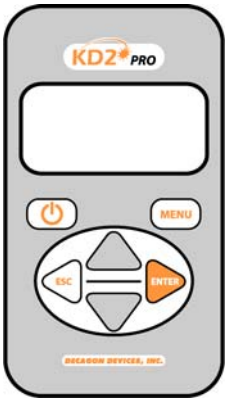
KD2 Pro

Thermal Properties Analyzer

Operator's Manual
Version 7



DECAGON DEVICES

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1. Introduction

Welcome to your new KD2 Pro Thermal Properties Analyzer. This guide is designed to help you understand and use your instrument to the best of its capability.

About the KD2 Pro

The KD2 Pro is a handheld device used to measure thermal properties. It consists of a handheld controller and sensors that can be inserted into the medium you wish to measure. The single-needle sensors measure thermal conductivity and resistivity; while the dual-needle sensor also measures volumetric specific heat capacity and diffusivity. Further details about the measurements and how they're made are given in chapters 2 and 3 of this guide. The KD2 Pro has many new and improved features over the original KD2:

- **Extended temperature range:** The KD2 Pro can now take readings between -50 and 150°C.
- **Multiple sensor support:** Unlike its predecessor, the KD2 Pro now offers three sensors to choose from: the standard single-needle sensor, an extended-length single-needle sensor, and a dual-needle sensor.
- **Data Storage:** Data measured by the KD2 Pro can now be stored and viewed on screen.
- **Download ability:** Data stored in the KD2 Pro can be downloaded to your computer using the included KD2 Pro Utility program. This program also helps you configure your KD2 Pro. Down-

loaded data can be displayed in two forms: the processed reading from the handheld device, or the raw data itself (so that you can process the data in another form if desired).

- **Unit Selection:** The KD2 Pro gives you the ability to select data to be displayed in either SI or English (Imperial) units.

Contact Information

- **E-mail us at:** support@decagon.com
- **Fax us at:** (509) 332-5158
- **Call us at:** 1-800-755-2751 (US/Canada only) or 1-509-332-2756

Warranty Information

The KD2 Pro has a 30-day satisfaction guarantee and a one-year warranty.

Seller's Liability

Seller warrants new equipment of its own manufacture against defective workmanship and materials for a period of one year from date of receipt of equipment (the results of ordinary wear and tear, neglect, misuse, accident and excessive deterioration due to corrosion from any cause are not to be considered a defect); but Seller's liability for defective parts shall in no event exceed the furnishing of replacement parts F.O.B. the factory where originally manufactured. Material and equipment covered hereby which is not manufactured by Seller shall be covered only by the warranty of its manufacturer. Seller shall not be liable to Buyer for loss, damage or injuries to persons (including death), or to property or things of whatsoever

kind (including, but not without limitation, loss of anticipated profits), occasioned by or arising out of the installation, operation, use, misuse, non-use, repair, or replacement of said material and equipment, or out of the use of any method or process for which the same may be employed. The use of this equipment constitutes Buyer's acceptance of the terms set forth in this warranty. There are no understandings, representations, or warranties of any kind, express, implied, statutory or otherwise (including, but without limitation, the implied warranties of merchantability and fitness for a particular purpose), not expressly set forth herein.

Repair Instructions

If your KD2 Pro should ever require a repair, call Decagon at **(509) 332-2756** or **1-800-755-2751** (United States and Canada). We will ask you for your address, phone number, your KD2 Pro's serial number, and your current firmware version. For non-warranty repairs, we will also ask for a method of payment.

Before shipping your instrument to Decagon, please contact Decagon to obtain a Request Maintenance Authorization Number (RMA). This will allow Decagon's repair staff to keep track of your KD2 Pro. Once you have acquired an RMA, send your KD2 Pro to Decagon. Please include a document listing the complete shipping address, name, and department of the person responsible for the instrument, as well as a description of the problem. This will better help our technicians and shipping department to expedite repair on your KD2 Pro, and ship it back to you.

Please pack your KD2 Pro carefully. Ship it back in the carrying case, preferably inside a cardboard box. Ship to:

Decagon Devices Inc.
2365 NE Hopkins Court
Pullman, WA 99163

Repair Costs

Manufacturer's defects and instruments under warranty will be repaired at no cost. For non-warranty repairs, costs for parts, labor, and shipping will be billed to you.

2. KD2 Pro Overview

The KD2 Pro is a battery-operated, menu-driven device that measures thermal conductivity and resistivity, volumetric specific heat capacity and thermal diffusivity. The KD2 Pro has been designed for ease of use and maximum functionality.

Specifications

Operating Environment:
Controller: 0 to 50 °C
Sensors: -50 to +150 °C

Power: 4 AA cells

Battery Life: Approx. 1800 readings in constant use or 3 years with no use (battery drain in sleep mode < 50 uA)

Case Size: 15.5 cm x 9.5 cm x 3.5 cm

Display: 3 cm x 6 cm, 128 x 64 pixel graphics LCD

Keypad: 6 key, sealed membrane

Data Storage: 4095 measurements in flash memory (both raw and processed data are stored for download)

Interface: 9-pin serial

Sensor cable length: 0.8 m

Read Modes: Manual and Auto Read

Sensors:

6 cm (small) single-needle (KS-1):
Size: 1.3 mm diameter x 60 mm long
Range: 0.02 to 2.00 W/(m · K) (thermal conductivity)
0.5 to 50 m · K/W (thermal resistivity)
Accuracy (Conductivity): ± 5% from 0.2 - 2 W/(m · K)
±0.01 W/(m · K) from 0.02 - 0.2 W/(m · K)

10 cm (large) single-needle (TR-1):
Size: 2.4 mm diameter x 100 mm long
Range: 0.10 to 2.00 W/(m · K) (conductivity)
0.5 to 10 m · K/W (resistivity)
Accuracy (Conductivity): ±10% from 0.2 - 2 W/(m · K)
±0.02 W/(m · K) from 0.1 - 0.2 W/(m · K)

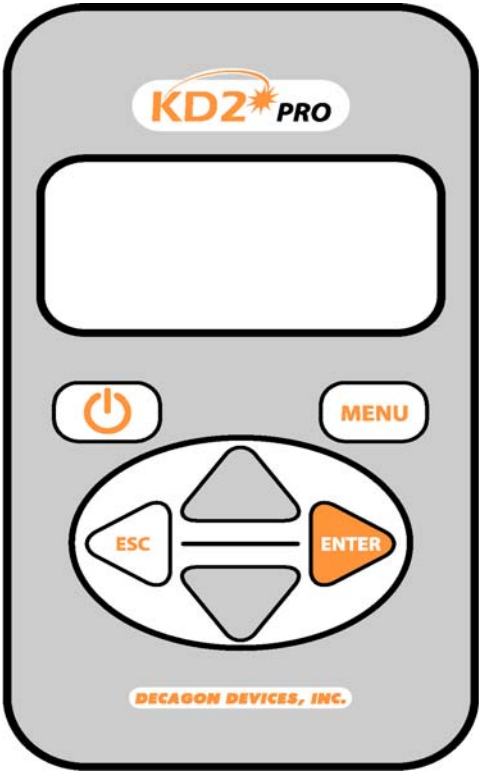
30 mm dual-needle (SH-1):
Size: 1.3 mm diameter x 30 mm long, 6 mm spacing
Range: 0.02 to 2.00 W /(m · K) (conductivity)
0.5 to 50 m · K/W (resistivity)
0.1 to 1 mm^2/s (diffusivity)
0.5 to 4 $mJ/(m^3K)$ (volumetric specific heat)
Accuracy: (Conductivity) ± 5% from 0.2 - 2 W/(m · K)
±0.01 W/(m · K) from 0.02 - 0.2 W/(m · K)
(Diffusivity) ±5% at conductivities above 0.1 W/(m · K)
(Volumetric Specific Heat) ±7% at conductivities above 0.1 W/(m · K)

Calibration

Decagon custom calibrates each KD2 Pro thermal sensor. This process stores the sensor's unique calibration in non-volatile memory in the sensor's circuitry. The KD2 Pro controller uses each sensor's calibration while making thermal measurments. This allows you to mix and match thermal sensors with KD2 Pro controllers without having to worry about creating or managing sensor calibrations.

