In situ permeability measurement with the BAT Permeameter

BAT®
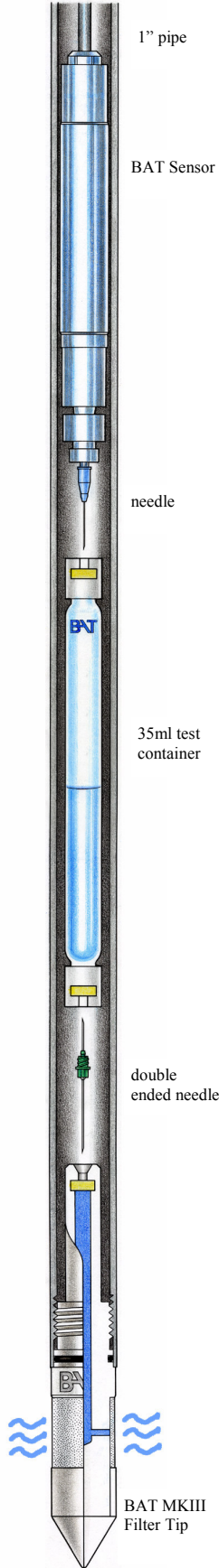
Contents

System description

The BAT Permeameter is used for in-situ measurement of soil permeability. The method used for evaluation of the coefficient of permeability k is of the type "falling head"-test. Depending on the groundwater situation, unsaturated or saturated zone, the test can either be done as an inflow or outflow test. Volume changes in the system are calculated based on measured pressure changes and by using Boyle´s law.

1" pipe

BAT Sensor

inflow test

outflow test

needle
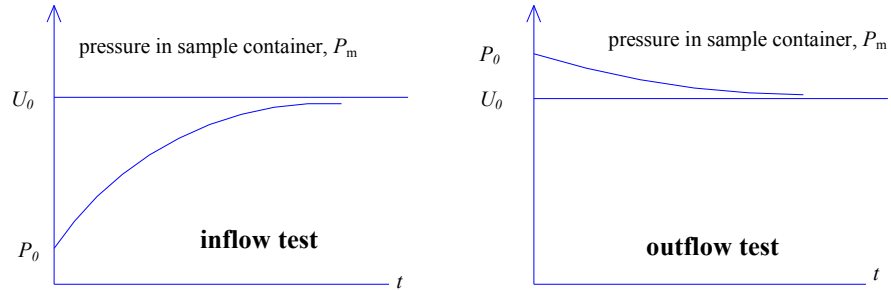
Calculation of the coefficient of permeability , k

The calculation of the out- or inflow volume in the sample container is made by using Boyle´s law as follows:

$$P_0V_0 = PV \quad \text{N.B. } P \text{ represents absolute pressure} \tag{1}$$

(After completion of the test, the actual out- or inflow volume can also be measured. The quality of the test can thus be checked by comparing the measured and calculated volumes).

35ml test container

The permeability coefficient, k, is calculated using the following equation:
(Bengtsson, P-E, 1984; Torstensson & Petsonk, 1986)

$$k = \frac{P_0V_0}{F \cdot t \cdot 10^3}\left(\frac{1}{U_0P_0} - \frac{1}{U_0P_m} + \frac{1}{U_0^{\,2}}\ln\left(\frac{P_0 - U_0}{P_0} \times \frac{P_m}{P_m - U_0} \right) \right) \tag{2}$$

in which:

k	coefficient of permeability	[m/s]
P_0	initial system pressure	[m H_2O]
V_0	initial system volume of air	[ml]
F	form factor of filter	[mm]
t	time for the test	[s]
U_0	pore pressure at equilibrium	[m H_2O]
P_m	system pressure at time t	[m H_2O]
V_t	system volume of air at time t	[ml]

double ended needle

The equation for the form factor F of the filter element is as follows:

$$F = \frac{2\pi d}{\ln\left(\frac{l}{d} + \sqrt{1 + \left(\frac{l}{d}\right)^2} \right)} \quad \text{where} \quad \begin{array}{ll} l = & \text{length of filter} \quad \text{[mm]} \\ d = & \text{diameter of filter} \quad \text{[mm]} \end{array} \tag{3}$$

For the BAT MKIII Filter Tip shown to the left the form factor is $F = 230$ mm. ($l = 35$mm, $d = 31{,}5$mm)

Time for stabilization - time of testing
The k-value can be computed at any time.

The BAT system makes use of only small volume changes. Thus the test can be carried out quickly.

Typical stabilization times, t_{stab}, as a function of the k-value are summarised below.

