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Experimental investigation of heat transfer by using pin fin of different materials in forced convection

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Abstract

The aim of the present study is to improve the heat transfer characteristics and to investigate the performance of fin efficiency by using fins of different materials in pin fin apparatus. Here the system follows forced convection as the mode of heat transfer and it is the principle used in it. This procedure followed for the fin of different materials, Reynolds number, Nusselt number are calculated and heat transfer coefficient and fin efficiencies are analysed.

Keywords: thermal conductivity, heat transfer coefficient, and reynolds number

1. Introduction

The heat conducted through solids, walls or boundaries has to be continuously dissipated to the surroundings or environment to maintain the system in steady state conduction. In many engineering applications large quantities of heat have to be dissipated from small areas. Heat transfer by convection between a surface and the fluid surroundings it can be increased by attaching to the surface thin strips of metals called fins. The fins increase the effective area of the surface thereby increasing the heat transfer by convection. The fins are also referred as "extended surfaces". Fins are manufactured in different geometries, depending up on the practical applications Most of the engineering problems require high performance heat transfer components with progressively less weights, volumes, accommodating shapes and costs. Extended surfaces (fins) are one of the heat exchanging devices that are employed extensively to increase heat transfer rates. The rate of heat transfer depends on the surface area of the fin. It increases the contact surface area, for example a heat sink with fins. The heat transferred through the fins provides the problem of determination of heat flow through a fin requires the knowledge of temperature distribution through it. This can be obtained by regarding the fin as a metallic plate connected at its base to a heated wall and transferring heat to a fluid by convection. The heat flow through the fin is by conduction. Thus the temperature distribution in a fin will depend upon the properties of both the fin material and the surrounding fluid. In this section, we will analyze certain basic forms of fins, with respect to heat rate, temperature distribution and effectiveness. The experiment is conduct to investigate the effect of the pressure loss and heat transfer characteristics in pin-fin channel, where dimples are located on the pin-fins. An aluminium fin of rectangular cross section with various dimple depth is fitted in a long rectangular duct. In the present work aluminium & brass plate were used as a test surface. Variation of Nusselt Number with Reynolds Number is investigated, with various parameter combinations. The experimental results gives heat transfer coefficient & efficiency of aluminium fin is greater than brass fin.

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Pin fin apparatus efficiency is being improved by adding different shape of fins and changing the geometric dimension of fin but they didn't change any materials, in these thesis various material such as copper, aluminium, brass is analyzed, of those material copper had higher thermal efficiency as well as higher heat transfer rate.

2. Experimental Setup

A brass fin of circular cross section in fitted across a long rectangular duct. The other end of the duct is connected to the suction side of a blower and the air flows past the fin perpendicular to the axis. One end of the fin projects outside the duct and is heated by a heater. Temperature at five points along the length of the fin. The air flow rate is measured by an orifice meter fitted on the delivery side of the blower. The apparatus consists of a pin-fin placed inside an open duct the other end of the duct to connected to suction side of a blower the delivery side of a blower is taken on through on orifice meter to atmosphere, the air flow rate can be varied by the blower speed regular and can be measured on the u tube manometer connected to one end of the pin fin. The panel of the apparatus consists of voltmeter, ammeter and digital temperature indicator, heat regulator in it.

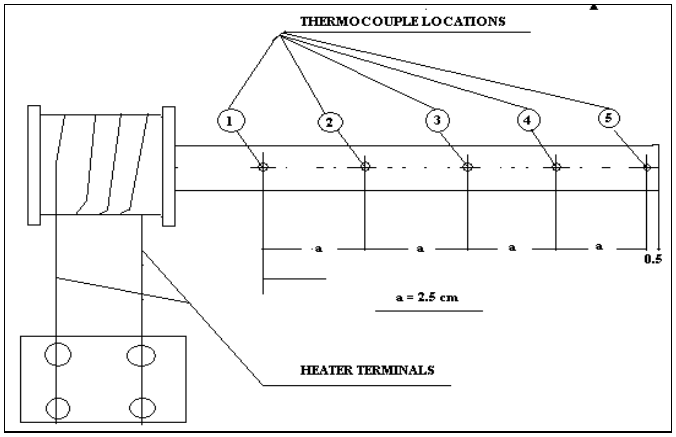

Fig 1: Schematic Diagram of Pin Fin Apparatus

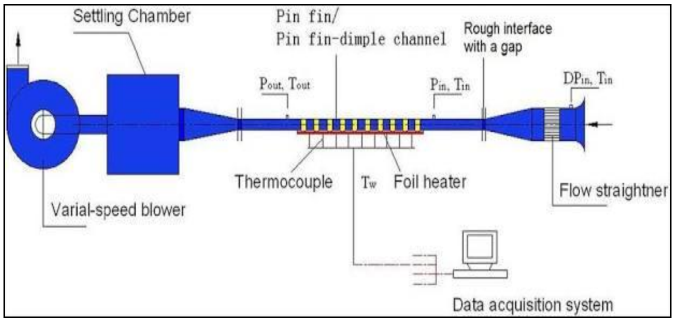

Fig 2: Block diagram of experimental setup

Fig 3: Copper fin

Fig 4: Aluminium fin

Fig 5: Brass fin

Specifications

1. Duct size = 150mm x 100mm.
2. Diameter of the fin = 24 mm
3. Diameter of the orifice = 18mm.
4. Diameter of the delivery pipe = 42mm.
5. Coefficient of discharge (or orifice meter) Cd = 0.64.
6. Centrifugal Blower 1 HP single-phase motor.
7. No. of thermocouples on fin = 5.
8. Thermal conductivity of fin material (Brass) =110w/m ^{0}C.
9. Temperature indicator = 0 – 300 ^{0}C with compensation of ambient temperature up to 50^{0}C.
10. Dimmer state for heat input control 230V, 2 Amps.
11. Heater suitable for mounting at the fin end outside the duct = 400 watts (Band type).
12. Voltmeter = 0 – 100/200 V.
    Ammeter = 0 – 2 Amps.

3. Result and Discussion

Consider the fin connected at its base to a heated wall and transferring heat to the surroundings.

Let, A = Cross section area of the fin.
C = Circumference of the fin.
L = Length of the fin.
T_1 = Temp. of the fin at the beginning.
T_f = Duct fluid temperatures.
ΔT = $(T - T_f)$ = Rise in temperature.

The heat is conducted along the rod and also lost to the surrounding fluid by convection.

Let, h =Heat Transfer coefficient.
K =Thermal conductivity of the fin material.

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

$$\frac{d^2\emptyset}{dx^2} - \frac{hc}{kA}\Delta T = 0 \text{..........................} \quad (1)$$

and the general solution of equation (1) is

$$\emptyset = C_1.\, e^{mx} + C_2.\, e^{-mx} \quad \text{..............................} \quad (2)$$

$$\text{Where } m = \sqrt{\frac{hc}{kA}}$$

With the boundary conditions of $\Delta T = \Delta T_1$ at x = 0

Where, $\Delta T_1 = T_1 - T_F$ and assuming the fin tip to be insulated. $\frac{dT}{dX} = 0$ at X = L results in obtaining equation (2) in the form

$$\frac{\Delta T}{\Delta T_1} = \frac{T - T_F}{T_1 - T_F} = \frac{\text{Coshm}(L-X)}{\text{Cosh ml}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This is the equation for the temperature distribution along the length of the fin. It is seen from the equation that for a fin of given geometry with uniform cross section, the temperature at any point can be calculated by knowing the values of T_1, T_F and X. Temperature T_1 and T_F will be known for a given situation and the value of h depends on whether the heat is lost to the surrounding by free convection or forced convection and can be o h = heat transfer coefficient calculated by using the correlations

$Nu = 0.023\, Re^{0.8}\, Pr^{0.3}$ ………… For2300< Re <100000

$Nu = 0.036\, Re^{0.5}\, Pr^{0.3}$ ………… For Re >2300

$$\text{Where } Nu = \frac{h\,D}{k_{Air}}$$

$$P_r = \frac{C_p\,\mu}{K_{Air}}$$

All the properties are to be evaluated at the mean film temperature. The mean film temperature is to arithmetic average of the fin temperature and air temperature.

Let, ρ =Density of air, Kg / m^3

D =Diameter of pin-fin, m

μ =Dynamic viscosity, N.sec/m^2

C_p =Specific heat, KJ/Kg.k

ν =Kinematic viscosity, m2/Sec

K =Thermal conductivity of air, W/m ^{0}C

G =Acceleration due to gravity, 9.81m/sec^2

$$Tm = \text{Average fin temperature} = \frac{T1+T2+T3+T4+T5}{5}$$

$\Delta T = T_m - T_F$

$$T_{mf} = \frac{T_m + T_f}{2}$$

β =Coefficient of thermal expansion = $\frac{1}{T_{mf}+273}$

ν = Velocity of air in the duct.

The velocity of air can be obtained by calculating the volume flow rate through the duct.

$$Q = C_d \frac{\pi}{4} \times d^2 \times \sqrt{2gH \frac{\rho w}{\rho_a}}\ m^3/sec$$

Where,

H = Difference of levels in manometer, M

ρ_w = Density of water 1000 Kg/m^3

ρ_a =Density of air at T_f

Cd =0.64

D =Diameter of the orifice = 18mm.

Velocity of air at $T_f = \frac{Q}{\text{Duct cross section area}}$ m/sec

Use this velocity in the calculation of R_e.

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

$$Q = \sqrt{h\,ckA}\ (T_i - T_f)\ \text{Tanh}\ (ml) \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

And the efficiency of the fin can also be calculated as,

$$\eta = \frac{\text{Tanh}(ml)}{ml} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

