

Heat

Heat transfer

Thermal conductivity

Determining the thermal conductivity of building materials using the single-plate method

Recording and evaluating with CASSY

Experiment Objectives

- Recording the temperature change as a function of time on different building material samples.
- Qualitative observation of the thermal equilibrium setting.
- Using the temperature difference to determine the thermal conductivity of the building material samples.

Principles

The single-plate method determines the thermal conductivity λ of a building material sample of thickness d and surface A by measuring the temperature difference $\Delta\vartheta$ and the thermal

flux $\frac{\Delta Q}{\Delta t}$ directly. From

$$\frac{\Delta Q}{\Delta t} = \lambda \cdot \frac{A}{d} \cdot \Delta\vartheta$$

we get

$$\lambda = \frac{\Delta Q}{\Delta t} \cdot \frac{d}{A} \cdot \frac{1}{\Delta\vartheta}.$$

It is important for the measurement that the thermal flux crosses the building material sample homogeneously and that no heat disappears by other ways. With the calorimetric chamber, this is achieved in particular by the heat insulating housing.

For the heat flux through the building material sample,
- the chamber is electrically heated on the inside, and
- ice is placed directly outside the sample.

In the thermal equilibrium, i.e. in stationary condition, in which the temperature is constant over time at every point, the electric power P exactly matches the thermal flux

$$P = \frac{\Delta Q}{\Delta t}$$

or

$$P \cdot t = W = Q$$

i.e. the inserted electrical energy W is equal to the thermal energy Q flowing through the building material sample.

The thermal conductivity λ of the sample's material thus results in

$$\lambda = P \cdot \frac{d}{A} \cdot \frac{1}{\Delta\vartheta}.$$



Fig. 1. Determination of the thermal conductivity of a building material sample using the single-plate method.

Apparatus

1 Calorimetric chamber.....	389 29
1 Building materials for calorimetric chamber ...	389 30
1 Transformer 2 to 12 V; 120 W	521 25
1 Sensor-CASSY 2	524 013
1 CASSY Lab 2.....	524 220
1 NiCr-Ni Adapter S, Type K.....	524 0673
2 Temperature probe NiCr-Ni, 1.5 mm, Type K	529 676
1 Connecting lead 19 A, 50 cm, black, pair	501 451
4 Connecting lead 32 A, 100 cm, black	501 33
Ice	
Thin plastic film	
1 PC with Windows XP/Vista/7/8	

The experiment measures the temperature on the building material sample's underside, i.e. inside the chamber, and outside (in this case ice).

The system is not in thermal equilibrium right after switching the hot plate on. To maintain the temperature difference in thermal equilibrium, record the temperatures' progression over enough time (in the magnitude of 1 hour).

The inside temperature's change over time is proportional to this temperature plus a constant:

$$\frac{\Delta \vartheta}{\Delta t} = a \cdot \vartheta + b.$$

This equation's solution for the temperature as a function of time $\vartheta(t)$ is:

$$\vartheta(t) = \vartheta_{TE} - \vartheta_{Diff} \cdot e^{-\frac{t}{\tau}}$$

where:

- ϑ_{TE} : inside temperature in thermal equilibrium
- $\vartheta_{Diff} = \vartheta_{TE} - \vartheta_{Begin}$: temperature difference
- τ : time constant

The temperature in thermal equilibrium on the heated side of the building material sample, adapting the function from the form

$$f(x) = A - B \cdot \exp(-x/C),$$

produces the values recorded in the experiment. The parameter A obtained by this adaption then corresponds exactly to the desired temperature ϑ_{TE} .

The ice keeps the outside temperature on top of the building material sample low and above all constant. Since there can nevertheless be small temperature fluctuations, the outside temperature's values are averaged, and then this average ϑ_{cold} comes into the calculation of the temperature difference

$$\Delta \vartheta = \vartheta_{TE} - \vartheta_{cold}$$

Finally, the thermal conductivity λ can thus be calculated.

Setup

a) Power Measurement

The experiment's setup is represented in Fig. 2.

Before actually carrying out the experiment, ascertain the hot plate's power P . To do this, briefly put the calorimetric chamber into operation without the building material plate.

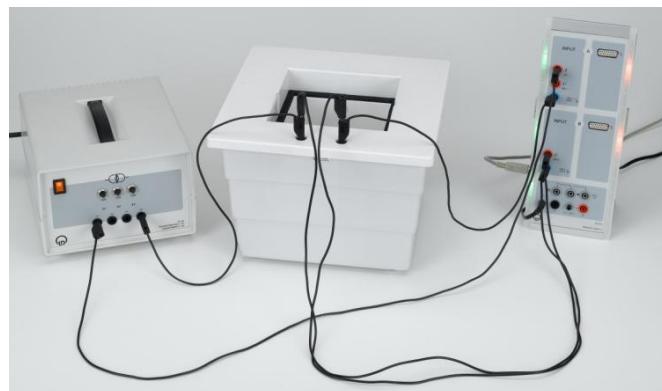


Fig. 2. Determination of the hot plate's power.

