Experiment No. 7: Thermal conductivity

Introduction:

Thermal conductivity is the heat flow per second per unit area per unit temperature gradient, it is the material's ability to conduct heat. Thermal conductivity is measured in watts per kelvin-meter W/(K·m). There are three main methods of heat transfer; conduction, convection, and radiation. The conduction is the easiest to explain and demonstrate.

In conduction, heat moves in three ways:

1. Impact of vibrations between bordering molecules.
2. Internal radiation.
3. By mobile electrons.

In convection, heat transfer by a fluid flow (liquid, air or gas)

In radiation, heat transfers through electromagnetic radiation.

Most metals have large numbers of mobile electrons, so most heat conduction is by this method. It also explains why thermal conduction in metals is often similar to electrical conduction.

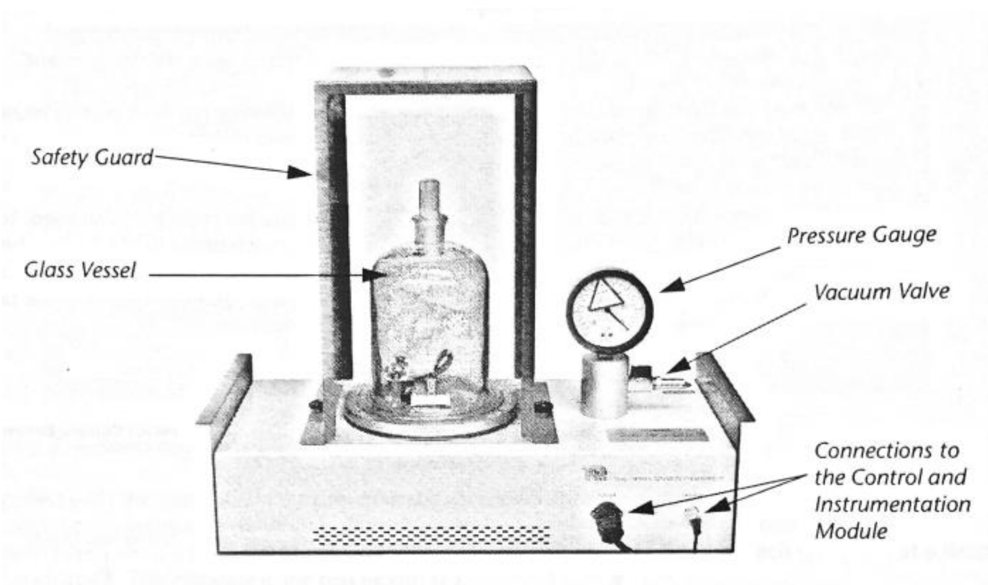


Fig. 1: The general layout of the (TE19) thermal conductivity equipment

Objectives:

1. To define thermal conductivity.
2. To know the methods of heat transfer through deferent types of materials.
3. To calculate thermal conductivity for different types of materials and compare the actual values with the theory.
4. To plot the thermal conductivity (vertical axis) against power (horizontal axis) for all specimens on a single graph and to locate the expected thermal conductivity for each material by drawing a dotted horizontal lines across the graph.
5. To identify the sources of error in the results and to conclude how to obtain the best results with any given specimen.

Parts needed:

The main parts of the apparatus are:

1. Base unit which include:
    a. Peltier cooler and specimen clamp.
    b. Heater sink and fan.
    c. Vacuum gauge.
    d. Molded glass vessel.
    e. Safety guard with transparent sides.
2. Control and instrumentation module.
3. Three specimens each of different metal with 2 thermocouples .
4. Vacuum pump.

