depth of 30 cm. Calculation of the amount of plant available soil water: At field capacity, pF2.0, the A horizon will contain 35 volume % of water. At the permanent wilting point, pF4.2, the A horizon will contain 8 volume % of water. As 1 volume % corresponds to 1 mm water per 10 cm of soil, the amount of available soil water in the A horizon is calculated as the volume % of water multiplied with the rooted depth of the soil horizon: A horizon: 35 - 8 = 27 volume % water x 20 cm soil depth 27 x 2 dm soil depth = 54 mm For the B horizon the calculation is similar. Notice that rooting depth is 40 cm, so roots will be present only in the upper 20 cm of the B horizon. At field capacity 27 % of water will be available, at the permanent wilting point only 6%. B horizon: 27 - 6 = 21 volume % of water * 20 cm rooted soil depth ° 21 * 2 = 42 mm water In total, 54 + 42 = 96 mm of water is available to plant growth in this particular soil.

References and literature

Klute, A. Water Retention: Laboratory Methods. IN: Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. 1986.

Koorevaar, P., G. Menelik and C. Dirksen. Elements of Soil Physics. Developments in Soil Science 13. 1983.

Reeve, M.J. and A.D. Carter. Water Release Characteristic. IN: Soil Analysis. Physical Methods. K.A. Smith and C.E. Mullins (eds.) 1991.

Van Reeuwijk, L.P. (ed.) Procedures for soil analysis. 1995. ISRIC Wageningen.

Stakman, W.P., G.A.Valk and G.G. van der Harst. Determination of soil moisture retention curves I. 1969. ICW Wageningen.

Stolte (ed.) Manual for soil physical measurements. Version 3. Technical Document 37. SC-DLO. 1997.

Topp, G.C. and W. Zebchuk. The determination of soil water desorption curves for soil cores. 1979. Canadian Journal of Soil Science 59: 19-26.

Appendix 1 Conversion factors

100 hPa	=	100 cm pressure head
	=	100 cm water column
	=	0.1 bar
	=	0.01 Pa
	=	0.01 N/m²
	=	1.45 PSI
	=	pF (^{10}log100) = 2.0

pF value	Matric potential in hPa	Pressure in bar
2.7	-500	-0.5
3.4	-2500	-2.5
4.2	-15500	-15.5

Appendix 2: Description of different pF-sets

To determine the soil moisture retention characteristic, the desired pF-set(s) is/are required. A balance with an accuracy of 0.01g, and a ventilated electrical drying oven (105 °C), are also necessary. Eijkelkamp supplies the following:

A universal drying-oven with temperature range 30 -220 °C, 220 V- 50 Hz.

A Sandbox for pF determination (pF0 -2.0). The Standard set for about 40 samples includes:

- Sandbox
- Containers with sand, particle size ± 73 mm, 12.5 kg each
- Filter cloth, 140 - 150 mm
- Set of 65 o-rings, diameter 49 mm: suitable for 5 cm diameter core rings

A Sand / kaolin box for pF determination (pF2.0 - 2.7). The Standard set for about 40 samples includes:

- Sand / kaolin box
- Vacuum pump and automatic suction level control system, 220 V
- Containers with synthetic sand, particle size ± 73 mm, 12.5 kg each
- Filter cloth, 140 - 150 mm
- Kaolin clay, container 2.5 kg
- Set of 65 o-rings for 5 cm diameter core rings

Pressure Membrane Apparatus (pF3.0 – 4.2). The standard set for about 15 samples includes:

- Pressure membrane extractor
- Cellophane membrane
- Soil sample retaining rings
- Filter cloth 140 - 150 mm
- Compressor 20 bar
- Air filter with support and hose

Appendix 3: Soil sampling

To determine the moisture retention characteristic or the pF-curve of a specific soil, *undisturbed* core samples must be collected. This is because of the major influences of both pore size distribution and soil structure on moisture retention, especially at the high matrix potentials of the operating range of suction tables.

There is no explicit prescription in literature for recommended sample sizes. Optimal sizes for core rings are determined by the size of structural elements in the soil. To obtain representative data, sample sizes should be large with respect to the size of soil aggregates, cracks, root channels or animal holes. From a practical point of view, sample diameters should not be too large as not to reduce the amount of simultaneously analysable samples, and sample height should be constrained to several centimeters; so that equilibrium conditions are reached in a reasonable period of time.
According to the Dutch NEN 5787 standard, samples with a volume between100 and 300 cm³ are usually used for the suction tables, while samples with a height of more than 5 cm are discouraged, because the time needed to establish equilibrium will be long, and the accuracy of determination of pF-values near saturation will be low.
In the procedures for soil analyses of the International Soil Reference and Information Centre (ISRIC), sample rings with a diameter of 5 cm and a volume of 100 cm³ are recommended, while in other publications heights of 2 or 3 cm are preferred.

Eijkelkamp Agrisearch Equipment recommends the use of a 100 cm³ volume core ring, with an inner diameter of 50 mm (outer diameter 53 mm) and a height of 51 mm.

When pressing the core rings into the soil, care should be taken not to disturb the original setting of the soil and to completely fill the ring. Sampling conditions are best when the soil is approximately at field capacity. Ring holders may be used to facilitate insertion, especially in the subsoil. After insertion to the desired depth, the rings are carefully dug out (e.g. using the spatula provided with the Eijkelkamp sample ring set), at some centimeters below the ring itself. The surplus of soil is reduced to a fewmillimeters, trimming it carefully with a fine iron saw, and the caps are placed on the ring for protection and to minimise evaporation losses. The remaining surplus of soil will protect the sample during transport and will be removed in the laboratory, prior to analysis. Transport the core rings in a protective case.

Since soil structure and pore size distribution have significant influence on soil water retention, several replicate samples are needed to obtain a representative pF-value. Depending on natural variability of the study area, three to six replicate samples per unit are advised.

In case the samples cannot be analysed on short notice, store the samples in a refrigerator to reduce microbial activity which might cause non-representative changes in soil structure.

☞ **Do not freeze the samples because soil structure will be influenced.**