Accu instruments

ghf-01S

A Guarded Heat Flow Meter Instrument for the quick and easy measurement of the Thermal Conductivity of solids

In a few words…

The instrument that you have acquired is suitable for the measurement of the thermal conductivity of solid materials over a range of 0.1 to 14 $Wm^{-1}K^{-1}$, with an uncertainty of 5% and a reproducibility of 1%. **At its present form the instrument measures the thermal conductivity of solids at ambient temperatures only.**

The main characteristics of the instrument are

- Measurement of the thermal conductivity of solids over a range of 0.1 to 14 $W\ m^{-1}\ K^{-1}$.
- The instrument operates according to Guarded-Heat Flow technique (ASTM E1530).
- Reliable results with an uncertainty of 5%.
- It includes reference samples of SS, Pyrex glass and PMMA.
- Requires a sample of 50.8 mm diameter (2 in) and thickness of up to 10 mm.
- It is easy to operate.
- Ideal for measuring the thermal conductivity of insulators or metals

The instrument is suitable for users in industry and academia, research and development institutions.

NOTE: **An external constant temperature bath producing a constant flow of water at 20'C must be available (it is not supplied).**

The Operating Manual has 3 sections:

- Section 1. Principle of Operation
- Section 2. Instrument's Calibration
- Section 3. Instrument Operation.

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Section 1

Principle of Operation

The ghf-01S operates according to the ASTM E1530 Guarded Heat Flow Meter technique [1], for the measurement of the thermal conductivity of solids. According to the technique, the sample is subjected to a steady-state axial temperature gradient. The thermal conductivity of the sample is obtained by measuring the temperature difference across it, and one additional temperature.

The instrument is composed from the following parts shown in Figure 1

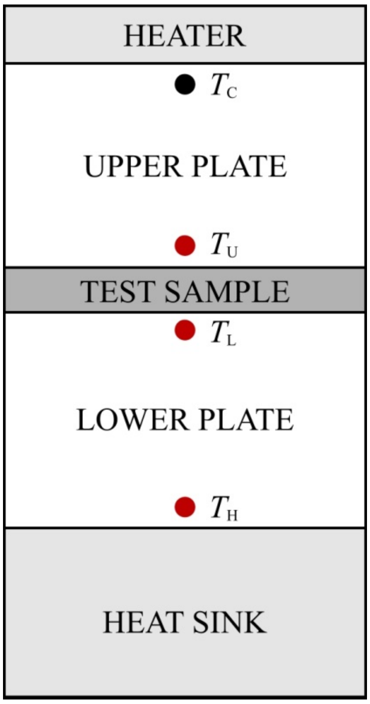


Figure 1. Schematic diagram of ghf-01S

a) A heater on the top of the stack, that provides the necessary heat electrically, kept at 50’C.

b) An upper plate. The heater controlling thermistor, T_C, is placed on its top, while another thermistor, T_U, records the temperature just over the sample.

c) The test sample placed between the upper and the lower plate.

d) The lower plate. On its top, just under the test sample, a thermistor, T_L, records the temperature, while at it bottom another thermistor, T_H, is used.

e) A heat sink, kept at 20’C by circulating water, is placed at the bottom of the stack.

The whole assembly in the actual instrument is made out of stainless steel, and in essence the heater is incorporated in the top part of the upper plate, while the heat sink is incorporated in the bottom part of the lower plate. Furthermore plastic Perspex is employed to insulate the stack.

The Fourier equation for steady-state heat conduction is

$$Q = \lambda \frac{dT}{dx} , \qquad (1.1)$$

where Q (W m^{-2}) is the heat transferred, and dT (K), is the temperature difference achieved over a distance dx (m), for a sample of thermal conductivity λ (W m^{-1}K^{-1}).