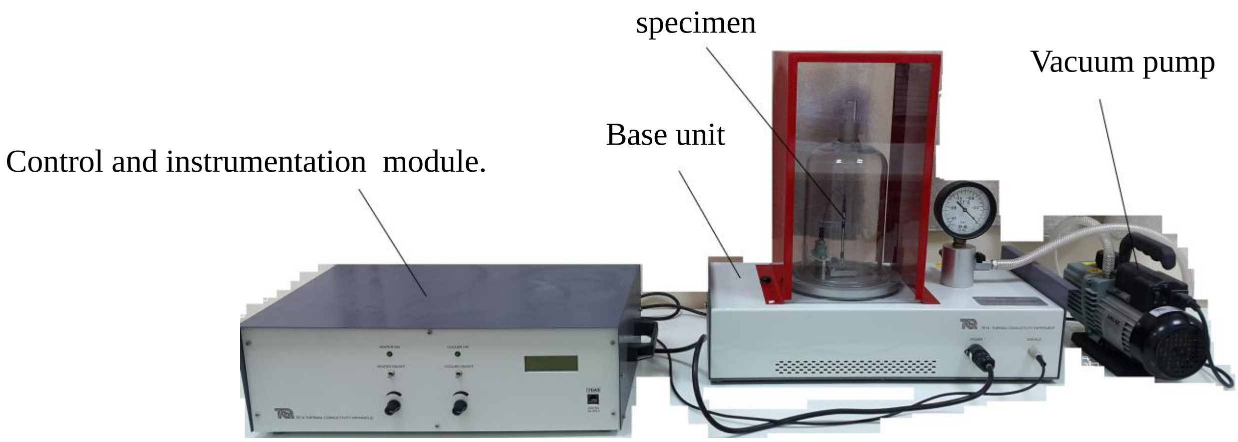


Fig. 2: parts needed

Theory:

To measure the thermal conductivity of a material, a controlled flow of heat energy must move along the specimen. The thermal conductivity apparatus has a controllable heater and cooler to create the heat flow.

For accurate results, the heat loss due to conviction and radiation must be minimized, so that all the heat is transferred by conduction. in a normal environment, much of the heat from the heater would be lost by conviction (see fig. 3), so the heat flow would be difficult to control and measure. If the average specimen temperature is within a few degrees of the surrounding surfaces the heat loss by relation is very small and can be ignored.

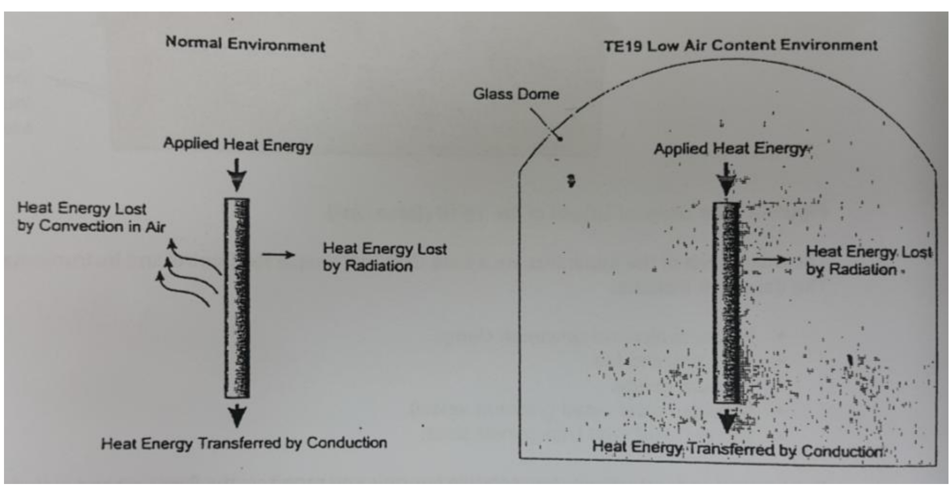


Fig. 3: heat loss in normal environment and in the TE19 low air environment

When the air is removed from around the specimen, there is no gas available for convection to take place, the heat flow is virtually all due to conduction. However, it is virtually impossible to remove all the air or other particles from an environment, this would create a perfect vacuum.

It is impossible to remove all the air, but the RE19 vacuum pump creates a very good vacuum, so that the error due to convection are very small.

Supplied with the apparatus are three different specimens (see fig. 4 and table 1 for more details). Each specimen is made of a different metal for comparison of thermal conductivity. At the end of each specimen is a small resistive heater. Two thermocouples are bonded to each specimen at a fixed distance apart. This distance is the test length (L).

