Heat Transfer
Experiment No. 2

Study of Temperature Distribution Along the Fin Length

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Roll No: ____________

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Aim:

- Measuring the temperature distribution along an extended surface and comparing the result with a theoretical analysis
- 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

Introduction

Extended surfaces or fins are used to increase the heat transfer rate from a surface to a fluid whenever it is not possible to increase the value of the surface heat transfer coefficient or the temperature difference between the surface and the fluid. The use of this is very common and they are fabricated in variety of shapes like circumferential fins around the cylinder of a motor cycle engine and fins attached to condenser tubes of a refrigerator are a few familiar examples. 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:

\[
\frac{d^2 \theta}{dx^2(x)} + m^2 \theta(x) = 0
\]  

where \( m^2 = \frac{hP}{kA_s} \), ‘P’ is perimeter, ‘As’ is surface area and ‘k’ is thermal conductivity of fin. 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).

\[
\frac{d\theta}{dx(x)} = 0 \quad \text{at } x = L \tag{2}
\]

therefore temperature distribution along length of fin can be written as

\[
\frac{\theta(x)}{\theta_0} = \frac{(T_x - T_a)}{(T_0 - T_a)} = \frac{\cosh m(L - x)}{\cosh mL} \tag{3}
\]

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.

Note: The distance between each thermocouple is 25 mm starting from 0.0 cm at \(T_0\).

D = Diameter of the rod = 1 cm

\(T_s\) = Average surface temperature of the rod (averaged from temperature \(T_1 - T_5\))

\(T_a\) = Ambient air temperature (\(T_6\))

The average CHT ‘h’ can be calculated from the formula given below

\[
Nu = \frac{hD}{k} = CRa^n \tag{4}
\]

Ra is ‘Rayleigh Number’ and can be calculated from ??

\[
RaD = \frac{g\beta(T_s - T_a)D^3}{\nu\alpha} \tag{5}
\]

where \(\beta\) is coefficient of volumetric expansion, \(\nu\) is kinematic viscosity of air, \(\alpha\) is thermal diffusivity of air.

Table 1: Nusselt Number correlation constants

<table>
<thead>
<tr>
<th>RaD</th>
<th>C</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10^{-10} - 10^{-2})</td>
<td>0.675</td>
<td>0.058</td>
</tr>
<tr>
<td>(10^{-2} - 10^2)</td>
<td>1.02</td>
<td>0.148</td>
</tr>
<tr>
<td>(10^2 - 10^4)</td>
<td>0.85</td>
<td>0.188</td>
</tr>
<tr>
<td>(10^4 - 10^7)</td>
<td>0.48</td>
<td>0.25</td>
</tr>
<tr>
<td>(10^7 - 10^{12})</td>
<td>0.125</td>
<td>0.333</td>
</tr>
</tbody>
</table>
**Specifications**

- Diameter of the fin: 12.7 mm
- Thermocouples on fins: 5 Nos.
- Ambient temperature: $T_6$
- Fin material: Brass
- Thermocouples on fins: $T_1$ to $T_5$

**Procedure**

1. Switch on the main switch.

2. Set the heater voltage to 40 V with the help of voltage control potentiometer.

3. Monitor temperature $T_1$ regularly and when $T_1$ reaches 100°C, reduce the heater voltage to 10 Volts (the initial higher setting will reduce the time taken for the temperature on the rod to stabilize).

4. Allow the temperature to stabilize till steady state reached.

**Observations**

1. Input Voltage (V)

2. Input Current (I)

3. Ambient Temperature $T_6 = °C$

4. Temperatures at various locations are recorded and are as shown in ??

**Calculations**

- Mean film temperature

\[ T_f = \frac{(T_s + T_a)}{2} \]  

(6)
Table 2: Temperatures along the length of the fin

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>T (°C)</td>
<td>t1</td>
</tr>
<tr>
<td></td>
<td>t2</td>
</tr>
<tr>
<td></td>
<td>t3</td>
</tr>
<tr>
<td></td>
<td>t4</td>
</tr>
<tr>
<td></td>
<td>t5</td>
</tr>
<tr>
<td></td>
<td>t6</td>
</tr>
<tr>
<td></td>
<td>t7</td>
</tr>
<tr>
<td></td>
<td>t8</td>
</tr>
</tbody>
</table>

- Coefficient of volumetric expansion
  \[ \beta = \frac{1}{T_f} \]  \(7\)

- Ra is ‘Rayleigh Number’ and can be calculated from ?? The properties are to be evaluated at \(T_f\). Refer Table ??

- Nusselt number
  Calculate Nusselt number using ?? and selecting the appropriate values from ??.

- Convective heat transfer coefficient ‘h’
  \[ h = \frac{Nu \times k_{air}}{D} \text{ W/m}^2 \text{ K} \]  \(8\)

- Fin parameter ‘m’
  \[ m = \sqrt{\frac{hP}{kA_c}} \]  \(9\)

- Temperature distribution along length Assuming end of fin to be insulated temperature distribution along the length can be calculated from ??
  \[ \frac{\theta(x)}{\theta_0} = \frac{(T_x - T_a)}{(T_0 - T_a)} = \frac{\cosh m(L - x)}{\cosh mL} \]  \(10\)

Calculate the temperature at a distance of 0, 25, 50, 75, 100, from the base of the fin.

- Heat transfer from the fin due to convection and conduction
  \[ Q = \sqrt{hPkA_c} \times (T_1 - T_a) \tanh mL \]  \(11\)
Efficiency of fin (for convective heat transfer only)

\[ \eta = \frac{\tanh mL}{mL} \]  

(12)

Results

1. Temperature at different locations of the fin is
   (a) \( T_1 \)
   (b) \( T_2 \)
   (c) \( T_3 \)
   (d) \( T_4 \)
   (e) \( T_5 \)

2. Heat transfer from fin due to conduction and convection \( (Q_{\text{conv}} \cdots) \) W

3. Heat supplied to the fin = \( 0.95 \times Q_s = V \times I \)

4. Efficiency of fin considering convection only =

Plots

Plot the predicted and actual temperature distribution along the length of fin

Conclusion

Comment on the results of temperature distribution predicted and experimental