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COMPARATIVE STUDY OF TEMPERATURE DISTRIBUTION ALONG DIFFERENT TYPES OF FINS MOUNTED ON HORIZONTAL SURFACE

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ABSTRACT

This paper is presented on comparative study of temperature distribution along different types of fins mounted on horizontal surface. In the present analysis, the fins that are of different cross sections and of same material (M.S) are considered. The knowledge of efficiency and effectiveness of the fin are necessary for proper design of fins. The main objective of our analysis is to determine the most effective cross section. The efficiency and effectiveness of various cross sections are determined experimentally by cross sectional area and volume as constant for each cross section. Observed values of temperatures are lesser than calculated values as radiation effects have not been taken into considerations. The temperature along the fin reduces as there is subsequent heat transfer by fins by conduction and convection. As rectangular fin surface area is more than triangular and circular fins, therefore heat transfer coefficient and heat transfer is more in rectangular fins.

Keywords: Convection, Temperature Distribution, Triangular Fin, Circular Fin, Rectangular Fin.

I. INTRODUCTION

Heat transfer is the transition of thermal energy from a hotter mass to a cooler mass. When an object is at a different temperature than its surroundings or another object, transfer of thermal energy, also known as heat flow, or heat exchange, occurs in such a way that the body and the surroundings reach thermal equilibrium; this means that they are at the same temperature. Heat transfer always occurs from a higher-temperature object to a cooler-temperature one as described by the second law of thermodynamics or the Clausius statement. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed.

A great number of experimental and analytical work has been carried out on this problem since Elenbaas [1], first introduced the problem of natural convection between parallel plates. Starner and Mcmanus [2] determined average heat transfer coefficients for vertical, Inclined and horizontal fin arrays. Harahap and McManus [3] extended the work of Starner and McManus with an objective of more fully investigating the horizontal fin arrays. Baskaya et al. [4] carried out a numerical study of natural convection heat transfer from horizontal rectangular fin arrays. They have used the Boussinesq approximation in the parametric study of natural convection heat transfer from horizontal fin arrays. Gray and Giorgini [5] showed that the error due to using

Boussinesq approximation is less than 10% for air as long as ΔT < 28.6°C. An analytical study was made to investigate the effects of buoyancy on laminar mixed convection in a shrouded fin array by Acharya and Patankar [6]. They concluded that the buoyancy forces significantly affect the heat transfer characteristics of laminar mixed convection. Taji S G et al. [7-9] investigated performance assessment of horizontal rectangular fin array heat sink under natural and mixed convection. Maughan and Incropera [10] investigated experimental results on the mixed convection heat transfer with longitudinal fins in a horizontal parallel plate channel.

It is seen that very little information available in the literature about the influence of flow pattern on heat transfer under natural convection. Earlier Investigators studied the flow pattern by interferometric technique, Schlieren shadowgraph technique, simple smoke technique. To achieve maximum heat transfer for a constant heat flux condition, the selection of fin spacing must be optimized. Thus, the purpose of present article is to investigate the problem experimental and theoretical comparative study of temperature distribution along different types of fins mounted on horizontal surface.

1.1 Convection

Convection is the transfer of thermal energy by the movement of molecules from one part of the material to another (Fig. 1.1). As the fluid motion increases, so does the convective heat transfer? The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid. When the fluid motion is caused by buoyancy forces that result from the density variations due to variations of temperature in the fluid.

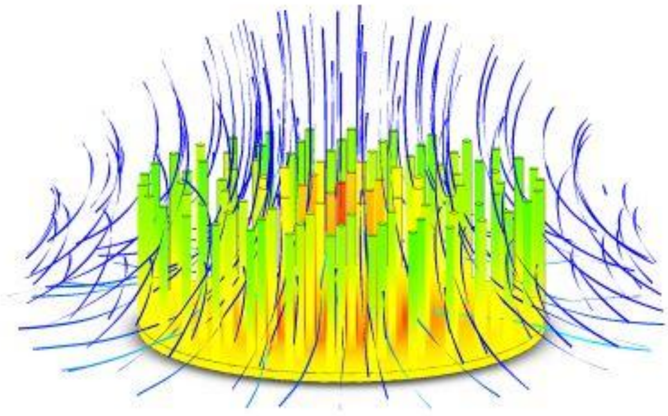

Fig 1.1: Air Flow Direction for Natural Convection

Whenever the available surface is found inadequate to transfer the required quantity of heat with the available temp drop & convective heat transfer coefficient, extended surface or fins are used. This practice is invariable found necessary in heat transfer between surface & gas as convective heat transfer coefficient is rather low in this situation.

