2826D20

OPERATING INSTRUCTIONS

Tension Infiltrometer **June 2008**

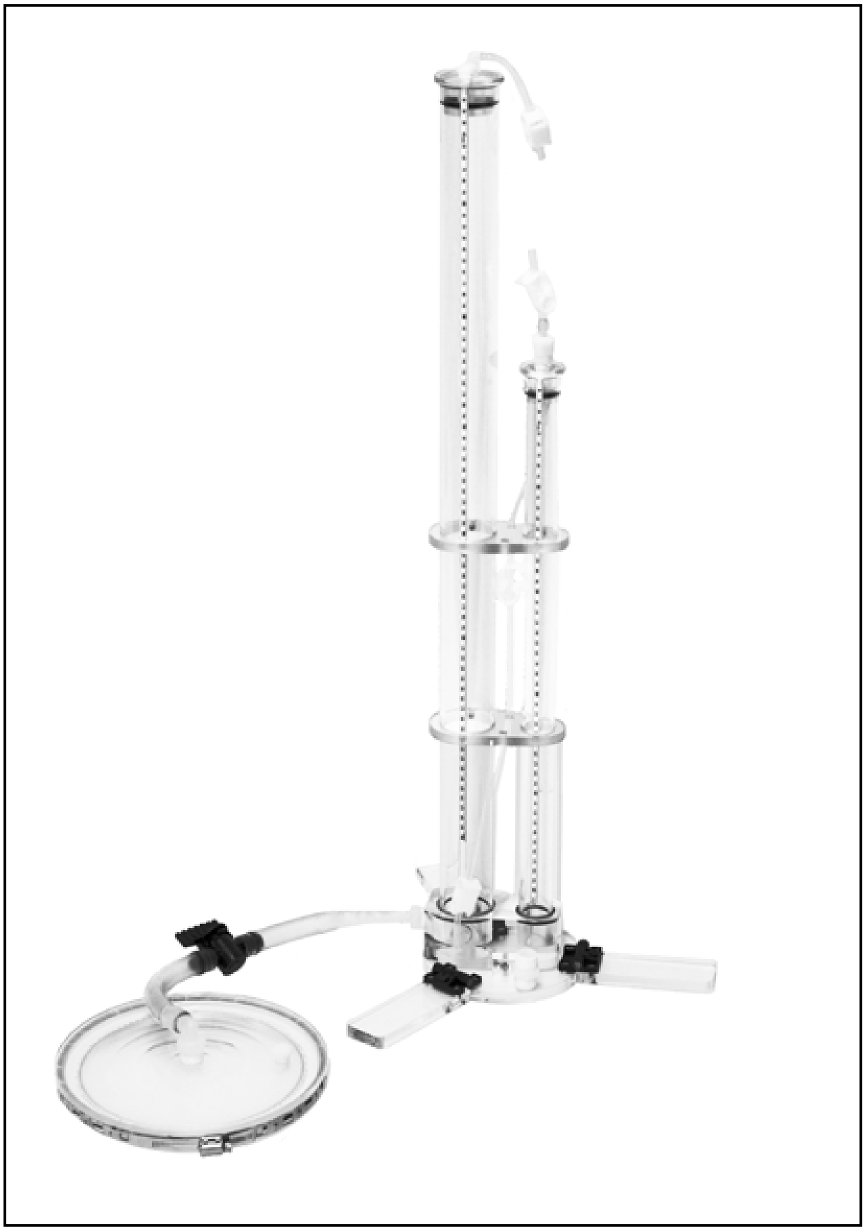

Fig. 1 2826D20 Tension Infiltrometer

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I. INTRODUCTION

The 2826D20 tension infiltrometer is designed to measure the unsaturated flow of water into soil rapidly, accurately, and easily. Applications of the infiltrometer include measurement of macropore and preferential flow, estimation of soil structure, and characterization of the soil hydraulic conductivity water potential relationship.

