In situ permeability measurement with the BAT Permeameter

Quick Manual
Inflow test

BAT®

BAT Geosystems AB
Box 1060
186 26 Vallentuna
Tel   +46851170600
Fax   +46851173361

BAT Geosystems AB
Hällebergsvägen 5
443 60 Stenkullen
Tel   +46317890600
Fax   +46851173361

www.bat-gms.com
info@bat-gms.com

Ver 2012-04-02

BAT®

Contents

Pre-test measures

1) **Installation of BAT MKIII Filter Tip**
   Install a BAT MKIII Filter Tip at desired depth and location. Follow the instructions from the "Installation of the BAT MKIII Filter Tip"-guide.

2) **Measurement of pore pressure**
   Measure the actual pore pressure. Follow the instructions given in the "BAT Pore Pressure Guide".

   Dissipation of disturbance effects
   When the BAT Filter Tip is pushed into the soil, excess pore pressures will be generated due to disturbance effects. The time needed for dissipation of these disturbance effects varies with the type soil. In soft, plastic clays it may take several days until the original pore pressure is restored. On the contrary, in stiff clay, silt and fine sand the dissipation of the excess pressures goes much quicker. The process of dissipation of excess pore pressures can be logged by the BAT Sensor.
   Make sure that the installation disturbance pore pressure has dissipated.before starting a permeability test. If unsure, leave the sensor connected to the BAT Filter Tip for 10 minutes. If , during this period, the he reading is stable (±0.01m H_2O) a permeability test can be performed.

3) **Checking BAT Sensor**
   Make sure that the <u>battery unit</u> of the sensor contains a fresh, akaline battery. If unsure, change the battery. Normal life time of a battery when constant logging (1 minute interval) is about 3-4 weeks.

The BAT Permeameter can measure **permeabilites, k, in the range from $1*10^{-7}$m/s and lower.**

An example of typical k-values for different soil types:

Fine gravel: $1 - 1*10^{-2}$m/s
Coarse sand: $1*10^{-1}$m/s - $1*10^{-3}$m/s
Medium sand: $1*10^{-2}$m/s - $1*10^{-4}$m/s
Fine sand: $1*10^{-3}$m/s - $1*10^{-5}$m/s
Coarse silt: $1*10^{-4}$m/s - $1*10^{-6}$m/s
Medium silt: $1*10^{-6}$m/s - $1*10^{-7}$m/s
Fine silt: $1*10^{-7}$m/s - $1*10^{-8}$m/s
Clay: $<1*10^{-8}$m/s

Typical time for stabilization for different k-values, i.e. <u>time of testing,</u> see also APPENDIX 3.

$k \approx 10^{-7}$ m/s ; $t_{stab} \approx 5$ minutes
$k \approx 10^{-8}$ m/s ; $t_{stab} \approx 10 - 50$ minutes
$k \approx 10^{-9}$ m/s ; $t_{stab} \approx 1-5$ hours
$k \approx 10^{-10}$ m/s ; $t_{stab} \approx 10-50$ hours

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 *):

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

Parameters:

F	=	Hvorslev´s flow factor	mm
		BAT MKIII Standard: 230 mm	
		BAT MKIII Vadose: 194 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 Hvorslev´s equation.

---

*) Hvorslev, M.J. 1951. ˝Time lag and soil permeability in ground water observations˝.
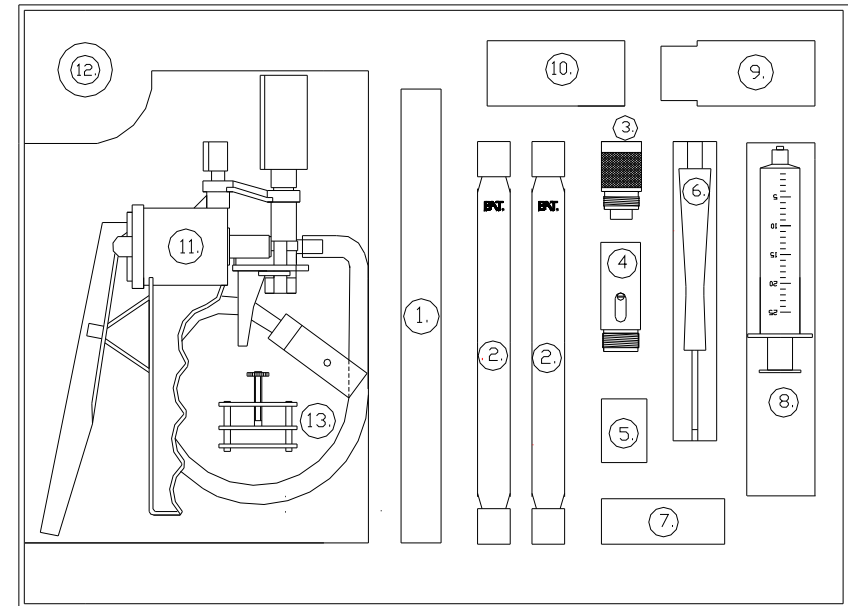
Contents:

1. Test container housing

2. Test container (35 ml)

3. Extension adapter

4. Quick coupling sleeve

5. Spare screws and springs

6. Screwdriver for mounting of double ended needle

7. Spare septas

8. Syringes (25 ml & 10 ml)

9. Container for used needles

10. Double ended needles

11. Vacuum pump with Manometer

12. Blue needles

13. Cable Clamp

Equipment Parts

BAT ®

- **BAT-sensor**
  #1-200 / 1-204

- **o-ring 11.1x1.78mm**
  #3-212

- **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
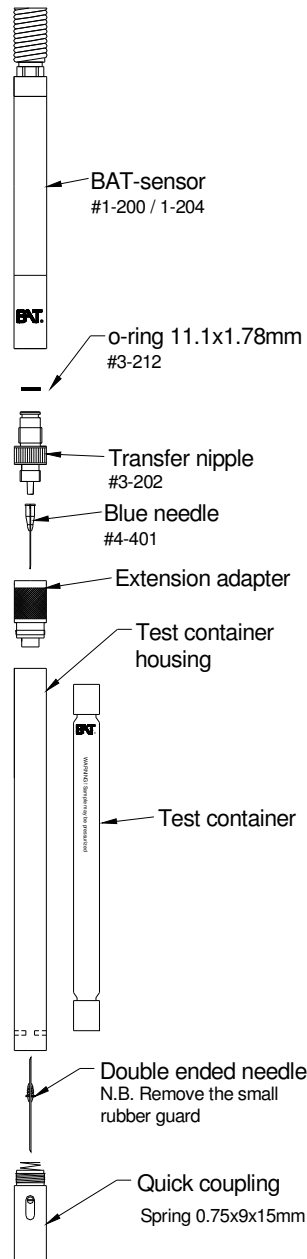
PRECAUTIONS

- Handle all parts carefully, especially the glass containers.

- Use only sharp needles. Do not re-use needles.

- Store the set in a dry environment.

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

BAT ®

Assembly of equipment - Stepwise

Transfer nipple & extension adapter
- Screw the transfer nipple until it seats in the sensor cavity. 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
Container housing assembly and connection of Pressure Sensor and IS Field Unit
- Carefully insert the test container into the container housing.
- Screw the extension adapter onto the open end of the container housing . The Pressure Sensor is now connected to the Test Container.
- Connect the IS Field Unit, choose Display Mode.
- The pressure in the test container can now be measured with the IS Field Unit .

