Thermal Conductivity

University of Jordan

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★ Objectives:

- To determine :
  - Heat conductivity (k) of a good conductor (copper & Stainless steel).
  - Rate of heat transfer ($\dot{Q}$).

★ Introduction & Theory

- When a temperature gradient exists in a solid body. An energy transfer from high-temperature region to low-temperature region takes place. In this case, it is said that the energy is transferred by conduction and that the heat transfer rate per unit area is proportional to the temperature gradient:

$$\dot{Q} = -kA\frac{dT}{dx} \quad \textbf{(}\textit{\textbf{Fourier's law}}\textbf{)}$$

Where :

$\dot{Q}$ = The heat transfer rate (W)

A = The cross sectional area (m^2)

$\frac{dT}{dx}$= The temperature gradient

k = The thermal conductivity of the material (W/m.K).

To determine thermal conductivity “k” of each specimen, both $\dot{Q}$ and $\frac{dT}{dx}$ are to be evaluated.

In this experiment $\dot{Q}$ is the rate of heat transferred to the cooling water (the substance that is used because it has a known specific heat) and is given by:

$$\dot{Q} = \dot{m}c(T_{out} - T_{in})$$

where :

$\dot{m}$ = the mass flow rate of water (kg/s)
c = Specific heat for water = 4.18 (kJ/kg ^{o}C)
T_{out} = water exit temperature(^{o}C).
T_{in} = water inlet temperature(^{o}C).

How to measure T_{in} and T_{out}?

The temperature gradient within the specimen can be approximated to be linear between the two thermocouple positions and given by:

$$\frac{dT}{dx} = \frac{T3 - T4}{L}$$

Where:
T4 = the thermocouple temperature (hot end) (^{o}C)
T3 = the thermocouple temperature (cold end) (^{o}C)
L = the distance between the two thermocouples (m)'

Eventually the experimentally found values of thermal conductivity will be compared with the theoretical values in the text book which are as follows:

Aluminum	210 W/mK
Copper	385 W/mK
Mild steel	42 W/mK
Stainless steel	30 W/mK

★ Apparatus

The apparatus. Figure 1, consists of a self-clamping specimen stack assembly with electrically heated source, calorimeter base, and Dewar vessel enclosure to ensure negligible loss of heat and constant head cooling supply tank. A multipoint thermocouple switch is mounted on the steel cabinet base and two mercury and glass thermometer are provided for water inlet and outlet temperature readings. Four NiCr/NiAl thermocouples are fitted and connections are provided for a suitable potentiometer instrument to give accurate metal temperature readings.

Figure 1 Thermal conductivity Apparatus

Four metal specimens are provided. Two holes are provided in each specimen for insertion of the thermocouples. A sketch of the specimen is shown in Figure 2.