$k \approx 10^{-7}$ m/s ; $t_{stab} \approx 1$ minute
$k \approx 10^{-8}$ m/s ; $t_{stab} \approx 10$ minutes
$k \approx 10^{-9}$ m/s ; $t_{stab} \approx 1$ hour
$k \approx 10^{-10}$ m/s ; $t_{stab} \approx 10$ hours

BAT MKIII Filter Tip
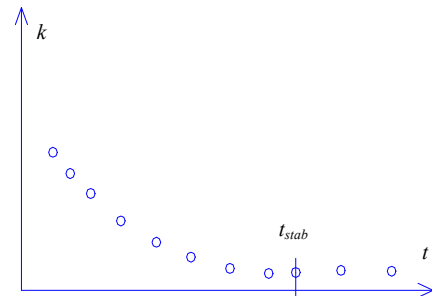
**System layout
(in- or outflow test)**

Theory of the BAT Permeability Test

´The BAT Permeability Test is a type of "falling head" test. The evaluation of the test is made by using Hvorslev´s equation [*)].

Parameters:

F	= Hvorslev´s flow factor	mm
k	= coefficient of permeability	m/s
U_0	= equilibrium pore pressure in-situ (absolute)	m H_2O
P_0	= initial system pressure (absolute)	m H_2O
P_m	= system pressure at time t (absolute)	m H_2O
V_0	= initial system volume of air	ml
t	= time for the test	s

At any time t the corresponding coefficient of permeability k can be calculated using the following equation (see foregoing page):

$$k = P_0 \cdot V_0 /(F \cdot t \cdot 10^3) \cdot \{1/U_0 \cdot P_0 - 1/U_0 \cdot P_m + 1/U_0^2 \cdot \ln[(P_0 - U_0)/P_0 \cdot P_m/(P_m - U_0]\} \qquad (4)$$

This equation has been derived, based on the following assumptions:

Constant temperature
It has been assumed that the temperature of the test equipment remains constant during the test. This means that Boyle´s law is applicable:

$$P_0 \cdot V_0 = P \cdot V \text{ (constant)} \qquad \text{Boyle´s law} \qquad (5)$$

For installation depths, greater that one meter below ground surface this condition is normally fulfilled.

For shallow installation depths, however, significant temperature changes of the testing equipment can occur during the test. In this case the general gas law would be applicable:

$$P_0 \cdot V_0 / T_0 = P \cdot V / T \text{ (constant)} \quad \text{general gas law} \qquad (6)$$

      in which: T = absolute temperature

The BAT Permeameter also contains a temperature sensor. Generally, the temperature shall always be measured simultaneously with the pressure measurements.

Contact BAT Geosystems for information on performing calculations, which consider the effect of temperature variation of the test equipment. (see "Literature" A.J.G. Schellingerhout, 2000. *Theory of the BAT permeability test*).

Pressure head
The above calculations do not take into account the effect of the column of water, present within the system, nor its variation during the test. Normally, that is, when large pressure differences are used, this has a negligible effect on the evaluation of permeability data.

For small pressure differences, however, this factor must be considered. Contact BAT Geosystems for information on performing calculations using such a method.

Evaluation of k - value
The coefficient of permeability, k , can normally be evaluated at a pressure equalization (pressure dissipation or pressure recovery) within the interval of 50-80%. The corresponding system pressure is denoted P_{50} and P_{80} respectively. Reference is made to "Protocol sheet" and "Excel calculation sheet". It is recommended not to evaluate the k-value beyond a pressure equalization of 80%.

[*)] Hvorslev, M.J. 1951. Time lag and soil permeability in ground water observations. Corps of Engineers, Waterways

BAT Permeability Testing – Some practical aspects and recommendations

Field of use
The BAT Permeameter can be used for in-situ permeability testing under both unsaturated and satu-rated soil conditions.

Inflow test – saturated soil conditions
Under saturated soil conditions it is recommended to perform the BAT Permeability test as an *inflow test.* The inflow test starts with an empty Test container, having an initial pressure P_0 which is smaller than the existing porewater pressure U_0 at the depth of testing.

The initial system pressure P_0 is applied in the Test container either by injecting or extracting a volume of air, ΔV_{air}, to/from the Test container.

Note: P_0 & U_0 represent absolute pressures.

Outflow test – unsaturated soil conditions
On the other hand, under unsaturated soil conditions, the BAT Permeability test must be performed as an *outflow test*.

The outflow test starts with a partly water-filled Test container, having an initial pressure P_0 which is higher than the existing porewater pressure U_0 at the depth of testing.

When conducting an outflow permeability test it is very important to consider **the risk of hydraulic fracture** in the soil surrounding the filter, in case a too high initial system pressure P_0 is applied. Hydraulic fracturing of the soil surrounding the filter tip will give misleading results of the permeability testing. The selection of P_0-values for permeability testing under unsaturated soil conditions is discussed in APPENDIX 1.

Permeability testing of compacted clay liners
The BAT Permeameter has been extensively used for permeability testing of compacted clay liners.

For compacted clay liners, normally unsaturated conditions are prevailing. Experience from this type of testing has shown that the initial porewater pressure (equilibrium pore pressure) U_0 can vary within the interval of approximately 1 – 10 m H_2O (absolute pressure).

The selection of P_0-values for permeability testing under these conditions is discussed in APPENDIX 1.

Range of *k*-values
The upper limit for the *k*-value that can be tested with the BAT Permeameter is determined by the flow-capacity of the double-ended needle.

In combination with BAT MkIII Std filter tip the flow capacity of the double-ended needle gives an up-per limit for the measureable *k*-value of $1 \cdot 10^{-6}$ m/s.

However, in order to avoid the risk misinterpretation of test data it is recommended to apply the BAT Permeameter testing only for *k*-values which are smaller than $1 \cdot 10^{-7}$ m/s. In other words, the BAT Permeameter is recommended to be used in the range of
$k \leq 1 \cdot 10^{-7}$ m/s.

Contact BAT Geosystems for further information, regarding permeability testing in soils, having *k*-values higher than $1 \cdot 10^{-7}$ m/s.

BAT Permeability Kit, art.no. 3-300.

The BAT Permeability kit contains supplementary equipment which combines with the BAT Pore Pressure kit for making in-situ permeability testing.


Complete system:

- BAT/IS-sensor #1-200
- o-ring 12.7x1.6mm #3-204
- Plexi-adapter #3-201
- o-ring 6.35x1.78mm #3-204
- Transfer nipple #3-202
- Blue needle #4-401
- Extension adapter
- Test container housing
- Test container
- Double ended needle N.B. Remove the small rubber guard
- Quick coupling Spring 0.75x9x15mm
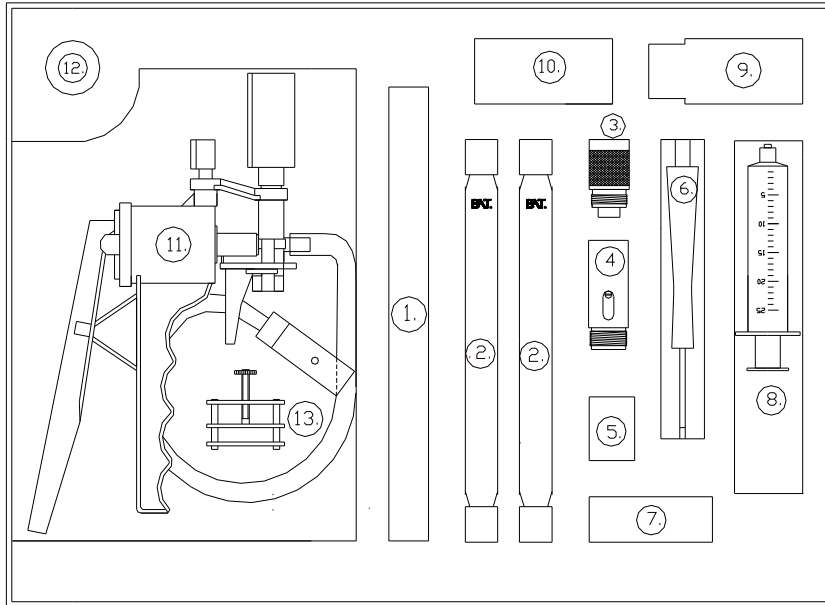
Contents:

|		Article no:
1.	Test container housing	# 3-302
2.	Test container (35 ml)	# 3-303
3.	Extension adapter	# 3-304
4.	Quick coupling sleeve	# 3-305
5.	Spare screws and springs	# 3-307
6.	Screwdriver for mounting of double ended needle	# 3-308
7.	Spare septas	# 3-306
8.	Syringes (25 ml & 10 ml)	# 4-404
9.	Container for used needles	# 5-110
10.	Double ended needles	# 4-403
11.	Vacuum pump with Manometer(see APPENDIX 1 for use of the Vacuum Pump)	# 3-309
12.	Blue needles	# 4-401
13.	Cable Clamp	# 3-310
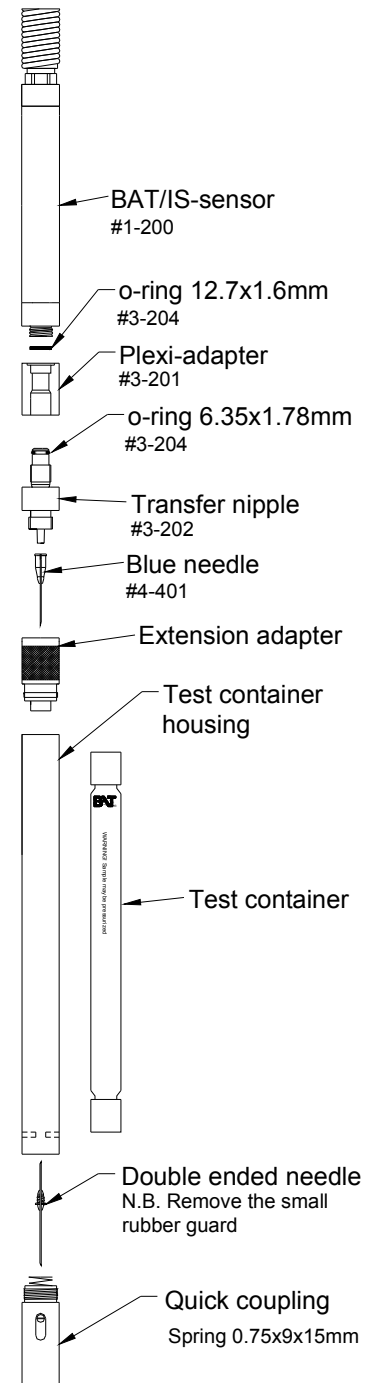
PRECAUTIONS

- Handle all parts carefully, especially the glass containers.

- Use only sharp needles. In general do not re-use needles, especially in case the set is used for sampling.

- Store the set in a dry and safe place.

- Do not use any tools to assemble the set. Finger tight is enough.

Preparations for a test

Procedure

- Use the BAT Test Protocol to fill in required information, see APPENDIX 2 & 3

- Measure the actual **absolute** pore pressure, U_m. Remember to add 0.2 mH$_2$O to the measured value, $U_0 = U_m + 0.2$ (see Test Protocol).

- Measure the atmospheric pressure using the Field Unit and note the pressure in the protocol. Start logging the air-pressure using the Field Unit´s internal sensor. An interval of 1 hour is recommended (see BAT Pore pressure manual page 6 & 7).

- Before lifting the sensor the following procedure is recommended:

  - Firstly, attach the cable clamp to the cable in order to mark the depth of filter tip installation.
  - Secondly, Lift the cable about 1 m, loosen the cable clamp and move it 0.5 m downwards and attach the clamp firmly to the cable.
  (NB. The cable clamp is used at a later stage, to hold the cable in the 1"- pipe during temperature stabilization of the Permeameter equipment just before the starting a permeability test, see "Temperature equilibrium").

- Lift the sensor out of the 1"-pipe for assembly and preparation of the permeability test equipment.

- ***Assemble and prepare*** the permeability test equipment as shown on **Page 6**. See also APPENDIX 1.

cable clamp

cable

1"pipe
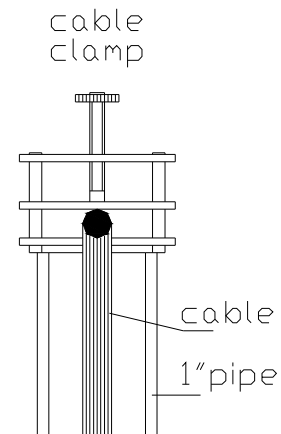
Temperature equilibrium

- Firstly, make sure that the Battery unit of the sensor contains a fresh, alkaline battery.

- Lower the test equipment down the 1"-inch pipe until the cable clamp rests on the top of the pipe. This will hold the cable steady and keep the equipment at its present depth, without being connected to the BAT Filter Tip.

- The test equipment must be kept at this position until it has taken on the temperature of the surrounding soil/groundwater.

- Start the IS Field Unit in *Display* mode. The pressure change in test container, caused by the temperature change, can then be monitored on the Display of the Field Unit.

- Depending on the specific conditions the time needed for reaching temperature equilibrium varies between 5 to 30 minutes. Normally, it is sufficient to wait 15 minutes for the temperature stabilization of the test equipment.

Starting a test
The equipment is now ready for starting a permeability test. See page 7 for details about the procedure for starting a test.
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Assembly of Test equipment

Transfer nipple & extension adapter
- screw the transfer nipple until it seats in the plexiadapter. Firstly, make sure the parts all are dry.
- Attach a blue needle onto the transfer nipple.
- Mount the extension adapter onto the transfer nipple.

Test container
Outflow test - unsaturated soil conditions
- Open the test container in one end by removing the screw cap and the septum.
- Fill the test container with a selected volume of water, using a syringe. See APPENDIX 1 for more details.
- Close the test container. Finger tight is enough!
Inflow test - saturated soil conditions
- For an inflow test, make sure the test container is dry. See APPENDIX 1 for more details.

Container housing assembly and connection of IS Field Unit
- Carefully insert the test container into the container housing.
- Screw the extension adapter onto the open end of the container housing .
- Connect the IS Field Unit, choose Display Mode (see page 7).
- The pressure in the test container can now be measured with the IS Field Unit (see also APPENDIX 1). After assembly hold the test unit horizontal or pointing downwards.

Application of initial system pressure P_0
Outflow test
- The initial system pressure P_0 is applied by injecting or extracting a volume of air, ΔV, to/from the test container, using a syringe, equipped with a blue, hypodermic needle. The applied pressure P_0 is directly displayed by the IS Field Unit.
- For calculation of P_0 and ΔV , see APPENDIX 1.
Inflow test
- For an inflow test a volume of air, ΔV, is either extracted or injected from/to the test container, see APPENDIX 1.

N.B. Normally, when the test equipment is lowered down the extension pipe the temperature will drop. Accordingly the applied initial pressure will be changed. For example a temperature drop of $10^{o}C$ will reduce the applied intial pressure P_0 by about 5%.

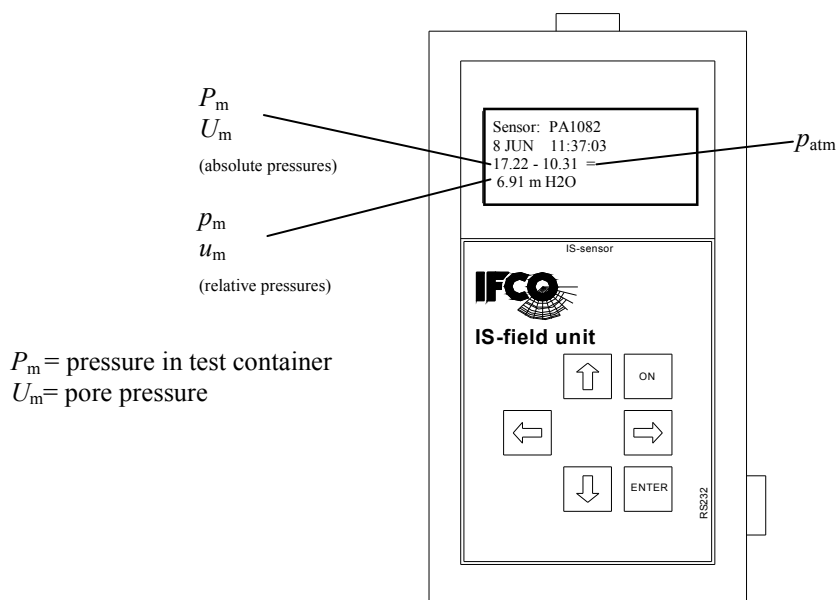**Double ended needle & Quick coupling sleeve**
- Prepare the double ended needle for mounting. N.B. Remove the small rubber hose.

- By using the needle adapter in the handle of the screwdriver, screw the double ended needle until it seats into the quick coupling sleeve. IMPORTANT! Make sure that the needle seats properly in the thread.

- Finally, screw the quick coupling sleeve onto the container housing.

- DONE!

Performing a permeability test - automatic logging of time & pressure

- Make sure that the battery unit of the sensor contains a fresh, alkaline battery.

- Prior to the start of the test, prepare the Field Unit by opening the "Start Measure" menu. Select both *sensor* and *temperature* logging (sensor+temp) and a suitable time interval. To start with it is recommended to use 1 min logging interval. At a later stage of the test the logging interval can be changed (increased) without any inteferece with the ongoing logging of test data.

- If the "clear data"-box is checked, another submenu may occur when selecting OK for *Start measure*. In case there are unsaved data in the sensor, you are given a reminder whether you want to overwrite these data or not. If not, press *Cancel* and choose to *Download data* to the IS Field Unit. Do this operation just before the start of the test. ´

- Thereafter, return once more to the "*Start Measure*" menu and just place the marker on the OK-option, without starting the logging.

- The next step is to connect the test equipment to the BAT Filter Tip. Thus, remove the cable clamp and gently lower the equipment the remaining 0.2 – 0.3 m down to the Filter Tip. At the same moment the equipment connects to the Filter Tip, press OK on the Field Unit and the test is running. Open the "*Display*" menu of the Field Unit to have a visual check that the test is running, i.e the pressure shall gradually change. During the test, the system pressure can be manually monitored on the display of the Field Unit, simultaneously to the automatic logging.N.B. The logging of test data will be running without the Need for the IS Field Unit to be connected.

- Depending on soil type the testing time may vary from 5 minutes up to 24 hours or more. After about one hour the measuring interval of the sensor can be increased to 10 minutes or more. This is simply done by activating the "*Start measure*" function of the IS Field Unit and select a new logging interval.

- The test can normally be evaluated at a pressure equalization of 50-80% (P_{50} - P_{80}). Before finishing the test take a reading of the atmospheric pressure and fill in the value in the Test Protocol

- Remove the BAT Permeameter, disassemble the equipment and measure the volume of water, V_{end} ,in the test container, using a syringe. Fill in the value of V_{end} in the Test Protocol.

- For processing of measurement data, reference is made to both page 9 the information given on the enclosed CD.

P_m
U_m
(absolute pressures)

p_m
u_m
(relative pressures)

Sensor: PA1082
8 JUN   11:37:03
17.22 - 10.31 =
6.91 m H2O

p_{atm}

IS-sensor

IFCO

IS-field unit

⇧ ON

⇦ ⇨

⇩ ENTER

RS232

P_m = pressure in test container
U_m = pore pressure

Manual readings of time and pressure
Manual readings of time and pressure can also be used for evaluation of the permeability. Use the Test Protocol shown in APPENDIX 4 to fill in the test data. These data can then be manually inserted in the Excel-sheet shown on Page 9 for calculation of the coefficient of permeability.