The following assumptions are made for analysis of heat flow through the fins:

1. Steady state heat conduction.
2. No heat generation within the fin.
3. Uniform heat transfer coefficient (h) over the entire surface of the fin.
4. Homogeneous & isotropic fin materials.
5. Negligible contact thermal resistance.

6. Heat conduction in one dimension.
7. Negligible radiation.

The fin surface widely used in economizer for steam power plant, conductor for steam and hot water heating system, radiators of automobile, air cooled engine cylinder head, cooling coil and condenser coil in refrigerator & air conditioners, small capacity compressor, electric motor bodies, transfers and electronics equipments.

Mild steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.29% carbon, therefore it is neither brittle nor ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm^3 (0.284 lb/in^3) and the Young's modulus is 210,000 MPa (30,000,000 psi).

1.2 Theory

A = Cross sectional area of the fin.

p = circumference of the fin.

L = length of fin

T_o = temperature of fin at beginning

The heat is conducted along the rod & also loss to surrounding fluid by convection.

Let,

h = heat transfer coefficient (W/m^2 K)

K = Thermal conductivity of the fin material. (watt/m K)

Applying 1st law of thermodynamics to a controlled volume along the length of fin at X the resulting equation of heat balance appears as

$$\frac{d^2\Phi}{dx^2} - \frac{hp}{KA}\Phi = 0 \qquad \text{.......(1)}$$

General sol^n of (1) is

$$\emptyset = c_1 e^{mx} + c_2 e^{-mx}$$

Where $\mathbf{m} = \sqrt[2]{\frac{hp}{KA}}$

For circular fin and rectangular fin

$$\frac{T-Tf}{T0-Tf} = \frac{\cosh(m(L-x)) + \frac{h}{mK}\sinh(m(L-x))}{\cosh(ml) + \frac{h}{mK}\sinh(mL)}$$

For triangular fin

$$\frac{T-Tf}{T0-Tf} = \frac{Io(2B\sqrt{x})}{Io(2B\sqrt{l})}$$

I_o is modified zero order Bessel function.

This is the equations for the temp. distribution along the length of fin. It seen from equations that for a fins of given geometry. Temp. at any point can be calculated on knowing the values of T_0, T_f & h.

Temperature T_0 & T_f will be known for given situation & value of h depends on whether heat is lost to the surrounding by free convection or forced convection & can be obtained by using correlations as given below.

For free convection,

Nu =1.1 (Gr Pr)$^{1/6}$ $\quad 10^{-1} <$ **Gr Pr** $< 10^{4}$

Nu =0.53(Gr Pr)$^{1/4}$ $\quad 10^{4} <$ **Gr Pr** $< 10^{9}$

Nu =0.13(Gr Pr)$^{1/3}$ $\quad 10^{9} <$ **Gr Pr** $< 10^{12}$

Where

Gr $= \frac{g*\beta*L^3\Delta T}{\vartheta^2}$ Grashof Number

Nu $= \frac{hL}{Kair}$ Nusselt Number

All properties are to be evaluated at the mean film temperature. The mean film temperature is the arithmetic avg. of avg.fin temp.& air temp.

Nomenclature

ϑ	Kinematic viscosity (m^2/s)
K_{air}	Thermal conductivity of air (W /m K)
g	Acceleration due to gravity(9.81 m/s^2)
T_m	Avg. fin temperature $= \frac{T0+T1+T2+T3+T4}{5}$

$$\Delta T = Tm - Tf$$

$$\mathbf{T_{mf}} = \frac{Tm+Tf}{2}$$

$$\beta = \frac{1}{Tmf+273}$$

The rate of heat transfer from the fin can be calculated as

$$q = \sqrt{hpkA}\ (T0 - Tf)\frac{\tanh(mL)+\frac{h}{mk}}{1+\frac{h}{mk}\tanh mL}$$ (For circular fin & rectangular fin)

$$q = 2W\sqrt{hk\frac{b}{2}}(T0 - Tf)\frac{I1(2B\sqrt{l})}{Io(2B\sqrt{l})}$$ (For triangular fin)

Effectiveness of fin can be calculated as:

$$\varepsilon = \frac{q}{hA(T0 - Tf)}$$

Equation for intermediate temperature for rectangular and cylindrical fin

$$\frac{\theta}{\theta_o} = \frac{t - tf}{t_0 - tf} = \frac{\cosh(m(l-x)) + \frac{h}{Km}[\sinh(m(l-x))]}{\cosh(ml) + \frac{h}{Km}[\sinh(ml)]}$$

Equation for intermediate temperature for triangular fin

$$\frac{\theta}{\theta_o} = \frac{t - tf}{t_0 - tf} = \frac{I_0\,(2B\sqrt{x})}{I_0\,(2B\sqrt{l})}$$

II. EXPERIMENTATION

2.1 Test Apparatus

The test apparatus consist of three types of fins namely rectangular, triangular circular and are made up of mild steel these fins are brazed to a mild steel plate of size 5×50×200 mm.