- Insert the hot plate into the calorimetric chamber. Do not turn on the transformer yet!
- Connect the transformer and the calorimetric chamber to Sensor-CASSY as shown in Fig. 2 to measure the voltage and current.

b) Temperature Measurement

The experiment's setup is represented in Fig. 1.

- Insert the hot plate into the calorimetric chamber.
- Prepare a building material plate for placement in the calorimetric chamber:
- Insert aluminum contact disks into the circular notches intended for this purpose on the building material plate at the end of the groove using heat conductive paste. In doing so, the contact disk must be turned so the notch is in line with the groove.
- Only apply the heat conductive paste on the contact disk.
- Carefully, i.e. without bending it, place a thin aluminum plate (0.3 mm thick) with the black side facing outward on the side of the building material sample prepared with heat conductive paste, and press the two plates together.
- Repeat this step for the other side.
- First, carefully, i.e. without bending it, push the temperature sensor's tip through the rubber stopper's hole (1.5 mm diameter). Do not put it in the calorimetric chamber yet!

- Insert the prepared building material sample into the chamber's opening, and place the temperature sensor on the top and bottom sides. If needed, raise the building material sample somewhat using the mounting hook.
- Connect the temperature sensor to Sensor-CASSY using the NiCr-Ni Adapter S, as shown in Fig. 1.
- Connect the transformer to the hot plate's connections. Do not turn on the transformer yet!
- Cover the calorimetric chamber with a thin but water-tight plastic film (e.g. plastic wrap). Lay a bag of ice cubes on top of the aluminum plate. Make sure no water can enter the chamber or come in contact with the cables.

Remarks: The bag may not be too small. The ice must contact the aluminum plate as well as possible. The smaller the ice cubes, the better the ice lies on the building material sample. A heavy object that can be placed on the bag without damaging it is also helpful.

Carrying out the Experiment

a) Power Measurement

- [Load the settings in CASSY Lab 2.](#)
- Connect the calorimetric chamber to the transformer according to the selected sample.

Remark: Because of the Rohacell plate's low thermal conductivity, the operating voltage may not exceed the 6 V limit, or else the calorimetric chamber could overheat!

- Switch the transformer on, observing and noting the voltage U_{B1} and the amperage I_{A1} on the screen.
- Make a note of the power P .
- Switch the transformer back off.

Remark: The transformer should be on for as little time as possible during the measurement. Then wait until the hot plate cools back down to room temperature.

Safety note

Do not heat the calorimetric chamber, the wall materials or the building material samples beyond 60 °C!

b) Temperature Measurement

- [Load the settings in CASSY Lab 2.](#)

Remark: If necessary, correct the temperature sensors before inserting them into the measuring chamber at the same temperature – e.g. in still water – in CASSY Lab 2, i.e. bring them to display the same temperature.

- Observe both temperatures ϑ_{A11} and ϑ_{A12} .
- Wait until the lower temperature stops changing.

Remark: Depending on the ice's temperature, it can very well be significantly below 0 °C. To keep this temperature as constant as possible during the measurement, it is recommended that the temperature be between -2 °C and +4 °C.

- Switch the transformer on. Do not start the measurement yet!
- Observe both temperatures and wait until the higher one starts to rise.
- Start the measurement with .
- The inside temperature rises, while the outside temperature under the ice remains constant. As soon as the outside temperature rises (already at a difference of 0.5 °C), fix the contact with the ice. If necessary, repeat this correction during the measurement.
- If the inside temperature reaches 60 °C, switch the transformer off and repeat the experiment with a lower voltage or power.
- If the inside temperature changes only slowly or stops changing (to about 0.15 °C per minute), the measurement can be stopped with .
- Switch the transformer off.

Remark: During disassembly, remove the temperature sensors first, and then lift the building material sample out using the mounting hook.

Measurement Example

Figs 3 through 6 represent the progressions of temperature over time for the various building material samples.

The temperature in thermal equilibrium ϑ_{TE} is determined from the curve of the inside temperature ϑ_{A11} (bottom of the sample) by adaptation. The continuous line is precisely the function obtained from the adaptation.

The average of the lower outside temperature ϑ_{A12} (top of the sample with ice) produces the temperature ϑ_{cold} .

This serves in calculating the temperature difference $\Delta\vartheta = \vartheta_{TE} - \vartheta_{cold}$.