Application of initial system pressure P_0
Inflow Test

The initial system pressure P_0 in the Test Container is applied by either by extracting or injecting a volume of air by using a 25 ml syringe.
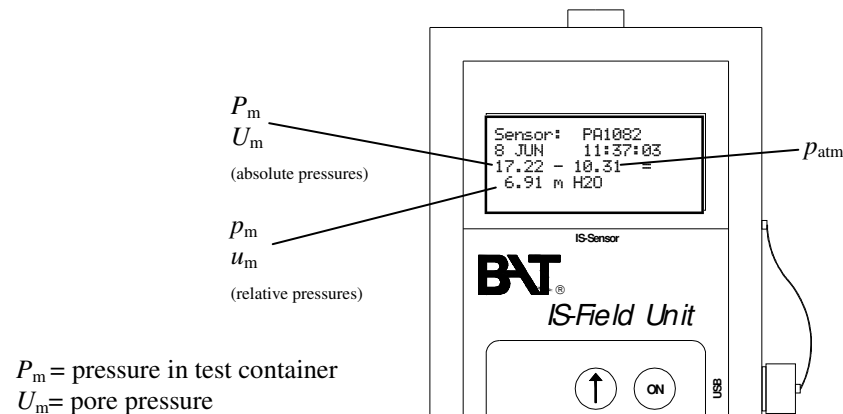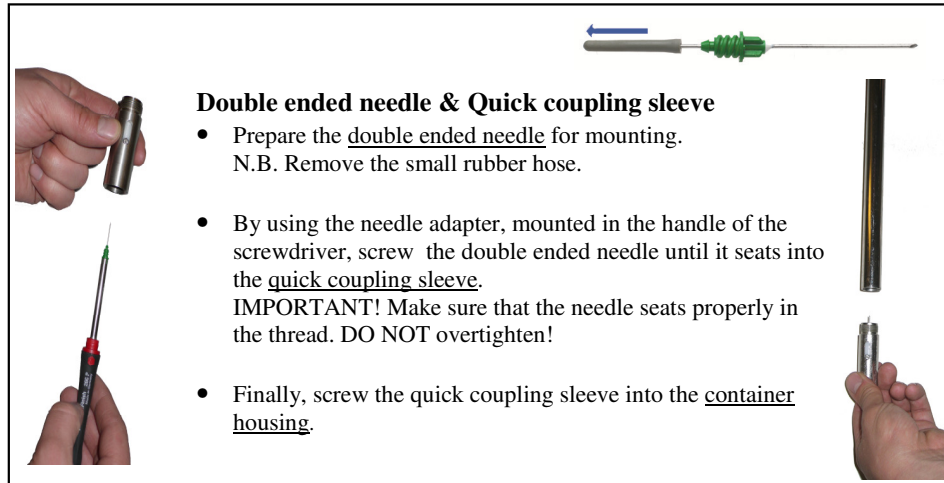
The volume of air to be extracted or injected is a function of the actual pore pressure U_0.

See page 7 for instructions regarding the application of the initial system P_0 in the test container.

Use the IS Field Unit for checking The actual pressure in the Test Container.

Do also check that the system is leakproof by reading the displayed pressure.

BAT ®

Double ended needle & Quick coupling sleeve

- Prepare the underlined double ended needle for mounting.
  N.B. Remove the small rubber hose.

- By using the needle adapter, mounted 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. DO NOT overtighten!

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

P_m
U_m
(absolute pressures)

p_{atm}

p_m
u_m
(relative pressures)

P_m = pressure in test container
U_m = pore pressure


```
Sensor:  PA1082
8 JUN    11:37:03
17.22 - 10.31 =
6.91 m H20
```

IS-Sensor

BAT ®

IS-Field Unit

USB

↑ ON
← →
↓ ENTER

BAT ®

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.:

$$U_0 > p_{atm}$$

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 HD Filter Tip.

Recommended procedure

When conducting the Inflow Test it is recommended to adjust the initial pressure P_0 so that at 80% pressure recovery, i.e. at P_{80}, the water volume in the Test container, ΔW_{80}, will be in the order of 15 ml.

Depending on the magnitude of U_0 the initial pressure in the Test container P_0 can be adjusted either **by extracting or injecting** a volume of air, ΔVair from/to the Test Container.

in which:
P_0 = initial pressure in Test container
ΔV_{air} = extracted or injected volume of air out of or into the Test container
P_{80} = pressure in Test container at 80% pressure recovery
ΔW_{80} = volume of water in Test container at P_{80}
See **APPENDIX 2** for more details about this recommended procedure.

Combined discrete sampling of porewater and permeability testing

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 90% .

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.
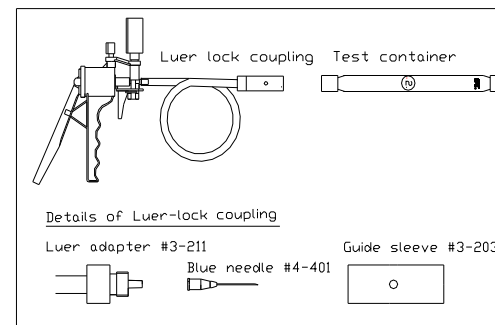
Hand-vacuum pump for evacuation of the Test container.

- *Assemble the Luer lock coupling*

- *Insert the Test container into the Guide sleeve*

- *Evacuate the test container*

See APPENDIX 2 for setting of the recommended value system pressure P_0.
With the system pressure P_0 set correctly the next steps are as follows:

Temperature equilibrium
With knowledgde of the installation depth, use the
cable clamp to fix the cable and let the BAT Permeameter
rest some 0.5 meter above the filter tip before starting the
test.
With the BAT/IS-Field Unit connected you can now monitor
the pressure change that occurs in the Test container due to
change of temperature. Temperature equilibrium is normally
reached after about 15 to 20 minutes.When the system
pressure P_0 is stable **note the P_0** value in the Test Protocol.,
see APPENDIX 1.

cable
clamp

cable

1"pipe
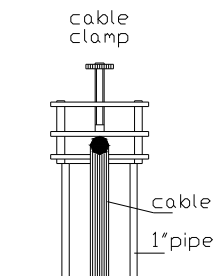
*Cable clamp to fix the
cable during tempera-
ture equalization.*

Starting the test
1)   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.

2)   To start with it is recommended to use 1 min logging interval. At a later stage of
       the test, the logging interval can be increased, without any inteferece with the
       ongoing logging of test data, see paragraph **6)** below.

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

4)   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 distance 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.

5)   Depending on soil type the time of testing may vary from about 5 minutes up to 24
       hours or more.

6)   After about one hour of logging it is recommended to increase the measuring
       interval of the sensor to 10 minutes or more. This is simply done by activating
       the "Start measure" function of the BAT/IS-Field Unit and select a new logging
       interval.

7)   **Finalizing the permeability test**
It is recommended to evaluate the permeability of the tested soil at a **pressure
equalization 80% , i.e at pressure level P_{80}.**

When finalizing the test the by following the following steps shall be taken:

A) Note the values of system pressure P_{end} and atmospheric pressure p_{atm} in the
     Test Protocol, APPENDIX 1.
     NB. In case a substantial change of the atmospheric pressure p_{atm} has occurred during
     the test this has to be taken into account when evaluating the test results.

B) Gently pull up the equipment and measure the volume of water W_{end} in the test
     container. The W_{end}-value shall be noted in the Test Protocol. The volume can be
     meaured by pouring the liquid into a syringe sealed with a rubber septa to the needle.
     It can also be measured more accurately using a scale at the office at a later stage.

C) Now the field part of the test is completed.
     Processing of test data and evaluation of the coefficient of permeability k_{80} can be
     done by using an Excel sheet shown in APPENDIX 3.

     NB. If running more tests before downloading the data to a PC, just remember **do not
     clear the data between the tests**. Keep notes on the starting time and starting
     pressures of each test and each set of test data so that the tests can be is easily separated
     when processing it on a PC.

     An Output Excel sheet with evaluated test data and diagrams is shown in
     APPENDIX 4.

D) Checking the quality of the permeability test
     The quality of permeability can be checked by calculation of the water volume ratio:
              W_{end}/W_{calc}
       in which W_{end} = measured water volume in the Test container   (ml)
                 W_{calc} = calculated water volume in the Test container   (ml)

     For approval of the test the water volume ratio shall fulfil the following
     requirement: :
                    $$0,9 \leq W_{end}/W_{calc} \leq 1,1$$

     NB. In case the soil contains free gas the water volume ratio will normally
          be: $W_{end}/W_{calc} < 0,9$

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: ...……….

Type of Filter Tip: ( ) BAT MkIII Standard Filter Tip
                             ( ) BAT MKIII Vadose Filter Tip
                             ( ) BAT MKIII HD Filter Tip

> NOTE! ALL PRESSURES ARE IN ABSOLUTE VALUES!

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_{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:…………………….

W_{calc}, calculated volume liquid in system at end of test, ml:……………………

$W_{calc} = 35 – (P_0*35)/ P_{end}$

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

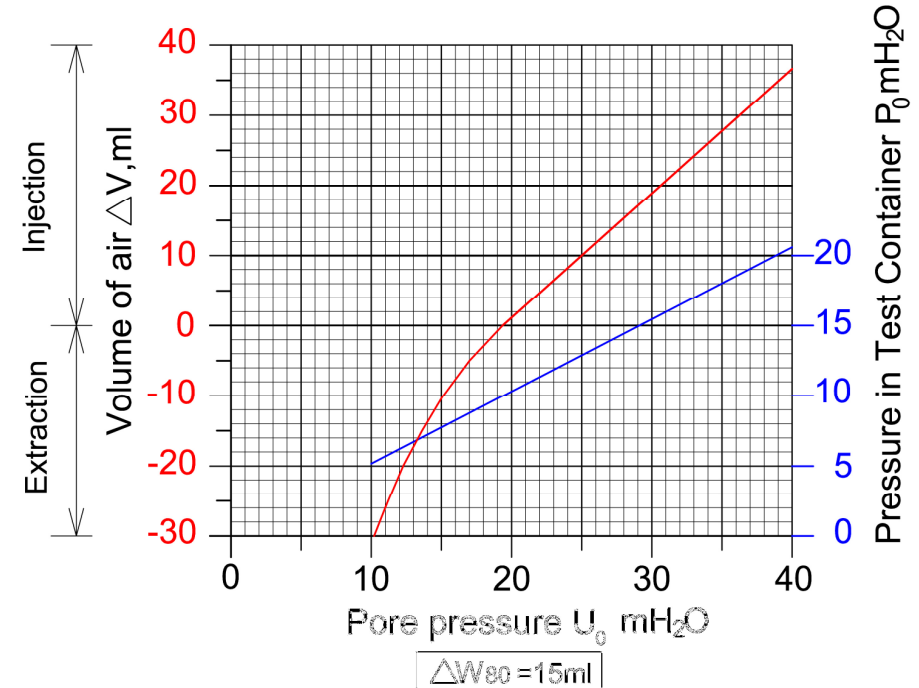Coefficient of permeability, k = ………*10^- m/s, calculated at …….% pressure equalization

Notes:_____

_____

Diagram for evaluation of ΔV_{air} as a function of U_0

Parameters

ΔV_{air} = **extracted** or **injected** volume of air out of or into the Test Container   ml
U_0 = equilibrium pore pressure (absolute pressure)   m H_2O
ΔW_{80} = volume of water in Test container at 80% pressure recovery ml
P_0 = initial pressure in Test container (absolute pressure)   m H_2O
P_{80} = pressure in Test container at 80% pressure recovery   m H_2Di

Evaluation of ΔV_{air} as a function of U_0 at $\Delta W_{80} =15$ ml
The above diagram enables evaluation of ΔV_{air} as a function of U_0 valid
for a volume of water in the Test container of $\Delta W_{80} =15$ ml .

Example 1.
$U_0 =$ 15 m H_2O gives ΔV_{air} = **-7,5 ml** (**extraction**) and a corresponding
P_0 equal to about **7,8 m** H_2O.

Example 2.
$U_0 =$ **25 m** H_2O gives ΔV_{air} = **10 ml** (**injection**) and a corresponding
P_0 equal to about **13m** H_2O.

Guide values of t_{80} for inflow test APPENDIX 3

U_0 m H2O	t80,hrs $k80=1,0E-8$ m/s	t80,hrs $k80=5,0E-9$ m/s	t80,hrs $k80=1,0E-9$ m/s	t80,hrs $k80=5,0E-10$ m/s	t80,hrs $k80=1,0E-10$ m/s
12	0,6	1,1	5,6	11,1	55,6
15	0,4	0,8	4,2	8,4	41,8
20	0,3	0,6	3,1	15,6	31,1
25	0,2	0,5	2,4	12,2	24,3
30	0,2	0,4	1,9	9,7	19,4
35	0,2	0,3	1,6	8,1	16,1
40	0,1	0,3	1,4	6,9	13,9
45	0,1	0,2	1,2	6,1	12,2
50	0,1	0,2	1,1	5,6	11,1
55	0,1	0,2	1,0	5,2	10,4
60	0,1	0,2	1,0	4,9	9,7
65	0,1	0,2	0,9	4,6	9,2
70	0,1	0,2	0,8	4,2	8,3
75	0,1	0,2	0,8	3,9	7,8
80	0,1	0,1	0,7	3,6	7,2

NB. U_0 Absolute pressure
Calculated guide values of t_{80}, i.e. time needed for 80% of pressure recovery in an inflow
permeability test, performed in accordance with the recommendations given in APPENDIX 2.

The value of t_{80} is a function of both the pore pressure U_0 and the coefficient of permeability
k_{80} as can be seen from the above table.

For intermediate k_{80} values the corresponding t_{80} values can simply be calculated by linear
interpolation. ΔW_{80} = volume of water in Test container at 80% pressure recovery.

APPENDIX 4   Input sheet data sheet - Inflow test

Site	Regionens Hus	Fill these cells with the starting	In these columns you paste data
Point	2	parameters before calculation	from the IS-sensor. If needed,
Date	2012-02-27		replace all dots with commas.
Installation depth of filtertip	43 m		
BAT/IS sensor no.	PA3822		
Operator	ST		
Length of filter, mm	35	(Standard Mk III = 35 mm) (Vadose Mk III =35 mm)	
Diameter of filter, mm	31,5	(Standard Mk III =31,5 mm) (Vadose Mk III =25 mm)	
Flow factor, mm	229,6		
P_0, m H_2O	8,22	Initial system pressure	
h_{end} mH_2O	0,3	Final water column in test container	k_{80}= 2,34E-10 t_{80}= 4:40:00
V_0, ml	35	Initial air volume	
U_0, m H_2O	51,00	Static pore pressure	
Air pressure, Pa	95230		
P_{end} mH_2O	50,85		
W_{calc}, ml	29,30	Calculated volume of water after test	
W_{end}, ml	26,83	Measured volume water after test	
P_{80}	42,44	P80 = System pressure at 80% pressure equalization. It is **recommended** to evaluate k-value at this pressure level	
P_{50}	29,61	P50: System pressure at 50% equalization.	

Date	Time	Pressure Pa	Time elapsed	Time elapsed seconds	System pressure m H2O	Water volume in test container,ml	Permeability k [m/s]
1	2	3		5	6	8	10	11
2011-11-10	09:10:00	80677,5	0:00:00	0	8,22	0,00	
2011-11-10	09:20:00	88661,2	0:10:00	600	9,23	3,15	6,57E-10
2011-11-10	09:30:00	95929,5	0:20:00	1200	9,99	5,56	5,35E-10
2011-11-10	09:40:00	103448	0:30:00	1800	10,76	7,70	4,80E-10
2011-11-10	09:50:00	110989	0:40:00	2400	11,54	9,56	4,42E-10
2011-11-10	10:00:00	118671	0:50:00	3000	12,33	11,21	4,13E-10

Downloading of and processing of measurement data
The procedure for downloading and processing of measurement data is described in
BAT´s manual for pore pressure measurement ”BAT/IS– system for Pore pressure
measurement. Make sure macros are activated.

Insertion of measurement data in Excel calculation sheet
1) Insert the the data from the Test Protocol into Input sheet.

2) Paste the downloaded data in the columns 1, 2 and 3.

If present, change the ”dots” to ”commas” in the pressure column.

Output sheet from PC-computation   APPENDIX 5   BAT ®

Site	Office		Filter Type	BAT MKIII Standard
Point	3		Sensor #	PA3221
Installation depth	43m			BAT Permeameter test
Date	2012-01-15			info@bat-gms.com
Operator	ST			www.bat-gms.com

Initial pore pressure	U_0	51	mH_2O
Initial system pressure	P_0	8,22	mH_2O
Final water volume (measured)	W_{end}	26,83	ml
Final water volume (calculated)	W_{calc}	29,3	ml
Water volume ratio	W_{end}/W_{calc}	0,92	
Final pressure	P_{end}	50,87	mH_2O
Pressure equalization		99,7%	Pressure equalization
Calculated permeability:	k_{80}	**2,34E-10 m/s @**	**4:40:00 hrs**
at system pressure: P_{80}		42,44	mH_2O

Permeability Time diagram

Pressure - Time diagram