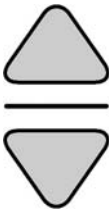
Although ASTM D5334-05 (Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure) and IEEE standard number 442 (Soil Thermal Resistivity Measurments) call for the user to calibrate thermal needle sensors, this is not commonly done. The magnitude of measurment errors from uncalibrated sensors depends primarily on the diameter of the sensor needle. The small diameter needle used on the KS-1 Sensor (1.3 mm diameter) approximates an ideal line heat source so calibration corrections are very small. Uncalibrated thermal conductivity data collected with the large diameter needle used on the TR-1 Sensor (2.4 mm diameter) is typically 20-30% higher than the true thermal conductivity values. Because of this, you may find it useful to see uncalibrated measurment data for comparison with previously collected or published data. The KD2 Pro Utility software has the option for including uncalibrated thermal conductivity (K) and thermal resistivity (R) in the downloaded data file for the TR-1 sensor. To enable this mode, check the "Include uncalibrated measurement data in data file" option on the Data File tab of the KD2 Pro Utility Preference window.

Keypad Operation



POWER: Located to the left below the screen, this key activates and deactivates the KD2 Pro. (Note: The device will automatically turn off if not used for more than 10 minutes, except while running in Auto Mode.)

MENU: Located to the right below the screen, this key cycles between the menus at the top of the screen.



ARROW KEYS: Located in the center of the keypad, these keys navigate within menus and sub-menus, and modify different settings in sub-menus. Holding down an arrow key allows you to scroll between different options quickly.

ESCAPE: This key backs out of sub-menus and can be used to cancel certain actions (see "Erase," in "Data Menu," Chapter 2).

ENTER: This key is used to make selections within menus and sub-menus, and also begins taking measurements (see "Making a Measurement," "Main Menu," below).

Choosing a Sensor

Here are some things to consider when deciding which sensor is right for you.

- The 6 cm small single-needle (KS-1) is best for thermal conductivity and thermal resistivity measurements on most samples, including liquids.
- The 10 cm large single-needle (TR-1) sensor is the least accurate and is meant primarily for use in hard materials.
- Use the 30 mm dual-needle (SH-1) sensor when diffusivity and/or specific heat data are needed. This sensor should not be used in any liquids.

Installing the Sensors

The KD2 Pro's three sensors have been designed for ease of installation and use. The following considerations should be observed when installing the sensors.

- **The sensor should be inserted all the way** into the medium to be measured.
- For the single-needle 10cm sensor, a drill bit has been included that can be used to drill a pilot hole in material such as stone, wood or hard soil.
- For the dual-needle sensor, **the needles must remain parallel to each other during insertion** to make an accurate reading. Therefore, take care in tough material, which can splay the prongs and adversely affect readings. Use the provided red tab with pilot holes to make sure that the needles are inserted properly.
- Because the sensors give off a heat pulse, **you must allow a minimum of 1.5 cm of material** parallel to the sensor in all directions, or errors will occur.
- **DO NOT BEND THE NEEDLES**, as this can damage the sensor beyond repair. If the needle becomes bent, **do not bend it back**; contact Decagon for a replacement.
- **Good thermal contact between the sensors and the medium being measured is critical** for accurate measurements if a hole is drilled for sensor insertion. Make sure that the sensor fits tightly into the hole. Use the Arctic Silver® thermal grease included with your KD2 Pro to improve contact in larger holes or grainy samples.

Measurements In Concrete

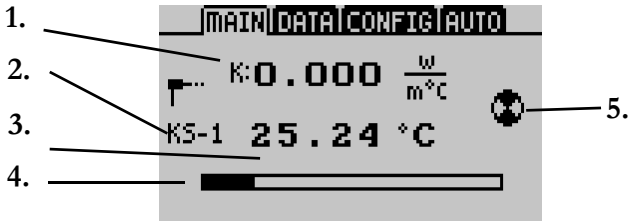
- Coat Concrete Pilot Pin with Vaseline.
- Install pin up to at least 100mm deep while concrete is still wet.
- Remove when concrete has dried.
- Coat the single 10cm sensor with Arctic Silver® thermal grease and insert sensor into the cast hole and begin to take readings.

3. The Menus

The KD2 Pro features four main menus: MAIN, DATA, CONFIG, and AUTO (respectively). These menus access the KD2 Pro's features, and have been designed for ease of use. Here is a more detailed description of each menu.

The Main Menu

The Main Menu is responsible for taking measurements from whatever medium a sensor is inserted into.



What you see:

1. The thermal property reading and the currently selected unit. The type of reading is indicated by the letter to the left of the reading:
   K = thermal conductivity
   C = specific heat capacity
   D = thermal diffusivity
   R = thermal resistivity
   NOTE: When the spinner icon is visible, press the arrow keys to scroll through and change the current unit and measurement type.

2. The currently connected sensor type and sensor name.

3. The measurement temperature in °C or °F

4. Progress bar that displays elapsed time.

5. Indicates the status of a reading.

The purpose of the Main Menu is to take measurements. The next section will explain how to do this.

Taking a Measurement

It is easy to take measurements with the KD2 Pro. The KD2 Pro has the three following sensors:

- **Single needle 6 cm (KS-1) -** Measures thermal conductivity and resistivity; most accurate for thermal conductivity and resistivity measurements, and for measuring fluids.
- **Single needle 10 cm (TR-1) -** Measures thermal conductivity and resistivity; used for samples where ASTM and IEEE conformity is required. Should not be used for liquid samples.
- **Dual-needle 30 mm (SH-1) -** Measures thermal conductivity, volumetric specific heat capacity, diffusivity, and resistivity. This sensor should not be used in any liquids.

Do the following to make a measurement:

NOTE: If the temperature of the sample medium is different from the temperature of the needle, the needle must equilibrate to the surrounding temperature before beginning a reading.

1. Attach appropriate sensor then turn on the KD2 Pro.

2. Properly insert the sensor into the material to be measured. (See "Installing the sensors" in this chapter for instructions.)

3. When the KD2 Pro turns on, you should be in the Main Menu. If not, press the Menu key until you arrive there. Press Enter to begin the measurement.

4. An icon will appear on the left and right side of the screen. The icon at left indicates the type of sensor connected. The circular icon indicates that a reading is underway. It will change to a thermometer icon to indicate whether the measurement is currently in heating or cooling mode; when the thermometer is rising, heat is applied to the needle, and when it is falling, heat is off. A progress bar shows the elapsed time.