The apparatus is divided into four sections

2.1.1 Fin and Heater Assembly

Heater coil is made up of nichrome wire having resistance of 96 ohm/m length the heater coil is bolted to the mild steel plate carrying the fin equally spaced at a distance of 50 mm from each other. The fins are brazed to the mild steel plate by means of brass brazing rods. Each type of fin is provided with four thermocouples at a distance of 20mm along its length. Two thermocouples are attached on the plate in order to measure average surface temperature. One thermocouple is exposed to atmospheric air to measure ambient air temperature. Thermocouples are used for the measurement of the temperature are made up of the copper constantan having the range of -200deg to 350 deg centigrade.

2.1.2 Power Section

This consists of voltage regulator (voltage rider) to control the power supplied to heater. Ammeter and voltmeter are used for measurement of supplied current and voltage. A main DPST (Double pole single throw) and SPST (single pole single throw) Switch is used to put on or off the power supply.

2.1.3 Temperature Section

In this section temperature indicator for the indication of the temperature is used. The range of the indicator is 0 – 500 deg. centigrade. Multipoint channel selector switches are provided to measure temperature across each thermocouple junction. Two way switches is used for the thermocouple group selection. Another switch is used to put power on or off to the indicator. Thermocouples have junction at one end and this end is secured to the respective location on the fin.

2.1.4 Main frame

The main frame is fabricated out of angle section 25×25×4inch and plywood of 6mm thick is used on all sides to fit all accessories on the box. Type T (copper–constantan) thermocouples are suited for measurements in the −200 to 350 °C range. Often used as a differential measurement since only copper wire touches the probes. Since both conductors are non-magnetic, there is no Curie point and thus no abrupt change in characteristics. Type T thermocouples have a sensitivity of about 43 µV/°C.

2.1.5 Specifications

Fins

1) Circular 8 × 100 mm.
2) Rectangular 8 × 12 × 100 mm.
3) Triangular 8 × 12 × 100 mm.
4) Base plate 5 × 50 ×200 mm.
5) Box 550 × 550 × 150 mm

Heating element

1) Wire gauge 46
2) Resistance/meter 96
3) Length of wire 3 m

1) Distance bet two turns 3 mm
2) Insulating material mica

Table 1: Technical Specifications of measuring Instruments

Measuring Device	Range	least count
Ammeter	0-2A	0.08A
Voltmeter	0-500V	20V
Temperature indicator	1℃	0-700

2.2 Procedure

1. Start heating the fin by switching on the heater and adjust the voltage regulator as per requirement.
2. Note down thermocouple readings 1 to 15 when steady state is reached. Reading number 13 is the ambient temperature.
3. Repeat the same experiment with different voltages.

Precautions to be taken while conducting the experiment

1. See the voltage regulator is at zero position before switching on the heater.
2. Before taking the thermocouple readings temperature indicator should be kept off preferably.
3. Operate the change over switch of temperature indicator gently.
4. Be sure the steady state is reached before taking the final readings.

2.3 Sample Observation Table

Case -1

Voltage (V):-140 V

Current (I):-0.4 A

Power Supplied (W=V×I) = 56 W

Base Temperature $(T_{14}+T_{15})/2=T$ = 133.5℃

Table 2 (a): Sample observations for Triangular fin

Type of fin	Fin temperatures (°C)				T_m (°C)	T_{mf} (°C)	h (w/m^2-°K)	q (W)	ε
	T_1	T_2	T_3	T_4					
Triangular	94	82	65	54	85.7	58.85	6.418	1.096	17.67

Table 2 (b): Sample observations for Rectangular fin

Type of fin	Fin temperatures (°C)				T_m (°C)	T_{mf} (°C)	h (w/m^2-°K)	q (W)	ε
	T_5	T_6	T_7	T_8					
Rectangular	90	82	70	54	85.9	58.95	6.421	2.063	32.95

