Engineering Growth Connection

HEAT TRANSFER FROM A PIN-FIN (HT-108)

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1. OBJECTIVE:

To study the heat transfer in a pin fin.

2. AIM:

2.1 To calculate the heat transfer coefficient experimentally & theoretically for free and forced convection.

2.2 Compare the theoretical temperature distribution with experimentally obtained distribution.

3. INTRODUCTION:

Extended surfaces or fins are used to increase the heat transfer rate from a surface to a fluid wherever 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 a variety of shapes circumferential fins around the cylinder of a motorcycle engine and fins attached to condenser tubes of a refrigerator are few familiar examples.

4. THEORY:

Natural convection phenomenon is due to the temperature difference between the surface and the fluid and is not created by any external agency. Forced convection phenomenon is due to the temperature difference between the surface and the fluid and is created by any external agency, such as blower, pump etc. The experimental heat transfer coefficient is given for both the free and forced convection.

$$h_{Ex} = \frac{Q_a}{A_S \Delta T}$$

Theoretical heat transfer coefficient for free and forced convection, can be calculated by following formulae:

$$h_{Th} = \frac{N_u k}{D}$$

Where h_{Ex}, h_{Th} are experimental and theoretical heat transfer coefficient respectively.

Q_a is amount of heat transfer, A_S is heat transfer area and ΔT is temperature difference. N_u is nusselt no., k is thermal conductivity and D is diameter.

It is obvious that a fin surface stick out from primary heat transfer surface. The temperature difference with surrounding fluid will steadily diminish as one moves out along the fin. The design of the fins therefore requires knowledge of the temperature distribution in the fin. The main object of this experimental set up is to study the temperature distribution in a simple pin fin.

Fin parameter

$$m = \sqrt{\frac{hC}{k_b A}}$$

Fin effectiveness

$$\varepsilon = \frac{\tanh mL}{mL}$$

The temperature profile within a pin fin is given by:

$$\frac{\theta}{\theta_o} = \frac{T - T_f}{T_b - T_F} = \frac{[\cosh m(L-x) + H \sinh m(L-x)]}{[\cosh mL + H \sinh mL]}$$

Where T_f is the free stream temperature of air; T_b is the temperature of fin at its base; T is the temperature within the fin at any x; L is the length of the fin and D is the fin diameter, m is the fin parameter, $\frac{\theta}{\theta_o}$ is temperature distribution profile.

5. DESCRIPTION:

It consists of pin type fin fitted in a duct. A blower is provided on one side of duct. Air flow rates can be varied by given flow control valve. A heater is provided to heats one end of fin and heat flows to another end. Heat input to the heater is given through variac. Digital voltmeter and digital ammeter are provided for heat measurement. Digital temperature indicator measures temperature distribution along the fin. Airflow is measured with the help of orifice meter and the water manometer fitted on the board

6. UTILITIES REQUIRED:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Floor Area Required: 1.5 m x 1 m.

7. EXPERIMENTAL PROCEDURE:

7.1 STARTING PROCEDURE (FOR FREE CONVECTION):

7.1.1 Ensure that mains ON/OFF switch given on the panel is at OFF position & dimmer stat is at zero position.

7.1.2 Connect electric supply to the set up.

7.1.3 Switch ON the mains ON / OFF switch.

7.1.4 Set the heater input by the dimmer stat, voltmeter in the range 40 to 100 V.

7.1.5 After 1.5 hrs. note down the reading of voltmeter, ampere meter and temperature sensors at every 10 minutes interval (till observing change in consecutive readings of temperatures ± 0.2 °C).