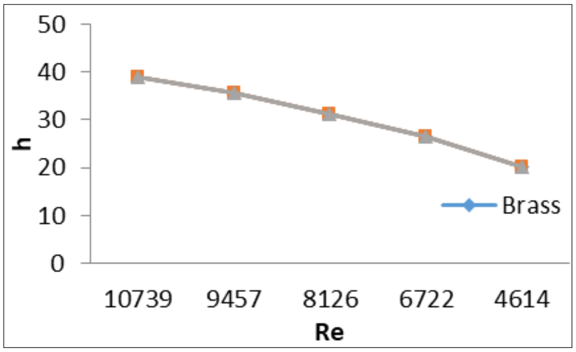

Fig 6: Variation of h Vs Re

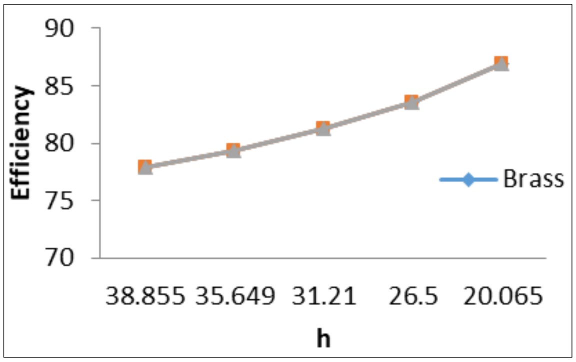

Fig 7: Variation of Efficiency Vs h

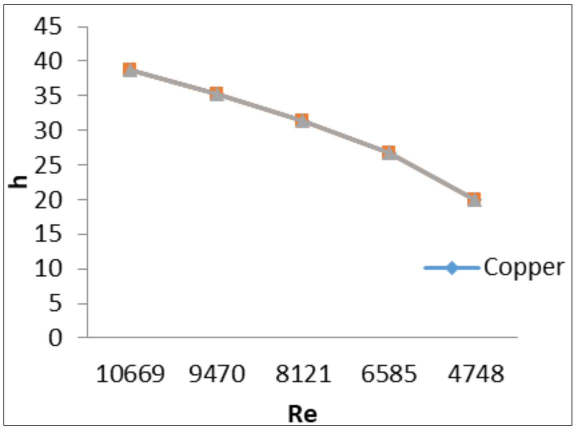

Fig 8: Variation of h Vs Re

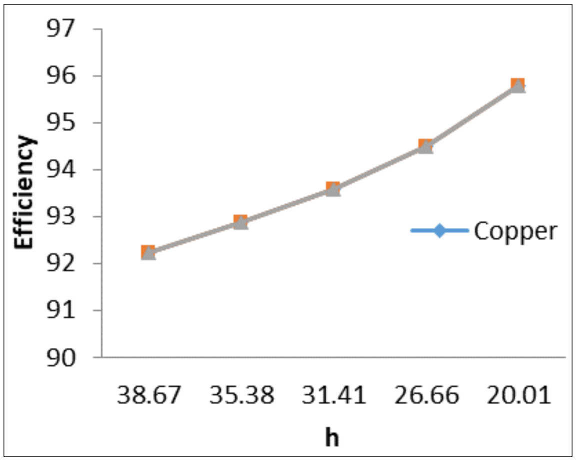

Fig 9: Variation of Efficiency Vs h

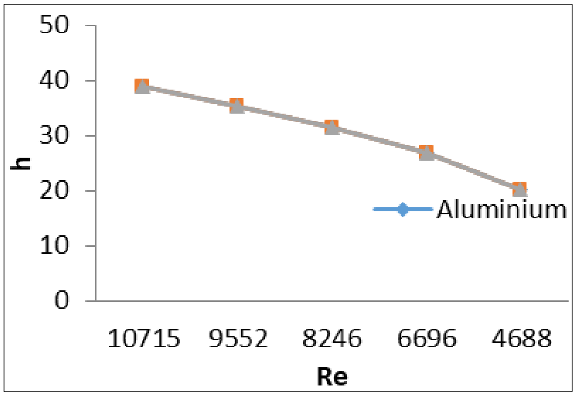

Fig 10: Variation of h Vs Re

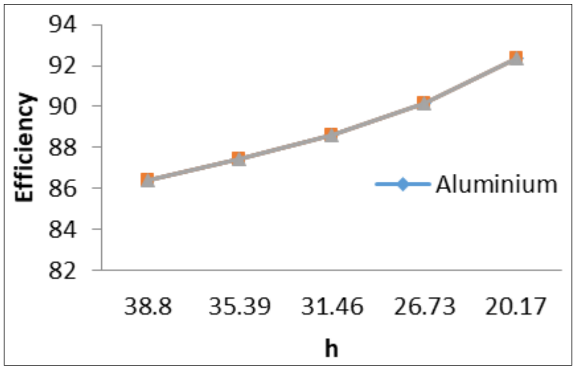

Fig 11: Variation of Efficiency Vs h

From the above figure the values of heat transfer coefficient (h) for Brass fin, Copper fin and Aluminium fin has found to be 45.895, 45.645 and 46.00 respectively i.e. Brass fin has maximum value of heat transfer coefficient (h). The values of Reynolds number for Brass fin, Copper fin and Aluminium fin has found to be 41.1, 40.8 and 41.27 respectively i.e. here Aluminium fin has maximum value of Reynolds number. Similarly, the values of Efficiency for Brass fin, Copper fin and Aluminium fin has found to be 75.12, 90.98 and 84.35 respectively i.e. Copper fin has maximum value of efficiency.

4. Conclusion

From the experimental analysis in this project the enhancement of heat transfer of fin for different materials is analyzed and we can conclude that

1. As Reynolds Number increases, the efficiency of pin fin decreases.
2. Heat transfer coefficient for Brass fin is more than others.
3. Nusselt Number remains almost same for all materials fin.
4. As Reynolds Number decreases, heat transfer coefficient also decreases for all materials fin.
5. As heat transfer coefficient decreases, Efficiency increases for all materials fin.
6. While material wise Copper is the most efficient material.

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