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Table 2 (c): Sample observations for Cylindrical fin

Type of fin	Fin temperatures (°C)				T_m (°C)	T_{mf} (°C)	h (w/m^2-°K)	q (W)	ε
	T_9	T_{10}	T_{11}	T_{12}					
Cylindrical	93	72	60	57	83.1	57.5	6.347	1.23	37.98

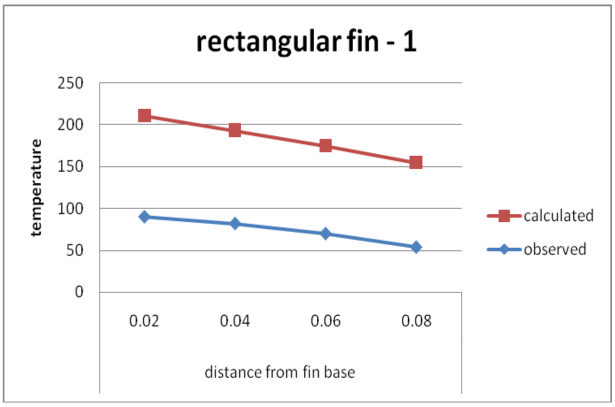
III. RESULTS AND DISCUSSIONS

Table 3: Sample Results for Triangular, Rectangular and Cylindrical fin

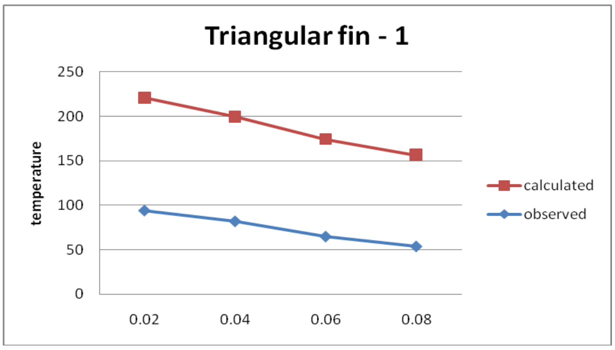
Sr. No.	Type of Fins	T_{mf} (°C)	Grashoff's Number	Prandtle Number	Nusselt Number	h (W/m^2K)	q (W)	ε
01	Triangular	58.75	4.41×10^6	0.696	22.18	6.418	1.096	17.53
02	Rectangular	60	4.41×10^6	0.696	22.19	6.421	2.063	32.95
03	Cylindrical	57.5	4.21×10^6	0.696	21.92	6.347	1.23	37.98

Table 4 : Temperature Distribution along fins

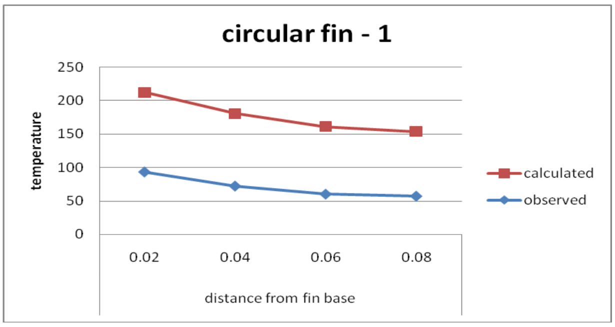
Types of Fins	Temperature (°C)	T_1	T_2	T_3	T_4
Triangular	Actual	94	82	65	54
	Theoretical	126.55	117.07	109.19	102.45
Cylindrical	Actual	93	72	60	57
	Theoretical	119.21	108.63	101.31	96.93
Rectangular	Actual	90	82	70	54
	Theoretical	120.9	111.4	104.9	100.95



(a)



(b)



(c)

Fig. 2 (a, b, c): Temperature distribution (Calculated and observed) along Length for different types of fins

1) As seen from the graphs calculated temperatures are higher than observed temperature in all types of fins
2) It is observed that temperature along the length of fins decreases from base towards tip in all three cases.
3) The average heat transfer coefficient is almost same for triangular and rectangular fin and more than circular fin.
4) Heat Transfer rate is more in case of rectangular fins than other types of fins
5) Effectiveness of Circular fins is found to be maximum.

IV. CONCLUSIONS

1. Observed values of temperatures are lesser than calculated values as radiation effects have not been taken into considerations.
2. The temperature along the fin reduces as there is subsequent heat transfer by fins by conduction and convection.
3. As rectangular fin surface area is more than triangular and circular fins, therefore heat transfer coefficient and heat transfer is more in rectangular fins.

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