5. When the progress bar has fully darkened, the results are displayed as follows:

On the left side of the screen are three measured values:

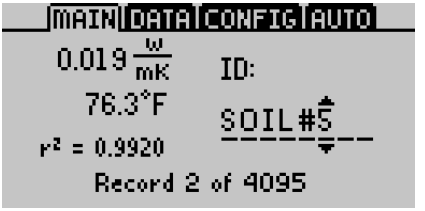
- **Thermal Properties Reading -** The calculated thermal measurement.
- **Starting Temperature -** The initial temperature prior to any heating or cooling.
- **r^2 Correlation Coefficient-** The r^2 value is the square of the correlation coefficient. It is a measure of how well the model fits the data (the Theory chapter of this manual describes the model that is fit to the data). The fraction of the variance in the data that is "explained" by the model is equal to r^2. If the model fits the data perfectly, then $r^2 = 1.0000$. The purpose of displaying this reading is to indicate possible problems with the data. A good data set will give r^2 values above 0.9990, except at very low thermal conductivity (e.g. insulation materials). Even then, acceptable values are above 0.9950. If the r^2 is below these values, discard the data, wait fifteen minutes and take another reading.

On the right side of the screen are three save options:

- **Save -** You can save your reading as is;
- **Annotate -** You can attach a sample ID to your reading;
- **Discard -** Cancel the current reading and return to the main screen.

NOTE: If the data memory is full or the sample temperature was unstable during a reading, an error message is displayed at the bottom of the screen. If this should happen, you may still take readings but you will be unable to save them to the KD2 Pro.

How to annotate a reading: When you select the "Annotate" option, you will see a series of lines with an arrow above and below the first position. Use the up and down arrow keys to select a letter or number and press Enter to move to the next character (as shown below). If you have annotated a previous reading, the old annotation will remain to be modified or deleted.



Repeat this until you reach the last character. When finished, simply continue to press Enter until you reach the

end of the row. Holding Enter or Escape will allow you to scroll left and right through the Sample ID quickly.

NOTE: It is important to wait for about fifteen minutes between readings, if the sensor is left in the same location! If multiple measurements of a sample are made too rapidly in succession, the sample's temperature will not have had enough time to equilibrate from the previous reading, and the resulting measurement will be inaccurate. For the best results, the sample should be as close to equilibrium as possible. An ideal environment for equilibration can be accomplished by placing the KD2 Pro sensor and sample in an isothermal chamber or styrofoam box.

The Data Menu

The Data Menu allows you to view stored data, download data to a computer, and erase the data from your KD2 Pro. It also displays how many readings have been recorded out of the total 4,095 that can be stored.

Here is description of each sub-menu:

VIEW: This menu allows you to view all data currently stored on your KD2 Pro. Press Enter to access the readings, and use the arrow keys to scroll through them. By

pressing Enter a second time, you can see more detail about a reading.

DOWNLOAD: This menu sends the data saved in the KD2 Pro to your computer. You have two download options:

- **Download All** - This downloads the temperature readings as well as the measured thermal properties.
- **Download Summary** - This downloads just the measured thermal properties.

NOTE: Your KD2 Pro comes with KD2 Pro Utility software for use with Microsoft Windows. The Utility makes downloading data to your computer very easy. In general, you should use the KD2 Pro Utility to download data instead of the download option on the KD2 Pro.

If you are unable to use the KD2 Pro Utility, you can use terminal software to transfer the data from your KD2 Pro to your computer. The following steps should apply to most terminal software programs:

1. Configure your terminal software with the following settings:
   - 9600 baud
   - 8 data bits, 1 stop bit, no parity
   - No software/hardware flow control
   - Append line feeds to incoming line ends
   - Echo typed characters locally.

2. Connect your KD2 Pro to an available serial port on your computer using the included RS-232 serial cable.

3. Set your terminal software to capture received data if you want to save the data.

4. Select the appropriate option from the Download menu in the KD2 Pro.

ERASE: This will erase all stored data on your KD2 Pro. **WARNING! This feature will completely erase all data on your KD2 Pro, and once activated, it cannot be undone!**

To erase data:

1. Press Enter to select the Erase sub-menu. The screen "Erase all stored data?" will appear.

2. Press Enter again to erase the memory or Escape if you decide not to continue. "Erasing..." will be displayed as data is being removed, which usually takes about 6 seconds.

3. When this is complete, you will be returned to the Data Menu.

The Configuration Menu

The Configuration Menu allows you to change system settings such as the date, time, measurement units, and also view information about your KD2 Pro. A battery icon will also display the remaining percentage of battery power. A description of each sub-menu follows.

DATE: To change the current date,

1. Press Enter to select the date display.

2. The current date will appear in the center of the screen, in day/month/year format. A pair of arrows will be present above and below the first number.

3. Use the up & down arrow keys to change this number.

4. Press Enter to move to the next number, and repeat step #3. If you need to return to the previous number, press Escape.

5. When you have finished changing the last number, press Enter and you will be returned to the Configuration Menu.

TIME: To change the current time,

1. Press Enter to select the Time display.

2. The current time will appear in the center of the screen, in 24-hour format. A pair of arrows will be present above and below the first number.

3. Use the up & down arrow keys to change this number.

4. Press Enter to move to the next number, and repeat step #3. If you need to return to the previous number, press Escape.

5. When you have finished changing the last number, press Enter and you will be returned to the Configuration Menu.

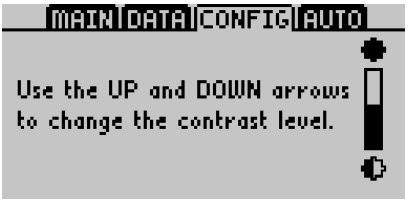
UNITS: You can choose to represent measurement data in either SI or English units. Press Enter to select an option. When you return to the Main Menu, pressing the arrow keys allows you to scroll through and change the current unit and measurement type.

SI and English Unit Equivalents

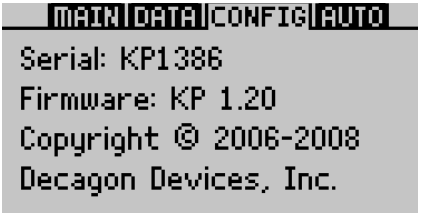
	Thermal Conductivity (K)	**Thermal Resistivity (R)**	**Volumetric specific heat (C)**	**Thermal Diffusivity (D)**
SI	$\frac{W}{(m \cdot K)}$	$\frac{(m \cdot K)}{W}$	$\frac{MJ}{(m^3 \cdot K)}$	$\frac{mm^2}{s}$
English	$\frac{BTU}{hr \cdot ft \cdot °F}$	$\frac{hr \cdot ft \cdot °F}{BTU}$	$\frac{BTU}{°F \cdot ft^3}$	$\frac{ft^2}{hr}$

NOTE: Readings in watts per meters-degree Celsius W/(m °C) are the same as readings in watts per meters Kelvin (W/m· K), as Celsius and Kelvin degrees are on the same temperature scale.

CONTRAST: Allows you to change the screen contrast level. Press Enter and follow the on-screen instructions to modify the contrast.

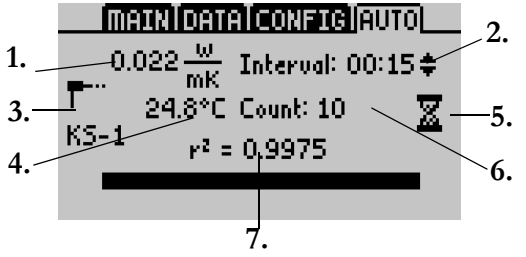


ABOUT: Displays the serial number and firmware version of your KD2 Pro.



The Auto Mode

The Auto Mode allows you to set up the KD2 Pro to take readings automatically. You can select a measurement time in intervals of 15 minutes. The reading will be taken in the currently selected unit from the Main Menu, and will begin as soon as you select this option. **NOTE:** Should the KD2 Pro's data memory ever become full (4,095 readings), you may still take readings, but you cannot save them until you erase the stored readings.



What you see:

1. Final measurement displayed in the selected unit.
2. Measurement interval. This time interval can be set either in the CONFIG menu or in the KD2 Pro Utility. **NOTE:** When the spinner icon is visible, press the arrow keys to change the interval time.
3. Icon showing connected sensor type.
4. Measurement temperature in °C or °F.
5. Hourglass icon indicating that time is elapsing until the next measurement.
6. Number of readings taken.
7. The r^2 value of your data (see description of r^2 value in the "Main Menu" section of this chapter for more details).

NOTE: The KD2 Pro Utility gives you more options to control how Auto Mode operates, including different time intervals, delayed start times, and others. Refer to the next chapter for more information.

4. The KD2 Pro Utility

KD2 Pro Utility main screen

The KD2 Pro Utility is a program designed specifically for interfacing with the KD2 Pro. Use this program to download measurement data to your computer, erase measurement data stored in the KD2 Pro, set the date and time, configure the KD2 Pro to take readings automatically, and see information about your KD2 Pro.

System Requirements

To use the KD2 Pro Utility, you must meet the following minimum system requirements:

- Microsoft Windows 98 or NT 4 (SP 5) or better
- Intel Pentium Pro or better processor
- One available serial port *or* one available USB port (most models of USB-to-serial adapters supported)
- Microsoft Excel 97 or better (for saving data as .xls files)

Installation

You can install the KD2 Pro Utility using the included CD-ROM (found in the inside cover of the KD2 Pro Operator's Manual). You can also download and install the latest version of the Utility on Decagon's download section of www.decagon.com.

Downloading Data
This will transfer all saved measurement data on the KD2 Pro to your computer. Do the following:

1. Make sure the RS-232 cable is connected to the KD2 Pro, and to a COM port on your computer.

2. Open the KD2 Pro Utility.

3. Choose the appropriate serial communication (COM) port from the "Use computer communication port" control on the main screen.

4. Click the "Download" button in the lower right-hand corner. You can also go to the File Menu, and select one of two options:
   1) Download Summary Data - Downloads and summarizes the data readings, but does not display per-second readings.
   2) Download All Data - Downloads all data currently stored in the KD2 Pro's memory. It displays complete data for each measurement, including per-second readings.

   If you encounter an error message after clicking this button, please refer to the Troubleshooting section for instructions.

   Name your data file, select where it will be saved to, and in what format. You may choose between the following formats:

   • Microsoft Excel Workbook (*.xls);
   • Comma delimited (*.csv);
   • Tab delimited (*.txt);
   • Raw data (also *.txt)

5. Click "Save" to download your data to the specified location. The progress bar shows the status of the download process:

KD2 Pro download dialog

NOTE: You can cancel a download in progress using the cancel button. If you cancel, no downloaded data are saved.

How Saved Data Are Organized

Measurment Data from the KD2 Pro is saved in the same basic format regardless of the file format chosen. You can choose to download just the summary data or all the measurment data which includes additional information. A description of each type of download follows.

Clicking the Download button or choosing "Download Summary Data" from the File Menu creates a file with the following columns:

- Measurment Time - Date and time when the reading was taken.
- Sensor - The model number of the sensor used for this reading.
- K (Thermal Conductivity) - as W/(m · k) or BTU/(hr · ft · °F).
- R (Thermal Resistivity) - as m · K/W or hr · ft · °F/BTU.
- Uncalibrated K - as W/(m · K) or BTU/(hr · ft · °F). Columns for Uncalibrated K and R are only included when enabled in the KD2 Pro Data File preferences (see Preferences) and when the downloaded data contains data measured with the TR-1 Sensor.
- Uncalibrated R - as m · K/W or hr · ft · °F/BTU. (TR-1 Sensor only when enabled in user preferences).
- C (Specific Heat) - as MJ/(m^3 · K) or BTU/(°F · ft^3). Columns for Specific Heat and Thermal Diffusivity are only included when the downloaded data contains measurments made with one of the dual-needle sensors (SH-1 and LSH).
- D (Thermal Diffusivity) - as mm^2/s or ft^2/hr (dual-needle sensors only).
- r^2 - Quality of fit of the data to the KD2 Pro theoretical model.
- Temp(0) - Initial temperature of the sample as °C or °F.
- Sample ID - If saved with the measurment.

Choosing "Download All Data" from the File Menu creates a file with all the data included in the summary file (listed above) and adds the following columns:

- Power - as W/m.
- Current - as amps.

The next 60 columns in the row hold the individual 1 -second temperature reading the KD2 Pro uses to calculate the thermal properties of the sample. The data is show as °C or °F

The KD2 Pro Utility formats measurement dates according to the Windows Local settings found in the Control Panel under "Regional and Language Options" ("Regional Settings" in Windows 98). You can override this by going to the Preferences Menu > Data File tab, and selecting an option under "Date/Time Format". You can set this value to day/month/year format, using a 12- or 24-hour clock. (The Preferences Menu is explained in more detail later in this chapter.)

Erasing Your Data

This will erase all data stored on your KD2 Pro.
WARNING! Once this feature is activated, all data will be permanently deleted from the KD2 Pro, and cannot be recovered!

To erase the data, do the following:

1. Make sure that the RS-232 cable is connected to the KD2 Pro, and to a COM port on your computer.

2. Choose the appropriate COM port from the "Use computer communications port" control on the main screen

3. Click "Erase," in the lower left-hand corner, or select "Erase Data..." from the File Menu.

   If you encounter an error message after clicking this button, please refer to the Troubleshooting section for instructions.

4. A progress bar shows the status of the erase process.

Setting the Date and Time

You can set the KD2 Pro's date and time by selecting "Set KD2 Pro Date/Time..." from the Actions Menu. This will automatically sync the KD2 Pro's date and time to your computer's time.

Setting the Auto Mode

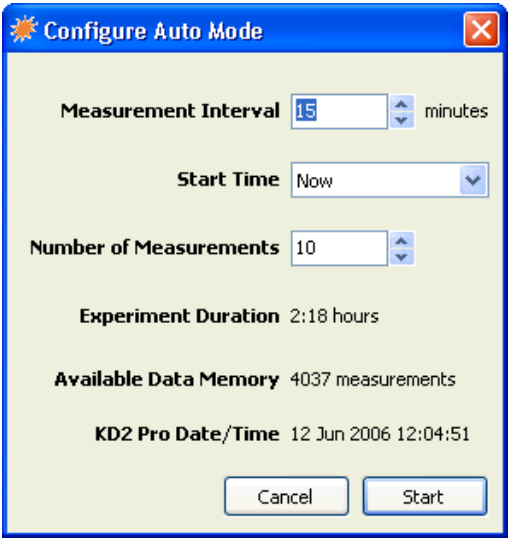
The Auto mode of the KD2 Pro allows you to perform automated, unattended measurements at specified time intervals. The KD2 Pro has pre-set measurement intervals to select for this mode, but you can better customize how the KD2 Pro operates in Auto mode using the KD2 Pro Utility software. For example, you can select specific measurement intervals, delayed start times, and the number of measurements from this menu.

To configure Auto Mode with the KD2 Pro Utility:

1. Connect your KD2 Pro to an available serial communication port on your computer. Select the name of

your chosen serial port in the "Use computer communication port" control.

2. Choose "Configure Auto Mode..." from the Actions Menu. The following screen appears:



3. Choose values for Measurement Interval, Start Time, and Number of Measurements. Each of these values is explained below.

Measurement Interval

This is the time interval (in minutes) that you want the KD2 Pro to wait between measurements. The instrument must have a minimum of 15 minutes between measurements to allow for thermal gradients to dissipate. Therefore, you can select any number over 15 minutes, up to 1440 minutes (24 hours).

Start Time

You can select when you want the auto measurement to begin. You can choose start times ranging from "Start Now" to delaying the start for 24 hours. If you select "Start Now," you will have about 30 seconds to connect your thermal properties sensor to the KD2 Pro before the reading will start.

Number of Measurements

This is the total number of measurements that you want the KD2 Pro to make while in Auto Mode. The number is between 1 and the amount of available memory. As you change this value, the Experiment Duration value will change. The KD2 pro will store up to 4095 readings.

Experiment Duration

This is the total amount of time that your KD2 Pro will operate in Auto Mode, according to your measurement interval and number of measurements selected. This gives you an idea of how long the total Auto Mode experiment time will take.

Available Memory

This shows how much memory you have available for storing measurements. The KD2 Pro Utility prevents you from defining an experiment that could exceed the amount of available memory. If you reach the limit of memory storage, the KD2 Pro will stop taking measurements in Auto Mode.

KD2 Pro Date/Time

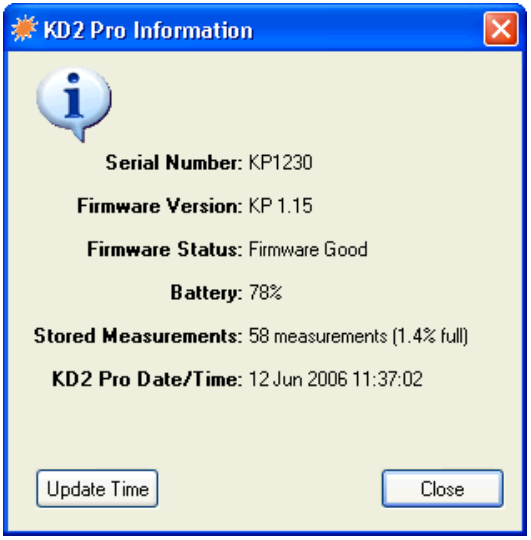
This shows the current time in your KD2 Pro. If the time is not correct, click the Cancel button, then choose "Set KD2 Pro Date/Time..." from the Actions Menu.

4. Click on the **Start** button. The KD2 Pro Utility will then send your settings to the KD2 Pro.

5. Unplug the serial cable from the KD2 Pro, then connect the desired thermal properties sensor to the instrument. Your KD2 Pro is now ready to make unattended measurements as you have programmed it.

Viewing KD2 Pro Information

Choose "View KD2 Pro Information..." from the Actions Menu to see information about your KD2 Pro:



KD2 Pro Information screen

This displays useful info about your KD2 Pro, including its serial number, firmware version and status, battery status, the number of currently stored measurements, and current data and time in the KD2 Pro's operating system.

The Menus and Their Functions

The KD2 Pro Utility features four main menus. These allow you to change program settings, as well as settings on the KD2 Pro. Below is a description of each menu and their functions.

File

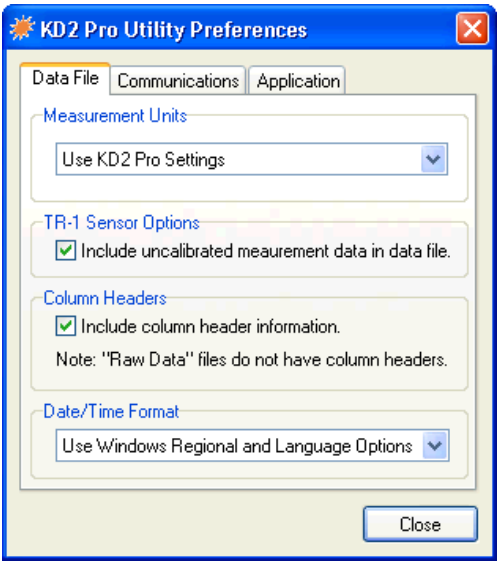
Download Summary Data/Download All Data. Please see the "Download Data" section of this chapter for a description of these options.

Erase Data... Erases all data in your KD2 Pro (see instructions above).

Edit

Preferences... This sub-menu modifies program settings, and settings for communicating with your KD2 Pro. It is divided into three sections called "tabs".

1. **Data File**



Preferences - Data File tab

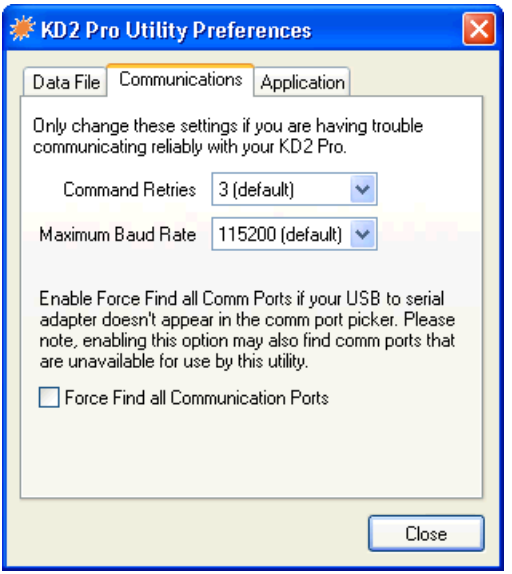
Measurement Units: If you select "Use KD2 Pro Settings," this will save all downloaded measurement data in the units used on the KD2 Pro. You can also choose to override the settings in the KD2 Pro and save your measurement data using either SI (metric) or English units.

TR-1 Sensor Options: Enabling the "Include uncalibrated measurment data in data file" option will include the uncalibrated data collected by the TR-1 Sensor in your data file. For more information on when you should use uncalibrated data, please see "Calibration" in Chapter 2 of this manual.

Column Headers: This option includes column headers (i.e. "Measurement Time," "Sample ID," etc.) for downloaded data. **NOTE**: *Raw data files do not have header information.*

Date/Time Format: Sets the date and time format for downloaded data files. See "How Saved Data are Organized" for more information.

2. **Communications**



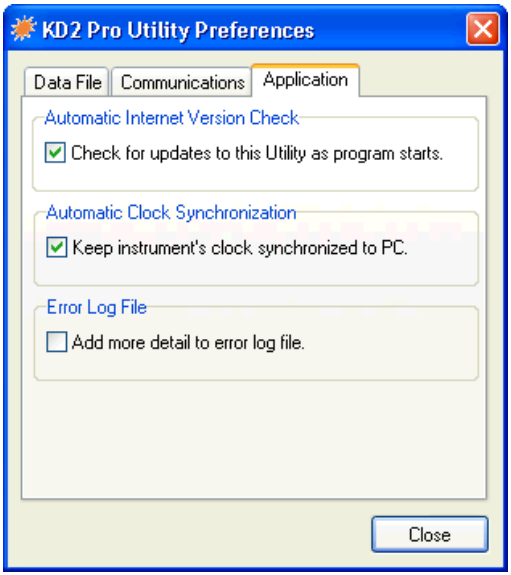
Preferences - Communications tab

Command Retries: If you encounter difficulty communicating with your KD2 Pro, you can set the number of times the computer should automatically try re-sending communications commands (up to 10).

Maximum Baud Rate: You can set the maximum baud rate for talking to your KD2 Pro. Choose a lower baud rate if you are not getting reliable communications from your device.

Force Find all Communications Ports: This will detect all COM ports on your computer, and should be used if your serial-to-USB adapter does not appear in the "Use computer communication port" control.

3. **Application**



Preferences - Application tab

Automatic Internet Version Checks: If you select this option, the KD2 Pro Utility will automatically check for a newer version using Decagon's internet version

check engine. It will notify you when a newer version is available when your computer is connected to the internet. You can turn off the automatic check by unchecking this option. You can manually check for updates anytime using the "Check for Utility Updates..." option in the Help Menu.

Automatic Clock Synchronization: Automatically sets the KD2 Pro's time to your computer's time, when you are connected to it. (See instructions above for setting this manually.)

Error Log File: This adds more troubleshooting messages to the error log, which can be sent to Decagon.

Actions

Set KD2 Pro Date/Time... See "Setting Date and Time" section earlier in this chapter for more information.

Set Auto Mode. Allows you customize how the KD2 Pro operates in Auto mode using the KD2 Pro Utility software. You can program specific time intervals and start times in this menu. See "Setting the Auto Mode" section earlier in this chapter for more information.

View KD2 Pro Information... Displays information about your KD2 Pro. See "Viewing KD2 Pro Information" section earlier in this chapter for more information.

Help

Help. Accesses the KD2 Pro Utility help file, which provides detailed information on how to use the program.

Send Feedback to Decagon

This menu item helps you send product feedback, bug reports, or feature requests to Decagon. Your computer must be connected to the internet for this feature to work. See Appendix B for more information.

Check for Utility Updates... If you select this function when connected to the internet, the KD2 Pro Utility will check for a newer version using Decagon's internet version check engine. It will notify you if a newer version is available.

Check for Firmware Updates... If you select this function when connected to the internet, the KD2 Pro Utility will check for updates for the KD2 Pro's operating system (firmware).

About KD2 Pro Utility... Displays the current program version and Decagon contact information.

Troubleshooting

The following descriptions should help you if you encounter any difficulty using the KD2 Pro Utility.

PROBLEM: The KD2 Pro Utility tells me the communication port I want to use is in use by another application, but I don't think any other programs are running.

SOLUTION: Some PDA synchronization software monitor serial communication ports. Disable Microsoft's ActiveSync or Palm's HotSync system software while using the serial port with the KD2 Pro Utility.

PROBLEM: My USB to Serial adapter is not showing in the communication port picker.

SOLUTION: Enable "Force find all Communication Ports" in Preferences by going to the Edit > Preferences, and to the Communication tab. Enable the check box at the bottom of the screen. Enabling this option may find other serial ports that are not available for use by the KD2 Pro Utility (for example, modems installed in your computer).

PROBLEM: Downloading data stops in the middle with an error message saying the Utility lost connection with the KD2 Pro.

SOLUTION: A noisy serial connection can disrupt the connection between the Utility and the KD2 Pro. If this error happens regularly, you can try setting your baud rate lower or increasing the number of times a command is sent to the KD2 Pro. Choose the "Communications" tab in Preferences to alter this.

5. Good Practices

The quality of the measurements you get with the KD2 Pro can be strongly affected by your experimental technique. The following suggestions will help you to recognize and avoid pitfalls in data collection so that the data you obtain can be as accurate as possible.

1. **Keep the temperature of the sample as constant as possible during the measurement.** The measurement is made by heating a needle that is placed in the sample and monitoring either the temperature of that needle or a second needle adjacent to the heater. The heat input is made as small as possible to avoid thermally driven redistribution of moisture in the sample. The temperature change from heating may therefore be only a few tenths of a degree. Sample temperature changes during the measurement period degrade the data and make it difficult for the inverse calculation to find the correct values for the thermal properties. The algorithms in the KD2 Pro are several orders of magnitude less sensitive to these errors than the conventional approach (plotting temperature vs. log time during heating and looking for a linear portion of the graph) but there can still be errors if the temperature changes too rapidly during a measurement. To minimize these sources of error:
    a. In the laboratory, allow samples and sensors to come to temperature equilibrium before the measurement starts. Fifteen to twenty minutes is a reasonable rule of thumb.

b. Allow time between readings for temperatures to re-equilibrate. Fifteen minutes between readings isn't too much.

c. If measurements are made in an oven or a freezer, make sure the sample temperature is relatively constant before the measurement starts. Measurements made on a sample taken from an oven and cooling to room temperature can show significant errors if the cool rate is too fast.

d. When measuring thermal properties in the field, allow a minute or so after sensor insertion for temperature equilibration.

2. **Minimize contact resistance.** In granular materials, or in solids where a hole has been drilled to accommodate the sensor, there is an additional thermal resistance between the heated sensor and the material into which the sensor is inserted. This extra resistance is called a contact resistance, and it decreases the thermal conductivity value registered by the sensor. This effect can be minimized by applying Arctic Silver® thermal grease to the sensor prior to inserting it as described in the Decagon Application Note "Reducing Contact Resistance Errors in KD2 Thermal Properties Measurements" located in the literature section of www.decagon.com/thermal. When a hole is drilled for the sensor, make sure the fit of the sensor in the hole is as tight as possible. The dual needle sensor (model SH-1) is less affected by contact resistance errors than the single sensor, so thermal conductivity in dry, gran-

ular materials are most accurate when measured with the dual needle sensor.

3. **Use the small sensor (model KS-1) for thermal conductivity measurements.** The KS-1 (60 mm) needle most closely approximates the infinite line heat source and causes the least disturbance to the sample, so it gives the most accurate measurements. Unfortunately, the larger TR-1 (100 mm) needle has been specified in ASTM and IEEE standards, and is therefore sometimes required. It is also difficult to drill small holes in rock or concrete, so the large needle may be required in these instances. In all others, we recommend using the small needle.

4. **Avoid convection in liquid samples.** Convection is the movement of a fluid relative to the sensor. This can be caused by allowing the sensor to move while a measurement is taking place, or by temperature gradients from the heated sensor itself. Convection always increases the thermal conductivity and diffusivity readings, often dramatically so. To minimize forced convection (sensor movement in the fluid during measurement) make sure the sensor is well supported in the liquid and the sensor and liquid are on a firm bench that will not shake during the measurement. For free convection, the viscosity of the fluid, the orientation of the sensor, and the temperature rise of the sensor during measurement determine whether or not convection will occur. The dual sensor can be used in liquids; however, readings taken in liquids will not be reliable and are in effect useless. With this sensor, free convection can occur even with a fluid as viscous as

glycerin. The single needle 6cm sensor uses much less heater power, and is therefore more suitable for this application. If the needle is vertical, this sensor can measure the thermal conductivity of a fluid like glycerin. If measurements need to be made on less viscous fluids, some material (such as agar or food thickener) needs to be added to increase viscosity (hopefully without altering the thermal properties). With water, agar in low concentration can stabilize it enough for a reliable measurement. For a more detailed explanation on measuring fluids with the KD2 Pro, refer to our application note "Using the KD2 to Measure Thermal Conductivity of Fluids" located in the literature section of www.decagon.com/thermal.

5. **Don't bend the needles.** Needle spacing on the dual needle sensor is critical for accurate measurements. A 1% change in needle spacing results in a 2% error in measurement of diffusivity and specific heat. A guide is provided for maintaining proper needle spacing during insertion of the sensor into a sample. The Delrin verification block included with your system shows the correct sensor spacing. If a needle is slightly bent, it can be carefully straightened until the tip spacing matches the hole spacing in the calibration block.

6. Care and Maintenance

Although the KD2 Pro has been built to high construction standards, proper care must be taken to ensure continuing operation.

Cleaning and caring for the sensors

The sensors are easy to clean. The sensor needles are stainless steel, and as such, when they need cleaning, wipe them with a damp cloth. Take care never to bend the needles. If the sensor becomes bent, *do not attempt to bend it back*; this may break it. You will need to contact Decagon to obtain a replacement sensor.

Changing the Batteries

Although the KD2 Pro has been designed to provide an excellent battery lifespan, the batteries will eventually require changing. When this happens, a low-battery indicator will appear in the upper left hand corner of the screen. The KD2 Pro requires four alkaline "AA" batteries. To change the batteries:

1. Carefully turn over the KD2 Pro and locate the battery cover.

2. Place your thumb on the grooves and push upward to loosen the cover.

3. Remove the old batteries and insert new ones. Be sure to orient the fresh batteries properly.

4. Update the time and date either in the Configuration Menu of the KD2 Pro, or by using the KD2 Pro Utility.

Troubleshooting

If you encounter problems with your KD2 Pro, refer to the following items to see if they resolve your problem.

PROBLEM: I am getting poor or inconsistent readings.

SOLUTION: The sensor needle(s) may not be completely inserted into the sample, or the needle(s) may be touching the sides of the measurement container. Thermal grease may need to be applied.

PROBLEM: The KD2 Pro says it does not recognize the connected sensor.

SOLUTION: Make sure the connection between the sensor and the KD2 Pro is secure, and that none of the connector pins are bent or broken off. If the KD2 Pro still fails to recognize the sensor, the sensor may be malfunctioning. Contact Decagon for more assistance.

Verifying Sensor Performance

With your KD2 Pro, you have received two standard materials with which you can verify that your KD2 Pro is

working correctly and maintaining accuracy: a clear vial of glycerine (glycerol), and a plastic Delrin block.

The glycerol should be used to verify performance of the single-needle sensors (KS-1 and TR-1). The cap of the vial is equipped with a septum allowing direct insertion of the needle into the vial through the cap. To conduct a performance verification, insert the needle fully into the glycerol. The needle should be oriented vertically, and it is best to turn the vial of glycerol upside-down on top of the needle, so that any bubbles in the glycerol float to the top away from the needle. The larger TR-1 needle is slightly longer than the vial, and cannot be fully inserted. This will not affect the measurement. The needle should be approximately centered in the vial, and must not be touching a side of the vial. Before taking a measurement in the glycerol, make sure that the system is not undergoing rapid temperature drift. Even the heat from holding the vial in your hand for a few seconds, or the cooling from direct air conditioning flow can decrease the accuracy of the measurement. It is best to place the needle and vial in an isothermal environment (e.g. insulated chamber or cooler), and allow 15 minutes of equilibration time before taking the measurement. The thermal conductivity of the glycerol is 0.285 W/(m · K) at 20 °C.

The Delrin block should be used to verify the performance of the dual-needle (SH-1) sensor. The sensor should be fully inserted into the pre-drilled holes in the Delrin, and allowed to equilibrate for at least 15 minutes before taking the measurement. Again, make sure that the system is not undergoing rapid temperature drift. Even the heat from holding the block in your hand for a few seconds, or the cooling from direct air conditioning flow can decrease the accuracy of the measurement. It is best to place the needle and block in an isothermal environment (e.g. insulated chamber or cooler), and allow 15 minutes of equilibration time before taking the measurement. The Delrin blocks have slightly different thermal conductivities from lot to lot, so the correct values for K, C, and D for your individual Delrin block are recorded on your Certificate of Quality Assurance.

7. KD2 Pro Theory

Carslaw and Jaeger [1], (p. 258-262) modeled the temperature surrounding an infinite line heat source with constant heat output and zero mass, in an infinite medium. When a quantity of heat, Q (J m^{-1}) is instantaneously applied to the line heat source, the temperature rise at distance, *r* (m) from the source is

$$\Delta T = \frac{Q}{4\pi k t} \exp\left(\frac{-r^2}{4Dt}\right) \tag{1}$$

where k is the thermal conductivity (W m^{-1} K^{-1}), *D* is the thermal diffusivity (m^2/s), and *t* is time (s). If a constant amount of heat is applied to a zero mass heater over a period of time, rather than as an instantaneous pulse, the temperature response is

$$\Delta T = -\frac{q}{4\pi k} Ei\left(\frac{-r^2}{4Dt}\right) \qquad 0 < t \le t_1 \tag{2}$$

where *q* is the rate of heat dissipation (W/m), t_1 is the heating time, and *Ei* is the exponential integral [2]. The temperature rise after the heat is turned off is given by:

$$\Delta T = -\frac{q}{4\pi k}\left[-Ei\left(\frac{-r^2}{4Dt}\right) + Ei\left(\frac{-r^2}{4D(t-t_1)}\right)\right] \quad t > t_1 \tag{3}$$

Material thermal properties are determined by fitting the time series temperature data during heating to eq. (2), and during cooling to eq. (3). Thermal conductivity can be obtained from the temperature of the heated needle (single needle), with r taken as the radius of the needle. Diffusivity is best obtained by fitting the temperatures measured a fixed distance (the KD2 Pro uses 6 mm) from the heated needle (k is also determined from these data). Volumetric specific heat (W/m^3°K) is determined from k and D:

$$C = \frac{k}{D} \tag{4}$$

In each case, k and D are obtained by a non-linear least squares procedure [3] which searches for values of k and D which minimize the difference between modeled and measured sensor temperatures. An additional linear drift factor is included in the inverse procedure. Most experiments will not occur under constant temperature conditions. We assume there can be a temperature drift that is linear with time and use an additional fitting parameter to fit this drift. This reduces errors substantially.

