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Lab Report content: ME-341, Heat and Mass Transfer

Experiments: 5 Heat transfer through extend surface

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   Submission date
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Note: Please do not submit incomplete report. Report must be arranged as per the points detailed above before submitting.

Experiment 1(a): Heat transfer through extended surface

1. Objective

I. Measuring the temperature distribution along an extended surface and comparing the result with a theoretical analysis
II. Calculating the heat transfer from an extended surface resulting from combined modes of free convection and radiation heat transfer and comparing the result with the theoretical analysis
III. Determining the thermal conductivity of the rod material

2. Method

By heating one end of a solid cylindrical rod (a pin) and measuring the temperature distribution along the surface of the rod

3. Equipment required

HT10X Heat Transfer Service Unit
HT15 Extended Surface Heat Transfer Accessory
PC with HT10X-90IFD Data Logging Accessory

4. Equipment set-up

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

Locate the HT15 Extended Surface Heat Transfer Accessory alongside the HT10X Heat Transfer Service Unit on a suitable bench. Since heat transfer from the extended surface relies on natural convection and radiation to the surroundings, the accessory must be located away from draughts or source of radiation.

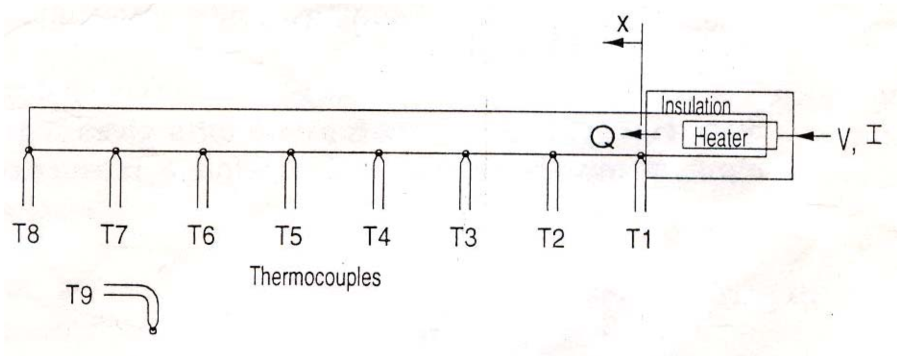

Figure 1. Schematic of experimental set-up

Connect the nine thermocouples on the HT15 to the appropriate sockets on the front of the service unit. Ensure that the labels on the thermocouples leads (T1 – T9) match the labels on the sockets. Set the voltage control potentiometer to minimum (anticlockwise) and selector switch to MANUAL then connect the power lead from the HT15 to the socket marked O/P 3 at the rear of the service unit.

5. Theory/ Background

Part I.

The term extended surface is commonly used to depict an important special case involving heat transfer by conduction within a solid and heat transfer by convection (and/or radiation) from the boundaries of the solid. The direction of heat transfer in extended surfaces from the boundaries is perpendicular to the principal direction of heat transfer in the solid. A temperature gradient exists along each fin or pin due to the combination of the conductivity of the material and heat loss to the surroundings (greater at the root and less at the tip).

The temperature distribution along the fin or pin must be known to determine the heat transfer from the surface to its surroundings. Since radiation and natural convection from the surface occur simultaneously, both of these effects must also be included in the analysis.

By considering the steady-state energy balance for an extended surface of uniform material and cross-sectional area, the following equation can be derived:

$$\frac{d^2\theta(x)}{dx^2} - m^2\theta(x) = 0$$

Where $m^2 = \frac{HP}{k_{brass}A}$; $\theta(x) = T_x - T_a$

Since H, P, K_{brass} and A are constant for a given rod with fixed power input, therefore m^2 must be a constant.

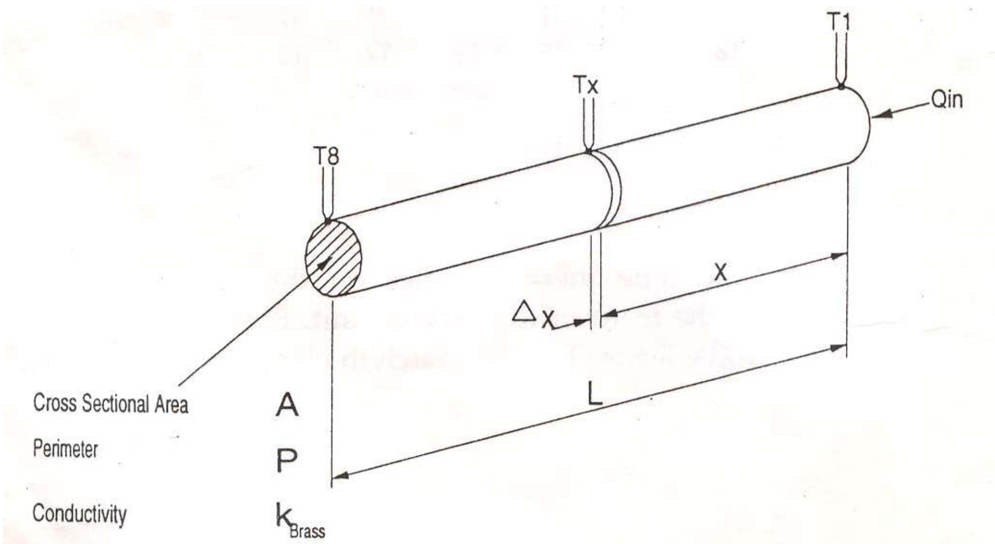

Figure 2. Geometrical description of experimental set-up

Assuming that the diameter of the pin is small in comparison with its length then heat loss at the tip can be assumed to be negligible (at the tip x=L).

$$\frac{d\theta(x)}{dx} = 0 \ at \ x = L$$

Therefore:

$$\frac{\theta(x)}{\theta} = \frac{T_x - T_a}{T1 - T_a} = \frac{\cosh m(L-x)}{\cosh mL}$$

Note that the magnitude of the temperature gradient decreases with increasing x. This trend is a consequence of the reduction in the conduction heat transfer with increasing x due to continuous convection and radiation losses from the fin surface.

Part II.

The total heat loss from the rod can be calculated as follows:

$Q_{tot} = H\, A_s\,(T_s - T_a)$ (W)

Where the heat transfer coefficient (HTC) H is the combined coefficient due to natural convection and radiation, i.e. H = Hc + Hr ($Wm^{-2}K^{-1}$)

and As = ∏ D L (Total area of the extended surface)

where: L = Length of the rod (distance from T1 to T8) = 35 cm

Note: The distance between each thermocouple thermocouple is 5 cm starting from 0.0 cm at T1.

D = Diameter of the rod = 1 cm

T_s = Average surface temperature of the rod (averaged from temperature T1 to T8)

T_a = Ambient air temperature (T9)

The average CHT Hc can be calculated from the formula given below (Fundamentals of heat transfer, Incropera and DeWitt):

$$Nu_c = \frac{Hc\ D}{k} = C\ Ra_D^n$$

Where $Ra_D = \frac{\beta g (T_s - T_a) D^3}{\vartheta \alpha}$, and constants of above equation for natural/free convection on a horizontal circular cylinder are given in the table below.

Ra_D	C	n
$10^{-10} - 10^{-2}$	0.675	0.058
$10^{-2} - 10^{2}$	1.02	0.148
$10^{2} - 10^{-4}$	0.850	0.188
$10^{4} - 10^{7}$	0.480	0.250
$10^{7} - 10^{12}$	0.125	0.333

The average radiative heat transfer coefficient Hr can be calculated as follows:

$$Hr = \sigma \varepsilon F \frac{(T_s^4 - T_a^4)}{(T_s - T_a)}$$

Where:

σ = Stefan Boltzmann constant = 5.67×10^{-8} ($Wm^{-2}K^{-4}$)

ε = Emissivity of the surface ≡ 0.85

F = View factor = 1

Part III.

Then the thermal conductivity of the material is given as:

$$k_{brass} \frac{HP}{m^2 A}$$

Where P = Perimeter of the pin = ∏ D

A = Cross sectional area of the pin = $\pi \frac{D^2}{4}$

6. Procedure

- Switch on the main switch.
- Set the heater voltage to 20 Volts with the help of voltage control potentiometer.
- Monitor temperature T1 regularly and when T1 reaches 80°C, reduce the heater voltage to 9 Volts (the initial higher setting will reduce the time taken for the temperature on the rod to stabilize).
- Allow the temperature to stabilize till steady state reached.
- Record the voltage and current supplied to the heater.
- Record the temperature at each position along the rod (T1 to T8) and ambient air temperature (T9).
- Set the heater voltage to 12 and 16 volts and follow the above steps.

7. Observation Tables

Measurement for 9 V										
Heater Voltage V (V) :			Heater current I (A) :			Heater Power Qin (W) :				
Thermocouple Description	Number	T1	T2	T3	T4	T5	T6	T7	T8	T9
	Location (cm)									-
Temperature T_x (°C)	Time 1:									
	Time 2:									
	Time 3:									

Measurement for 12 V										
Heater Voltage V (V) :			Heater current I (A) :			Heater Power Qin (W) :				
Thermocouple Description	Number	T1	T2	T3	T4	T5	T6	T7	T8	T9
	Location (cm)									-
Temperature T_x (°C)	Time 1:									
	Time 2:									
	Time 3:									

Measurement for 16 V										
Heater Voltage V (V) :			Heater current I (A) :			Heater Power Qin (W) :				
Thermocouple Description	Number	T1	T2	T3	T4	T5	T6	T7	T8	T9
	Location (cm)									-
Temperature T_x (°C)	Time 1:									
	Time 2:									
	Time 3:									

8. Results and calculations

Perform the results and calculation based on the recorded data as per formulas mentioned above.

Part I.

- Find the value of constant 'm' using any iterative technique for thermocouple T1 to T8 (the initial guess for the value of 'm' can be taken 8.0).
- Calculate the theoretical temperature T_x at each point along the rod using average value of 'm'.
- Estimate the cumulative influence of the experimental errors on your calculated values for 'm' and measured values for T1 to T9, x and L.
- Plot measured surface temperature Tx from experiment and theoretical temperature profile (calculated using average value of 'm') against position x (in same plot) along the extended surface clearly showing the data points on the plot.

Part II.

- Compare the measured power Q_{in} to the heater with the calculated heat loss Q_{tot} from the rod.

Part III.

- Compare the measured thermal conductivity with the suggested thermal conductivity for brass rod k_{brass} = 121 $Wm^{-2}K^{-1}$.

9. Discussion on results

Discuss about your findings in the results and explain/ provide reasons for deviations of the experimental results with the theoretical/analytical solution/s.

10. Conclusions

Conclude the experimental results obtained in the experiments.