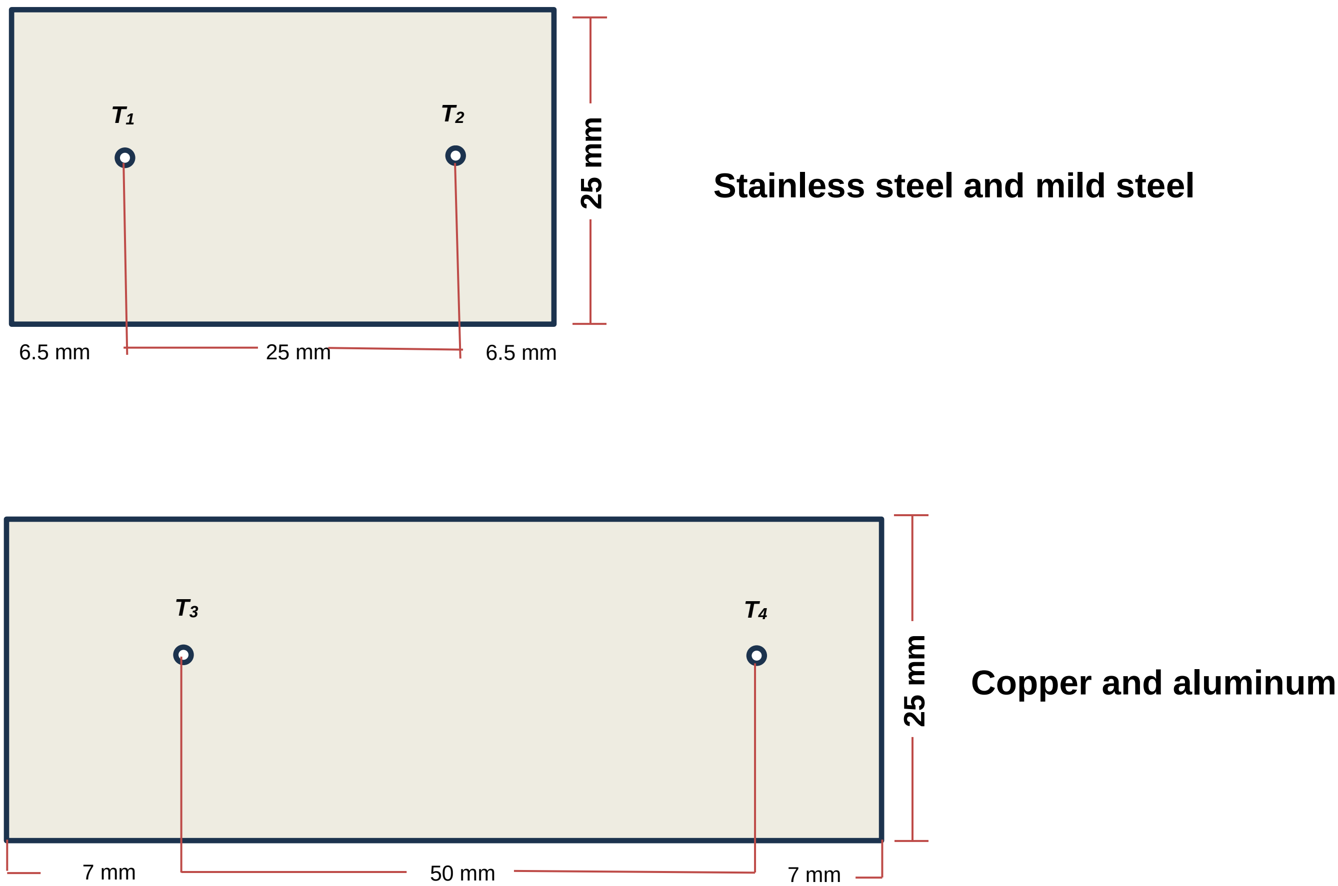

Figure 2 A sketch of the specimen

★ Procedure

1. The apparatus Is assembled with one short specimen (mild steel or stainless steel, in lower position, and on long specimen in upper position, ensure that they are completely free from dirt especially at the ends of the where contact is to be made.
2. Operate the clamp by moving the protruding lever positioned on the front of the apparatus to a downward position and place specimens between heating element and clamp. Ensure that the

holes for the thermocouples are accessible. Release the lever, thereby clamping specimens in position. Insert thermocouples into holes provided.

3. Ensure that the thermostat adjustment control which is situated on front of heating element is turned fully clockwise. This sets cutout temperature to approximately 210°C. The normal maximum working temperature is 200 °C.
4. place the Dewar vessel in position over specimens.
5. Fit the thermometer into the special leak proof connections provided on top of calorimeter base.

   a-Connect water pipes water supply to header tank, header tank to inlet on apparatus, and header tank overflow to drain.

   b-Turn on water supply. Adjust flow rate through the apparatus by means of the inlet flow valve positioned at inlet pipe. Note that the actual flow rate is not critical, however . a temperature difference of about 8°C should be sought.
6. Connect the potentiometer instrument to the two terminals provided on the front of the apparatus.
7. Connect the control box to the socket on the right-hand side of the conductivity apparatus, and connect the control box to a single phase AC mains. Check that the supply voltage is correct.
8. Switch on the electrical supply and check that that indicating lights on both control box and calorimeter base are operative.
9. Before readings can be obtained from the apparatus, the heat flow must reach a steady state condition.

a)Set current input to a maximum, this being about 0.55 amps. Maintain this until a temperature of 200°C obtained from the thermocouple nearest the element (T_4). This will take 15-20 minutes. Reduce the current to 0.3 amps until the temperature have become steady. This will take 20-25 minutes.

b) Set current to 0.3 amps. Leave for a period of approximately 2 hours.

