ME341A-HEAT AND MASS TRANSFER

Experiment - 6

Heat Transfer through Extended Surface

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<u>Group – G1(a)</u>

Shikhar Shivraj Jaiswal – 150670
Anutosh Nimesh – 150125
Avinash Kumar - 150169

Objective

Using analytical transient-temperature/heat flow charts to determine the conductivity of a solid cylinder from the measurements taken on a similar cylinder but having a different conductivity.

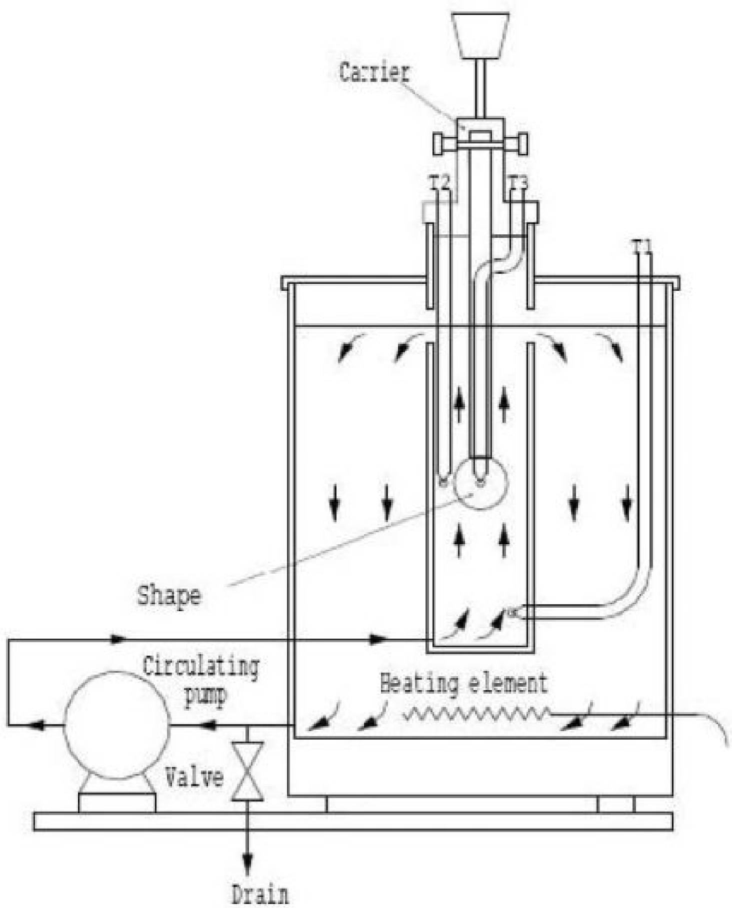
Experimental Setup:

Before proceedings with the exercise ensure that the equipment has been prepared as follows:

Locate the hot water bath of the HT17 Unsteady State Heat Transfer accessory alongside the HT10X/HT10XC Heat Transfer Service Unit on a suitable bench. Ensure that the lid of the hot water bath is fitted and the inlet at the base of the flow duct is connected to the outlet of the circulating pump using flexible tubing.

Ensure that the drain valve on the water bath is closed then fill the bath with clean water until the level is coincident with the centre of the holes in the vertical flow duct as shown in the diagram below.

Connect thermocouple T1 from the flow duct inside the water bath (lead exits via a grommet in the lid of the water bath) to socket T1 on the front of the HT10X/HT10XC service unit.



Connect thermocouple T2 on the shape holder to socket T2 on the front of the HT10X/HT10XC service unit.

Connect thermocouple T3 inside the large brass shape to socket T3 on the front of the HT10X/HT10XC service unit.
Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the selector switch to MANUAL then connect the power lead from the circulating pump alongside the water heating tank to the socket marked Output 2 at the rear of the service unit.