7.2 CLOSING PROCEDURE (FOR FREE CONVECTION):

7.2.1 When experiment is over set the dimmer stat to zero position.

7.2.2 Switch OFF the mains ON/OFF switch.

7.2.3 Switch OFF electric supply to the set up.

7.3 STARTING PROCEDURE (FOR FORCED CONVECTION):

7.3.1 Ensure that mains ON/OFF switch given on the panel is at OFF position & dimmer stat is at zero position.

7.3.2 Connect electric supply to the set up.

7.3.3 Fill water in manometer up to half of the scale, by opening PU pipe connection from the air flow pipe and connect the pipe back to its position after doing so.

7.3.4 Switch ON the mains ON / OFF switch.

7.3.5 Set the heater input by the dimmer stat, voltmeter in the range 40 to 100 V.

7.3.6 Switch ON the blower.

7.3.7 Set the flow of air by operating the valve V_1.

7.3.8 After 0.5 hrs. note down the reading of voltmeter, ampere meter, manometer and temperature sensors at every 10 minutes interval (till observing change in consecutive readings of temperatures ± 0.2 °C).

7.4 Closing Procedure (For Forced Convection):

7.4.1 When experiment is over set the dimmer stat to zero position.

7.4.2 Switch OFF the blower.

7.4.3 Switch OFF the mains ON/OFF switch.

7.4.4 Switch OFF electric supply to the set up.

8. Observation & Calculation:

8.1 Data:

Thermal conductivity of fin material k_f	= 204.2 W/m°C
Density of manometric fluid ρ_w	= 1000 kg/m^3
Density of air ρ_a	= 1.093 kg/m^3
Acceleration due to gravity g	= 9.81 m/sec^2
Diameter of orifice d_o	= 0.026 m
Diameter of pipe d_P	= 0.052 m
Diameter of fin D	= 0.020 m
Length of fin L	= 0.170 m
Orifice coefficient C_o	= 0. 64
Distance of first temperature sensors (T_1) from the one end point X_1	= 0.045 m
Distance of second temperature sensors (T_2) from the one end point X_2	= 0.07m
Distance of third temperature sensors (T_3) from the one end point X_3	= 0.095 m
Distance of fourth temperature sensors (T_4) from the one end point X_4	= 0.12 m
Distance of fifth temperature sensors (T_5) from the one end point X_5	= 0.145 m
Distance between temperature sensors (T_6) and temperature sensors (T_7) X_o	= 0.01m

8.2.a Observation Table (For Free Convection):

Sr.No.	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)

8.2.b Observation Table (For Forced Convection):

Sr. No.	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)	h_1 (cm)	h_2 (cm)

8.3 Calculations:

Free Convection: Experimentally

$$T_m = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} \text{ (°C)}$$

$$T_f = T_8 \text{ (°C)}$$

$$\Delta T = T_m - T_f \text{ (°C)}$$

$$A = \frac{\pi}{4} D^2 \text{ (m}^2\text{)}$$

$$Q = \frac{k_f \times A \times (T_6 - T_7)}{X_o} \text{ (W)}$$

$$A_S = \pi D L \text{ (m}^2\text{)}$$

$$h_{Ex} = \frac{Q}{A_S \Delta T} \text{ (W/m}^2\text{ °C)}$$

Free Convection: Theoretically

$$T_m = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} \text{ (°C)}$$

$$T_f = T_8\,(^{\circ}\mathrm{C})$$

$$\Delta T_1 = (T_m + 273.15) - (T_f + 273.15)\ (\mathrm{K})$$

$$T_{mf} = \frac{(T_m + 273.15) + (T_f + 273.15)}{2}\ (\mathrm{K})$$

Find the properties of air (β, k, ν, P_r) at temperature T_{mf} from data book.

$$\beta = \frac{1}{T_{mf}}\ (\mathrm{K}^{-1})$$

$k =$ ______ (W/m°C)

$\nu =$ ______ (m^2/sec)