★Data collection

Test material : **Copper & Stainless Steel**
Current : **0.3 amp**
Water flow rate : **0.166 ml/min**
Time to reach steady state : **2 hrs**
Temperature readings :-

Test no	Time(min)	T_1(°C)	T_2(°C)	T_3(°C)	T_4(°C)
1	0	75.7	157.7	182.6	188.9
2	2.5	75.8	156.5	180	187.8
3	5	75.5	157.1	180.6	185.5
Total	7.5	227	471.3	543.2	562.2
Average	2.5	75.67	157.1	181.06	187.4

$T_{in=}18^{o}C$ $T_{out=}34^{o}C$

★Sample of calculations

* Stainless - steel :-

$\dot{m} = \dot{V} \rho$

$\dot{V} = \frac{10\times10^{-6}}{60} = \boxed{1.67\times10^{-7}\ \frac{m}{s}}$

$\dot{m} = 1.67\times10^{-7} * 1000 = \boxed{1.67\times10^{-4}\ \frac{kg}{s}}$

$\therefore Q_w = \dot{m} C_p \Delta T$

$= 1.67\times10^{-4}\ \frac{kg}{s} * \cancel{416}\ 4186\ \frac{J}{kg.°c} * (34 - 18)$

$\boxed{Q_w = 11.167\ W}$

now • $A = \frac{\pi}{4}(d)^2 = \frac{\pi}{4}(25\times10^{-3})^2 = \boxed{4.91\times10^{-4}}$

$\frac{dT}{dx} = \frac{T_1 - T_2}{L} = \frac{75.67 - 157.1}{25\times10^{-3}} = -3257.2\ \frac{°c}{m}$

$* Q = -k_{ss} * A \frac{dT}{dx}$

$\therefore 11.185 = -k_{ss} * 4.91\times10^{-4} * -3257.7$

$\boxed{k_{ss} = 7\ \frac{W}{m.K}}$

$Error = \frac{|Exp - theo|}{theo} * 100\% = \boxed{76.67\%}$??

* Copper :-

$Q_w = 11.167\ W$

$A = 4.91\times10^{-4}\ m$

$\frac{dT}{dx} = \cancel{75.67}\ \frac{181.06 - 187.4}{50\times10^{-3}} = -126.8\ \frac{°c}{m}$

$11.167 = -k_{copp} * 4.91\times10^{-4} * -126.8$

$\boxed{k_c = 179.36\ \frac{W}{m.K}}$

$Error = \frac{|179.36 - 385|}{385} * 100\% = \boxed{53.413\%}$

★Result and discussion

1-Draw the temperature vs the length of the specimen used in the experiment.

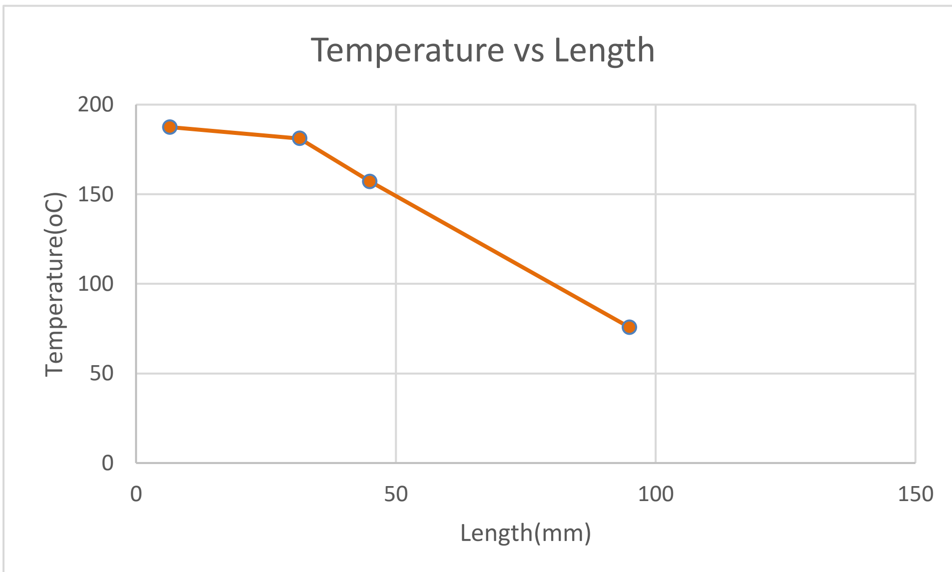

Figure 3. Temperature vs length

It is noticeable that as we go further from the source of heat the temperature decreases.

Considering the error values, There are mainly two sources of error:

1) **The experiment was conducted for the non-steady state phase (2hrs).**
2) **Observational error (Time, Temperature,…etc.).**

2-Determine the thermal conductivity of each specimen in the experiment.

Already calculated above