Tension infiltrometer enhancements with automated pneumatic control and more durable base plate

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Received 4 April 2008; accepted 14 January 2009; published 13 May 2009.

[1] Measurement of soil hydraulic retention and conduction parameters using tension infiltrometers has been found to be useful but has suffered from unreliable instrument membranes at the soil interface and the need for manual control, which limits the range of boundary conditions that can feasibly be established. An automated design is presented that is capable of maintaining time-varying pressure and flux using high-speed computer-regulated pneumatic valves. Further, a durable stainless steel supply membrane designed to withstand multiple uses under harsh field conditions with bubbling pressure head <-0.60 m H_2O is demonstrated.

Citation: Selker, J. S., J. D. Suter, R. H. Cuenca, B. A. Flugstad, and S. F. Kelly (2009), Tension infiltrometer enhancements with automated pneumatic control and more durable base plate, *Water Resour. Res.*, *45*, W00D37, doi:10.1029/2008WR007075.

1. Introduction

[2] Using well known mathematical models [e.g., *Wooding*, 1968; *Philip*, 1969], data from tension infiltrometers can be used to obtain values for sorptivity, saturated hydraulic conductivity, and the Gardner sorptivity parameter, α [*Gardner*, 1958; *Cuenca et al.*, 1996, 1997]. Most contemporary infiltrometers make use of two main mechanical components: a Marriott column to maintain pressure, and a woven nylon membrane to allow water to permeate while preventing air entry into the instrument. The bubbling column regulation method is used because of its simplicity and utility in maintaining a nearly constant tension [*Clothier and White*, 1981; *Ankeny et al.*, 1988]. This approach has several limitations, most notably that the pressures must be manually adjusted, and the widely discussed pressure oscillation due to the release of bubbles from the air inlet tube [*Constantz and Murphy*, 1987; *Ankeny et al.*, 1988; *Ankeny*, 1992; *Casey and Derby*, 2002]. Proposed solutions have reduced noise in the recorded signal, however the variation in the actual base plate pressure remains, often greater than ± 0.01 m of head. This is problematic since many tests are run with > -0.05 m head, leading to significant uncertainty. A solution that would provide more constant pressure would be desirable.

[3] The nylon membranes frequently fail under field conditions, usually due to puncture by sharp soil particles. For example there was a 25% mechanical failure rate for tests attempted in the 230 tension infiltrometer tests of the BOREAS experiment, greatly decreasing productivity [*Cuenca et al.*, 1997]. Most of these failures were due to membrane bubbling, often at locations where no visible damage had occurred, but could only be staunched by the replacement of the membrane. We describe an infiltrometer allowing automated readjustment of boundary conditions, either being prescribed or based on the progress of the experiment, with a membrane that is robust and which can withstand repeated field deployment without failure.

2. Infiltrometer Design

[4] The water supply and pressure measurement system consists of inner and outer water columns connected via interface ports at the top of the columns to pressure transducers and high-speed (response time of approximately 0.001 s) electronically controlled pneumatic (air) reed valves located inside the control unit (Figure 1 and Figures S1 and S2 in the auxiliary material).[1] Transducers measure the air pressure at the top of each column. Air entry is controlled into each of the columns via valves in the control unit. Employed together, these allow both measurement and control of the pressure at the soil interface versus time during infiltration tests. As an example the inner column can be used to measure the tension or pressure at the soil interface (base plate) by maintaining a known fixed water level in that inner column during the tests and simultaneously measuring the tension at the top of that column. In that scenario infiltration would occur via the water level dropping in the outer column while the water level is held fixed in the inner column. This approach allows the user to preprogram the device to establish a sequence of fixed or variable outflow rates, providing an entirely new level of operational flexibility compared to the current manually adjusted systems.

[5] Before starting an infiltration test the ball valve is opened with the air valves closed, filling the base plate with water. The pressure measurements are then zeroed by dipping the base plate in water and recording the transducer values at the top of each column. In the infiltration test,

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0043-1397/09/2008WR007075

[1]Auxiliary materials are available in the HTML. doi:10.1029/2008WR007075.

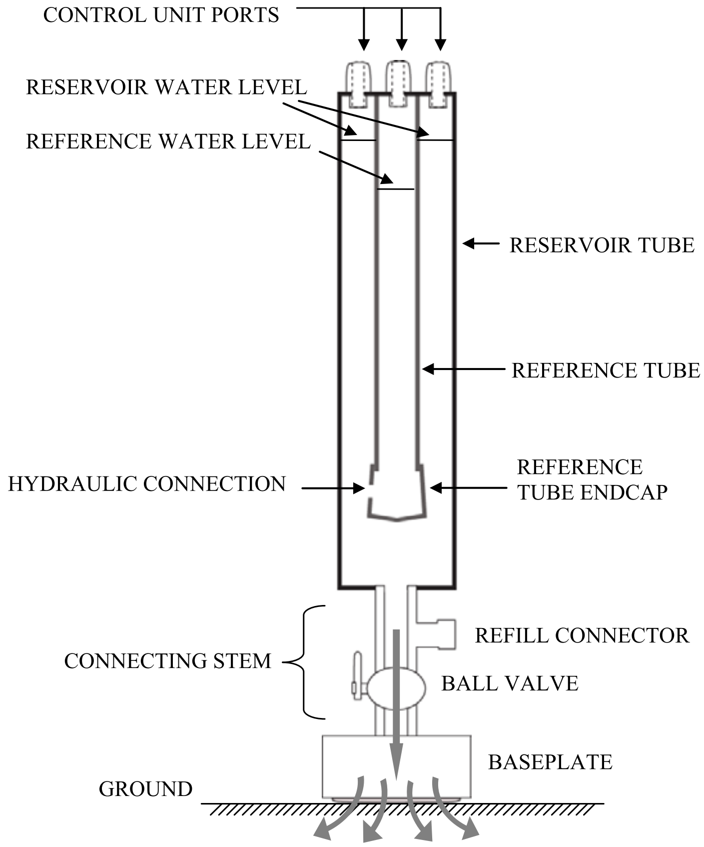

Figure 1. Infiltrometer components. The pneumatic valves are attached to the control ports either directly or via tubing. The contact area of the screen employed here was a circle of 8.5 cm diameter.

the pneumatic (air entry) reed valve is opened for 1–100 ms intervals into the column providing the infiltration to establish and maintain the desired base pressure as monitored by the other column. As is the case in the Marriott designs, water delivery is determined by the difference in pressure between the reference and reservoir. The capacity of the system as constructed was 2 L. The control module employed in these tests was a field-portable microprocessor controlled unit with a 0.05×0.07 m display screen that ran for 24 h on one charge of a 7A-h battery.

3. Base Plate Design

[6] Our objective for the base plate design was to provide an easily constructed device with < -0.5 m bubbling pressure, that offers no resistance to flow, with contact membrane which could reasonably be expected to be serviceable for

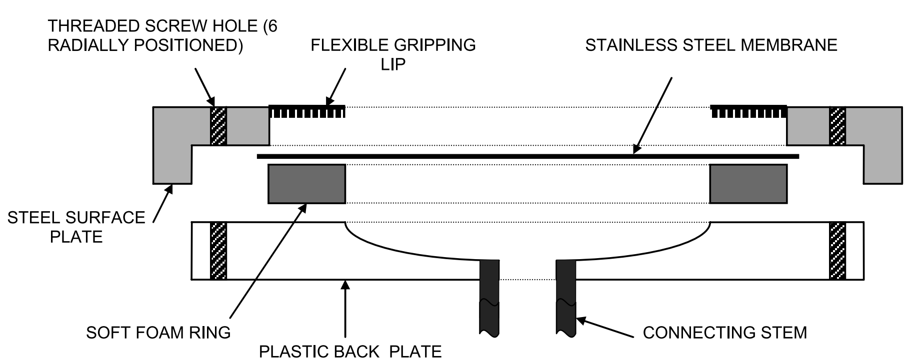

Figure 2. Base plate design showing screw assembly and serrated gripping lip. Note that the compression plate is shown prior to assembly. When assembled, the flexible gripping lip is in firm contact with the membrane, both pressing it against the rubber and holding it from slipping as it is tensioned. The unit used to generate the data shown has an overall diameter of 0.18 m, a contact diameter of 0.090 m, and a thickness of the entire device of 0.028 m.

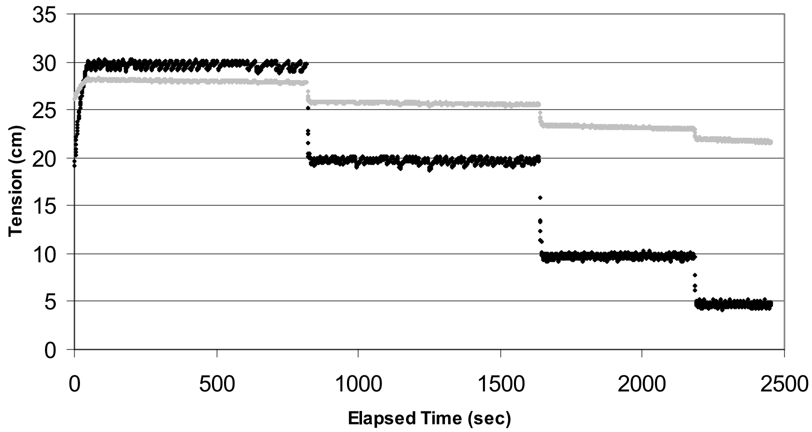

Figure 3. Test results from experiment carried out in a 50–1 drum packed with Willakenzie silt-loam soil: negative pressure head (tension in cm) over time at membrane (black diamonds) and 0.2 times the reservoir head space pressure (gray diamonds), from which the delivered volume is computed. Data points are separated by 1 s. The rate of infiltration is computed from the slope of the reservoir pressure via the density of water and surface area of water in the reservoir.

>100 tests without degradation from specified performance. The base plate designs employ 18 micron absolute 165 × 1400 T-316 Stainless Steel ANSI/ASTM A555-79 Twill Dutch Weave filter cloth (Toyota Corporation). The metal cloth is tensioned by successively tightening an aluminum disk (AD) against a compressible rubber gasket (Figures 2 and S1). This method never failed our performance and durability tests (zero failures after several years of use), but required considerable precision machining (about 10 h). *Castiglione et al.* [2005] employ a competing approach for tension infiltration, the use of 0.32 cm thick fritted stainless steel. This product has mean pore size of two 2×10^{-7} m, so the typical flow path to traverse the plate crosses on the order of 3.22×10^{-3} m/22×10^{-7} m = 10,000 pores. Contrary to this, the woven mesh has flow paths with exactly one pore to traverse. This is the price of making the membrane rigid, which we achieve by tensioning over a rigid perforated plate. The mean pore size of the woven product is 10^{-5} m. This hundredfold larger size for the same bubbling pressure is allowed because the pores are completely regular in shape, whereas the fritted steel has randomly distributed pore size, requiring the mean aperture to be many standard deviations smaller than that dictated by the bubbling pressure. Since resistance to flow is proportional to the mean pore size squared, having pores 50 times larger provides and additional factor of 2,500 in permeability of each pore. This, in addition to the path length difference, means that the woven screen is over 10^8 more permeable than the fritted plate, so that water poured on the screen passes through unimpeded, while the fritted plate has significant pressure loss under common flow rates.

4. Results and Discussion

[7] The base plate consistently held pressure head < −0.6 m. To maintain this performance it is necessary to periodically wash the screen with hot soapy water and rinse to remove contamination. A 2500 s experiment was conducted and programmed using the automated control system to establish a stepped profile versus time of −0.30, −0.20, −0.10, and −0.05 m pressure heads (Figure 3) in a silt-loam soil. Pressures were quickly attained (<20 s between pressures). Upon commencing measurement the device can take some time to come to the set pressure as the soil withdraws sufficient water from the device to reach the set pressure (Figure 3). This can be avoided by pretensioning the system by either briefly setting it on a dry towel, or pulling out some air from the reservoir port. When the set point is reached, the valves will open to establish the desired pressure. The standard deviation at each pressure head was approximately 0.003 m. While better than that recorded by *Ankeny et al.* [1988], we believe there is opportunity for improvement through further development of the control algorithm controlling the air entry valve. The new design provides more flexible control of tension infiltrometer boundary conditions, and improves field serviceability because of improved base plate durability.

[8] **Acknowledgments.** We thank the Oregon Experiment Station and the USDA SBIR program for support of this research and the three anonymous reviewers for their helpful suggestions.

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