$P_r =$ ______

$$G_r = \frac{g\,\beta\,D^3\,\Delta T_1}{\nu^2}$$

$$N_u = 0.53(G_r \times P_r)^{1/4}$$

$$h_{Th} = \frac{N_u k}{D}\ (\mathrm{W/m^2\,^{\circ}C})$$

$$C = \pi D\ (\mathrm{m})$$

$$A = \frac{\pi}{4} D^2\ (\mathrm{m^2})$$

$$m = \sqrt{\frac{h_{Th} C}{k_f A}}\ (\mathrm{m})$$

$$\varepsilon = \frac{\tanh mL}{mL}$$

$$H = \frac{h_{Th}}{k_f m}\ (\mathrm{m})$$

$$T_b = T_1\ (^{\circ}\mathrm{C})$$

$$T_{Th1} = \left[\frac{[\cosh m(L - X_1) + H \sinh m(L - X_1)]}{[\cosh mL + H \sinh mL]} (T_b - T_f) \right] + T_f\,(^{\circ}\mathrm{C}) \qquad (X = X_1)$$

$$T_{Th2}=\left[\frac{[\cosh m(L-X_2)+H\sinh m(L-X_2)]}{[\cosh mL+H\sinh mL]}(T_b-T_f)\right]+T_f\,(^{\circ}C) \qquad (X = X_2)$$

$$T_{Th3}=\left[\frac{[\cosh m(L-X_3)+H\sinh m(L-X_3)]}{[\cosh mL+H\sinh mL]}(T_b-T_f)\right]+T_f\,(^{\circ}C) \qquad (X = X_3)$$

$$T_{Th4}=\left[\frac{[\cosh m(L-X_4)+H\sinh m(L-X_4)]}{[\cosh mL+H\sinh mL]}(T_b-T_f)\right]+T_f\,(^{\circ}C) \qquad (X = X_4)$$

$$T_{Th5}=\left[\frac{[\cosh m(L-X_5)+H\sinh m(L-X_5)]}{[\cosh mL+H\sinh mL]}(T_b-T_f)\right]+T_f\,(^{\circ}C) \qquad (X = X_5)$$

$$T_{Ex1}=T_1\ (^{\circ}C)$$

$$T_{Ex2}=T_2\ (^{\circ}C)$$

$$T_{Ex3}=T_3\ (^{\circ}C)$$

$$T_{Ex4}=T_4\ (^{\circ}C)$$

$$T_{Ex5}=T_5\ (^{\circ}C)$$

CALCULATION TABLE(FOR FREE CONVECTION):

S.No.	X (m)	T_{Th} (°C)	T_{Ex} (°C)

Forced Convection: Experimentally

$$T_m=\frac{T_1+T_2+T_3+T_4+T_5}{5}\ (^{\circ}C)$$

$$T_f=T_8\,(^{\circ}C)$$

$$\Delta T=T_m-T_f\ (^{\circ}C)$$

$$A=\frac{\pi}{4}D^2\ (m^2)$$

$$Q = \frac{k_f \times A \times (T_6 - T_7)}{X_o} \text{ (W)}$$

$$A_S = \pi D L \text{ (m}^2\text{)}$$

$$h_{Ex} = \frac{Q}{A_S \Delta T} \text{ (W/m}^2\,^oC)$$

Forced Convection: Theoretically

$$T_m = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} \text{ (}^oC)$$

$$T_f = T_8 \text{ (}^oC)$$

$$T_{mf} = \frac{(T_m + 273.15) + (T_f + 273.15)}{2} \text{ (K)}$$

Find the properties of air (ρ_{a1}, k, μ) at temperature T_{mf} from data book.