Applying this equation over a sample of thickness *d* (m), see Fig. 1.1, and for the temperatures T_U (K) and T_L (K), Eq.(1.1) becomes

$$Q = \lambda \frac{T_U - T_L}{d} \tag{1.2}$$

or

$$\frac{d}{\lambda} = \frac{T_U - T_L}{Q} . \tag{1.3}$$

In the present configuration, the thermistors that measure temperatures T_U and T_L are not placed exactly on the top and bottom surface of the sample but rather on the bottom of the upper plate and the top of the bottom plate respectively. This results to an additional small thermal resistance R_{int}, that incorporates also contact resistances, and Eq.(1.3) becomes

$$\frac{d}{\lambda} = \frac{T_U - T_L}{Q} - R_{int} . \tag{1.4}$$

If the thermal resistance of the sample is denoted by $R_S = d/\lambda$ (m^2 K W^{-1}), then,

$$R_S = \frac{T_U - T_L}{Q} - R_{int} . \tag{1.5}$$

An equivalent relation to Eq.(1.2), can be written for the lower plate, as

$$Q = N\,(T_L - T_H)\,, \tag{1.6}$$

where the coefficient *N* (W m^{-2} K^{-1}), is equal to the ratio of the thermal conductivity of the material of the lower plate, divided by the distance between the place of thermistors T_L and T_H. We note that the same heat flux, *Q* (W m^{-2}), is transferred across the whole stack.

Substituting *Q* from Eq.(1.6) in Eq.(1.5), and introducing a new constant $F = 1/N$ (m^2 K W^{-1}), we obtain:

$$R_S = F\left[\frac{T_U - T_L}{T_L - T_H}\right] - R_{int} \tag{1.7}$$

or

$$R_S = F\left[\frac{\Delta T_S}{\Delta T_B}\right] - R_{int}\,, \tag{1.8}$$

where ΔT_S is the temperature difference across the sample, and ΔT_B is the temperature difference across the bottom plate.

Eq.(1.8) is linear in form, and is the working equation of the instrument.

Section 2

Instrument's Calibration

As discussed in Section 1, Eq.(1.8), shown here again

$$R_S = F\left[\frac{\Delta T_S}{\Delta T_B}\right] - R_{int}\ , \qquad (2.1)$$

is linear in form, and is the working equation of the instrument. Constants F ($m^2\ K\ W^{-1}$) and R_{int} ($m^2\ K\ W^{-1}$), can be obtained by calibration of the instrument. To this effect, samples of known thermal conductivity and hence, thermal resistance, are employed.

The calibration employs four samples of known thermal conductivity (and thickness). Consider for example, 2 reference samples of stainless steel (of different thickness) and 2 of PMMA. **Once thermal equilibrium is reached**, the procedure adopted for every sample is the following:

a) The three temperatures, T_U, T_L, and T_H are recorded, and from them, the temperatures differences, ΔT_S and ΔT_B are calculated.

b) The thermal resistance R_S (= λ/d) is calculated from the ratio of the known thermal conductivity, λ, and the known thickness, d.

c) The four pairs of ($\Delta T_S/\Delta T_B$) and R_S, are placed in a graph, see Figure 2, and form the straight line defines by Eq.(2.1). Its intercept with the R_S-axis will produce the thermal resistance R_{int}, while its slope will give the constant F.

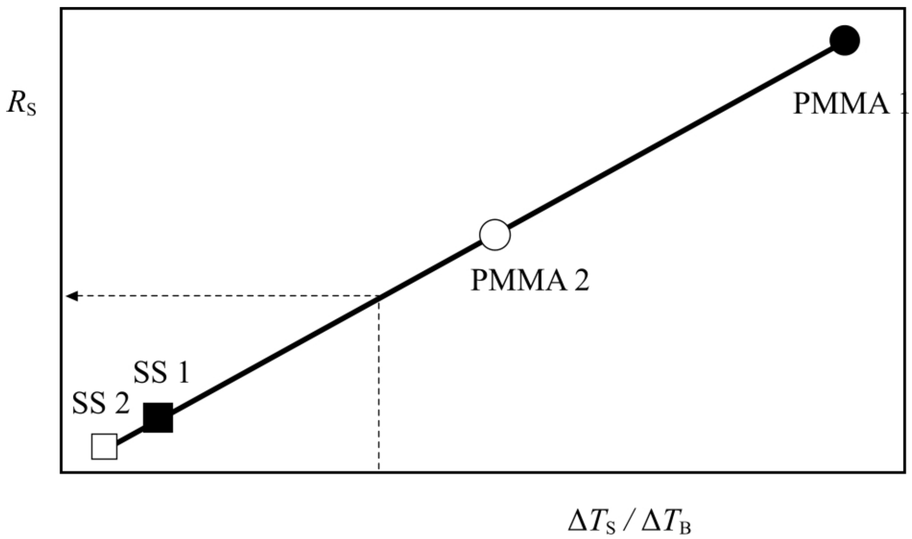


Figure 2. Calibration line of GHFM-01S

Therefore, for an unknown sample, since F and R_{int} are known, by recording the three temperatures, we can obtain R_S, and thus its thermal conductivity, as it can also be seen from Fig. 2.

Section 3

Instrument's Operation

Figure 3. The Instrument

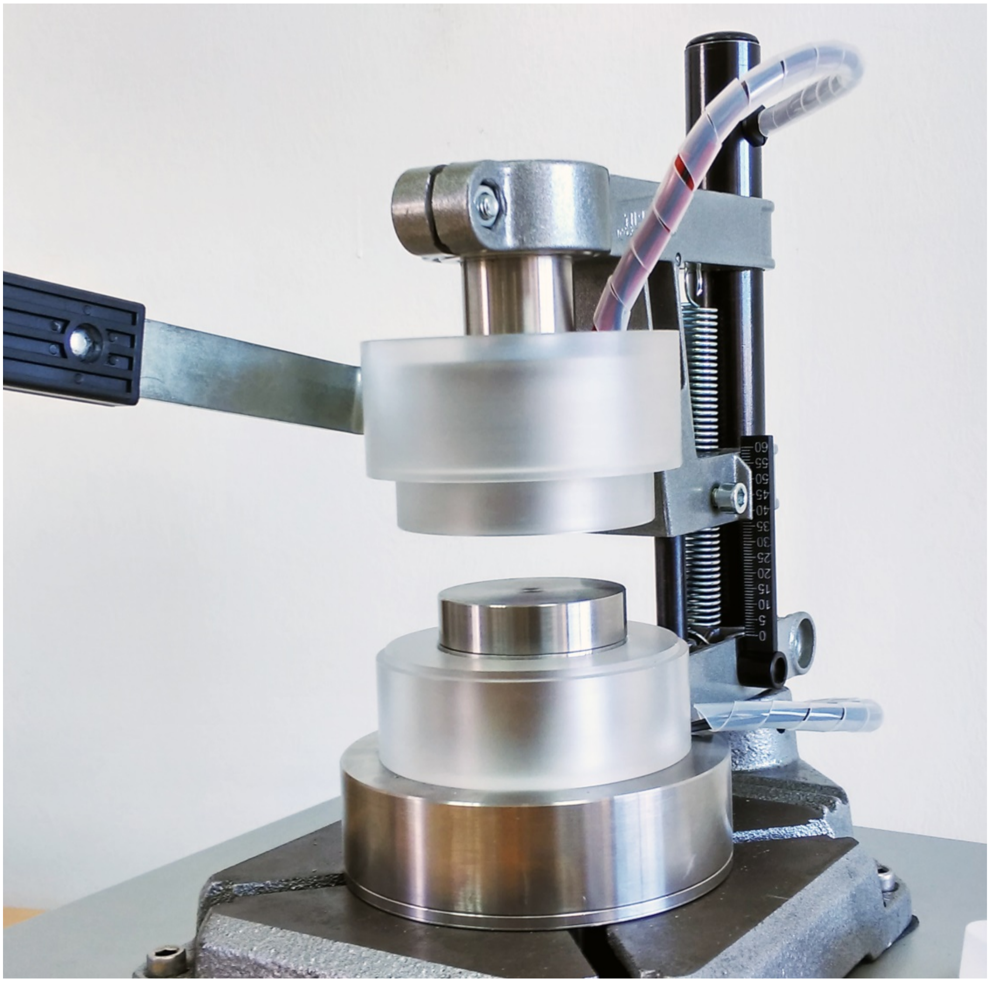


Figure 4. Detail of placing the sample (lifting up the handle and the outside ring, the sample can be placed over the lower plate)

Figure 3 shows the whole instrument. The Guarded Heat-Flow Meter is placed directly over the electronic components. It requires a 20 ‘C constant water supply, circulated from an external bath, not supplied with the instrument. Two fittings are available at the bottom heater for the inlet and outlet of the water (standard ¼ inch plastic tube, just push in).

The electronic components include a) the controller of the heater over the top plate, the controlling thermocouple and its display, and b) the arduino circuit that records the three thermistors and its display.

To operate the instrument (see also Figure 5)

1) Connect the water supply. Start the water circulation. Make sure there is no leak. Allow plenty of time for the water temperature to stabilize.
2) Connect the electronic box to mains (220 V). Switch on the mains on the back of the box. The display of the three temperatures should be lighted and also the heater switch and *the* controlling thermocouple’s display.
3) Lift the metal handle, and tighten the side screw to keep it in position.
4) Lift the outside protective plastic ring.
5) See Figure 4. Place the first reference sample after applying uniformly a very small quantity of heat paste on both sides.
6) Unscrew the side screw and lower the handle. Lower the outside protective ring.
7) Switch the heating on. (Controller’s set temperature is set to 50 ^{o}C) – see footnote.
8) Wait for thermal equilibrium. Make sure the temperatures have reached equilibrium.
9) Record the three temperatures. This is your first calibration point. Repeat steps 3-9, three times, one for every sample with different thickness. Please consider that the uncertainty of the **calibration line** determines the uncertainty of your measurements.
10) Once the calibration line is obtained, place the unknown sample between the plates. From the measurement of the three temperatures and its thickness, the thermal conductivity is obtained.

Instructions for Controller PXR3

Your controller is setup for type-K thermocouple and 50 ^{o}C temperature SET POINT. You should not need to change these.

Selecting type-K thermocouple

1) Press SEL for three seconds, P appears in screen
2) Using arrows find P-n2 and press SEL to select
3) Using arrows find 3 (corresponds to thermocouple K) and press SEL to select
4) Press SEL for two second to return to start screen

Selecting SET POINT temperature

1) Press SEL, using arrows select 50 (50 ^{o}C). SV is lighted. Press SEL to select.
2) Screen shows current thermocouple’s temperature.
3) Green light indicates controller is supplying heat.

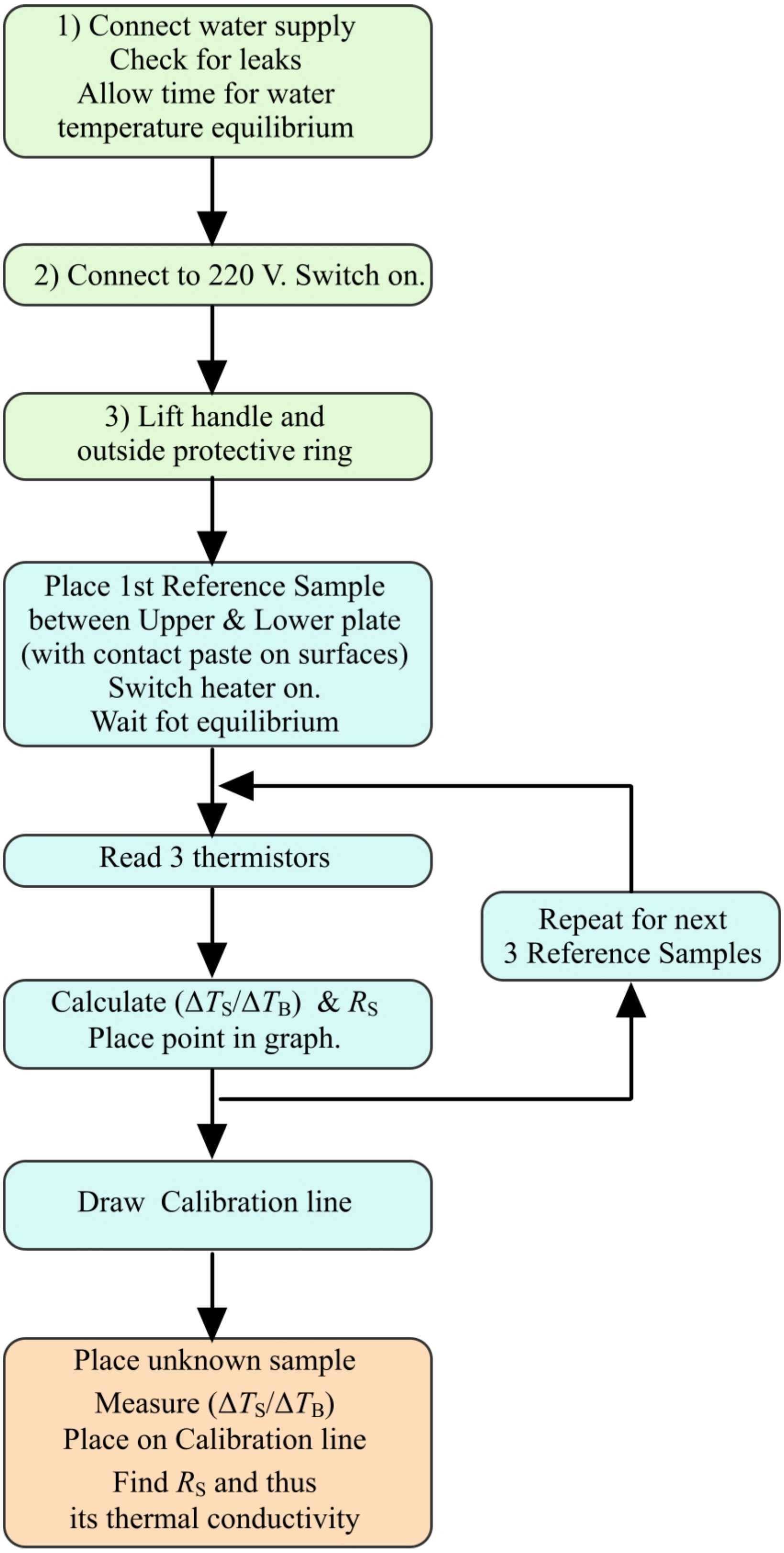
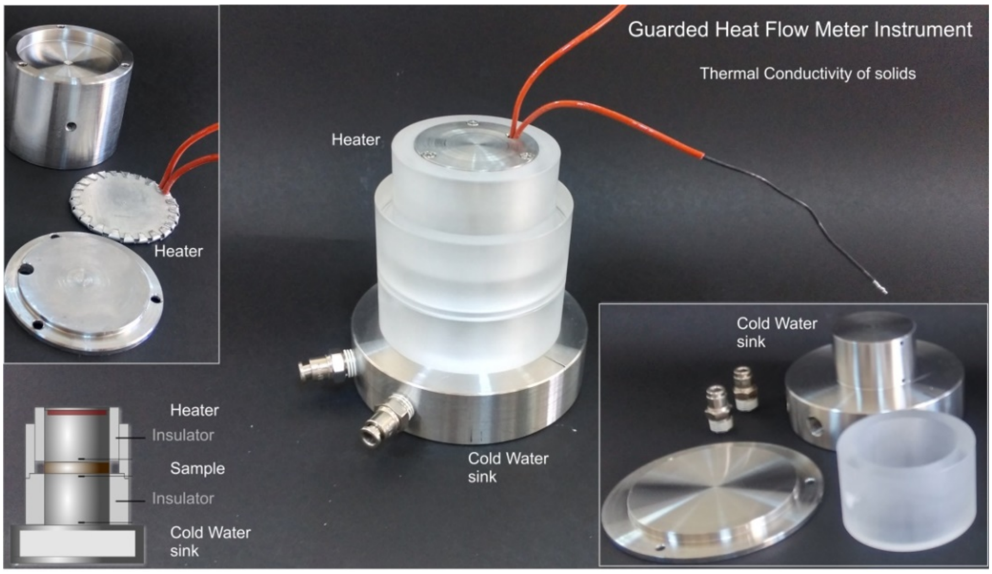


Figure 5. Instrument's Operation



References

1. ASTM E1530: "Test Method for Evaluating the Resisstance to Thermal Transmission of Thin Specimens of Materials by the Guarded Heat Flow Meter Technique", Americal Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

Accu instruments

AccuInstruments is a startup company, currently based in Greece, created by people that have been in this field for more than thirty years. Our instruments are a result of the latest technology developed under an excellent cooperation between Laboratories in Greece and China.

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