Computer processing of measurement data

	A	B	C	D	E	F	G	H	I	J	K
1	Permeability test in situ with the BAT-system										
2	Outflow test										
3	Note! All pressures are absolute pressures in Pa resp m H2O										
4											
5	Site	site					In these columns you paste				
6	Point	point					data from the logger				
7	Date	date									
8	Installation depth of filtertip	meter/inches					Orange cells are manual				
9	BAT/IS sensor no.	PAXXXX					input cells				
10							yellow cells are output cells				
11	Length of filter, mm	35	(Standard Mk III = 35 mm)	(Cheramic filter =35 mm)							
12	Diameter of filter, mm	25	(Standard Mk III =31,5 mm)	(Cheramic filter =25 mm)							
13	Flow factor, mm	193,2									
14	P_0, m H2O	14,007	Initial system pressure								
15	V_v, ml	10	Initial liquid volume								
16	V_0, ml	25	Initial air volume								
17	U_0, m H2O	12,20	Equlibrium pore pressure								
18	Initial air pressure, mH_2O	9,86									
19	Final air pressure, mH_2O	9,90									
20	starting temperature, K	278,9									
21	P_{end} m H_2O	12,45	Final system pressure								
22	V_{calc}, ml	6,87	Calculated volume remaining after test								
23	V_{end}, ml	6,62	Measured volume remaining after test								
24	P_{80}	12,56	It is not neccessary to run the test further when reaching this pressure								
25	P_{50}	13,10	At this pressure a relevant value of the permeability is given								
26	Date	Time	Pressure	Temp, T	Time elapsed	Time elapsed	eff Pressure	Remaining volume	Permeability	Temp T	T0/Tt
27			Pa	*C		seconds	m H2O	of water in vial, ml	k [m/s]	Kelvin	
28	*	*	*	*							
29	2006-03-29	12:26:59	1,37E+05	5,9	00:00:00	0	14,01	10,00	########	278,9	1
30	2006-03-29	12:30:00	1,34E+05	6	00:03:01	181	13,65	9,34	1,16E-08	279	0,9996
31	2006-03-29	12:35:00	1,32E+05	6,1	00:08:01	481	13,46	8,98	7,27E-09	279,1	0,9993

This is the Excel-sheet used for data-processing of the measured values for an outflow test. In the orange cells you fill in information such as site, depth and date etc. Further down in the sheet you fill in the filter diameter (depending on type of filter tip), starting volume, equilibrium pore pressure, U_0 , and initial system pressure, P_0 (all absolute values from the protocol sheet). The initial and final values of the atmospheric pressure P_{atm}, shall also be filled in.

In the A ,B,C and D-column at row 28 the values from the IS-sensor are pasted. Please refer to the BAT Pore Pressure manual for how to obtain these sensor data.

Copy and paste the other columns to fit the IS-sensor data. N.B. If logging is continued overnight, a manual input for the E-column is needed at the midnight value. The formula that calculates the time elapsed from the previous measurement has to be changed as explained in the example below:

> Say that midnight occurs at row 42. The time is 00:00:00 (B42) which cannot be used as a reference in calculations by Excel. The formula in E42 is "E41+(B42-B41)" and by changing "B42-B41" to "B41-B40" this problem is solved.

At the bottom of the sheet, the tabs for the pressure/time curve and permability/time curve are found. Adjust these diagram to fit the actual length of the set of data.

Pressure - Time diagram / Perm - Time diagram / Calculation sheet /

Maintenance and trouble shooting

General recommendations regarding maintenance:

Before a longer period of storage always

- unscrew the quick coupling sleeve, remove and clean the moving parts inside if necessary
- unscrew the container housing, clean if necessary
- unscrew the extension adapter
- remove all needles (it is recommended not to re-use the needles)
- unscrew the caps of the test container and make sure the parts are dry

Trouble shooting:

Problem			Possible cause			Solution		
The pressure will not change when starting the test			The double ended needle has been bent			Exchange needle		
The pressure will not change when starting the test			Obstacles or dirt in the 1" pipe			Try to clean the pipe or in the worst case, reinstall the filter tip		
The system pressure, Pm, drops without being connected to the filter tip			Leakage in the test container			Clean the rubber septas or change if necessary Tighten the screw caps		
The system pressure, Pm, drops without being connected to the filter tip			Leakage between sensor and plexi adapter or between transfer nipple and plexi adapter			Remove the plexi adapter, clean and change the o-rings and clean the surfaces		

For eventual problems with the Field Unit or the sensor, please refer to the Pore Pressure Guide.

Initial system pressure P_0

The initial system pressure P_0 is applied in the test container either by injecting or extracting a volume of air ΔV to/from the test container.

This operation is made, using a syringe, equipped with a blue hypodermic needle.

The BAT Permeability test can be combined with a simultaneous collection of a porewater sample for chemical analysis. In this case, it is recommended to evacuate the test container by using the hand vacuum pump for creating highest possible vacuum. Maximum achievable vacuum using the hand pump is in the order of 95% .

Unsaturated soil conditions & negative pore pressure situation
OUTFLOW TEST

For unsaturated soil conditions the BAT Permeability test must be carried out as an outflow test. It is also assumed that a negative pore pressure situation is prevailing, i.e.:

$$U_0 \leq p_{atm} \tag{7}$$

in which U_0 = equilibrium pore pressure (absolute pressure) m H_2O)
p_{atm} = atmospheric pressure (m H_2O)

This condition is normally prevailing for *compacted clay liners*.

The outflow test starts with a partly water-filled Test container.

For the outflow test it is recommended to use the BAT MkIII Vadose Filter Tip. This filter tip has a fine porous ceramic filter which makes possible to measure negative pore pressures down to about 1 m of H_2O absolute pressure (i.e. ≈ 90% vacuum).

In order to create a suitable outflow gradient in the partly water-filled container, an over-pressure is created by injection of a volume of air, ΔV_{air}, into the test container. It is in this connection very I mportant to consider **the risk of hydraulic fracture** in the soil surrounding the filter, in case a too high initial system pressure P_0 is applied. Hydraulic fracturing of the soil surrounding the filter tip will give misleading results of the permeability testing.

Depending on the magnitude of the equilibrium pore pressure U_0 the following initial system pressures P_0 are recommended:

Equilibrium pore pressure interval (m H_2O):	$9 < U_0 \leq p_{atm}$	$8 \leq U_0 \leq 9$	$1 \leq U_0 < 8$
Recommended initial system pressure (m H_2O):	$P_0 = 1{,}1 \cdot U_0$	$P_0 = 1{,}25 \cdot U_0$	$P_0 = p_{atm}$

NB: All pressures are in absolute values.

Initial water volume ΔV_{H20}

Porewater pressure interval $8 \leq U_0 \leq p_{atm}$
For the porewater pressure interval of $8 \leq U_0 \leq p_{atm}$ the test container is filled with <u>10 ml of water</u>ΔV_{H20}.
Thereafter the the initial system pressure P_0 is applied by injection of a volume of air, ΔV_{air}, into the test container with the aid of a syringe.

Porewater pressure interval $1 \leq U_0 < 8$
For the porewater pressure interval $1 \leq U_0 < 8$ the volume of water, ΔV_{H20}, filled into the Test container, is a function of the equilibrium pore pressure. The water volume, ΔV_{H20}, can be calculated as follows:

$$\Delta V_{H20} \approx (35 - 3{,}1 \cdot U_0) \quad (ml) \tag{8}$$

Thereafter the initial system pressure $P_0 = p_{atm}$ is simply applied by puncture the septum with a vented, blue needle.

Saturated soil conditions & positive pore pressure situation
INFLOW TEST

For saturated soil conditions it is recommended to carry out the BAT Permeability test as an inflow test. It is also assumed that a positive pore pressure situation is prevailing, i.e.:

$$U_0 > p_{atm} \tag{9}$$

in which U_0 = equilibrium pore pressure (absolute pressure) (m H_2O)
     p_{atm} = atmospheric pressure (m H_2O)

The inflow test starts with an empty Test container.

For the inflow test it is recommended to use either the BAT MkIII Std Filter Tip or the BAT MkIII SS Filter Tip.

Recommended pressure head difference
In order to create a suitable inflow gradient, it is recommended to apply an *initial pressure head difference ΔP of 5 m H_2O*:

$$P_0 = (U_0 - \Delta P) \tag{10}$$

in which ΔP = applied head difference ~ 5 m H_2O
     U_0 = equilibrium pore pressure (absolute pressure) (m H_2O)
     P_0 = initial system pressure (absolute pressure) (m H_2O)

Depending on the magnitude of U_0, this head difference is created either by injecting or extracting a volume of air, ΔV_{air}, to/from the Test container. ΔV_{air} can be calculated using Boyle´s law.

a) Porewater pressure interval : $p_{atm} \leq U_0 \leq 15$ m H_2O
For the porewater pressure interval of $p_{atm} \leq U_0 \leq 15$ m H_2O, the initial pressure in the test container, P_0, is applied by <u>extracting</u> a volume of air ΔV_{air} from the test container as given by eq. (11):

$$\Delta V_{air} \approx 35(15 - U_0)/(U_0 - 5) \quad \text{(ml)} \tag{11}$$

b) Porewater pressure interval : $U_0 > 15$ m H_2O
For the porewater pressure interval of $U_0 > 15$ m H_2O the initial pressure in the test container, P_0, is applied by <u>injecting</u> a volume of air ΔV_{air} into the test container as given by eq. (12):

$$\Delta V_{air} \approx 3,5(U_0 - 15)(\text{ml}) \tag{12}$$

A typical pressure recovery curve from an inflow test is shown in Figure 1.