$k =$ _____ (W/m°C)

$\mu =$ _____ (kg/m-sec)

$\rho_{a1} =$ _____ (kg/m³)

$$a_p = \frac{\pi}{4} d_p^2 \text{ (m}^2\text{)}$$

$$a_o = \frac{\pi}{4} d_o^2 \text{ (m}^2\text{)}$$

$$\Delta H = \frac{h_1 - h_2}{100}\left(\frac{\rho_w}{\rho_a} - 1\right) \text{ (m)}$$

$$Q_a = \frac{C_o a_p a_o \sqrt{2g\Delta H}}{\sqrt{a_p^2 - a_o^2}} \text{ (m}^3\text{/sec)}$$

$$V_o = \frac{Q_a}{a_p} \text{ (m/sec)}$$

$$V_1 = \frac{V_o \times T_{mf}}{[T_f + 273.15]} \text{ (m/sec)}$$

$$R_e = \frac{DV_1\rho_{a1}}{\mu}$$

$$N_u = 0.615(R_e)^{0.466}$$

$$h_{Th} = \frac{N_u k}{D} \text{ (W/m}^2\ {}^{o}\text{C)}$$

$$A = \frac{\pi}{4}D^2 \text{ (m}^2\text{)}$$

$$C = \pi D \text{ (m)}$$

$$m = \sqrt{\frac{h_{Th}C}{k_f A}} \text{ (m)}$$

$$\varepsilon = \frac{\tanh mL}{mL}$$

$$H = \frac{h_{Th}}{k_f m} \text{ (m)}$$

$$T_b = T_1$$

$$T_{Th1} = \left[\frac{[\cosh m(L - X_1) + H\sinh m(L - X_1)]}{[\cosh mL + H\sinh mL]}(T_b - T_f)\right] + T_f \,({}^{o}\text{C}) \qquad (X = X_1)$$

$$T_{Th2} = \left[\frac{[\cosh m(L - X_2) + H\sinh m(L - X_2)]}{[\cosh mL + H\sinh mL]}(T_b - T_f)\right] + T_f \,({}^{o}\text{C}) \qquad (X = X_2)$$

$$T_{Th3} = \left[\frac{[\cosh m(L - X_3) + H\sinh m(L - X_3)]}{[\cosh mL + H\sinh mL]}(T_b - T_f)\right] + T_f \,({}^{o}\text{C}) \qquad (X = X_3)$$

$$T_{Th4} = \left[\frac{[\cosh m(L - X_4) + H\sinh m(L - X_4)]}{[\cosh mL + H\sinh mL]}(T_b - T_f)\right] + T_f \,({}^{o}\text{C}) \qquad (X = X_4)$$

$$T_{Th5} = \left[\frac{[\cosh m(L - X_5) + H\sinh m(L - X_5)]}{[\cosh mL + H\sinh mL]}(T_b - T_f)\right] + T_f \,({}^{o}\text{C}) \qquad (X = X_5)$$

$$T_{Ex1} = T_1 \ ({}^{o}\text{C})$$

$$T_{Ex2} = T_2 \ ({}^{o}\text{C})$$

$$T_{Ex3} = T_3 \ (^{\circ}C)$$

$$T_{Ex4} = T_4 \ (^{\circ}C)$$

$$T_{Ex5} = T_5 \ (^{\circ}C)$$

CALCULATION TABLE(FOR FORCED CONVECTION):

S.No.	X (m)	T_{Th} (°C)	T_{Ex} (°C)

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A	Cross sectional area of fin	m^2	Calculated
a_o	Area of orifice	m^2	Calculated
a_p	Area of pipe	m^2	Calculated
A_S	Surface heat transfer area	m^2	Calculated
C	Perimeter	m	Calculated
C_o	Orifice coefficient	*	Given
D	Fin diameter	m	Given
d_o	Orifice diameter	m	Given
d_p	Diameter of pipe	m	Given
g	Acceleration due to gravity	m/sec^2	Given
G_r	Grashoff's number	*	Calculated
H	Parameter	m	Calculated
$h_1 - h_2$	Manometer reading	cm	Measured
h_{Ex}	Experimental heat transfer coefficient	$W/m^2 \, ^{\circ}C$	Calculated
h_{Th}	Theoretical heat transfer coefficient	$W/m^2 \, ^{\circ}C$	Calculated
k	Thermal conductivity of air at temperature T_{mf}	$W/m \, ^{\circ}C$	Calculated
k_f	Thermal conductivity of fin material	$W/m \, ^{\circ}C$	Given
L	Fin length	m	Given
m	Fin parameter	m	Calculated
N_u	Nusselt number	*	Calculated