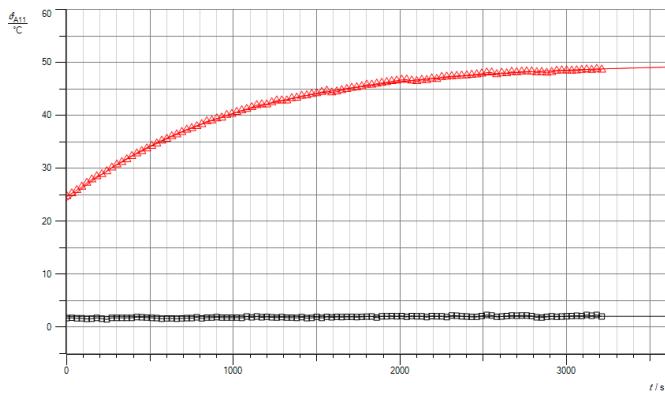


Fig. 3: Polystyrene

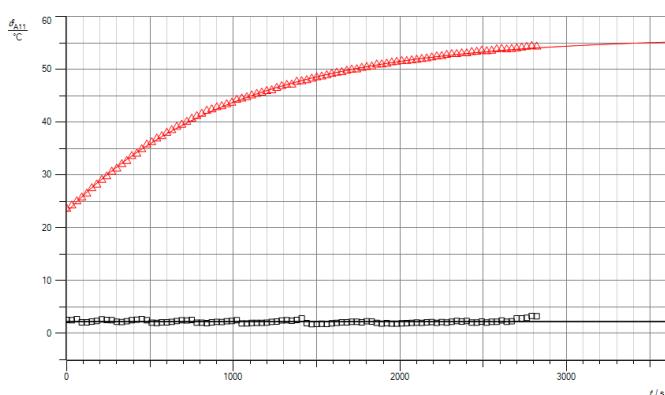


Fig. 4: Wood chip

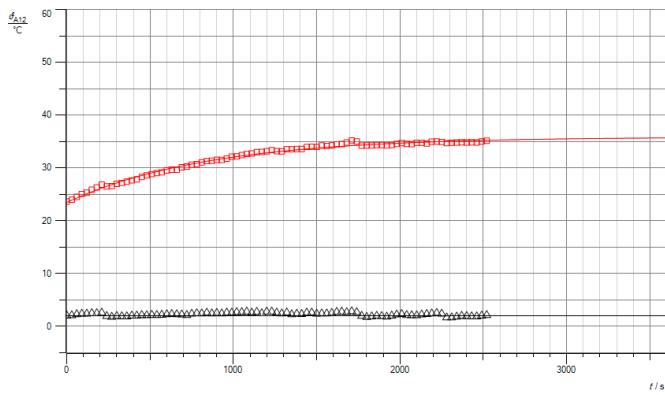


Fig. 5: Fermacell (gypsum)

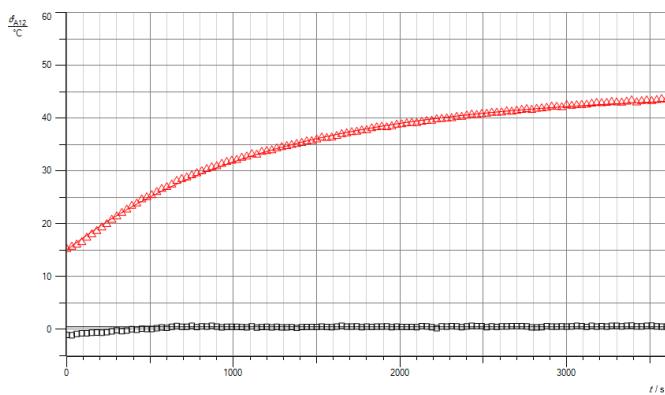


Fig. 6: Rohacell (insulating foam)

	Polystyrene	Wood chip	Fermacell (gypsum)	Rohacell (insulating foam)
$\frac{A}{m^2}$			0.0225	
$\frac{d}{m}$			0.01	
$\frac{U}{V}$	12	12	12	6
$\frac{P}{W}$	21.2	21.2	21.2	5.3
$\frac{\Delta \vartheta}{K}$	48	54	34	45
$\frac{\lambda}{W \cdot m^{-1} \cdot K^{-1}}$	0.19	0.17	0.28	0.05
$\frac{\lambda_H}{W \cdot m^{-1} \cdot K^{-1}}$	0.16-0.18	0.07-0.17	0.23-0.28	0.02-0.05

Table 1: Summary of the readings.
The values for λ_H come from the manufacturer.

The smaller the thermal conductivity, the greater the inner temperature. It should be noted that Rohacell (insulating material) requires a much lower power to reach a similar temperature.

Comment

The calculated thermal conductivity is systematically a little higher than the actual conductivity. The heat losses explain this. The calculation assumes the electric power P corresponds exactly to the thermal flux. For the calculated thermal conductivity λ ,

$$P = \lambda \cdot \frac{A}{d} \cdot \Delta \vartheta.$$

But since during the measurements, only the thermal flux $\frac{\Delta Q}{\Delta t}$ crosses the samples, for the actual thermal conductivity,

$$\frac{\Delta Q}{\Delta t} = \dot{Q} = \lambda_{act} \cdot \frac{A}{d} \cdot \Delta \vartheta.$$

From this we get

$$\lambda = \lambda_{act} \cdot \frac{P}{\dot{Q}}.$$

Since the thermal flux \dot{Q} crossing the plate is smaller than the electric power P , the ratio $\frac{P}{\dot{Q}}$ is greater than 1. So the measured thermal conductivity is a little higher than the actual conductivity.