Theory:
Analytical solutions are available for temperature distribution and heat flow as a function of time and position for simple solid shapes which are suddenly subjected to convection with a fluid at a constant temperature. A typical chart is included below which is constructed for a long cylinder of radius b where the whole of the surface is suddenly subjected to a change in temperature (the effect of the end faces is considered to be negligible). To use the charts it is necessary to evaluate appropriate dimensionless parameters as follows:

$$\theta = \frac{T(r,t) - T_\infty}{T_i - T_\infty}$$ (Dimensionless quantity)

$$\tau = \frac{\alpha t}{b^2}$$ (Fourier Number)

$$B_i = \frac{hb}{k}$$ (Blot Number)

α = thermal diffusivity of the cylinder (m^2s^{-1})
h = Heat transfer coefficient ($Wm^2\,{}^oC^{-1}$)
k = thermal conductivity (W/m^oC)

Procedure

1. Refer to the Operation section in the HT17 instruction manual if you need details of the instrumentation and how to operate it.
2. Switch on the front Mains switch (if the panel meters do not illuminate check the RCD and any other circuit breakers at the rear of the service unit, all switches at the rear should be up).
3. Check that the water heater is filled with water then switch on the electrical supply to the water heater (switch on the RCD which is located on the connection box adjacent to the water heater).

4. Ensure that the red light is illuminated on the water heater indicating that electrical power is connected to the unit.
5. Adjust the thermostat on the water heater to setting '4' and check that the red light is illuminated indicating that power is connected to the heating element.
6. Set the voltage to the circulating pump to 12 Volts using the voltage control box on the mimic diagram software display.
7. Allow the temperature of the water to stabilise (monitor the changing temperature T1).
8. The water must be in the range 80 - 90oC for satisfactory operation. If outside this range adjust the thermostat and monitor T1 until the temperature is satisfactory.
9. Attach the large brass shape to the holder (insert the insulated rod into the holder and secure using the transverse pin) but do not hold the metal shape or subject it to a change in temperature. Check that the thermocouple attached to the shape is connected to T3 on the HT10X/HT10XC. Check that the thermocouple wire is located in the slot at the top of the shape holder. Check that the temperature of the shape has stabilised (same as air temperature T2).
10. Switch off the electrical supply to the water bath (switch off the RCD on the connection box) to minimise fluctuations in temperature if the thermostat switches on/off).
11. Start continuous data logging by selecting the icon on the software toolbar.
12. .Allow the temperature of the shape to stabilise at the hot water temperature (monitor the changing temperature T3 on the mimic diagram software screen).
13. .When temperature T3 has stabilised, select the icon to end data logging.
14. .Select the icon to create a new results sheet.
15. .Switch on the electrical supply to the water bath to allow the thermostat to maintain the water temperature.
16. .Remove the large brass cylinder from the shape holder then fit the stainless steel cylinder.
17. Repeat the above procedure to obtain the transient response for the stainless steel cylinder.
18. Remember to create a new results sheet afterwards ready for the next set of results.
19. Remove the stainless steel cylinder from the shape holder then fit the small brass cylinder.
20. Repeat the above procedure to obtain the transient response for the small brass cylinder.
21. If time permits the response of the other shapes can be determined using the same procedure as above. These additional results can be used in exercise HT17C.

Calculations

To determine heat transfer coefficient **for brass sphere**

$\alpha = 3.7\text{x}10^{-5}$, $T_\infty = 72.8^o C$, $T_i = 26.5^o C$, $T = 68.2^o C$, $t = 81$ seconds

$\theta = (T(r,t) - T_\infty)/(T_i - T_\infty) = 0.11$

$\tau = \alpha t/b^2 = 5.92$
From Heisler Chart for spheres, Bi (Biot Number) = 0.13
k=121 W/m°C
From the formula Bi = hb/k
h=699.1 W/m^2 °C

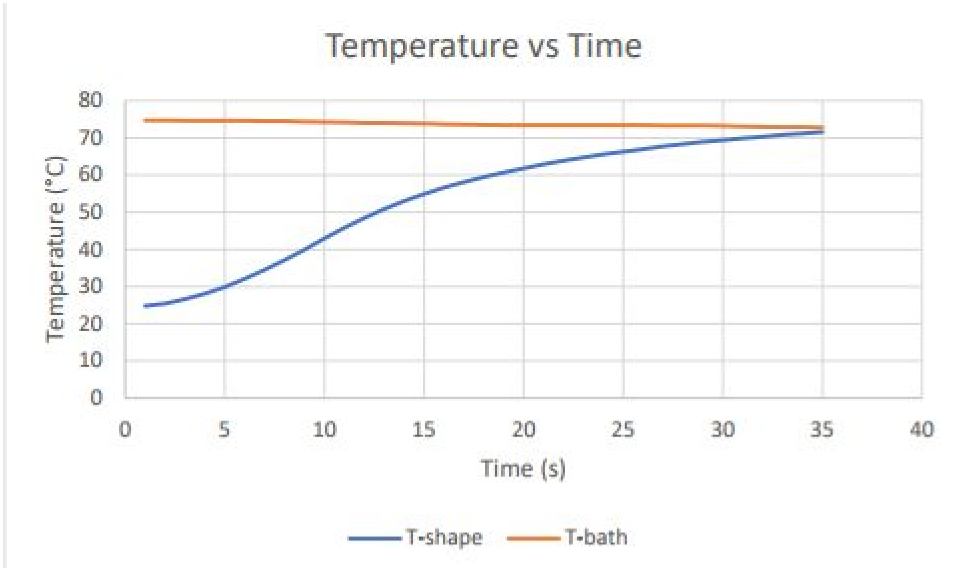
To determine heat transfer coefficient **for brass cylinder**
$\alpha = 3.7 \times 10^{-5}$, T_∞ = 71.3°C, T_i=26.6°C, T=68°C, t=32 seconds, k=121 W/m°C, Diameter = 20mm, Length = 100mm
$\theta = (T(r,t) - T_\infty)/(T_i - T_\infty) = 0.073$
$\tau = \alpha t/b^2 = 11.84$
From Heisler Chart Bi (Biot Number) = 0.083
From the formula Bi = hb/k
h=1007.93 W/m^2 °C

To determine conductivity **for steel sphere**
$\alpha = 0.6 \times 10^{-5}$, T_∞ = 71.8°C, T_i=26.1°C, T=66.9°C, t=130 seconds
$\theta = (T(r,t) - T_\infty)/(T_i - T_\infty) = 0.107$
$\tau = \alpha t/b^2 = 1.54$
From Heisler Chart for spheres, Bi (Biot Number) = 0.67, using h for brass sphere since surface conditions are the same
From the formula Bi = hb/k
k=23.47 W/m°C

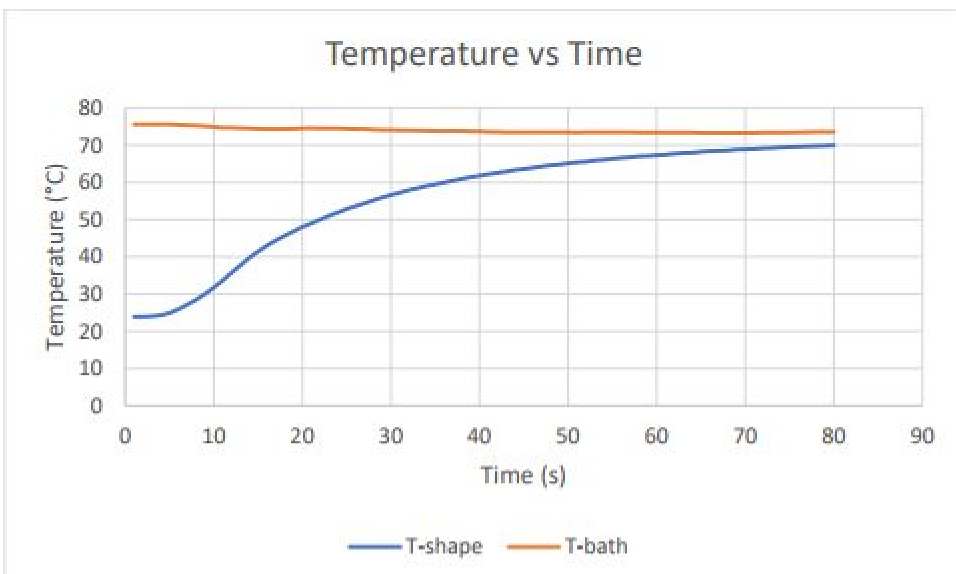
To determine heat transfer coefficient **for steel cylinder**
$\alpha = 0.6 \times 10^{-5}$, T_∞ = 70.9°C, T_i=24.3°C, T=68.1°C, t=54 seconds
$\theta = (T(r,t) - T_\infty)/(T_i - T_\infty) = 0.06$
$\tau = \alpha t/b^2 = 3.24$
From Heisler Chart, Bi (Biot Number) = 0.29, using h for brass cylinder since surface conditions are the same
From the formula Bi = hb/k
k= 34.75 W/m °C

Results:

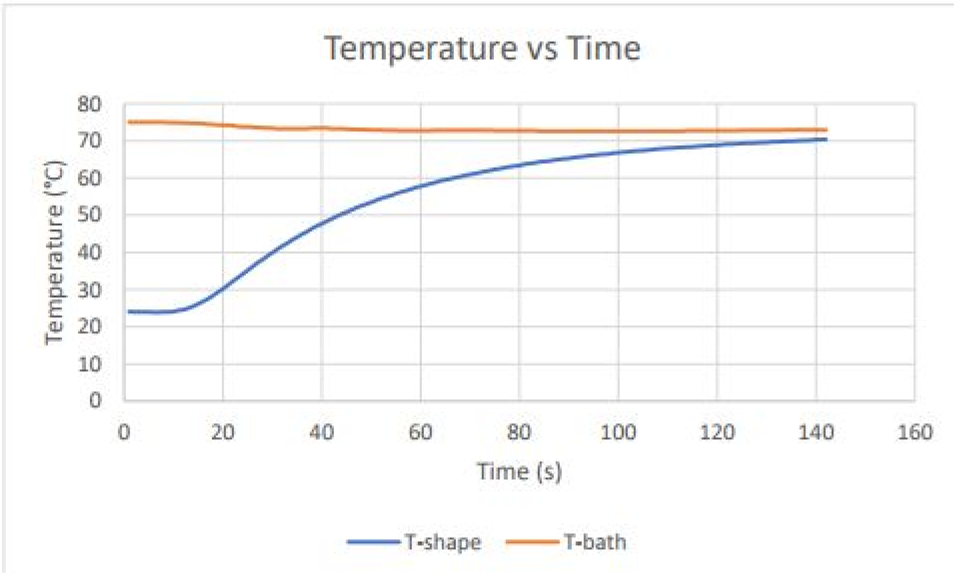
Brass Cylinder:



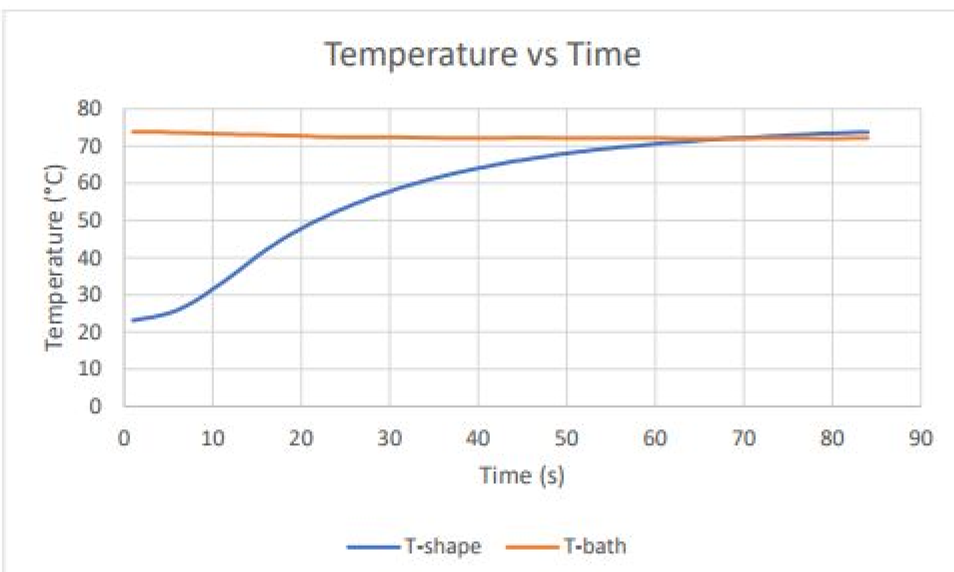
Brass Sphere:



Steel Sphere:



Steel Cylinder:



Sources of Error:

1. There might be error in reading the Heisler's chart.
2. The thermocouple might give wrong readings.
3. The temperature of the surrounding might keep changing hence affecting the conditions of the experiment.