II. DESIGN FEATURES

The 20 cm diameter infiltrometer has been designed to operate in two modes. In mode one the infiltration disc is separated from the water tower. In mode two the infiltration disc is attached to the bottom of the water tower, using the supplied connector. Operating the infiltrometer in mode one is especially advantageous when taking measurements under windy conditions. If the infiltration disc is attached to the water tower, even a small movement of the water tower by wind, or by accidentally touching it, will affect the contact between the disc and the soil surface and thereby the rate of infiltration of water into the soil. By separating the control tower from the disc, chances of affecting the contact between the disc and the underlying soil are greatly reduced. A second advantage of operating the infiltrometer in this mode is that the weight of the infiltrometer disc is constant during the measurements. In mode two the weight of the infiltrometer, and thus the pressure on the soil surface, changes during measurements as the water tower empties. Operating the infiltrometer in mode two is advantageous where space is limited, such as in a soil pit or in a small excavation.

In both modes 1 and 2 the water level in the water reservoir can be determined by reading the level on the attached centimeter scale, or by measuring the pressure in the upper end of the water reservoir. The pressure in the air pocket at the top of the water reservoir (always negative) is linearly related to the height of water in the reservoir. A centimeter change in water height means a centimeter change in pressure in the air pocket. Thus, infiltration rates can be monitored by recording pressure changes measured with a pressure transducer with digital read-out, or with pressure transducers and a datalogger over time. Using two pressure transducers, one on top of the water reservoir, and a second one mounted on the infiltrometer disc, gives the most complete information. Using two pressure transducers virtually eliminates bubbling ‘noise’ which increases measurement precision (Ankeny, et.al. 1988).

Figure 1 shows the 2826D20 infiltrometer. The major components are A) the bubble tower (the shorter 1” ID tube) which controls tension at the soil surface, B) the water reservoir (the longer 2” OD tube) which empties as water flows into the soil, C) the disc to establish hydraulic continuity with the soil, and D) the 1/2” ID tube between the disc and the water tower. Note the one way valve, in the middle of the 1/2” ID tube.

III. INITIAL SETUP AND USE

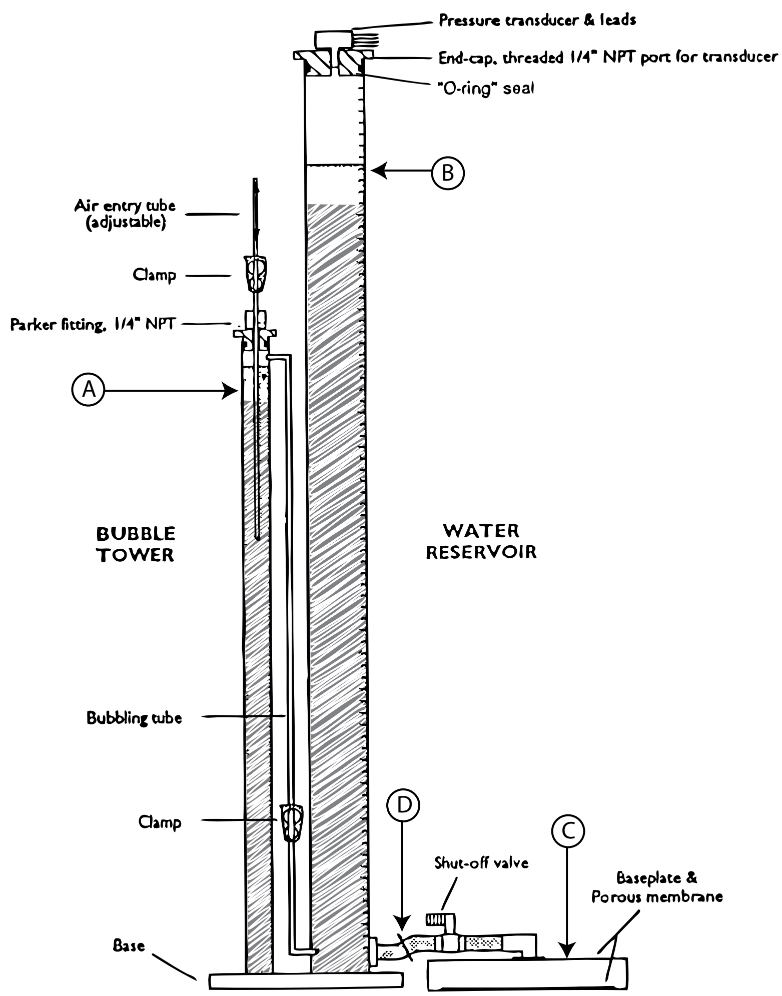

Figure 1 View of the tension infiltrometer

INITIAL TESTS

The tension infiltrometer has been tested before shipment; however, after extensive use in the field, there may on occasion be a need to check for air leaks. This is best accomplished as follows. Separate the disc from the water tower, by removing the 1/2-inch tygon tubing from the disc elbow. Close all valves. Inflate the infiltrometer to a pressure of 100 mbar (100 cm water pressure) using a small hand pump. Use care not to over-inflate the infiltrometer; this may damage the instrument. Use a sensitive manometer, or a water column to check the pressure. Now hold the lower part of the infiltrometer under water in a large bucket, and check for air bubbles. Following this, hold the top part of the infiltrometer under water. Again no continuous stream of air bubbles should come from the infiltrometer. In case there is a leak, repair the leak using either (depending on where the leak is) nylon tape, or vacuum grease.

Filling the infiltrometer in the field

To fill the infiltrometer disc, it is most convenient to submerge the disc, without the 1/ 2-inch tubing attached, in a dishpan with water. This will completely wet the pores of the nylon mesh attached to the disc, and allows one to eliminate all air from the disc. Close the one-way valve of the 1/ 2-inch tubing connected to bottom of the water tower, and remove the top from the water

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supply tube. Fill the water supply tube until about 5 cm from the top. When full, replace the top. Hold the water tower over the dishpan holding the disc, and slip the open end of the 1/2” flexible tube over the elbow of the disc. Open the one-way valve, and move the water tower back and forth so that all air in the 1/2” tubing moves to the top of the water reservoir. Place the disc and water tower on a flat, clean surface, and then fill the bubble tower until 7 cm from the top. When full replace the top with pressure adjusting tube. To fill between measurements close the valve in the tubing between the tower and the disc, remove the top, and refill the water reservoir tube until about 5 cm from the top. Replace the top and re-open the 1/2-inch valve.

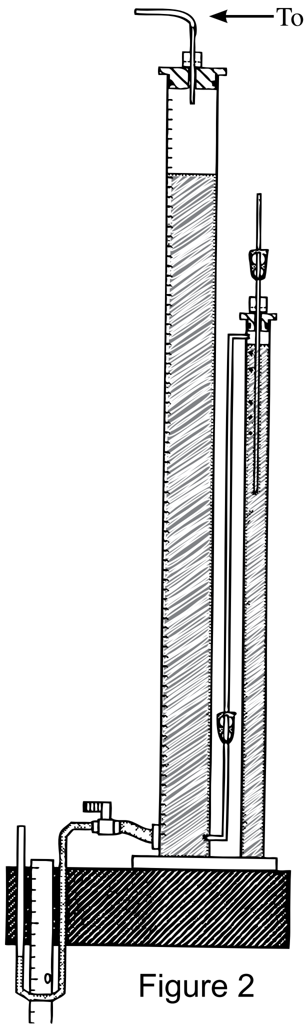

Figure 2

Calibration

It is recommended to check the calibration of the infiltrometer, before taking the unit to the field. Tension at the soil surface is controlled by the relative position of the air entry tube in the bubble tower. By turning the setscrew on top of the bubble tower counter clock wise, the air entry tube is loosened, and can be moved up and down. The air entry tube slides up or down easiest when wet. Once the tube is set, turn the setscrew clockwise till it is finger tight. This will ensure that the closure is airtight.

Under normal operating conditions the air entry tube has to be set such that its lower end is 4.0 + x cm below the water level in the bubble tower. For example, if the first measurements are to be taken at a surface tension of -15 cm H20, then the lower end of the tube should be set at 19.6cm below the water level. If the next readings are to be taken at -10 cm, then the tube outlet should be set at 14.6>cm below the water level. However, it is good practice to verify this in the laboratory, before taking the unit to the field.

To calibrate the air entry tube settings in the laboratory, disconnect the 1/2” tube between the disc and the water tower at the disc. Connect a 75 cm length of 1/4” or similar tygon tubing to the open end of the tube. Use a regular tubing connector for this purpose. The 1/4” tygon is used as a water manometer as shown in Figure 2. The water manometer is connected to the 1/2” tube with valve and looped over the bench top adjacent to a meter stick (Figure 2). After filling the water tower, open the 1/2” valve for a short time to force all air out of the manometer and out of the 1/2” tube to avoid calibration errors. Water will spill out of the open end of the manometer tube. Now apply a small vacuum to the top of the water reservoir tube, such that air bubbles are seen rising in the tube. This can be done with a small hand pump available from soilmoisture, or better with a regulated vacuum source. Then open the tubing clamp on the tubing between the water tower and the bubble tower, as well as the tubing clamp on the short end of tubing on top of the air entry tube. Slide the air entry tube up or down until the desired tension on the manometer is reached. Tension is read directly off the meter stick taped to the bench top edge; The bench top is the zero reference, which represents the soil surface. The vertical distance between the bench top and the water level in the left arm of the manometer represents the tension (in cm water) that will be applied to the soil surface. Figure 2 shows the infiltrometer at 8.0 cm water tension. To accomplish this, the air entry tube had to be set at about 12 cm below the water level in the bubble tower.

Following are step by step instructions on how to set the tensions

1. Place the infiltrometer water tower on a table or bench top.

2. Close the one way valve and remove the cap on the water tower.

3. Fill the water tower until 5 cm below the top. Replace the cap.

4. Fill the bubble tower until 7 cm below the top, and place the cap with the air entry tube on top of the bubble tower.

5. Attach 1/4 inch tygon tubing to a hand held vacuum pump.

6. Remove the end cap from the water tower. Unscrew the pipe plug from the end cap, and replace this plug with a 1/4" NPT tubing adaptor. If no suitable pipe plug can be found, use a one-hole stopper to close the upper end of the water tower. Push a short end of plastic tube through the hole, and attach the tygon tubing from the hand pump to this tube.

7. Attach tygon tubing to the valve and bend it under the bench in front to a meter stick to make a manometer (see Figure 2).

8. Quickly open and close the 1/2" one way valve after removing the end cap from the water tower. This causes water to force all air out of the 1/2" tube and out of the manometer tubing. Attach the manometer tubing to the meter stick. Verify there is no air in the tubing near the valve or in the valve. Replace the end cap on the water tower.

9. Open the clamp on the tubing between the water tower and the bubble tower. Also open the clamp on the air entry tube. Apply vacuum with the hand pump until a steady stream of bubbles appears in the water column. It is best to use quick, relatively short pump strokes.

10. Slide the air entry tube up or down, until the correct reading on the manometer is obtained For example, if a 5 cm tension is desired at the membrane, the manometer should read 5cm (distance from the top of the bench to the top of water in the tube of the manometer with the water reservoir bubbling). If, necessary adjust the air entry tube up or down. Keep pumping in short strokes to keep the air bubbles moving.

Setting tensions Con’t

11. Now (while the air is moving), determine the vertical distance in em, between the water level in the bubble tower, and the lower end of the air entry tube. For a 5 cm tension this distance should be approximately 9 cm.

12. Repeat step 11 for tensions of 10 and 15 cm. Verify that the correction factor is about 4 em for all tensions. If this is not the case apply different correction factors for each tension setting to be used in the field.

13. It is recommended to perform the calibration in the laboratory.

14. In the laboratory a precisely regulated source of vacuum is much more convenient than the use of a hand pump.

While tensions can in principle be calibrated to an accuracy of millimeters, the precision of tension control is limited by tension fluctuations due to bubbling (+ / - approximately 1 cm), Therefore, at very low tensions, soil surface tension may fluctuate to zero potential. This fluctuation should be given careful consideration before measuring or interpreting infiltration rates less than two or three centimeters tension. The 400 mesh nylon membrane will bubble if tensions are set for greater than 35 cm. Tension settings of 3-,6-, and 15 cm have proven convenient across a variety of soils and soil conditions.

IV. FIELD USE OF THE TENSION INFILTROMETER

1. Estimating measurement times

For the analysis presented in section V it is necessary to reach steady state infiltration. The time needed to obtain a steady-state rate in unconfined infiltration measurements depends upon initial soil water content and upon hydraulic properties of a given soil. In general, drier soil and lower hydraulic conductivity result in a longer infiltration period needed to reach steady-state infiltration. The change in rate over time should be monitored to confirm that steady-state rates are reached. Data is collected for 16 min 40 sec (1000 seconds) under most conditions except for dry, high bulk density areas. Not reaching steady-state results in an overestimate of hydraulic conductivity. In very porous and sandy soils, steady-state rates are reached much earlier and measurement times can be shorter.

2. DATA COLLECTION

The water level in the water reservoir can be read directly on the em scale attached to the water reservoir. A simple timer or stopwatch is useful to obtain readings at regular time intervals. The water level may also be recorded with one or two pressure transducers, a datalogger, and a Model 5305 - PSI differential pressure transducer, available from Soilmoisture Equipment Corp., is recommended.

3. PREPARING THE SOIL SURFACE

Infiltration can be measured with or without removal of any soil crust. Typically, about 2-3 cm of soil surface is removed in a 40 cm diameter. A pointing trowel works well to prepare the surface. If the soil is too wet to avoid smearing, the measurement should wait. Gently press the metal ring into the prepared surface. When the soil is cracked, or otherwise has many visible “macro pores”, place 3 layers of cheesecloth on the soil surface in the ring to reduce soil slaking into the macro pores. Place the contact material (e.g., fine white, slightly moistened, silica sand) in the ring and level with a straightedge. There should be no sand outside the ring. Center the infiltrometer disc over the ring and gently press the device down onto the sand. Inspect the sand/device interface to assure good contact. Poor contact results in poor data. Note that the effective diameter for calculating the conductivity is the diameter of the sand circle. It is very important that the bottom of the bubble tower and the nylon membrane be at the same elevation during measurement. If this is not the case the tension at the membrane will be different than set with the air entry tube.

4. STARTING THE MEASUREMENTS

Remove the sand outside the ring. The effective diameter for calculating the conductivity is the diameter of the sand circle. Remove the metal ring and place the disc on the sand.
Inspect the sand/disc interface to assure good contact. Poor contact results in poor data.
Make sure the bottom of the bubble tower and the disc membrane are at the same elevation during measurement (use of a carpenters level is recommended). If this is not the case, the tension at the membrane will be different than set with the air entry tube. Start infiltration as quickly as possible after putting the disc on the sand surface. If this is not possible, and in order to prevent air bubbles from entering the disc through the membrane, use a water atomizer (used to spray house plants) to moisten the surface of the sand before placing the disc on the sand. It is recommended to make measurements from high to low tensions (e.g. 15, 6, 3,). If the soil is wet initially, for example after an experiment at h=-3 cm, then it will take some time before air bubbles commence at a higher tension, e.g. at h=-15.

V. INFILTRATION DATA ANALYSIS

1. Theory: from 3-D rates to hydraulic conductivity

The following method based on Wooding's work (1968) can be used to calculate the hydraulic conductivity versus water content relationship from unconfined infiltration. Wooding proposed the following algebraic approximation of steadystate unconfined infiltration rates into soil from a circular source of radius r (cm)

$$Q = \pi r^2 K\left[1 + \frac{4}{\pi r \alpha}\right] \quad \textbf{(1)}$$

Where Q is the volume of water entering the soil per unit time (cm3 hr-1), K (cm hr-1) is the hydraulic conductivity, is a parameter, and h (em) is the matric potential or tension at the source. The value of h will normally be negative corresponding to a tension at the water source; however, it can also be zero. It is assumed that the unsaturated hydraulic conductivity of soil varies with matric potential h (cm) as proposed by Gardner (1958).

$$K(h) = K_{sat}\exp(\alpha h) \quad \textbf{(2)}$$

Where K_{sat} is the saturated hydraulic conductivity (cm hr^{-1}). Although (1) can be used for unsaturated and ponded infiltration, (2) applies only for h ≤ 0.

With the tension infiltrometer one measures the volume of water (Q) entering the soil per unit time through the porous membrane at a minimum of two tensions, e.g. h_1 and h_2.

For unsaturated soil, and upon replacing K in (1) with Ksat exp (*a* h), and after substitution of h_1 and h_2, respectively for h in the combined equation one obtains:

$$Q(h_1) = \pi r^2 K_{sat}\exp(\alpha h_1)\left[1 + \frac{4}{\pi r \alpha}\right] \quad \textbf{(3)}$$

$$Q(h_2) = \pi r^2 K_{sat}\exp(\alpha h_2)\left[1 + \frac{4}{\pi r \alpha}\right] \quad \textbf{(4)}$$

Dividing (4) by (3) and solving for *a* yields:

$$\alpha = \frac{\ln[Q(h_2)/Q(h_1)]}{h_2 - h_1} \qquad (5)$$

Because Q(hl) and Q(h2) are measured, and h_1 and h_2 are known, *a* can be computed directly from (5).

With *a* known, one can now calculate K_{sat} from (3) or (4). Once K_{sat} and *a* are known, their values can be substituted in (2), yielding the relationship between hydraulic conductivity and tension for the soil. This relationship can be used to calculate the unsaturated conductivity at the desired tensions. Note however, that the K_{sat} value obtained with the above method may be different from the value obtained for K_{sat} if measured directly. One reason is that the relationship of K(h) versus h is often not linear near h=0.

Example:

The inside diameter of the water supply tube of the tension infiltrometer is 4.45 cm, and it's radius is 4.45/2=2.225 cm.

Assume that the radius of the sand layer between the membrane and the soil is 10 cm. Assume further that upon reaching steady state, the water level in the supply tube fell on average at a rate of 60 cm/hour for h_1= -5 cm, and at a rate of 10 cm/hour when the tension was set at -15 cm.

Calculations:

Based on the above date, the infiltration rates were:

Q_1 = (3.14) $(2.225)^2$ (60) = 933 cm^3/hour at h_1 = -5

Q_2 = (3.14) $(2.225)^2$ (10) = 155 cm^3/hour at h_2 = -15

Calculate *a* from (5):

$$\alpha = \frac{\ln(155/933)}{-15-(-5)} = \frac{-1.795}{-10} = 0.1795 cm^{-1}$$

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From (3) one obtains:

$$933 = (3.14)(10.0)^2 K_{sat} \exp[0.1795(-5)]\left[1 + \frac{4}{(3.14)(10.0)(0.1795)}\right]$$

Ksat = 4.3 cm/hour

With a and Ksat known, (2) becomes:

K(h)=4.3 exp (0.1795 h) (6)

From (6) one can calculate the unsaturated hydraulic conductivity, as follows:

h = -40 cm, K(-10) = 0.71 cm/hour ID
h = -10 cm, K(-20) = 0.12 cm/hour
h= -20 cm, K(-40) = 0.0033 cm/hour

2. MATRIC FLUX POTENTIAL

Partitioning of unconfined flow in the above method yields both hydraulic conductivity and matric flux potential Φ=K/*a*. Note the supply potential does not have to be zero.

3. SORPTIVITY

Estimation of sorptivity, S (‘PI, ‘P2) is discussed in detail by White and Perroux (1989). Because sorptivity is often sought as a means of obtaining hydraulic conductivity, this manual focuses on the more direct method above. Note that sorptivity can be calculated directly from the short time behavior following White and Sully, 1987.

4. CAPILLARY LENGTHS

Calculation of capillary lengths is also discussed by White and Perroux (1989). Philip (1985) proposed the use of the macroscopic sorptive length. A length scale simply related to the sorptive length is the macroscopic capillary length, Ac (White and Sully, 1987), where:

$$\lambda_c = \left[K(\psi_0) - K(\psi_n)\right]^{-1} \int_{\psi_n}^{0} K(\psi)\, d\psi \qquad \textbf{(7)}$$

Wooding’s results (1986) were based on (2) for which AC is simple a^{-1}. White and Sully (1987) and others have used the more basic definition (7) as a basic soil property, but note that AC is a function of the integration limits as well as K(‘P) for the general case.

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VI. TROUBLESHOOTING

1. MAIN BODY OF DEVICE

This device is constructed of poly carbonate (Lexan) and plexiglass. Therefore, the device should withstand normal field abuse. If any piece of plastic does crack or leak, a syrupy solution of plexiglass dissolved in dichloromethylene should seal the pieces together. A glue gun will usually seal a leak, also. The tubing on the air entry ports may lose its resiliency over time due to the pinch clamps. Periodic replacement increases ease of use.

2. POROUS BASE PLATE

During long term storage, the infiltrometer should by emptied to prevent decay of the membrane on the base. A dirty base also promotes short-term decay.

If the nylon membrane is damaged, the base will leak. If the base leaks, first try to knock any entrapped air out of the membrane by bumping the base into the bottom of a shallow pan of water. If this fails, the membrane will need replacing. Unscrew the stainless steel tubing clamp. Now remove the damaged screen and replace it with new membrane material Z2826D20-001 (available from Soilmoisture). Lay the membrane over the base plate, and force the 0ring over the membrane and the base plate, such that the membrane material is tight. Replace and tighten the tubing clamp. Wetting the membrane by soaking it in water will facilitate its installation. Only after testing the new membrane for leaks, should the extra membrane material be cut off. Use a razor blade to trim the membrane on the edges.

If tensions beyond 30 cm tension are to be imposed on the soil surface, the bubbling point of the nylon membrane may be exceeded. Membranes down to submicron pore diameter are available. Nylon filters are recommended because they are thin, tough, and hydrophilic. A caveat: high tensions usually mean low flow rates. As flow rates decrease, other factors become more of a problem. Expansion of water due to heating by the sun in the water reservoir may make it difficult to maintain tension. Electronic noise and calibration errors also become more of a problem.

3. TEST INFILTROMETER FOR LEAKS

Remove disc from the infiltrometer.
Close side hole with a stopper.
Close all the white clamps on the infiltrometer bubble tower.
Close the water reservoir with a septum stopper.
Pressurize the unit to about 60 cm water pressure (60 mbar).
Hold the complete unit under water and check for leaks.

4. CHECK DISC FOR LEAKS

- Before replacing the mesh screen material, the disc and the material should be free from soil particles. They might cause leaking.

- Connect 1/4” tygon tubing (2 feet long) with connector to the disc.
Immerse the disc and tubing in water. The tubing should be completely full of water. Make sure there is no air under the membrane or in the tubing.

- Close open end of tubing with a tubing clamp or with a small stopper.

- Remove disc with attached tubing from water.
- Turn the disc, so the screen is facing up.
- Position tubing so end of tubing is at the same level as the top of the screen. Open the tubing, and slowly lower the end of the tubing. Watch for air bubbles to appear below the screen. Air bubbles should start appearing when the open end of the tubing is 25-30 cm below the level of the screen. This is the bubbling pressure of the nylon fabric.

If air bubbles appear when the tubing outlet is less than 25 cm below the screen level, then there is a leak in the screen. Replace the screen, making sure no loose particles are lodged between the screen and the screen support, or between the o-ring and the screen.

APPENDIX I

Elevation of the water tower and disc

In the sample calculations shown in the manual it was assumed that the bottoms of the disc and the water tower are at the same elevation. In order to make sure that the bottoms of the disc and the water tower are at the same elevation in the field, a simple carpenters level can be used as shown in the picture below. Support one end of the level on the disc, and the other end on the small adjustable support block attached to the water tower. Increase or decrease the elevation of the water tower by removing or adding soil till the air bubble in the horizontal level glass is between its two lines. Note that the support block attached to the water tower can be adjusted up or down a small distance. The reason for this is that commercially available acrylic does not always have the same thickness. To correctly set the small adjustable support block, place the water tower and the disc on a clean level surface. Then using a carpenters level, adjust the support block on the water tower up or down until the carpenters level is perfectly level. Tighten the setscrew, and from this time on no further adjustments need to be made to the small support block.

Notes

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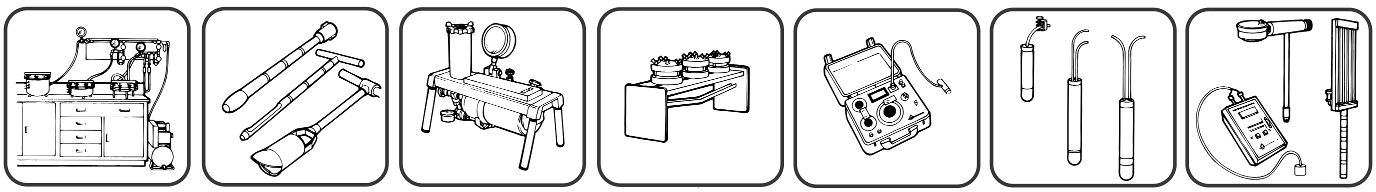

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