P_r	Prandtl number	*	Calculated
Q	Amount of heat transfer	W	Calculated
Q_a	Volumetric flow rate of air through the pipe	m^3/sec	Calculated
R_e	Reynolds number	*	Calculated
T_1- T_5	Temperatures of the pin fin test section surface	^oC	Measured
T_6- T_7	Temperature at center of pin fin at X_o distance	^oC	Measured
T_8	Temperature of the suction duct surface	^oC	Measured
T_b	Fin base temperature	^oC	Calculated
T_{Ex}	Experimental temperature within the fin	^oC	Calculated
T_{Ex1}	Experimental temperature at the first sensor	^oC	Calculated
T_{Ex2}	Experimental temperature at the second sensor	^oC	Calculated
T_{Ex3}	Experimental temperature at the third sensor	^oC	Calculated
T_{Ex4}	Experimental temperature at the fourth sensor	^oC	Calculated
T_{Ex5}	Experimental temperature at the fifth sensor	^oC	Calculated
T_f	Fin temperature at any point	^oC	Calculated
T_m	Fin mean temperature	^oC	Calculated
T_{mf}	Fluid mean temp	^oC	Calculated
T_{Th}	Theoretical temperature within the fin	^oC	Calculated
T_{Th1}	Theoretical temperature at the first sensor	^oC	Calculated
T_{Th2}	Theoretical temperature at the second sensor	^oC	Calculated
T_{Th3}	Theoretical temperature at the third sensor	^oC	Calculated
T_{Th4}	Theoretical temperature at the fourth sensor	^oC	Calculated
T_{Th5}	Theoretical temperature at the fifth sensor	^oC	Calculated
V_o	Velocity of air	m/sec	Calculated
V_1	Velocity of air at temperature T_{mf}	m/sec	Calculated
X	Distance of the sensors from one end of the fin	m	Given
X_1	Distance of first temperature sensors (T_1) from the one end point	m	Given
X_2	Distance of second temperature sensors (T_2) from the one end point	m	Given
X_3	Distance of third temperature sensors (T_3) from the one end point	m	Given
X_4	Distance of fourth temperature sensors (T_4) from the one end point	m	Given
X_5	Distance of fifth temperature sensors (T_5) from the	m	Given

	one end point		
X_o	Distance between temperature sensors (T_6) and temperature sensors (T_7)	m	Given
ρ_a	Density of air	kg/m^3	Given
ρ_{a1}	Density of air at temperature (T_{mf})	kg/m^3	Calculated
ρ_w	Density of manometeric fluid	kg/m^3	Given
β	Coefficient of thermal expansion of fluid	K^{-1}	Calculated
ε	Fin effectiveness	*	Calculated
μ	Dynamic viscosity of air	kg/m-sec	Calculated
ν	Kinematic viscosity of air	m^2/sec	Calculated
ΔH	Head loss	m	Calculated
ΔT	Temperature difference on fin surface	^oC	Calculated
ΔT_1	Temperature difference on fin surface	K	Calculated

* Symbols represent unitless quantity

10. Precaution & Maintenance Instructions:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Operate selector switch of temperature indicator gently.

10.4 Always keep the apparatus free from dust.

11. Troubleshooting:

11.1 If electric panel is not showing the input on the mains light. Check the main supply.

12. References:

12.1 Holman, J.P (2008). *Heat Transfer*. 9th Ed. ND: McGraw Hill. pp 39-46.

12.2 Kumar, D.S (2008). *Heat & Mass Transfer*. 7th Ed. ND: S.K Kataria & Sons. pp 233-239, 253-256, 260-262.

13. Block Diagram: