

# **TPSYS02**

Thermal Conductivity Measurement  
System

## **TPSYS02 manual v2010**

Edited & Copyright by:

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## **Safety Issues:**

Putting a voltage of over 15 VDC, or a voltage of the wrong polarity on TPSYS02 may result in permanent damage to the system.

The needles of most Non-Steady-State Probes are vulnerable. In case of doubt if it can penetrate the medium, a hole should be pre-drilled.

The needles of most Non-Steady-State Probes are vulnerable. When not being used, it is recommended to have the protective cover over the needle.

When calibrating in glycerol, the user is assumed to be familiar with the glycerol safety data. These can be found at the end of this manual.





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## List of symbols

Thermal diffusivity	$a$	$m^2/s$
Distance from the heating wire	$r$	$m$
Heating cycle time	$H$	$s$
Thermal conductivity	$\lambda$	$W/mK$
Time	$t$	$s$
Temperature	$T$	$K$
Differential temperature, or temperature rise	$\Delta T$	$K$
Electrical resistance	$R_e$	$\Omega$
Electrical resistance per meter	$R_{em}$	$\Omega/m$
Thermal resistivity	$R_{th}$	$mK/W$
Diameter	$D$	$m$
Volumetric heat capacity	$C_v$	$J/Km^2$
Density	$\rho$	$kg/m^3$
Current	$I$	$A$
Power	$P$	$W$
Power per meter	$Q$	$W/m$

### Subscripts

Property of Pt 1000 sensor	sen
Property of the heating wire	heat
Property of the needle	needle
Property, at $t = 0$ , at $t = 180$ , $t = h$ seconds	0, 180, h

### Acronyms

PC	Personal Computer
MCU	Measurement Control Unit
KD	Keyboard Display
St-mode	Standard operation mode
Sc-mode	Scientific operation mode





## Introduction

The system TPSYS02 consists of a Measurement and Control Unit and a Non-Steady-State Probe. This probe can either be a TP02 or TP08. The TPSYS02 is intended to measure the thermal conductivity of the medium in which the probe is inserted. The measurement generates an estimate of the thermal conductivity plus a standard deviation. The datafile of the complete measurement is stored inside the TPSYS02 memory for later analysis.

This manual describes the use of TPSYS02 in combination with TP02. The use of TPSYS02 with TP08 is similar. There are slight differences in requirements for heating time, sample size and the use of containers for the sample. In order to avoid confusion, we refer to the TP02 and TP08 manuals for recommended practices and specifications.

The general text of this manual covers laboratory experiments. Field measurements are possible as well, but are less common. These are treated in the appendix.

When performed by users who are unaware of possible error sources, measurements with Non-Steady-State probes tend to be unreliable.

The user is supposed to read the manual of the probe as well as the TPSYS02 manual.

The TPSYS02 gives an estimation of thermal conductivity and a standard deviation. For scientific or otherwise critical use, review of the full measurement curve is recommended.

When performed in the appropriate way, the measurement complies with IEEE Guide for Soil Thermal Resistivity Measurements (IEEE Standard 442-1981) as well as with ASTM D5334-14 Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock.

In case the system has been ordered with internal battery pack and with Keyboard display, it is possible to perform experiments without the use of external power supply and without the use of a PC. For this mode of operation, please consult the appendix on use with CR1000KD.





The user is supposed to have read the TP02 and CR1000 manual and to be familiar with the working principle of TP02 and CR1000.

In the course of time, new versions of the tpsys vXXXX.CR1 program will be released at Hukseflux. These new versions can be installed by the user.

Support of the user is offered by telephone or e-mail. In case support is necessary: please mail to [info@hukseflux.com](mailto:info@hukseflux.com) to ask for a contact person to help you and suitable telephone number. Also available via this email address is a special Excel worksheet which allows the data to be analysed visually.

The measurement method is based on the so-called Non-Steady-State Probe technique (NSSP), which uses a probe (also called thermal properties sensor or thermal needle) in which both a heating wire and a temperature sensor are incorporated. The probe is inserted into the soil. From the response to a heating step the thermal resistivity (or the inverse value, the conductivity) of the soil can be calculated.

In general a NSSP consists of a heating wire, representing a perfect line source, and a temperature sensor capable of measuring the temperature at this source. The probe is inserted into the soil that is investigated. The NSSP principle relies on a unique property of a line source: after a short transient period the temperature rise,  $\Delta T$ , only depends on heater power,  $Q$ , and medium thermal conductivity,  $\lambda$ :

$$\Delta T = (Q / 4 \pi \lambda) \{ \ln t_0 - \ln t_1 \}$$

With  $\Delta T$  in K,  $Q$  in W/m,  $\lambda$  in W/mK,  $t$  the time the heater is on in s. By measuring the heater power, and tracing the temperature in time,  $\lambda$  can be calculated.



# 1 General Overview

## 1.1 System description

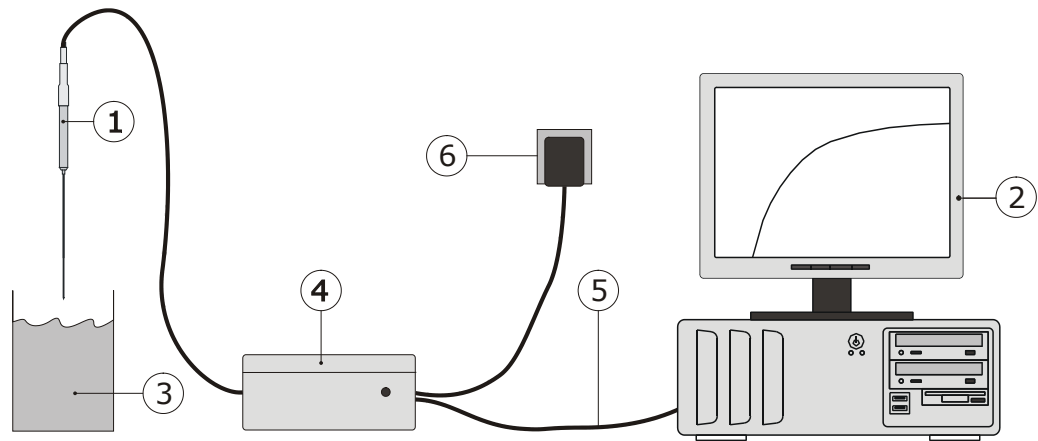


Figure 1.1.1 system diagram of TPSYS02. The main components are the TP02 (or TP08) thermal properties sensor (1), the CR1000 Measurement and Control Unit (MCU) (4), a PC (2). The actual program that is executed, called *tpsys vXXXX.CR1*, is residing in the CR1000 system. The LoggerNet software serves to give instructions (by toggling flags) and to transfer the TP02 (or TP08) parameters to the CR1000 system. LoggerNet or the KD acts as the "user interface". The PC is not part of the delivery.

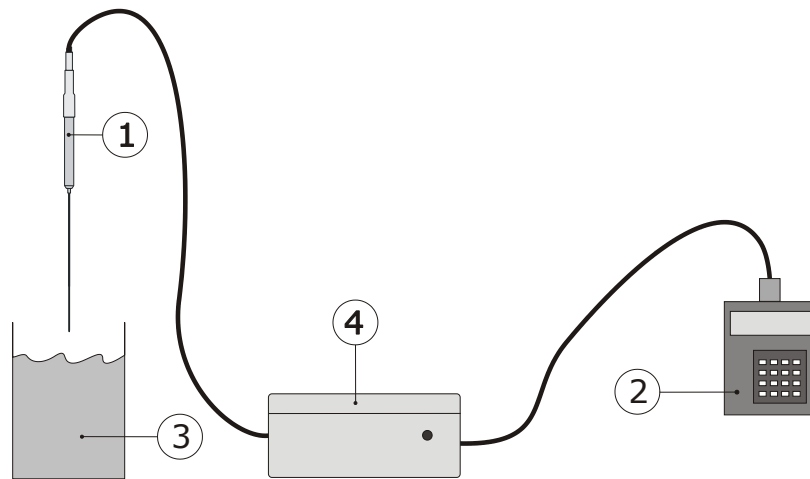


Figure 1.1.2 *In case the system is ordered including battery pack and Keyboard display, it is possible to work without external power and PC. Power will come from a battery pack in the MCU (4). By pressing the buttons on the KD (2), the measurement is activated. Readout of the measurement result can also be done on the KD. The details of the measurement are stored in the MCU, and can always be retrieved when back in the laboratory.*





## 1.2 Delivery

The delivery is as follows:

MCU, TP02, PC cable	<p>The MCU, a CR1000 measurement and control module. The interface cable: a USB or RS-232 interface.</p> <p>In case of a system with KD and battery pack: the MCU housing contains a PS12E power supply. Do not confuse the RS-232 PC connection with the CR1000KD connection. Cable length PC to MCU: about 1m. Cable length of TP02: about 2m.</p>
Optional USB Driver	In case of USB connection: USB driver on CD-ROM.
Adapter 12 VDC	<p>This adapter can be used with any mains supply from 100 to 240 VAC, 50 or 60 Hz. If possible it is recommended to use this adapter. It can be connected to the MCU directly using the plug that is connected to its cable. Cable length to MCU: about 1 meter. Note: please make sure that the adapter has the right output level. If available, 13.8 volts should be chosen, otherwise 12 VDC is sufficient.</p>
Optional Charger	In case the system is battery operated: a charger is supplied.
Software LoggerNet	To be installed on the PC for communication with the MCU. Delivered on CD-ROM.
Plastic jar	<p>A jar with some plastic fibres that can be used as a "known substance" for training the operator as well as for performing a system check. Glycerol has to be added by the user.</p>
Software for TPSYS	A program that is specially developed for use with TPSYS02. Delivered on a USB flash drive.

Table 1.2.1 *Delivery: parts and their function.*





### 1.3 General operation

In every measurement, the TPSYS program creates the following:

1. *A measurement result*: the estimated thermal conductivity, Lambda and its standard deviation Lambda\_sd.
2. *Remark messages* containing possible problems that have been encountered and may need attention. Note that these may contain false alarm, as they are automatically generated.
3. *A file* containing a summary of the measurement results as well as the raw measurement data, and the measurement parameters, such as an experiment number and the heater resistance.

There are two modes of operating the TPSYS. The Standard Operation mode (St-mode) can be applied when analysing batches of similar materials and when the measurement accuracy is not too critical, for instance in most field experiments. The Scientific Operation mode (Sc-mode) is recommended when the measurement needs to be as accurate as possible. Both will be explained in table 1.3.2.

Note: it is possible to change parameters, in two ways: using the Numerical Display screen provided by the LoggerNet software on a PC or by the optional Keyboard Display. (see appendix 8.6). Changes that are made are held by the MCU memory even after the power is disconnected. Chapter five describes operation using the software on a PC.





General rules
Check if the software Version is the same one as described by this manual. Read the comment in the TPSYS vXXXX.CR1 file. This can be done in LoggerNet using dedicated CRBasic compiler or in any text editor.
Check if the TP02 resistance that is entered into the CR1000 is the same as engraved on the TP02. The TP02 resistance can be changed in the numerical display screen in the LoggerNet software, or using the KD.
Select a proper measurement cycle time for your type of material. Change this time if the material changes. Rules for deciding how long this cycle should take can be found in the TP02 manual. The heating cycle time can be changed in the Numerical Display screen or the KD.
Select a proper heating level. When using a second power switch, three levels can be used. Otherwise, only one power level is available. The heating level can be changed toggling the proper boolean flags: low_heating, medium_heating or high_heating.
For deciding if the cycle time is right, it is strongly recommended that a measurement file is downloaded to PC and analysed visually at least once. Please note that the logged values are in millivolt. The calculations as in the TP02 manual should be applied for full analysis.

Table 1.3.1 *The general rules for working with a TPSYS02.*





<b>Standard operation</b>	<b>Scientific operation</b>
Perform all measurements using the readout on the PC screen (or by the optional Keyboard Display)	Use the readout on screen only for temporary review if the measurement succeeded
Use the Standard Deviation as a quality indicator	Download the raw measurement data from the CR1000 to the PC
Use the remark messages (see section 5.3) as a quality indicator	Analyse every individual measurement by using a spreadsheet or a mathematical program
Take the results down on paper by hand	Enter an experiment number in the files for every measurement. In this way there is perfect traceability
Use a high heating level at all times	Use the lowest heating level that returns a reliable data set
	Copy the logged data to the PC for further graphical analysis.

Table 1.3.2 *There are two ways of operating the TPSYS02 system. The standard operation is less accurate and has less traceability. For general application, it works reasonably well, but at the same time one always has to be suspicious to factors possibly cause errors.*

The data review on PC can serve to increase the reliability of the measurement. The general idea is that with automatic analysis, there still is the risk of wrong data being accepted.

The figure below gives an example of data analysis using Excel, using the measured data that is downloaded from the MCU to the PC.



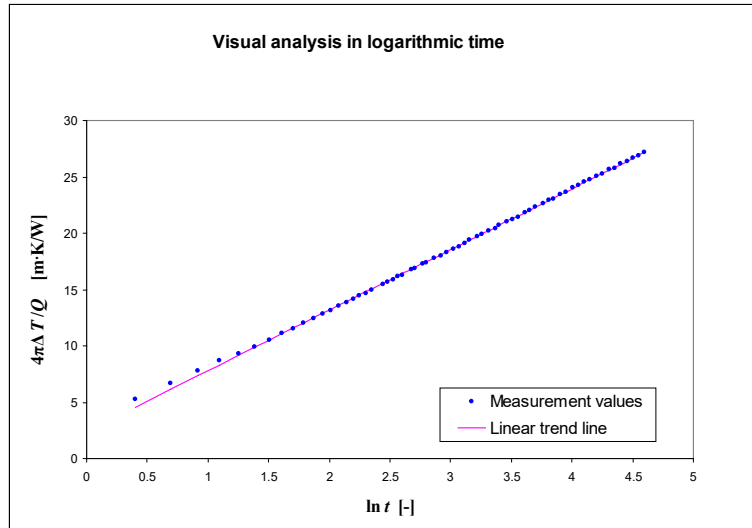


Figure 1.3.1 Typical measurement results in the Hukseflux calibration cylinder

Note: Uploading new software will result in losing the data stored on the logger!



## 2 Preparation

It is recommended to have the following items available:

A logbook	The measurement time and results are stored in the MCU, but the location (in case of outdoor measurements) and sample features are not.
Copies of a test form	An example is added in the probe manual.
Power supply	Preferably mains power for the Adapter. This can be 100-240 VAC, 50/60 Hz. If this is not available, a power source of 10 to 13 VDC, at 5 Watts is sufficient. The absolute value of the power supply is not important as long as it is constant within 1% during 5 minutes. A normal battery will be able to meet this specification. The power supply must be available within 1 meter from the point of measurement.
PC	PC, running MS Windows XP or later, with CD-ROM drive and with one free USB port, and one USB port or COM port.
Glycerol as a reference material (or a PMMA calibration cylinder)	As the transport of fluids is not allowed by most carriers without special permission, the user must purchase glycerol locally. Glycerol or glycol can be purchased at most pharmacies. Glycerol Fluid, consumer quality of at least 96% purity, 1 litre. An optional calibration cylinder can be purchased at Hukseflux company.

Table 2.1 *Items that need to be available.*



### **3 Step 1: When the System Arrives**

When the system arrives, it is recommended to check if all is there. See table 1.2.1 for a general check. It is possible that additional items were ordered (extension cables, sample containers). It is recommended to compare to the original order.



## 4 Step 2: Software

<p>The software is usually arriving with the system, but can also be received by e-mail. It should be installed on the PC.</p>	<p>Make a backup of all received files.</p> <p>First install the copy of the LoggerNet software. This is quite straightforward, and normally the program location will be c:\campbellsci\loggernet. It is supplied on CD-ROM.</p> <p>The TPSYS02 software can be configured for a either the operation of a TP02 or a TP08 probe and is supplied on a USB flash drive. All files should be copied to a directory on the hard drive.</p>
<p>Read the program and the comment in the program file.</p>	<p>It is recommended, in particular when receiving a new version of the software, to read the program that controls the experiment. The tpsys vXXXX.CR1 file, as received on the USB flash drive, contains the description of the program as well as the operation and of the wiring schedule of the system. The file can be opened in any text editor, or using the CRBasic compiler of LoggerNet.</p>
<p>USB communication</p>	<p>When operating with USB: install the USB driver of the CD-ROM. See chapter 5.2.</p> <p>The USB interface is used by Windows as virtual COM port.</p>

Table 4.1: *Software installation and review of the measurement and control program.*







## 5 Step 3: Installation and Testing

The third step is to install the system and do an overall system check by performing a measurement in the glycerol fluid or the optional calibration cylinder. The purpose of this procedure is twofold; the system performance is checked, and the operator is trained.

### 5.1 Powering the system

It is assumed the standard system is supplied. In case of a battery powered system, see the appendix. The TPSYS02 system must be connected to 12 VDC power. In a normal laboratory experiment this can be done using the Adapter.

Connect the Adapter to mains power	Make sure the adapter is on 12 VDC (usually there is some switch at the side). In case a battery pack is included in the MCU, a higher voltage is recommendable for optimum charging (typically 13.8 V up to 18 V). Please consult the manual of the battery about this.
Connect the plug to the three pin socket of the MCU.	Only one orientation is possible.
Press the power button near the red LED.	The red LED should start burning, confirming that the system is powered.

Table 5.1.1 *Powering the system*



## 5.2 Connecting the TPSYS02 to the PC

The TPSYS02 MCU now can be connected to the PC using the LoggerNet software and the "TPSYS vXXXX.CR1"-software to make contact.

Install LoggerNet software
Install the SC-USB driver from the Campbell Scientific CD-ROM (Use executable sc_usb.exe or run it through index.html after auto load), if necessary
Use the supplied USB or RS-232 cable the connect the MCU with the PC.
Start the LoggerNet software

Table 5.2.1 connection to the PC step 1

The following figure appears.

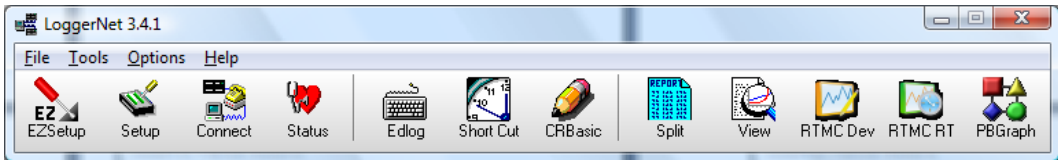


Figure 5.2.1 The heading of the LoggerNet software.

*Setup is used during Installation only.  
During normal operation only "Connect" is used.*

Select Setup
Select the correct COM port or add a COM port. To see which COM port is allocated to the SC-USB device please refer to the windows device manager, "ports (COM & LPT)"
Select Add Device, and add a CR1000 to the COM port
Confirm by clicking "save edits"

Table 5.2.2 Connection to the PC step 2: defining the Setup

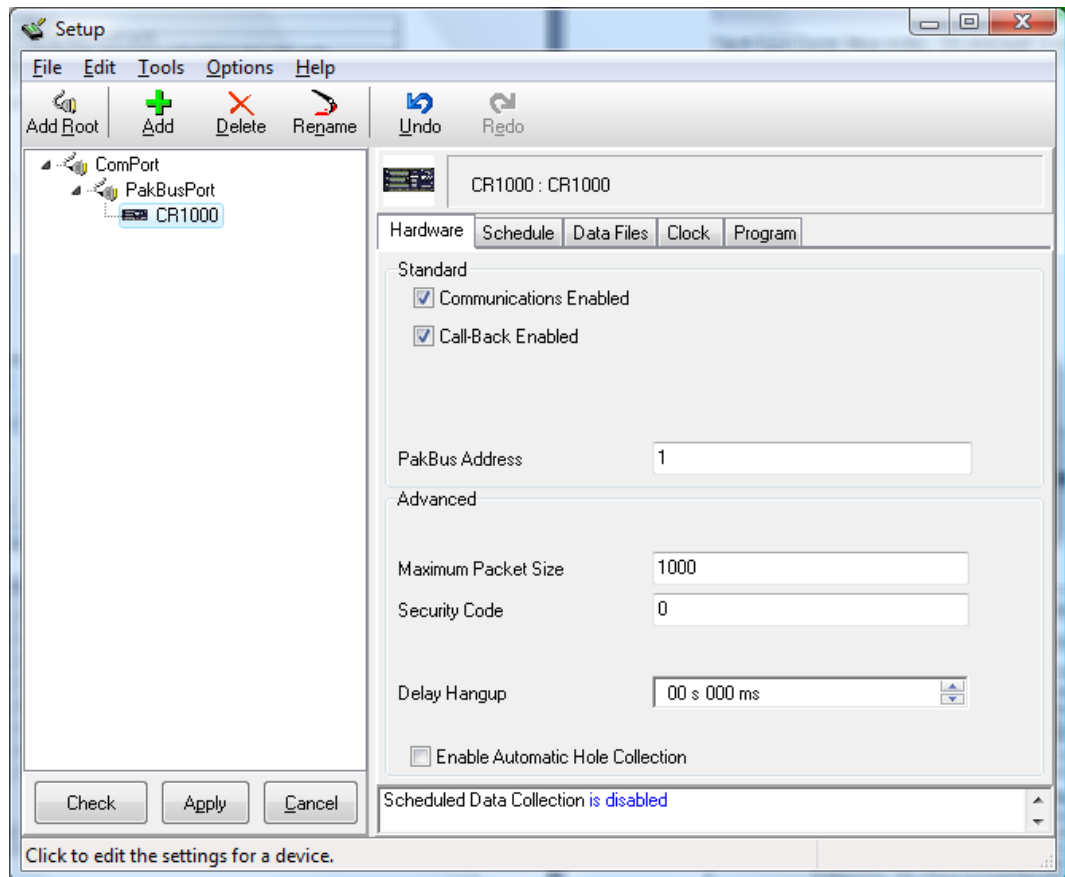


Figure 5.2.2 Typical Setup screen. The datalogger is connected to the USB port here. It is possible that in the setup a USB will appear as a new COM port.

### 5.3 Communicating with the TPSYS02 / defining the user interface.

The TPSYS02 MCU is now connected to the PC. The LoggerNet software has been instructed which port to look at. We now go back to the heading of LoggerNet.



Figure 5.3.1 The heading of the LoggerNet software.

Press the Connect icon to open the connect screen for controlling the system during normal operation.

The following screen will appear:

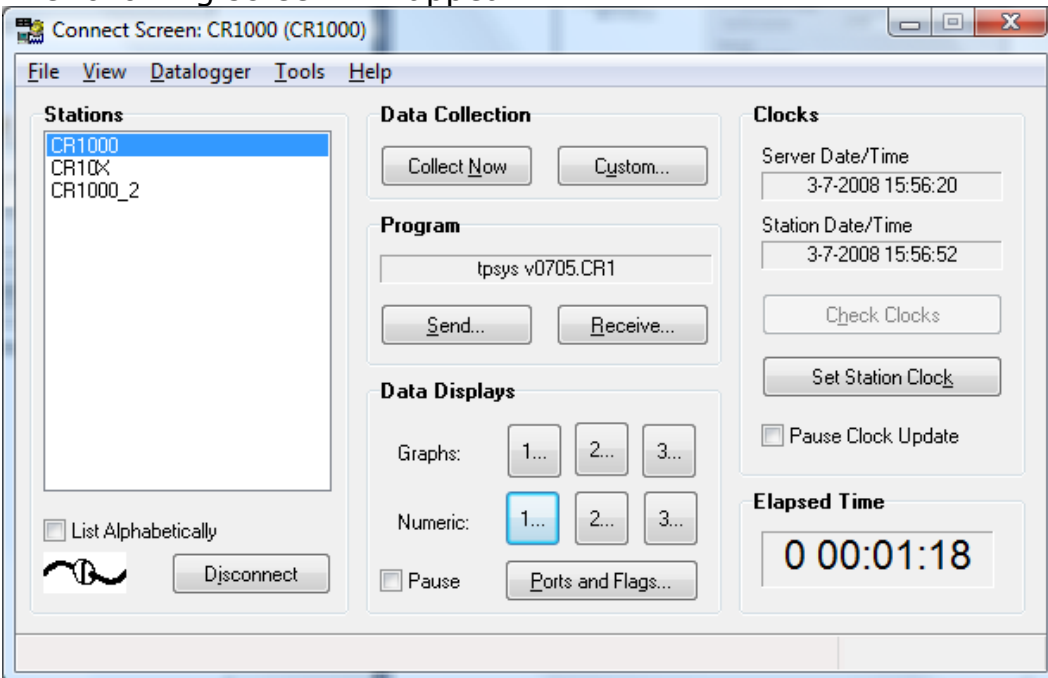


Figure 5.3.2 The screen in Connect. During Normal operation the Numeric and Graph buttons are used for on-screen data display, and the "Ports and Flags..." button is used to control the experiment.



Before starting operation user has to perform a few elementary functions:

When the software has made a connection, the CR1000 the lower left hand corner of the screen in Connect shows "Connected", and the clock synchronisation of the upper right hand corner shows that the Datalogger time/date is running.	If not, press "Connect..." in the lower left hand corner.
Press "Set Station Clock" to set it to the correct date and time.	
The program running on the TPSYS02 must be known to the LoggerNet program. Press "Send..." to upload and activate a (new) program into the datalogger.	The file must have the extension CR1. Select program included on CD-ROM.
Press "Ports and Flags..." and a display showing ports and controls flags will appear. Select the top left field and press "Add...". Choose "Public" on the left list and press "Paste".	The flags "Remark" and starting with "R_" intended for informing the user only.
Select one of the numbers just after the text "Numeric:". By pressing "Add..." you can drag and drop variables to create a screen as in figure 5.3.4.	This screen should be sufficient to inform the user for normal use.
Select "Graph" 1 in the Data Display window. By pressing setup and clicking on variables, while keeping the control button down, variables for display can be selected as in figure 5.3.5	

Table 5.3.1 *verification of contact, synchronising data and time, defining the data logger program, giving the buttons a name, creating graphic and numeric screens for in/output purposes.*



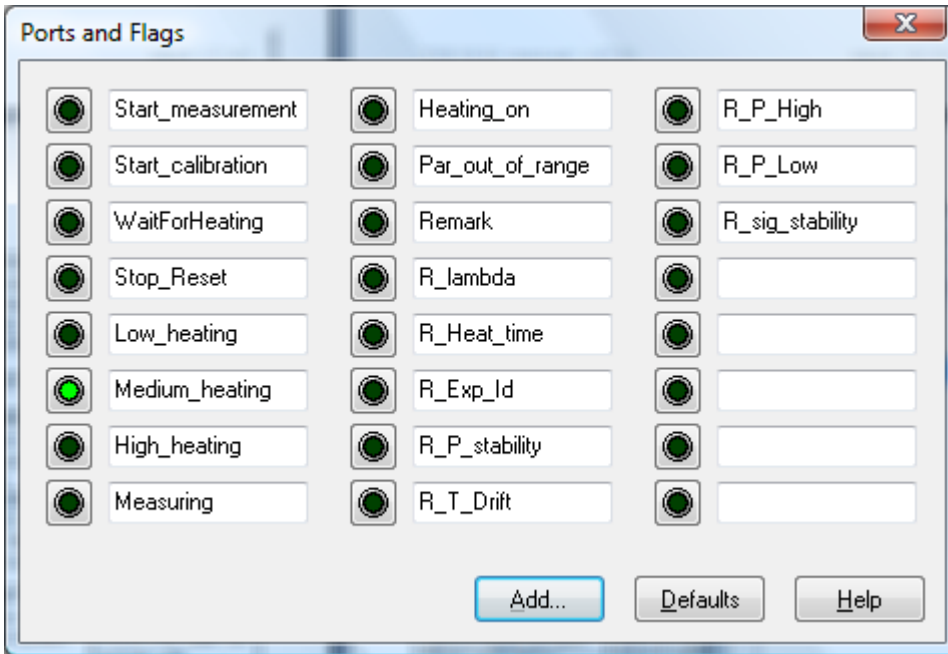


Figure 5.3.3 The "Ports and Flags"-window can be displayed on top of the Numeric or the Graph screen.

Start_measurement	start a measurement.
Start_calibration	start a calibration
Stop_Reset	interrupt all and set back to initial values
Low_heating	<b>**only with external power switch**</b> set heating level to low power
Medium_heating	<b>**only with external power switch**</b> set heating level to medium power
High_heating	<b>**only with external power switch**</b> set heating level to high power
Measuring	A measurement or calibration is active
Heating_on	indicates power is provided to the heater
Par_out_of_range	when high, warning, measurement is not started because the measurement parameters are not accepted

Table 5.3.2 User control flags and their function.

To inform the user with some information about the quality of the measurement there are remark flags shown. If any attention is needed the "Remark" flag will be set high. In table 5.3.3 all remark flags and their meaning are shown.



Remark	A remark is generated.
R_lambda	A remark that the thermal conductivity is out of a range of reasonable values.
R_Heat_time	Warning that the heating cycle time is out of range.
R_Exp_Id	A warning that the identification, i.e. the experiment number has not been entered. Although this has no effect on the results, it is good practice to number experiments.
R_P_stability	Indicator that the power supply is not sufficiently stable. A more stable power supply should be selected. This warning should not be ignored.
R_T_Drift	Indicator that the probe was not sufficiently in thermal equilibrium with the soil before the measurement. More time should be allowed before performing a measurement. In case after repeated attempts the warning keeps appearing, the measurement can proceed but the results must be manually analysed before drawing final conclusions.
R_P_High	A remark that the heater level is possibly too high; a lower level could be tried.
R_P_Low	Warning that the heater power is too low. A higher heater power should be tried by using the external switched power supply
R_sig_stability	Indicating that the signal has not been rising monotonously; probably the probe has been moving. In case after repeated attempts the warning keeps appearing, the measurement can proceed but the results must be manually analysed before drawing final conclusions.

Table 5.3.3 Remark flags mend to provide the user with information on the quality of the measurement.

It must be noted that not in all cases, when one of the remarks flag lights up, there is a standard solution. It may well be that the quality of the data set is still good enough to determine a value of the thermal conductivity. For example using the Excel sheet available on request at Hukseflux or using other analysis software.



CR1000 Numeric Display 1: Real Time Monitoring (Connected)

Exp_Id	10.00	T_hot	24.19	Tdiff	0.33		
Countdown	300.00	T_cold	23.86	P_heat	0.00		
Remark	false	Tdiff	0.33				
lambda	0.18	P_heat	0.00				
lambda_sd	0.00	R_lambda	false				
T_average	25.48	R_Heat_time	false				
P_heat_m	2.61	R_Exp_Id	false				
Cal_OK	Nan	R_P_stability	false				
Batt_Volt	12.25	R_T_Drift	false				
Heat_time	150.00	R_P_High	false				
Re	84.28	R_P_Low	false				
lambda_cal	0.00	R_sig_stabilit	false				
lambda_ref	0.19	Pt_1000	24.89				
ec	0.00	T_hot	24.19				
Pt_1000	24.89	T_cold	23.86				

Figure 5.3.4 A typical screen of the Numeric Display.

The "Countdown" indicates the number of seconds of the current measurement still left. The "Tdiff" indicates the differential sensor signal. The T indicates the temperature of the measurement system in degrees Celsius. The Lambda gives the result of the measurement. The Lambda\_sd gives the standard deviation of Lambda. The latter two are in W/mK. At good start for the duration of the heating cycle, "Heat\_time", to start with is 100 seconds.

Alternatively, the data can be presented graphically. This is solely used for a qualitative check of the parameter values. By pressing one of the numbers behind "Graphs:" in the "Connect"-screen, a screen similar to figure 5.3.5, will appear. To add a parameter for display, press "Add..." select the desired parameter from the "Public" list and press "Paste". Using the option button, several changes to the graphical representation of the graph can be made.



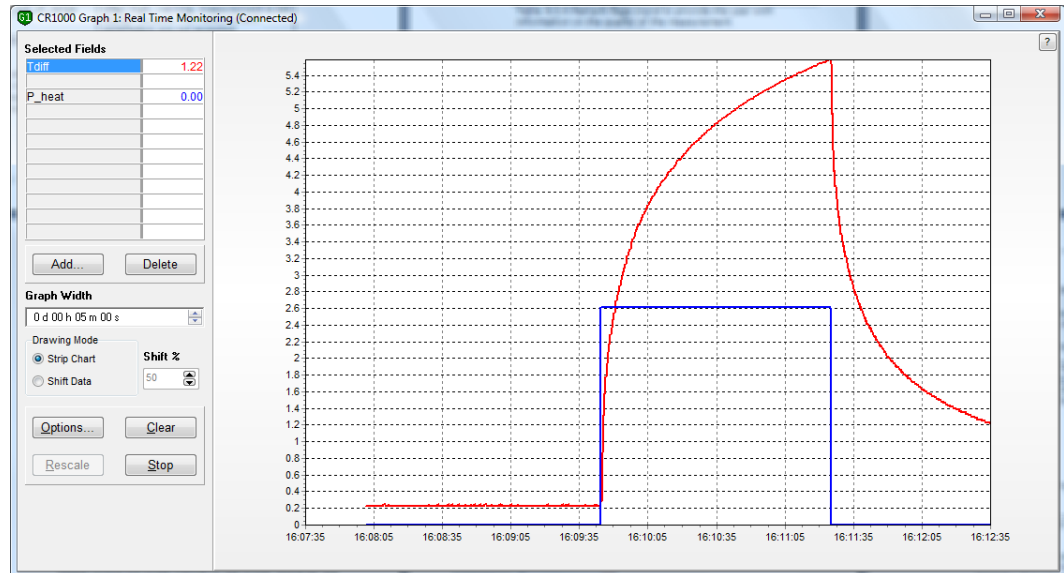


Figure 5.3.5 Graphical display of the measurement process. This is an example of a typical temperature profile. The heater power is just switched between zero and the set value (i.e. low, medium or high).

## 5.4 Changing the heating cycle time and the probe heater resistance

With any probe and any sample, the program needs to have the information on heating cycle time and probe heater resistance. Please consult the probe manual on the proper choice for the heater cycle time. Typically, first measurement is done with default or typical value as indicated in the manual. The heater resistance is an individual probe property. It is engraved on the base of each probe.

There are two ways to change these parameters. One is using the keyboard display (optional, see appendix 8.6) and one is directly in the Numerical Display screen. Both methods are equivalent, but during measurements with no PC or laptop available the keyboard display is a convenient alternative. One disadvantage is that there is a limited possibility to display the parameter values graphically.

Values once set by the user will be kept, even after the power supply has been switched off. Only when a (new) software program is uploaded into the system all parameters will be reset to their default values and need to be set again.



### 5.5 Changing values in the Numerical Display screen

The “Numeric Display”-screen is, besides viewing parameter values (see previous section), also used to set probe characteristics and measurement variables. Modifying a value can be done by right clicking on the value and selecting “View/Modify value...” or double clicking on the field (see figure below).

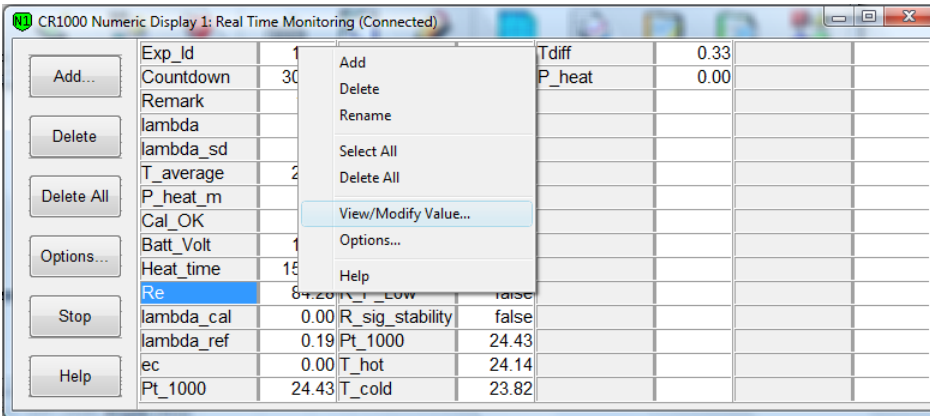


Figure 5.5.1 *Modifying a parameter in the Numeric Display screen.*

After this, a window pops up and the user can edit the value. Note that not all parameters can be changed in this way. To change parameters critical for proper functioning of the system the software code must be modified.

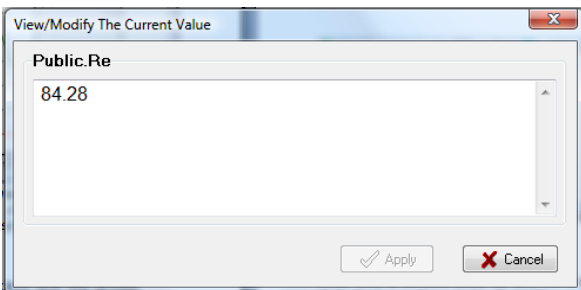


Figure 5.5.2 *Popup window in which a parameter can be changed.*

Another option is to double click on the field that has to be changed and key in the value directly. Press Enter to confirm



## 5.6 Performing a test

Having followed the directions of section 5.3 and 5.4, the system is now ready for a measurement.

First we test the probe to ensure it is working properly:

Connect the probe and remove the protective cover	
Touch the needle with your hand. Look at the Numeric Screen (or KD).	Study the probe manual to see if the observed reaction is correct. With some probes, like TP02 there are two joints in the probe that should give a reaction in opposite directions. With other probes, like TP08, there is one joint only located in the needle.
Look at the signal "T_cold"	The temperature should be within +/- 5 degrees from the ambient temperature.

Table 5.6.1 *Testing the functionality of the probe*

There are two standard methods to perform a test to ensure the system is performing the measurements and data analysis correctly. Note that this test is referred to as a calibration (i.e. a *calibration* cylinder), but this is strictly speaking not a test to *calibrate* the system, it is only a way to test the performance. In the appendix is a method described by which the system may be calibrated in a certain way.

The cheapest way is using a bottle filled with plastic fibres and glycerol fluid (see also appendix) and a second, more sophisticated method, is using a special calibration cylinder available at Hukseflux company (type: CRC01). It must be noted that both methods give results sufficient for most users, that is: within the specified uncertainty of the probe.

For the quality check performed by the system first the thermal conductivity of the calibration medium should be set. This is done by assigning a reference value (at zero degrees Celsius) to the parameter "lambda\_ref" and a temperature coefficient to "ec". In case the temperature dependence is negligible, "ec" can be set to zero. A heating time of 100 seconds should be set using into the parameter "Heat\_time". This makes the length of the total procedure  $2 \times 100 = 200$  seconds long. The calibration





procedure can be started using the flag "Start\_calibration" the parameter "type" will show "Calibration".

First we describe a test using the bottle filled with glycerol fluid.

Take a Test Report Sheet to document this test.	
Prepare glycerol	Pour the glycerol that has been locally purchased into the bottle with plastic fibres. Mix.
Open the glycerol bottle	The glycerol bound together by 2 mass percent plastic fibres. Its thermal properties are like those of glycerol.
Check if the plastic fibres are homogeneously distributed.	The purpose of using fibres with the glycerol is to avoid convection which would disturb the measurement
Put the jar in a low position, e.g. on the ground next to the table on which TPSYS02 is located, such that we can hang the probe in the fluid.	When having a container, the container can be used.
Position the needle into the glycerol, such that the entire needle is covered.	
Verify that the heating cycle time and the heater resistance are correct.	This can be done in the numeric screen, by dragging and dropping the right parameters.
Fix the position of TP02 so that it does not move.	
Wait for 10 minutes, verify that the Tdiff output drift (changes over time) is no more than +/- 0.1 degree in one minute.	This is best done in the graphical screen.
Press flag "Start_Calibration". The countdown should start at the default value, the "Heating_on" should go high to indicate that the system is active.	When 50% of the default measurement time is reached, the heating starts. This is clear from a jump in P_heat, the heating power and a rising Tdiff.
Wait until countdown reaches 0 and the flag "Measuring" is low.	Now a "Lambda" is displayed indicating the measured thermal conductivity, a "Lambda_sd" indicating the standard deviation.





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The parameter "Cal_OK" should read "Yes" if the value for Lambda is stays is equal to the set literature value within 5%.	Lambda_sd should have a value lower than 0.03 (again 10%).
Take a look at the remarks	These all should stay low (green indicators off)
Fill out the Test Report, and archive this.	For measurements that fail, please consult the section on remarks

Table 5.5.2 *A test measurement in glycerol*

A calibration cylinder, made of amorphous plastic, gives in general more accurate results and is easier to handle. The values for to calculate the thermal conductivity can be found on a datasheet provided with the calibration cylinder. The calibration procedure is very similar to using glycerol fluid.

Take a Test Report Sheet to document this test.	
Put the TP02/TP08 gently in the calibration cylinder. Make sure there is a certain amount of glycerol liquid present in the cylinder to improve thermal contact.	Although the diameter of the needle of the TP08 differs a little bit from the TP02, the same calibration cylinder can be used for both needles.
The nominal value of the thermal conductivity is approximately 0.189 W/Km.	Check the data sheet provided with the cylinder for the exact value including temperature dependence.
Wait until the temperature drift in "Tdiff" is smaller than 0.1 degree Celsius per minute.	It is preferable to put the cylinder in the same room as the calibration procedure will be performed a few hours in advance.
Press flag "Start_Calibration". The countdown should start at the default value, the "Heating_on" should go high to indicate that the system is active.	When 50% of the default measurement time is reached, the heating starts. This is clear from a jump in P_heat, the heating power and a rising Tdiff.
<b>CONTINUED ON NEXT PAGE</b>	





<b>CONTINUED</b>	
Wait until countdown reaches 0 and the flag "Measuring" is low.	Now a "Lambda" is displayed indicating the measured thermal conductivity, a "Lambda_sd" indicating the standard deviation.
The parameter "Cal_OK" should read "Yes" if the value for Lambda is stays is equal to the set literature value within 5%.	Lambda_sd should have a value lower than 0.03 (again 10%).
Take a look at the remarks	These all should stay low (green indicators off)
Fill out the Test Report, and archive this.	For measurements that fail, please consult the section on remarks

Table 5.5.3 *A test measurement using the calibration cylinder.*





## 6 Step 4: Performing standard measurements

It is assumed that the user has installed the software and has tested the functionality of the equipment in an indoor test. The user is now supposed to be familiar with the working principles of the TPSYS02. Now it can be used in standard measurements.

### Performing a measurement

Wait until the Tdiff output changes no more than +/- 0.1 degree in one minute.	This requirement can be relaxed. This will result in a larger standard deviation of the end result.
Verify that the heating cycle time and the heater resistance are correct.	
Press flag "Start_Measurement". The countdown should start at the default value, the "Measuring" should go high to indicate that the system is active.	When 50% of the default measurement time is reached, (normally at 100 seconds), the heating starts. This is clear from a jump in P_heat, the heating power, a rising Tdiff and from "Heating_on" which goes high.
Wait until countdown reaches 0 and "Measuring" gets low.	Now a "lambda" is displayed indicating the measured thermal conductivity, a "lambda_sd" indicating the standard deviation.
Check the value for thermal conductivity.	It is suggested to compare the value that is found to the table of typical values in the probe manual. The lambda_sd should be a value lower than again 10% of the value of lambda. If not, please consult the appendix on the subject.
Take a look at the remarks (in particular "R_P_stability", "R_sig_stability", R_T_Drift)	If not zero, please consult the text of tabl 5.3.3 or the tpsys vXXXX.CR1 file on this subject.
<b>CONTINUED ON NEXT PAGE</b>	





<b>CONTINUED</b>	
Fill out the document, and archive the measurement data. In case of high accuracy measurements or new media, review of the complete measurement curve is recommended.	This can be done using a specially developed Excel sheet available at Hukseflux company (see next section) or using other data analysis software.

Table 6.1 *Performing a normal measurement.*







## 7 Step 5: Data retrieval and analysis

The measurement with the TP02 program is not guaranteed to be fool-proof. Before using a certain heating time for a certain category of samples, it is recommended to do a critical review of the obtained data.

### Data retrieval

The measurement data are stored in the CR1000. When necessary, these data can be retrieved for further analysis.

Check where the files will be stored using "Setup" icon in the LoggerNet main screen, select the logger you want to configure (i.e. "CR1000"), choose the tap "Data Files" and key in a directory for each data table or use "..."-button to select one.	The tables "Status" and "Public" don't have to be stored.
Detailed measurement data can now be retrieved using "Collect Now" in the "Connection Screen".	In case there is already a file in that directory, new data will be added to that file.
When retrieving data, immediately make a backup	e.g. on a CD or somewhere else on your hard disk or network.
Details regarding data analysis can be found in the manual of the probe. An Excel program for data analysis can be obtained at Hukseflux (see appendix)	

Table 7.1 *Retrieval of measurement data*

The resulting files are comma separated ASCII. These files easily can be imported in Excel.