The theory introduced above is based on heat flow from an infinite line heat source. For the analytical solutions just given to accurately describe the physical behavior of a system, the heat source must closely approximate an infinitely long, thin line. Kluitenberg et al. [4] give solutions for pulsed cylindrical sources that are not ideal line heat sources. For a heated cylindrical source of radius a (m) and

length *2b* (m), with temperature measured at its center, the temperature rise during heating ($0 < t \leq t_1$) is:

$$\Delta T = \frac{q}{4\pi k} \int_{r^2/4Dt}^{\infty} u^{-1} \exp(-u) \exp[-(a/r)^2 u] I_o(2au/r) erf\left(\frac{b}{r}\sqrt{u}\right) du \quad (5)$$

During cooling ($t > t1$) it is:

$$\Delta T = \frac{q}{4\pi k} \int_{r^2/4Dt}^{r^2/4D(t-t_1)} u^{-1} \exp(-u) \exp[-(a/r)^2 u] I_o(2au/r) erf\left(\frac{b}{r}\sqrt{u}\right) du \quad (6)$$

Here, $I_0(x)$ represents a modified Bessel function of order zero, *erf(x)* is the error function, and *u* is an integration variable. As pointed out by Kluitenberg et al. [4],

$$\exp[-(a/r)^2 u] I_o(2au/r)$$

approaches unity as a/r approaches 0, and

$$erf\left(\frac{b}{r}\sqrt{u}\right)$$

approaches unity as b/r approaches infinity, reducing eqs. (5) and (6) to (2) and (3).

Inversion of these equations is not practical on a micro-controller such as the KD2 Pro uses, but we compared results from these equations with those from equations (2) and (3) for the sensors used in the KD2 Pro. It was found that eqs. (2) and (3) fit the temperature data as well as eqs. (5) and (6), but give slightly different values for the fitting

parameters *k* and *D*. The differences are accounted for in calibration, so the simpler equations (2) and (3) can be used reliably to determine the thermal properties.

It should be pointed out that, even though a value for *D* is obtained from fitting these equations to the single needle data, that value is not a reliable estimate of *D*. Reliable measurements of *D* are only obtained from the dual needle measurement. It can also be noted that the needle spacing, *r* is squared in eqs. (2) and (3). The practical effect of this is that measurements of heat capacity and diffusivity are very sensitive to needle spacing errors. If the needles are bent so that the actual spacing is 1% different from the assumed 6 mm spacing, the error in *C* and *D* will be 2%.

References:

1. Carslaw, H.S. and J.C. Jaeger (1959) *Conduction of Heat in Solids, 2nd Edition*. Oxford, London.

2. Abramowitz, M. and I. A. Stegun (1972) *Handbook of mathematical functions*. Dover Publications, Inc., New York

3. Marquardt, D. W. (1963) "An algorithm for least-squares estimation of nonlinear parameters" J. *Soc. Indust. Appl. Math.* 11:431-441.

4. Kluitenberg, G. J., J. M. Ham, and K. L. Bristow (1993) "Error analysis of the heat pulse method for measuring soil volumetric heat capacity" *Soil Sci. Soc. Am. J.* 57:1444-1451.

Further Reading

Bristow, K.L., White, R.D., Kluitenberg, G.J., 1994. "Comparison of Single and Dual Probes for Measuring Soil Thermal Properties with Transient Heating." *Australian Journal of Soil Research*, 32:447-464.

Bruijn, P.J, van Haneghem, I.A., Schenk, J. 1983. "An Improved Nonsteady-State Probe Method for Measurements in Granular Materials." Part 1: Theory. *High Temperatures - High Pressures,* 15:359-366.

Shiozawa, S., Campbell, G.S., 1990. "Soil Thermal Conductivity." *Remote Sensing Rev.* 5:301-310.

van Haneghem, I.A., Schenk, J., Boshoven, H.P.A., 1983. "An Improved Nonsteady-State Probe method for Measurements in Granular Materials. Part II: Experimental Results." *High Temperatures - High Pressures*, 15:67-374.

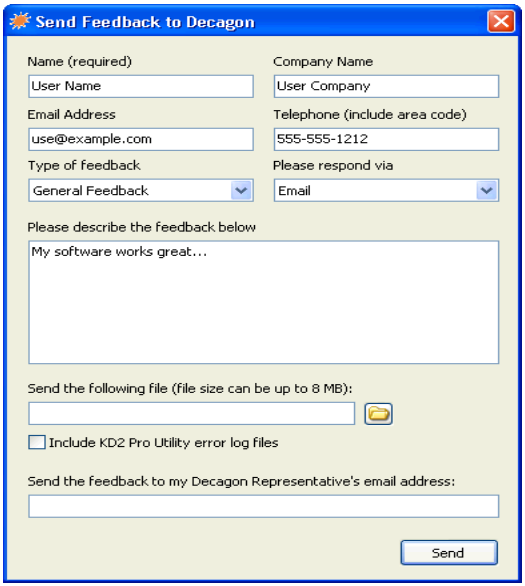
Please visit **www.thermal.decagon.com** for more information on thermal properties in relation to density, water content, and temperature.

Appendix A: Table of Thermal Units

	Column 1: SI Unit	To convert Column 1 into Column 2, multiply by:	Column 2: English Unit	To convert Column 2 into Column 1, multiply by:
heat	Joule	0.000952	BTU	1054
heat	Joule	0.239	cal	4.186
heat flux density	W/m^2	0.00143	$cal/(cm^2\ min)$	698
thermal conductivity	$W/(m \cdot K)$	0.578	$BTU/(hr \cdot ft\ °F)$	1.73
thermal conductivity	$W/(m \cdot K)$	6.93	$BTU \cdot in/(hr \cdot ft^2\ °F)$	0.144
thermal resistivity	$m \cdot K/W$	1.73	$ft \cdot hr\ °F/BTU$	0.578
thermal resistivity	$m \cdot K/W$	0.144	$ft^2\ hr \cdot °F/(BTU \cdot in)$	6.93
specific heat	$J/(kg \cdot K)$	2.39×10^{-4}	$BTU/(lb \cdot °F)$	4179
diffusivity	mm^2/s	0.0388	ft^2/hr	25.794
diffusivity	m^2/s	.1076	ft^2/s	9.29

Appendix B: Send Feedback to Decagon

Decagon Software makes it easy to send feedback, bug reports, and feature requests to Decagon or your Decagon



Distributor. Choose "Send Feedback to Decagon..." from the help menu. This opens the window shown below.

Enter your name, company name, and other contact information. Tell us what type of feedback you are sending (General Feedback, Feature Suggestions, Bug Report, or Other). Indicate how you want us to respond to your feedback (E-mail or Telephone).

Use the description area to give details for your feedback. If you are reporting a bug, it is very helpful for you to tell us what steps you took for the bug to happen and any error message you saw. By default, bug reports also include the software error files.

You can send Decagon a file using this form too. This is useful for sending data files that you have questions about.

If you work directly with a Decagon representative, put their E-mail address in the field at the bottom of the form. This sends the contents of the form to them. Your Decagon representative can follow-up with you directly.

KD2 Pro CE Compliance

DECLARATION OF CONFORMITY

Application of Council Direction:	89/336/EEC
Standards to Which Conformity is Declared:	EN55022: 1987 EN500082-1: 1991
Manufacturer's Name:	Decagon Devices, Inc. 2365 NE Hopkins Ct. Pullman, Washington 99163 USA
Type of Equipment:	Thermal properties meter
Model Number:	KD2 Pro
Year of First Manufacture:	2006

This is to certify that the KD2 Pro Thermal Properties Meter, manufactured by Decagon Devices, Inc., a corporation based in Pullman, WA, USA meets or exceeds the standards for CE compliance as per the Council Directives noted above. All instruments are built at the factory at Decagon and pertinent testing documentation is freely available for verification.

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