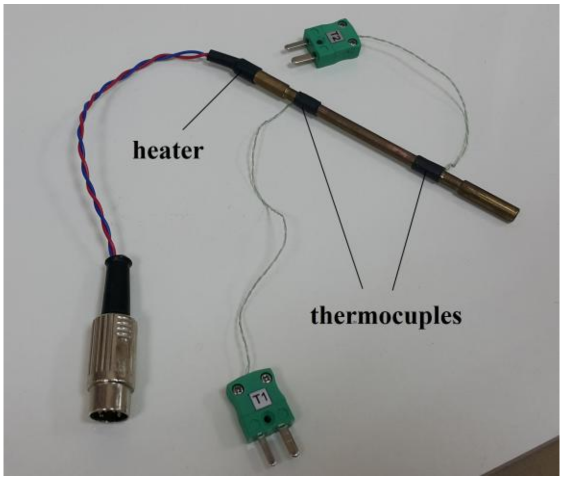


Fig. 4: One of the three specimens with heater two thermocouples

Item	Details
material	Aluminum (6082), Brass (CZ121) and Copper (C101)
Heater	0.6 W 100 R Resister
thermocouples	'K' type
Total length	126 mm
Test length (between tips of thermocouples)	49 mm
Test length diameter	Nominal 4.7 mm
Note: All dimensions are approximate measure the specimen for accurate results	

Table1: technical details for specimens

Heat energy is transferred from the hot end of a heat conductor to the cold end. Conceder a cylindrical conductor as shown in figure 7, where the temperature at T1 is greater than at T2, the heat energy flows from the hotter end at temperature T1 to the cooler end at temperature T2 (fig. 7).

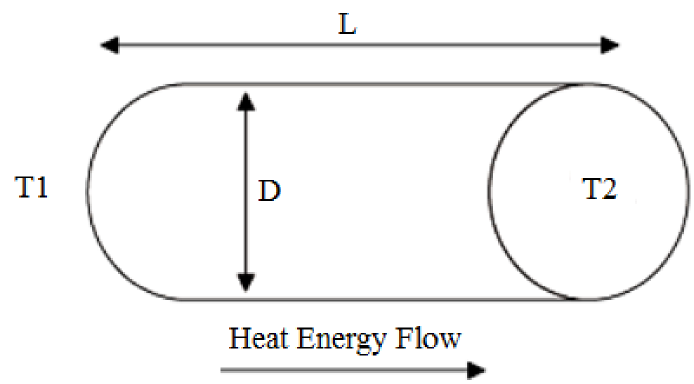


Fig.7: A cylindrical conductor

The temperature gradient along a material is the temperature change per unit length. So, for the example in figure7, the temperature gradient is:

$$(T1 - T2) / L$$

The heat energy (Q) flowing along the cylinder each second of time is Q/t.

For materials better conductors than others, their material has an effect on the rate of heat transfer. This effect is its thermal conductivity (k). from the definition of thermal conductivity, it is the heat flow per second per unit area per unit temperature gradient, so the full equation includes the area (A) of the cylinder.

$$Q/t = KA (T1 - T2) / L$$

The standard form of this equation is:

$$Q / At = K (T1 - T2) / L$$

Therefore, to calculate the thermal conductivity of material, the equation must rearranged to give:

$$K = QL / (T1-T2) At$$

The units of thermal conductivity are J / s m k

However, as Joule per second (J / s) is equal to watt (W), it is more useful to write as (W/ m.k).

Table 2 shows the thermal conductivity of some common materials, note that metals (electric conductors) have a higher conductivity than most other materials (electrical insulators). This suggests a link between electrical and thermal conductivity.

Material (at 24.85 C (298 k))	**Thermal Conductivity (K) (W / m.k)**
Aluminum (grade 6082)	170
Brass (type CZ121)	123
Copper (type C101)	388

Table 2: thermal conductivity of a selection of materials

In the thermal conductivity apparatus, the power applied to the heater (Wh) and cooler (Wc) is calculated from the product of the voltage and current that flows through them.

$$Wh = I.V$$
$$Wc = I.V$$

To achieve steady state conditions, the cooler power is set to the same value as the heater. This helps the thermal equilibrium to stabilize as quickly as possible. The calculations could use either the heater or the cooler power, as they are kept equal, but this guide uses the heater power (Wh).