An example of a data file is printed below (figure 7.1). In the example, the data structure is as follows:

There is always first a header. The first line of the header contains the following information from left to right; file format, station name as in setup, type of data logger, serial number





logger, software version of the CR1000 operating system, file name of the used CR1000 program, data file identification number and the name of the data table. Names of the parameters stored in the corresponding columns are stated in the second line and the units of the data are displayed in line three. The fourth line gives information on the mode in which the data is collected.

All lines starting with 100 contain raw data:

The following tables show the parameters and there meaning in the two used data files:

<b>RawData</b> ; in this table contains raw, directly measured data. These data can be used for further analysis.	
TIMESTAMP	Time at which this record is stored
RECORD	Record number
Exp_Id	Experiment ID of the different measurements
Re	Resistance of the heater wire in the probe
time	Timepoint into the current measurement cycle
I_heat	Current trough the heater wire
U_sen	Voltage signal from the hot thermocouple junction
U_cold	Voltage signal from the cold thermocouple junction, only TP02 probe
Pt_1000	Temperature signal from the Pt1000 in the probe base
T_hot	Temperature signal of the hot thermocouple junction

Table 7.2: *Meaning of the parameters in the data table "RawData".*

<b>Results</b> ; result of the real time data processing performed by the system.	
TIMESTAMP	Time at which this record is stored
RECORD	Record number
Batt_Volt	Current voltage of the power source
Exp_Id	Experiment ID of the different measurements
type	Type of measurement, either "Measurement" or "Calibration"
<b>CONTINUED ON NEXT PAGE</b>	

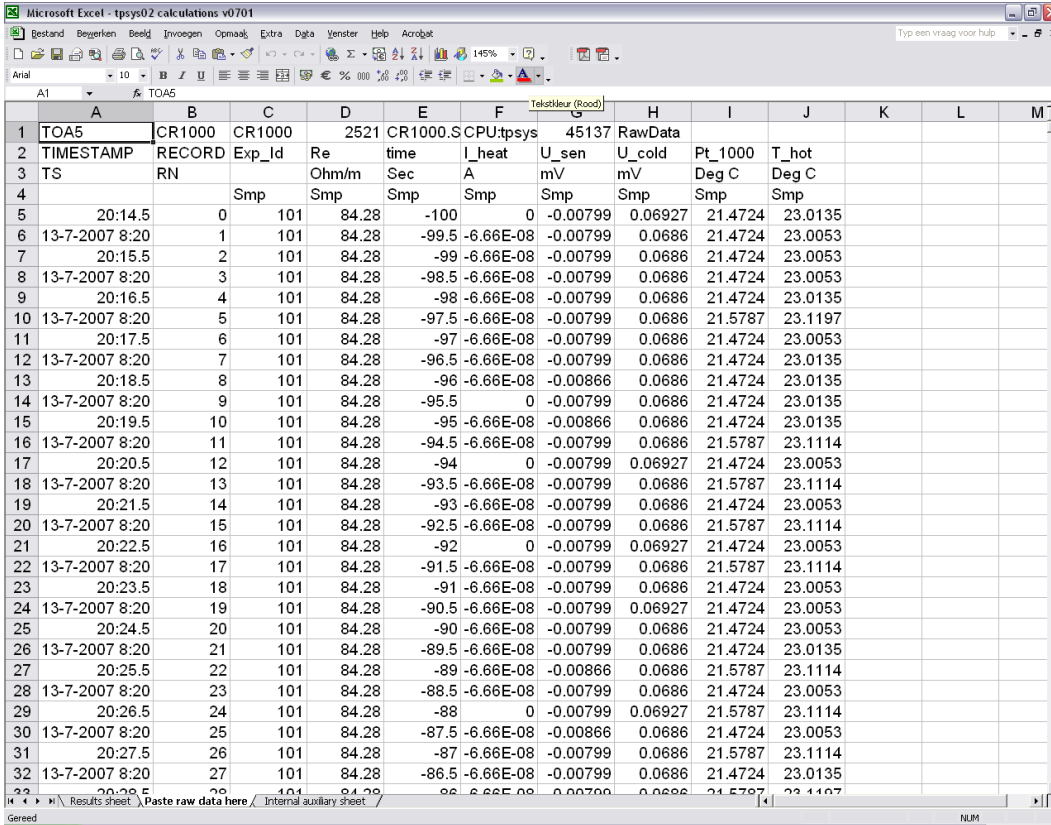




<b>CONTINUED</b>	
Cal_OK	In case of a calibration; "Yes" in case results in within margins and "No" otherwise. For a normal measurement "NAN" will be stored.
lambda	Thermal conductivity determine with a covariance algorithm
lambda_sd	Standard deviation corresponding to the thermal conductivity
Remarks	Is 1 (high) if any remarks are generated by the program. Also the status of these remarks are stored, not displayed in this table. See table 5.3.4 for more information.
T_average	Average temperature over last half of the heating period
P_heat_m	Mean power supplied to the heater wire over the heating period
Heat_time	Length of the heating period
C_n	First four coefficients of the sensitivity polynomial of a K-type thermocouple (n=0,1,2,3)
Re	Resistance of the heater wire in the probe
Cycle_Cancelled	When the "Stop_reset" flag is used (the measurement cancelled), this parameter takes on the value 1 and 0 otherwise.

Table 7.2: *Meaning of the parameters in the data table "Public".*





The screenshot shows an Excel spreadsheet with the following columns and data:

1	TOA5	CR1000	CR1000	2521	CR1000.S	CPU:tpsys	45137	RawData					
2	TIMESTAMP	RECORD	Exp_id	Re	time	I_heat	U_sen	U_cold	Pt_1000	T_hot			
3	TS	RN		Ohm/m	Sec	A	mV	mV	Deg C	Deg C			
4			Smp	Smp	Smp	Smp	Smp	Smp	Smp	Smp			
5	20:14.5	0	101	84.28	-100	0	-0.00799	0.06927	21.4724	23.0135			
6	13-7-2007 8:20	1	101	84.28	-99.5	-6.66E-08	-0.00799	0.06886	21.4724	23.0053			
7	20:15.5	2	101	84.28	-99	-6.66E-08	-0.00799	0.06886	21.4724	23.0053			
8	13-7-2007 8:20	3	101	84.28	-98.5	-6.66E-08	-0.00799	0.06886	21.4724	23.0053			
9	20:16.5	4	101	84.28	-98	-6.66E-08	-0.00799	0.06886	21.4724	23.0135			
10	13-7-2007 8:20	5	101	84.28	-97.5	-6.66E-08	-0.00799	0.06886	21.5787	23.1197			
11	20:17.5	6	101	84.28	-97	-6.66E-08	-0.00799	0.06886	21.4724	23.0053			
12	13-7-2007 8:20	7	101	84.28	-96.5	-6.66E-08	-0.00799	0.06886	21.4724	23.0135			
13	20:18.5	8	101	84.28	-96	-6.66E-08	-0.00866	0.06886	21.4724	23.0135			
14	13-7-2007 8:20	9	101	84.28	-95.5	0	-0.00799	0.06886	21.4724	23.0135			
15	20:19.5	10	101	84.28	-95	-6.66E-08	-0.00866	0.06886	21.4724	23.0135			
16	13-7-2007 8:20	11	101	84.28	-94.5	-6.66E-08	-0.00799	0.06886	21.5787	23.1114			
17	20:20.5	12	101	84.28	-94	0	-0.00799	0.06927	21.4724	23.0053			
18	13-7-2007 8:20	13	101	84.28	-93.5	-6.66E-08	-0.00799	0.06886	21.5787	23.1114			
19	20:21.5	14	101	84.28	-93	-6.66E-08	-0.00799	0.06886	21.4724	23.0053			
20	13-7-2007 8:20	15	101	84.28	-92.5	-6.66E-08	-0.00799	0.06886	21.5787	23.1114			
21	20:22.5	16	101	84.28	-92	0	-0.00799	0.06927	21.4724	23.0053			
22	13-7-2007 8:20	17	101	84.28	-91.5	-6.66E-08	-0.00799	0.06886	21.5787	23.1114			
23	20:23.5	18	101	84.28	-91	-6.66E-08	-0.00799	0.06886	21.4724	23.0053			
24	13-7-2007 8:20	19	101	84.28	-90.5	-6.66E-08	-0.00799	0.06927	21.4724	23.0053			
25	20:24.5	20	101	84.28	-90	-6.66E-08	-0.00799	0.06886	21.4724	23.0053			
26	13-7-2007 8:20	21	101	84.28	-89.5	-6.66E-08	-0.00799	0.06886	21.4724	23.0135			
27	20:25.5	22	101	84.28	-89	-6.66E-08	-0.00866	0.06886	21.5787	23.1114			
28	13-7-2007 8:20	23	101	84.28	-88.5	-6.66E-08	-0.00799	0.06886	21.4724	23.0053			
29	20:26.5	24	101	84.28	-88	0	-0.00799	0.06927	21.5787	23.1114			
30	13-7-2007 8:20	25	101	84.28	-87.5	-6.66E-08	-0.00866	0.06886	21.4724	23.0053			
31	20:27.5	26	101	84.28	-87	-6.66E-08	-0.00799	0.06886	21.5787	23.1114			
32	13-7-2007 8:20	27	101	84.28	-86.5	-6.66E-08	-0.00799	0.06886	21.4724	23.0135			
33	20:28.5	28	101	84.28	-86	-6.66E-08	-0.00799	0.06886	21.5787	23.1197			

Figure 7.1 Example of the structure of a datafile in Excel.





## Data analysis

An Excel spreadsheet can be obtained at Hukseflux company via email. Below is a brief explanation how this sheet can be used to analyze raw data obtained in a measurement. The spreadsheet uses the formula mentioned in the Introduction section and determines a fit over a specified interval using the method of least squares. It is recommended to use this spreadsheet when the temperature profile is expected to deviate from the linear model, for example, in case certain compounds of the medium under test are sensitive to evaporation or when convection is allowed.

Using the spreadsheet:

Make sure you always keep a backup of the original spreadsheet file in case something goes wrong and it is not working properly anymore.

The spreadsheet uses the data stored in the "RawData" table. Open the spreadsheet in Excel. Make sure you allow Macro's to be executed by setting macro security level to "Medium" in the options screen, by choosing option from the menu extra choosing the Security tab and press the "Macro Security" button. Next, open the spreadsheet and choose "Enable Macro's". The spreadsheet is now ready to use.

Now, import the RawData file. Chose "Open" from the "File" menu and select "All Files" for the option "Files of type" and browse to the directory in which the data is stored. Select the file and chose "Open". Press "Next" in the dialog that appears; tick "Comma" in the separation sign frame. Press "Finish". The data file will now look similar to figure 7.2.



	A	B	C	D	E	F	G	H	I	J
1	TOA5	CR1000	CR1000	2521	CR1000.S	CPU:tpsys	45137	RawData		
2	TIMESTAM	RECORD	Exp_Id	Re	time	I_heat	U_sen	U_cold	Pt_1000	T_hot
3	TS	RN		Ohm/m	Sec	A	mV	mV	Deg C	Deg C
4			Smp	Smp	Smp	Smp	Smp	Smp	Smp	Smp
5	20:14.5	0	101	84.28	-100	0	-0.00799	0.069268	21.47243	23.01
6	#####	1	101	84.28	-99.5	-6.66E-08	-0.00799	0.068601	21.47243	23.01
7	20:15.5	2	101	84.28	-99	-6.66E-08	-0.00799	0.068601	21.47243	23.01
8	#####	3	101	84.28	-98.5	-6.66E-08	-0.00799	0.068601	21.47243	23.01
9	20:16.5	4	101	84.28	-98	-6.66E-08	-0.00799	0.068601	21.47243	23.01
10	#####	5	101	84.28	-97.5	-6.66E-08	-0.00799	0.068601	21.57869	23.11
11	20:17.5	6	101	84.28	-97	-6.66E-08	-0.00799	0.068601	21.47243	23.01
12	#####	7	101	84.28	-96.5	-6.66E-08	-0.00799	0.068601	21.47243	23.01
13	20:18.5	8	101	84.28	-96	-6.66E-08	-0.00866	0.068601	21.47243	23.01
14	#####	9	101	84.28	-95.5	0	-0.00799	0.068601	21.47243	23.01
15	20:19.5	10	101	84.28	-95	-6.66E-08	-0.00866	0.068601	21.47243	23.01
16	#####	11	101	84.28	-94.5	-6.66E-08	-0.00799	0.068601	21.57869	23.11
17	20:20.5	12	101	84.28	-94	0	-0.00799	0.069268	21.47243	23.01

Figure 7.2: Click the top left area (marked red) to select all data in the current tab.

The next step is to copy the data into the spreadsheet select all data clicking in the top left corner of the data window as in figure 7.2. Copy the selection by pressing "Ctrl"-key and "C" simultaneously. Go to the "Paste raw data here" tab in the spreadsheet. Again select all cells in the tab and import the data just copied by pressing "Ctrl"-key and "V" simultaneously. The data is now imported in the spreadsheet.

Go to the "Results sheet" tab (see figure 7.3). The cells marked yellow will new to be filled in by the user. The most important data that must be filled in is the experiment number and the interval over which the linear fit must is made (In t\_begin and In t\_end).

The blue cells display the result of the calculations made and information on the quality of the measurement. A thick black line marks the cells that display the most important results.

Normally, the procedure is to first fill in the experiment number and then press the "Update Lambda" button. The graph on the left will now show the corresponding data in logarithmic time. In the processing the TPSYS02 system performs automatically the analysis interval is from 3.91 to 4.60. Adapt these limits and press the "Update Lambda" button subsequently until a good linear fit on the data is found. A physically correct set of point

should increase linearly with time and is never horizontal for sure (as the last portion in figure 7.3).

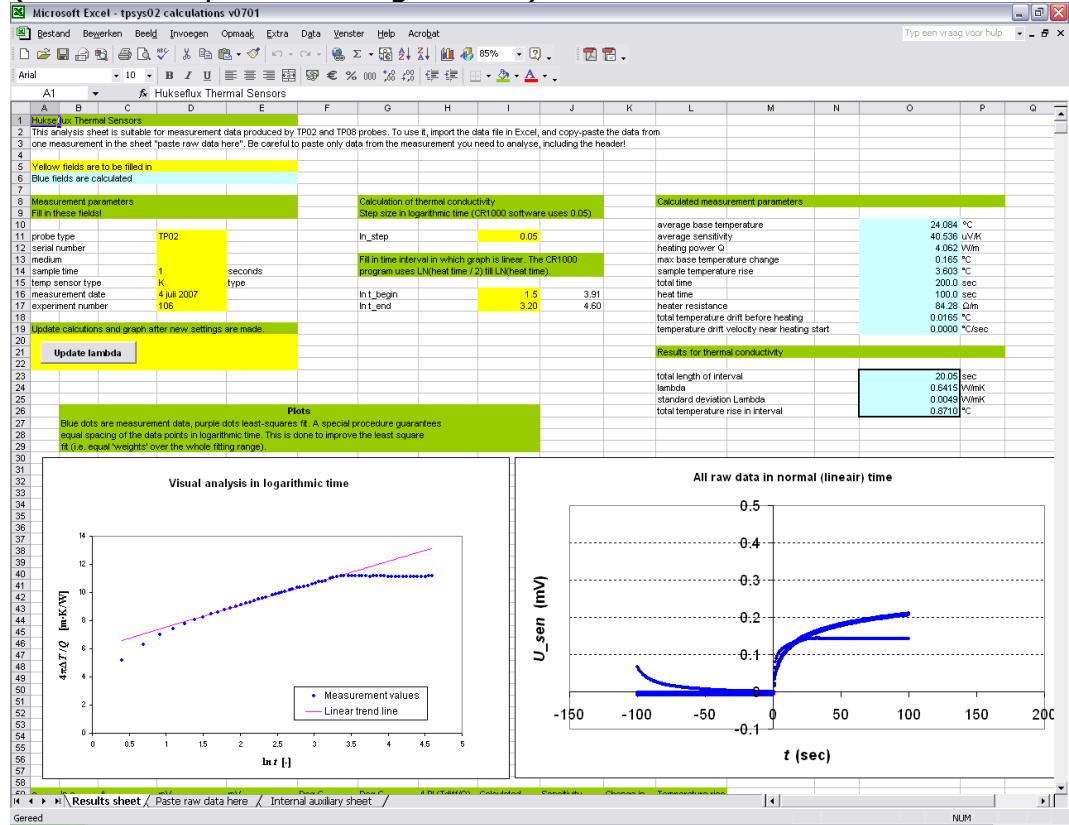


Figure 7.3: An example of how the Results sheet will look like after the data is imported and calculations are performed. The left graph show the data corresponding to the selected experiment number in logarithmic time and the right one all raw data in normal, linear time. This data set is an example of a measurement, were convection in the medium (water) spoiled the model and a linear portion has to be selected visually.

## 8 Appendices

### 8.1 Appendix on power supply

Warning: always check the polarity of the power supply plug before inserting the plug into the TPSYS02.

When supplied without battery pack, TPSYS02 must be powered from a DC source supplying between 10 and 13 VDC at 5 Watts. The absolute value of the voltage is not important as long as it is constant within 1% during the 5 minutes of a typical measurement.

The 5 Watt power is the maximum value used during the heating. Power consumption before and after heating is less than 0.5 Watt.

Preferably the Adapter (part of the delivery) is used as power supply. This adapter can be connected to mains power. This can be 100-240VAC, 50/60 Hz.

Alternatively other sources can be used, like normal batteries or car batteries. In case of using car batteries, it is suggested to put the motor or generator off while using TPSYS02.

TPSYS02 can e.g. be powered from a Campbell Scientific PS200 Smart 12 V Power Supply with Charging Regulator and 7 Ah Rechargeable Battery.

To power TPSYS02 from a custom power supply (e.g. an external battery), the power supply must be connected to the TPSYS02 MCU using a Bulgin Standard Buccaneer®, PX0731/P, 3 pole connector with pins. The connector wiring is explained in Table X.X.X. Batteries or connector must be purchased separately. Hukseflux Thermal Sensors does not supply batteries or connectors to power TPSYS02.

**Table 8.1.1** Wiring of a custom power supply (e.g. an external battery) to a Bulgin Standard Buccaneer®, PX0731/P, 3 pole connector with pins.





Custom power supply	Recommended wire colour	Bulgin Standard Buccaneer®, PX0731/P
+ 12 VDC	<b>Red</b>	L
GND	<b>Black</b>	N
not connected	-	E

In case the system is supplied with a battery pack, the voltage can usually be put on a higher level in order to have optimal battery loading. Please consult the battery manual.

## 8.2 Appendix on performing measurements in the field

NOTE: there is an alternative to using the PC: in case of fully battery powered systems it is often more practical possible to use the CR1000KD keyboard display for control and readout. This is powered from the same battery as the TPSYS02. In this case a set of separate directions is available for operating TPSYS02 with the CR1000KD.

NOTE: instead of the CR1000KD one also has another option for measurements without a computer. A button can be connected to the CR1000 wiring panel, and two LEDs. Note that the only functionality in this case is starting a measurement. No readout is provided, nor can one change parameters. See the appendix on this option.

NOTE: The probe manuals contain general directions for field measurements, and a table of soil types with the expected values for thermal conductivity.

NOTE: Hukseflux manufactures special heavy duty probes for field measurements. Please inquire; these might be more suitable to your experiment.

For field experiments we recommend to take the following:

Small hammer	For forcing needles for pre-drilling into the ground
Metal pin or smallest available diameter ground drill capable of drilling to a depth equal to the needle length	To cover the situation that the soil is harder than expected. A diameter of up to 6mm is recommended, up to 1 cm is allowable in extreme cases (see appendix)
Mobile phone	For calling support

Table 8.2.1 *Recommended items to be available with a field experiment*





field measurements it is recommended to take several measurements at different locations, geographically spread around the area of interest.

Temperature differences can be larger than expected; the effect of soil moisture content on thermal conductivity is very high. Usually the extreme values are of interest.

The ASTM standard requires that forms are filled for every single measurement, an example can be found in the probe manual.

The system produces a value for the thermal conductivity of the soil, a standard deviation and warnings. The thermal conductivity data should be recorded on the form. In addition these measurements are recorded in the TPSYS02 memory. The detailed measurement data can later be retrieved if necessary. It is however essential that a manual record of time and place of the measurement is kept.





Confirm that the field test will be done with the same PC as the one with which the last indoor test was done. Confirm that time and date are adapted to the local time and date.	This is to avoid problems with compatibility.
Check table 8.2.1 to see if all necessary items are there	

Table 8.2.2 *First check for a field measurement*

Connect the Adapter to mains power or connect the cable that normally leads from the Adapter to the TPSYS02 to an alternative power source like a car battery.	
Verify that the polarity at the plug of the Adapter or Cable	Use the multimeter in the 40V DC range, hold the red (+) pin to the interior of the plug, the black (-) pin to the exterior. The readout should show a POSITIVE value between 10 and 13 VDC.
Connect the plug to the TPSYS02	The red lamp should start burning, confirming that the system is powered.

Table 8.2.3 *Powering the system in the field*

The soil around the TP02 needle should be as undisturbed as possible. There should be good thermal contact between needle and soil. There should be as little air gaps as possible. Directions for inserting the needles into the soil can be found in the TP02 manual.

### 8.3 **Appendix on the serial numbers of the equipment**

The serial number of the CR1000 can be found on its side on a sticker.  
 The serial number of the probes and the individual figure of the resistance of the probe heater in Ohm/m, is engraved on every single probe.





## 8.4 Appendix on TPSYS02 wiring diagram

A wiring diagram can be found in the tpsys vxxxx.CR1 file. This file can be opened in the Program mode of the LoggerNet or in any text editor. Two wiring schemes are provided; one containing an external power switch, and one without.

## 8.5 Appendix on using a button and LEDs to control measurements

To perform measurements in the field, the user can connect a button and LEDs to control the probe without a computer. A wiring scheme and shopping list can be found in the CR1 file.

## 8.6 Appendix on working with CR1000KD

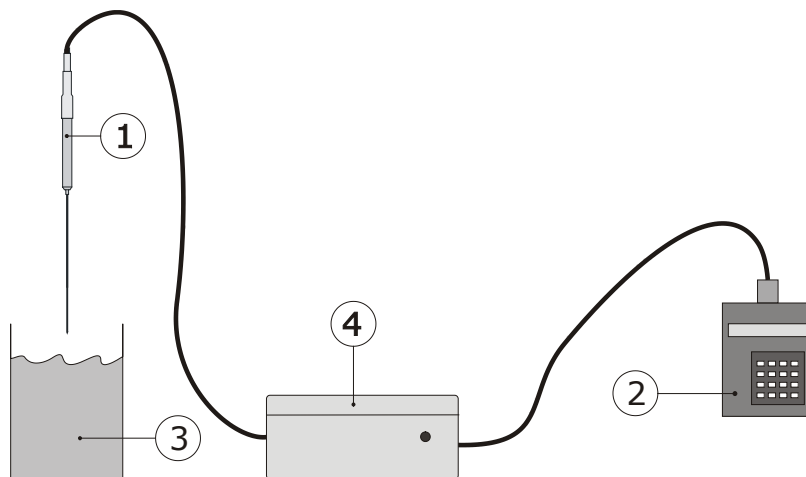


Figure 8.6.1 *In case of field experiments, when there is no PC and mains power available, it is possible to work with the CR1000KD Keyboard Display. Typically power will come from a battery pack in the same housing as the CR1000. By pressing the buttons on the display, the measurement is activated. Readout of the measurement result can also be done on the display. The details of the measurement are stored in the logger, and can always be retrieved when back in the laboratory.*

Especially in a field experiment using a portable system, it can be convenient to use a keyboard display (CR1000KD). In this case it is recommended to work in the "Standard Operation". Changed parameters will be kept in the same way as using the Numeric Display, even after the power is cut off. When returning





to the laboratory it is always possible to retrieve the data from the CR1000. These are automatically stored.

Changing/Displaying parameters:

When the user knows the measuring of the parameters it should be quit straight forward to use the keyboard display (KD). Use a RS-232 cable to connect the KD to the port labelled "CS I/O" on the casing panel. If the system is start up the display also starts automatically. After a certain amount of time the KD will switch off automatically and can be activated again by pressing any button on the KD.

The first screen will look as in figure 8.6.2. By pressing the "Enter" button the main menu will appear, showing the submenus "Controls", "Monitor", "Parameters" and the "System Menu". One can navigate trough the menus using the arrow-keys, "Enter" to go one level down in the menu and "Esc" to go one level back up. The (blue) "Shift" key is used to key in the (blue) characters stated above the buttons. "Controls" contains the main flags to control the program flow, "Monitor" is used to view the most important measurement parameters, including a submenu containing the remarks on the measurement. Using "Parameters" the user is able to modify parameters values.

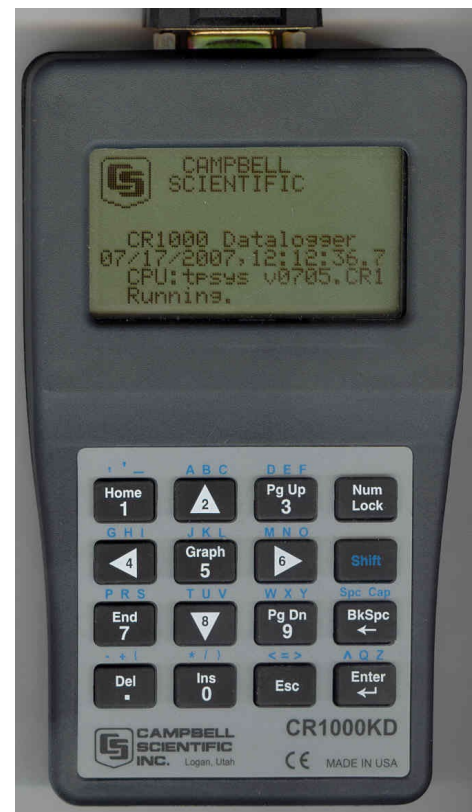


Figure 8.6.2 The starting screen of the Keyboard Display CR1000KD.

Main rule: configure the logger in the lab, before going out to the field, using the normal procedures. Test in the lab using first LoggerNet and then using the CR1000KD. In the field it is recommended to use one heating cycle time and one power level: 400 seconds and high power are recommended unless there are reasons to do differently.

Table 8.6.1 Main rules when using the Keyboard Display





## 8.7 Appendix on calibration

It is in principle never necessary to calibrate the system. The system is calibrated during manufacturing and it is highly unlikely that the probe characteristic will deviate. Furthermore, in case characteristic deviate due to degeneration of the probe or because it is not treated properly, is it unlikely that a calibration as described below will give any improvement to the accuracy of the measurement.

But in case it is needed to push the accuracy of the measurement really to the limit there is a possibility to calibrate the probe to a known material, which is preferably the amorphous plastic calibration cylinder (type: CRC01) available at Hukseflux.

Follow the calibration procedure described in Table 5.5.3 and take special care to the thermal stability of the calibration cylinder, the probe and the environment. Avoid for example air lock due to open doors, windows or air conditioning. This may cause an uncontrolled temperature change of the probe or calibration cylinder.

Compare the resulting value for lambda to the literature value. In case the deviation is larger than 5% it is recommended to contact the glycerol supplier. Also lambda\_sd should be smaller than 1% of the with respect to lambda for a good calibration measurement.

Use the following formula to compute a new wire resistance out of the known value of for the thermal conductivity of the medium and the observed thermal conductivity:

$$R_{\text{new}} = R_{\text{current}} \cdot (\lambda_{\text{literature}} / \lambda_{\text{observed}})$$

where  $R_{\text{new}}$  is the newly calculated value for the wire resistance,  $R_{\text{current}}$  (parameter "Re") the currently used wire resistance,  $\lambda_{\text{literature}}$  the literature value of the thermal conductivity and  $\lambda_{\text{observed}}$  (parameter "Lambda") the observed value. Take the temperature dependence of the thermal conductivity, as stated on the calibration cylinder data sheet, into account to get the highest accuracy. Calculate the corrected literature value of the thermal conductivity using the following formula:

$$\lambda_{\text{literature}} = \lambda_{\text{ref}} + ec \cdot \Delta T$$

where  $\lambda_{\text{ref}}$  is the thermal conductivity in W/Km at zero degrees Celsius,  $ec$  the temperature coefficient and  $\Delta T$  the temperature of the cylinder before the measurement with respect to zero degrees Celsius, all stated on the calibration cylinder data sheet.





### 8.8 Appendix on TPSYS02 specifications

TPSYS02 Thermal Conductivity Measurement System is used for determining the thermal conductivity or resistivity of the soil in which it is inserted. It consists of a Non-Steady State Probe (NSSP) (typically of type TP02), MCU Measurement and Control Unit. TPSYS02 is normally PC controlled, optionally the control can be performed by Keyboard Display.

<b>GENERAL SPECIFICATIONS</b>	
Measurement method	Absolute measurement, according to the standards ASTM D5334-14 and IEEE Std 442-1981.
Specified measurements	Thermal conductivity of soil as specified under suitable soils. Directions from the manual should be followed.
Suitable soils	Soils with grain size smaller than 3 mm, slurries, mud and soft rock in the thermal conductivity ( $\lambda$ ) range of 0.1 to 6 W/m.K. Essentially this includes all known soil types.
Soil requirements	Preferably the soil is in good contact with the NSSP. Hard soil or soft rock may be pre-drilled. Filling material may be used to promote contact. The soil must be thermally stable ( $dT/dt < 1\%$ of the heater induced change typically, 5 % max) and reasonably homogeneous. In case of soil samples: please consult Hukseflux about alternative needles.
Duration of the heating cycle H	H must be as short as medium and readout allow. 100 seconds (typical). Empirically verified for each soil type.
Heating Power / meter Q	Q must be as low as the medium and readout allow. Typically Q is adjustable so that the temperature rise is no more than 3 degrees. Typically lower than 5 W/m.
Temperature range	Needle and cable: -55 to +180 °C MCU: 0 to +50 °C
ISO requirements	TPSYS02 is suitable for use by ISO certified laboratories
<b>CONTINUED ON NEXT PAGE</b>	





<b>CONTINUED</b>	
Shipment	Total weight including all accessories & packing: approx. 15 kg (net approx. 12 kg)
CE requirements	TPSYS02 complies with CE directives
<b>MEASUREMENT SPECIFICATIONS</b>	
Data analysis	First automatic analysis: by MCU Second review: Using Excel software on the PC the stored data can be transmitted from the MCU to the PC and be exported to a spreadsheet (Excel) or a dedicated mathematical program.
Expected accuracy	Thermal conductivity: $\pm$ (3% +0.02 W/mK) for homogeneous soils with good contact to the probe. Temperature reading: +/- 2 Degrees C
Repeatability	Thermal Conductivity: $\pm$ 2 %
<b>NON STEADY STATE PROBE SPECIFICATIONS</b>	
	See manual
<b>MCU MEASUREMENT AND CONTROL UNIT SPECIFICATIONS</b>	
Measurement specifications	Display of thermal conductivity and standard deviation of the thermal conductivity Variable heating level Variable heating time
Data Storage	More than 30 measurements can be stored. Including text comment. (file size depends on measurement duration H)
Power supply	External: Adapter included for 100-240 VAC operation. Optional: internal battery pack
Software	New software versions can be downloaded through the COM port
Data transfer	RS-232 / USB
Control	External PC Optional: by Keyboard Display
<b>LOGGERNET SOFTWARE SPECIFICATIONS</b>	
Required PC	Windows XP or higher, CD-ROM drive, one free COM port, 100MB harddisk space
<b>CALIBRATION</b>	
Recalibration interval	Every year using glycerol reference fluid

Table 8.8.1 *List of TPSYS02 specifications.*







### 8.9 Appendix on maintenance and storage

TPSYS02 does not need a lot of maintenance.

In case of optional internal batteries in the MCU, it is important to take care that the day before use the batteries are re-charged. See the appendix on recharging.

After use the equipment can be cleaned using water.

The MCU should be stored in a dry place.

Usually errors in functionality will appear as unreasonably large or small measured values. As a general rule, this means that a critical review of the measured data is the best form of preventive maintenance.

At regular intervals the quality of the cables and probe should be checked. On a yearly interval the calibration should be checked.

Every 1 year	Perform calibration of the entire system using glycerol
--------------	---

Table 8.9.1 recommended schedule for calibration of TPSYS02.

### 8.10 Appendix on glycerol/glycerine

The procedure for calibration relies on the use of glycerol. This substance is also known under the name glycerine. Chemical datasheets can be found in separate appendices (12.15 and 12.16).

Glycerol is safe. It can be bought in every pharmacy.

During calibration the glycerol is supposed to be static, in other words, not to flow. This is why at Hukseflux the glycerol is mixed with polyester fibres. This suppresses convection. At the same time, the fraction of polyester fibres is so low (less than 1% by mass) that the thermal conductivity of the glycerol is not affected.

The properties of glycerol at 0 to 1 mass % plastic fibres closely resemble those of glycerol:

Thermal conductivity: 0.29 W/m.K, at 20 degrees C.





### 8.11 Appendix on USB connection

As an option a USB connection can be offered.  
The USB connection does require installation of a special USB driver. This driver is supplied with the instrument on a CD-ROM.

### 8.12 Appendix on arctic system

A special system was developed for use in arctic conditions.

Special features are:

- 1 datalogger specified to -50 degrees C.
- 2 packaging in a metal casing
- 3 protection case of high grade plastic.
- 4 rechargeable batteries rated to -30 degrees C
- 5 power switch to prevent battery power loss during transport and storage
- 6 activation button for measurement start, with green LED

The system is supplied with a charger.