Combined permeability testing and discrete sampling of porewater
The BAT Permeability test can be combined with a simultaneous collection of a porewater sample for chemical analysis.

In this case, it is recommended to evacuate the test container by using the hand vacuum pump for creating highest possible vacuum. Maximum achievable vacuum using the hand pump is in the order of 95% .
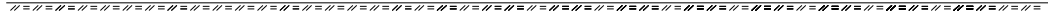
The logged pressure/time data from the filling of the Test container can readily be used for evaluation of the *k*-value for the tested soil.
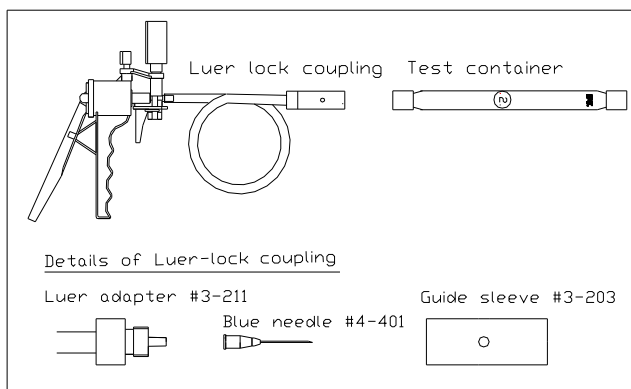
Hand-vacuumpump for evacuation of the Test container.
-*Assemble the Luer lock coupling*
- *Insert the Test container into the Guide sleeve*
- *Evacuate the test container*

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Site:……………………   Date:……………..

Measuring point.: ………………..   BAT/IS sensor nr.: ………………

Installation depth of filter tip:……………   Test performed by :………………….

Initial atmospheric pressure :   ………………mH$_2$O   time: ………………
Final atmospheric pressure :   ………………mH$_2$O   time: ………………

Form factor F,   BAT MkIII standard filter tip: F = 230 mm
             BAT MKIII vadoze filter tip: F = 194 mm
             BAT MKIII stainless: F = 213 mm

NOTE! ALL PRESSURES ARE IN ABSOLUTE VALUES!

U_0, pore pressure at equlibrium, m H$_2$O:…………………….
($U_0 = U_m + 0,2$ m H$_2$O)

P_0, initial system pressure of test (at temperature equilibrium), m H$_2$O:………………..
(displayed P_m value)

P_{50}, system pressure at 50% pressure dissipation, m H$_2$O: ………………….
P_{80}, system pressure at 80% pressure dissipation, m H$_2$O: ………………….
$P_{50} = P_0 - 0,5(P_0 - U_0)$
$P_{80} = P_0 - 0,8(P_0 - U_0)$

P_{end}, final system pressure, m H$_2$O:…………………

V_v, volume liquid in system at start of test, ml: …………………..

V_0, volume of air in system at start of test, ml: $(35 - V_v)$ ………………….

V_{calc}, calculated liquid volume in the sample container at end of test ml:……………
$V_{calc} = [P_0 V_v -35(P_0 - P_{end})]/ P_{end}$

V_{end}, measured volume liquid in the sample container after performed test, ml: ………….

Coefficient of permeability, k = ………*10$^-$ m/s, calculated at …….% pressure equalization

Notes:………………………………………………………………………..

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Protocol—In situ permeability measurement
INFLOW TEST

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Site:…………………   Date:……………..

Measuring point.: ………………..   BAT/IS sensor nr.: ………………

Installation depth of filter tip:……………   Test performed by :………………….

Initial atmospheric pressure :   ………………m H_2O time: ………………
Final atmospheric pressure :   ………………m H_2O time: ………………

Form factor F,   BAT MkIII standard filter tip: F = 230 mm
                        BAT MKIII vadoze filter tip: F = 194 mm
                        BAT MKIII stainless: F = 213 mm

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│   NOTE! ALL PRESSURES ARE IN ABSOLUTE VALUES!   │
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U_0, pore pressure at equilibrium, m H_2O:…………………………..
($U_0 = U_m + 0.2$ mH_2O)

P_0, system pressure at start of test (at temperature equilibrium), m H_2O:………………….
(displayed P_m value)

P_{50}, system pressure at 50% pressure recovery, m H_2O: …………………….
$P_{50} = P_0 + 0,5(U_0 - P_0)$

P_{80}, system pressure at 80% pressure recovery, m H_2O: …………………….
$P_{80} = P_0 + 0,8(U_0 - P_0)$

P_{end}, final system pressure, m H_2O:…………………….

V_{calc}, calculated volume liquid in system at end of test, ml:……………………
$V_{calc} = 35 - (P_0*35)/ P_{end}$

V_{end}, measured volume liquid in sample container at end of test, ml: ……………………..

Coefficient of permeability, $k =$ ………$*10^-$ m/s, calculated at …….% pressure equalization

Notes:…………………………………………………………………………………..

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