The heat energy transfer rate (Q / t) is replaced by the power (Wh) for this apparatus and the experiment. This changes the general equation to:

$$K = Wh \,.\, L / A \,.\, (T1 - T2)$$

Procedure:

1. Make sure that the apparatus is in a place where the temperature is stable and has been in position for at least three hours, so that it is at the same temperature as the room it is in.
2. Prepare a blank table of results similar to table 2.
3. Accurately measure and record the diameter of the specimen and the ambient temperature. The effective length (L) of the specimen is the distance between each thermocouple tip (see technical details in table 1)
4. Set up the apparatus in a place where the ambient temperature does not change, away from any sources of heated or cooled air (heaters or air conditioning outlets for example).
5. Fit the ‘O’ ring seal to the circular groove in the test area of the base unit, add a small amount of silicone grease (supplied) to the ‘O’ ring seal if required to help keep it in place.
6. Place the specimen on the specimen mount and use the hexagon key (supplied) to tighten the specimen clamp screw.
7. Connect the plug from the specimen heater and the two sockets of the thermocouples to their positions on the connection stand, (pay attention for the correct direction when mounting plugs and sockets). The upper thermocouple is number 1, and the lower thermocouple is number 2.
8. Carefully lower the glass vessel into place around the specimen.
9. Fit the safety guard in place over the vessel. Make sure the controls for the heater and cooler are switched off and turned fully anticlockwise (minimum power). Switch on the control and instrumentation module..
10. Shut the pressure release valve, open the vacuum line valve (control valve) and start the vacuum pump.
11. The apparatus is ready for test when the pressure gauge indicates approximately -0.8 to -0.9 bar. (-1.0 bar is almost impossible to achieve with normal equipment).
12. Switch on the heater and cooler and slowly increase their power to around 0.1 W. Wait for at least twenty minutes to allow the system to stabilize, Then record all the data.
13. Increase the heater and cooler power to 0.2 W, wait until conditions stabilize (this can take up to thirty minutes), and record all the data. Repeat for heater and cooler powers of 0.3 W, 0.4 W and 0.5 W.
14. Reduce the heater power to minimum, then reduce the cooler power to minimum. Turn off the control and instrumentation module.
15. Shut the vacuum line valve (control valve) and switch off the pump. Open the release valve to allow air back into the test area. Open the vacuum line valve.

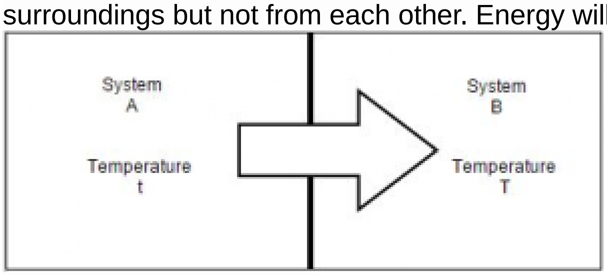
Caution: always shut the control valve before you switch off the pump. If you switch off the pump when it is connected to a vacuum, the vacuum will suck oil from the pump and will damage its seal.

16. Change the specimen for one of the other two supplied with the apparatus and repeat the experiment.

Questions for further discussion:

Circle the correct answer:

1. The literature of heat transfer generally recognizes distinct modes of heat transfer. How many modes are there?
   a) One
   b) Two
   c) Three
   d) Four
2. Consider system A at uniform temperature t and system B at another uniform temperature T (t > T). Let the two systems be brought into contact and be thermally insulated from their surroundings but not from each other. Energy will flow from system A to system B because of

   a) Temperature difference
   b) Energy difference
   c) Mass difference
   d) Volumetric difference
3. The unit of rate of heat transfer is
   a) Joule
   b) Newton
   c) Pascal
   d) Watt
4. Thermal conductivity is bigger for which material.
   a) Brass
   b) cupper
   c) Aluminum
   d) wood

5. Heat transfer takes place in liquids and gases is essentially due to
   a) Radiation
   b) Conduction
   c) Convection
   d) Conduction as well as convection
6. Most metals are good conductor of heat because of
   a) Transport of energy
   b) Free electrons and frequent collision of atoms
   c) Lattice defects
   d) Capacity to absorb energy
7. Heat conduction in gases is due to
   a) Elastic impact of molecules
   b) Movement of electrons
   c) EM Waves
   d) Mixing of gases

Conclusion:

Student should write a conclusion upon his results and the objectives achievement.