Figure 8.12.1 *Arctic system complete ready for shipment*





Figure 8.12.2 Arctic system measuring in glycerol, with keyboard display



Figure 8.12.3 Arctic System special features:  
1 above: power switch: Red: on  
2 below: measurement switch. Green flashing: on, green burning: heating  
3 in between: connectors for USB and charging



### **8.13 Glycerol Material Safety Data Sheet (93 / 112 EC)**

This safety sheet is a copy of the Material Safety Data Sheet Version according to 93/112 EC of 10-08-2000 of the company Ephuysen Chemie. The user is responsible for obtaining the latest Version of this sheet from the manufacturer when purchasing glycerol.





<p><b>1 identification of the substance / preparation and of the company/ undertaking</b></p> <ul style="list-style-type: none"><li>• Production details -</li><li>• Trade Name: Glycerine</li><li>• Article Number: 013311</li><li>• Manufacturer / Supplier: Ephuysen Chemie N. V. Noordeweg 3 3336 LH Zwijndrecht The Netherlands Tel: 00-31-78-612702 Fax: 00-78-6121129 e-mail <a href="mailto:ppelt@ephuysen.com">ppelt@ephuysen.com</a></li><li>• Further information available from: environmentally Department</li><li>• Information in case of emergency: see above</li></ul>
<p><b>2 Composition / information on the ingredients</b></p> <ul style="list-style-type: none"><li>• Chemical characterisation: Cas No Description: 56-81-5 Glycerol</li><li>• Identification numbers: -</li><li>• EINECS Number: 200-289-5</li></ul>
<p><b>3 Hazards identification</b></p> <ul style="list-style-type: none"><li>• Information concerning to particular hazards to man and environment: Not applicable</li></ul>
<p><b>4 First-aid measures</b></p> <ul style="list-style-type: none"><li>• General information: No special measures required</li><li>• After inhalation: Supply fresh air; consult a doctor in case of complaints</li><li>• After skin contact: Generally the product does not irritate the skin</li><li>• After eye contact: Rinse opened eye for several minutes under running water</li><li>• After swallowing: If symptoms persist consult a doctor</li></ul>
<p><b>5 Fire fighting measures</b></p> <ul style="list-style-type: none"><li>• Suitable extinguishing agents: Use fire extinguishing methods suitable to surrounding conditions</li><li>• Protective equipment: No special measures required</li></ul>
<p><b>6 Accidental release measures</b></p> <ul style="list-style-type: none"><li>• Person-related safety precautions: Not required</li><li>• Measures for environmental protection: Dilute with plenty of water</li><li>• Measures for cleaning / collecting: Absorb with liquid binding material (sand, diatomite, acid binders, universal binders, sawdust).</li><li>• Additional information: No dangerous substances are released</li></ul>





## **7 Handling and storage**

- Handling :-
- Information for safe handling: No special measures required
- Information about fire - and explosion protection: No special measures required
  
- Storage:
- Requirements to be met by storerooms and receptacles: No special requirements
- Information about storage in one common storage facility: Not required
- Further information about storage conditions: None
- Storage class: -
- Class according to regulation an flammable liquids: void

## **8 Exposure controls / personal protection**

- Additional information about design of technical facilities: No further data; see item 7
- Ingredients with limit values that require monitoring at the workplace: 56-81-5 glycerol OEL: 10 mg/m<sup>3</sup>
- Additional Occupational Exposure Limit Values for possible hazards during processing: Glycerine is (almost) odourless. The MAC-value can exceed the limit unnoticed.
- Additional information: The lists valid during the making were used as a basis
  
- Personal protective equipment: -
- General protective and hygienic measures: The usual precautionary measures are to be adhered to when handling chemicals
- Respiratory protection: not required
- Protection of hands: not required
- Eye protection: Goggles recommended during refilling





### **9 Physical and chemical properties**

- Form: viscous
- Colour: Colourless
- Odour: Odourless
- Change in condition: -
- Melting point / Melting range: 18.2 °C
- Boiling point / Boiling range: 290°C
- Flash point: 177 °C
- Ignition temperature: 400 °C
- Danger of explosion: the product does not present an explosion hazard
- Explosion limits:
- Lower: 0.9 Vol%
- Vapour pressure: at 50 °C 0.003 hPa
- Density: at 20 °C 1.26 g/ cm<sup>3</sup>
- Solubility in / Miscibility with water: Fully miscible
- PH value; Not determined
- Viscosity:
- Dynamic: at 20 °C 106.9 mPas

### **10 Stability and reactivity**

- Thermal decomposition / conditions to be avoided: No decomposition if used according to specifications
- Dangerous reactions: No dangerous reactions known
- Dangerous decomposition products: No dangerous decomposition products known

### **11 Toxicological information**

- Acute toxicity: LD/ Lc50 values relevant for classification: 56-81-5 glycerol Oral LD50: 250 mg/kg(mus)
- Primary irritant effect:
- On the skin: It is not irritating
- On the eye: No irritating effect
- Sensitisation: No sensitisation effects known.
- Additional toxicological information: When used and handled according to specifications, the product does not have any harmful effects to our experience and the information provided to us. The substance is not subject to classification according to the latest Version of the EU lists.

### **12 Ecological information**

- Ecotoxicological effects:
- Aquatic toxicity: 56-81-5 glycerol LC50/24 h: > 5000 ppm (fish)
- General notes: generally not hazardous for water





### **13 Disposal considerations**

- Product
- Recommendation: Smaller quantities can be disposed with household waste
- Uncleaned packaging
- Recommendation: Disposal must be made according to official regulations
- Recommended cleansing agents: Water, if necessary together with cleansing agents.

### **14 Transport information**

- Land transport ARD / RID (cross border)
- UN-Number: -
- Hazard label: -

### **15 Regulatory information**

- Labelling according to EU Guidelines: The substance is not subject to classification according to EU lists and other sources of literature known to us. Observe the general safety regulations when handling chemicals; the product is not subject to identification regulations under EU Directives and the Ordinance on Hazardous Materials (German GefStoffV).
- National regulations
- Classification according to VbF: Void
- Technical instructions (air): Class Share in %: NK 100.0
- Waterhazard class: Generally not hazardous for water.

### **16 Other information**

This information is based on present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship.

- Department issuing MSDS: Environmentally Department
- Contact: P. van Pelt







### **8.14 International Chemical Safety Card for Glycerol**

The following pages contain information on the International Chemical Safety Card for glycerol. The user is responsible for obtaining the latest Version of this card from the glycerol manufacturer when purchasing glycerol.





<b>International Chemical Safety Cards</b>			
<b>GLYCEROL</b>			ICSC: 0624
<b>GLYCEROL</b> Glycerine 1,2,3-Propanetriol 1,2,3-Trihydroxypropane $C_3H_8O_3$ / $CH_2OH-CHOH-CH_2OH$ Molecular mass: 92.1 CAS # 56-81-5 RTECS # MA8050000 ICSC # 0624			
<b>TYPES OF HAZARD/ EXPOSURE</b>	<b>ACUTE HAZARDS/ SYMPTOMS</b>	<b>PREVENTION</b>	<b>FIRST AID/ FIRE FIGHTING</b>
<b>FIRE</b>	Combustible. Gives off irritating or toxic fumes (or gases) in a fire.	NO open flames.	Powder, alcohol-resistant foam, water spray, carbon dioxide.
<b>EXPLOSION</b>			In case of fire: keep drums, etc., cool by spraying with water.
<b>EXPOSURE</b>		Prevent generation of mists!	
<b>INHALATION</b>	Cough	Ventilation.	Fresh air, rest.
<b>SKIN</b>	Dry skin.	Protective gloves.	Remove contaminated clothes. Rinse skin with plenty of water or shower.





<b>EYES</b>	Redness. Pain.	Safety goggles.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then take to a doctor.
<b>INGESTION</b>	Nausea Vomiting	Do not eat, drink, or smoke during work.	Rinse mouth Give plenty of water to drink. Rest. Refer for medical attention.
<b>SPILLAGE DISPOSAL</b>		<b>STORAGE</b>	<b>PACKAGING &amp; LABELLING</b>
Ventilation. Collect leaking liquid in covered containers. Absorb remaining liquid in sand or inert absorbent and remove to safe place.		Separated from strong oxidants. Dry.	
<b>SEE IMPORTANT INFORMATION ON BACK</b>			
<b>ICSC: 0624</b>	Prepared in the context of cooperation between the International Programme on Chemical Safety & the Commission of the European Communities © IPCS CEC 1993		
<b>International Chemical Safety Cards</b>			
<b>GLYCEROL</b>			
<b>IMPORTANT DATA</b>	<p><b>PHYSICAL STATE; APPEARANCE:</b>  <b>HYGROSCOPIC, VISCOUS COLOURLESS LIQUID.</b>  <b>PHYSICAL DANGERS:</b></p> <p><b>CHEMICAL DANGERS:</b>          The substance decomposes on heating producing corrosive fumes of acrolein. Reacts with strong oxidants causing fire and explosion hazard. Reacts violently with acetic anhydrides in the presence of a catalyst.</p> <p><b>OCCUPATIONAL EXPOSURE LIMITS</b></p>	<p><b>ROUTES OF EXPOSURE:</b>          The substance can be absorbed into the body by inhalation of its mist.</p> <p><b>INHALATION RISK:</b>          Evaporation at 20°C is negligible; a nuisance-causing concentration of airborne particles can, however, be reached quickly on spraying.</p> <p><b>EFFECTS OF SHORT-TERM EXPOSURE:</b>          The substance irritates</p>	



	<b>(OELs):</b> TLV: ppm; 10 mg/m <sup>3</sup> mist (ACGIH 1995-1996).	the eyes, the skin and the respiratory tract.  <b>EFFECTS OF LONG- TERM OR REPEATED EXPOSURE:</b>
<b>PHYSICAL PROPERTIES</b>	Decomposes below boiling point at 171°C Melting point: 18.2°C Relative density (water = 1): 1.26 Solubility in water: miscible Vapour pressure, Pa at 20°C: <0.1	Relative vapour density (air = 1): 3.17 Flash point: 177°C. Auto-ignition temperature: 370°C Explosive limits, vol% in air: 0.9 Octanol/water partition coefficient as log Pow: -1.76
<b>ENVIRON- MENTAL DATA</b>		
<b>NOTES</b>		
	Also consult ICSC # 0090, acrolein.	
	NFPA Code: H1; F1; R0	
<b>ADDITIONAL INFORMATION</b>		
<b>GLYCEROL</b>		
<b>ICSC: 0624</b>		
<b>© IPCS, CEC, 1993</b>		
<b>IMPORTA NT LEGAL NOTICE:</b>	Neither the CEC or the IPCS nor any person acting on behalf of the CEC or the IPCS is responsible for the use which might be made of this information. This card contains the collective views of the IPCS Peer Review Committee and may not reflect in all cases all the detailed requirements included in national legislation on the subject. The user should verify compliance of the cards with the relevant legislation in the country of use.	





### 8.15 CE Declaration of Conformity



According to EC guidelines 89/336/EEC, 73/23/EEC and 93/68/EEC

We: Hukseflux Thermal Sensors

Declare that the product: TPSYS02

Is in conformity with the following standards:

Emissions: Radiated:	EN 55022: 1987 Class A
Conducted:	EN 55022: 1987 Class B

Immunity: ESD	IEC 801-2; 1984 8kV air discharge
RF	IEC 808-3; 1984 3 V/m, 27-500 MHz
EFT	IEC 801-4; 1988 1 kV mains, 500V other

Delft,  
November 2008