"Experimental Investigation and Thermal Analysis on Electroplating Coated Pin -Fins under Natural Convection"

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Abstract – *The previous work done on performance analysis of extended surfaces (fins) under free and forced convection in order to determine the enhancement in the heat transfer rate. The effects of geometric parameters, fin height,fin diameter, fin material and base to ambient temperature difference on the thermal conductivity and heat transfer performance of composite pin fin, where aluminium pin is fitted in a hollow brass and copper cylindrical fin whose inner diameter is equal to the outer diameter of the solid pin fin. There are different shapes of fins generally used in practical applications. Aluminium is the basic metal preferred to make fins due to their light weight and cost. In general the heat transfer from fins depends upon different factors, like the material used to make the fin, thermal conductivity of the material, its shape, surface area, mode of heat transfer allowed, size / shape of fin, etc.*

*In the present work, an attempt is made to fabricate circular pin fin made of different materials. Aluminium, Brass, Mild steel, Mild steel coated with brass and copper, Aluminium coated with copper as composite bars and analyzed their performance in terms of fin, heat transfer coefficient, heat transfer rate, efficiency and temperature distribution along the fin. A constant power is supplied to the heater and the fin is placed horizontally along the axis. Results infer that the highest heat transfer rate is observed for the coated pin fin made of copper coated over on Aluminium **(1.80 watts)** and highest efficiency is observed for the coated pin fin made of copper coated over on Mild steel **(96.60 %)** .*

Keywords: *Coated Pin fin, Thermal conductivity, Conduction, Convection, Heat transfer coefficient, Heat transfer rate, Fin efficiency, Temperature distribution.*

1.0 Introduction

In the Universe, each and every system or substance undergoes the process of heat transfer to make the system equilibrium. It occurs due to difference in temperatures in the substance. This temperature difference acts as s potential force to transfer heat from one place to another. But the rate of heat transfer depends on the various factors like media surrounded by the substance, the material used to make the substance, temperature difference in the substance, force applied (if any) to occur heat transfer in the substance etc.

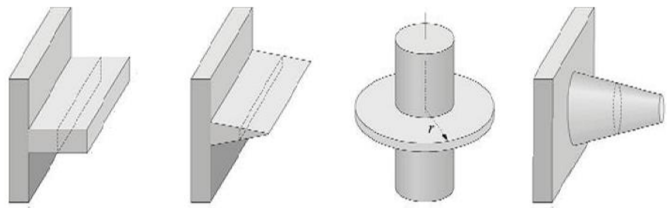
Thermal analysis is the process of finding the values of temperature at different points when the material is in steady state condition. A steady state is the material condition where there is input heat energy equal to output heat energy. The important factors which mainly affect the heat transfer rate are the thermal conductivity of material, size of material etc. Different materials have different thermal conductivity and it affects the rate of heat transfer. By increasing the length and diameter of the pin fin, the heat transfer rate can be improved but the fin faces the difficulty of increased self-weight and size. The design of heat sink device is predicted

1.1 Fins:

Extended surfaces called Fins are mostly used in the field of automobile, electronic components; electrical motors etc., to increase heat transfer rate, to increase the life and efficiency of the device. The heat transfer from one place to another place occurs by three mechanisms, namely Conduction, Convection and Radiation. An extended surface configuration is generally classified for straight fin an annular fin or spine. The term straight fin is applied to the extended surface attached to a plane wall where a annular fin are provided circumferentially to a cylindrical surface.

1.2 Types Of Fins :

1. Rectangular fin
2. Triangular fin
3. Pin fin
4. Circumferential fin



(a) (b) (c) (d)

Fig 1.2: Different Shape of fins

Straight fin is an extended surface attached to the plane wall. It may be of uniform cross-sectional area or its cross sectional area may vary along its length to form a triangular, parabolic or trapezoidal shape. Fig.1.2 (a) shows the straight fin of uniform cross section & fig.1.2 (b) shows a straight of non-uniform cross section.

An annular fin is a fin circumferentially attached to a cylinder and its cross section varies with radius from centre line of cylinder. Fig.1.2(c) shows a annular fin of rectangle cross section. A pin fin is an extended surface of circular cross section whose diameter is much smaller than its length. The pin fin may also be of uniform or non-uniform cross section. Pin fin is show in fig.1.2 (d)

1.3 Fins Based On Different Cross-Section

Some of the very common types of fins based on cross section of fins profiles are as shown in the figures:

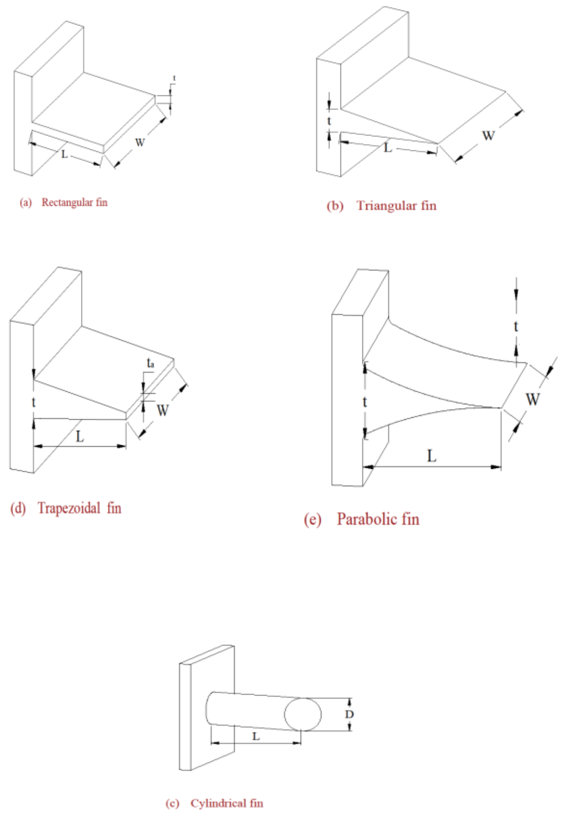


Fig 1.3: Different Cross Section

1.4 Coated / Composite Metals :

These are metals made from two or more constituent metal with significantly different properties. That when combined, produce a metal with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new metal may be preferred for many reasons; common examples include metals which are stronger, lighter or less expensive when compared to traditional metals.

One can choose or prefer composite or coated metals due to their enhanced properties like reduction in its wear and tear of metals, improvement in its strength, reduction in its weight and improvement in its thermal

1.5 Materials Of Fins

Aluminium, Copper, Brass, Mild Steel and their composites / electroplating – coating properties etc.

Table -1: Properties & Specifications of Metals

S. No.	Fin Material	Dia. (mm)	Fin Length (mm)	Thermal Conductivity of fin material (W/m-K)
1	Copper	16.00	125	401
2	Aluminium	16.00	125	232
3	Brass	16.00	125	110
4	Mild Steel	16.00	125	46
5	Aluminium with Cu Coated	16 .04	125	277
6	Mild Steel with Cu Coated	16 .04	125	272
7	Mild Steel with Brass Coated	16 .04	125	252

1.6 General Equation For A Pin Fin:

The methodology to find the fin efficiency, heat transfer rate, Heat transfer coefficient is considered from basics of Heat transfer. (Ref. No. 28, 29, 30 and 31).

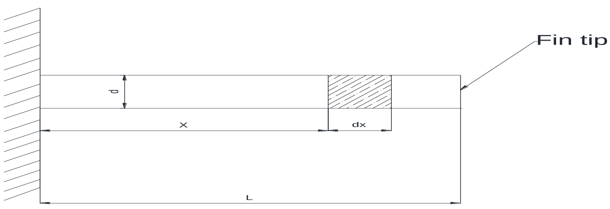


Fig.1.5: Circular Pin Fin

1.7 Heat Transfer Coefficient (h):

$$h = (Nu*Ka) / d \qquad W/m^2\text{-}K$$

Average surface temperature of fin
$T_m = T_{avg.} = (T_1+T_2+T_3+T_4+T_5) / 5\,^oC$
Duct fluid temperature $T_a = T_f = T6\,^oC$
Temperature difference of fin and fluid temperature

$$\Delta T = (T_m - T_f) \quad ^oC$$

Mean Film temperature $T_{mf} = (T_{avg.} + T_a)/ 2 \quad ^oC$
Property of air at T_{mf}
ρ = Density of air kg/m^3
υ = Kinematic of viscosity of air m^2/s
K_a = Thermal Conductivity of air W/m-k
C_p = Specific heat J/kg K
μ = Absolute viscosity Ns/m^2
Pr = Prandtle number

1.8 Temperature distribution along the fin:

$$(\theta/\theta b) = [\cosh m (L-x)] / \cosh mL$$

Where $\theta = (T-T_f)$ K
θb = Temperature difference between the base of the fin and air inlet temperature = $T_1 - T_f$
L = Fin length m
m = Fin parameter = $\sqrt{(h*p / k_f*A)}$ m^{-1}
$k_{f=}$ Fin material thermal conductivity W /m-K
P = Perimeter of the fin = $\pi*d$
A = Cross sectional area of the fin = $\pi d^2/ 4$ m^2

1.9 Fin Efficiency(η_f):

$$\eta_f = \frac{\tanh(mL)}{mL}$$

1.10 Heat Transfer Rate (q):

$$q = \sqrt{(h*p*k*A)}(T_1 - T_f) \tanh (mL) \quad \text{Watt}$$

1.11 Pin Fin Performance:

The fins are used to increase the heat transfer rate from surface by increasing the effective surface area. The use of fin on a surface cannot be recommended unless the increase in heat transfer justifies the added cost and complexity associated with fin. However,the fin itself puts conduction resistance to heat transfer from original surface. For this reason, there is no assurance that the heat transfer rate will be increased through the use of fins. Therefore, the performance of fin generally assessed on the basis of the following parameters:

1. Fin Efficiency.
2. Fin Effectiveness.

1.12 Fin selection and Application:

Generally ,the fin are used on the surface where the heat transfer coefficient is very low. The selection of the fin is made on the basis of the thermal performance and the cost. The selection of the fin geometery requires a compromise among the cost, the weight, available space, pressure drop of heat transfer fluid and heat transfer characteristic of the extended surface. It should be noted that the fins of triangular parabolic and hyperbolic profiles contains less material and are more efficient than the fins of rectangular profiles and thus are more suitable for application that require minimum weight such as space application. The rate of heat transmission from the fin decreases with the increase of fin length and hence, then entire heat transfer surface of a fin may not be equally utilized. For this reason, there is a continuous effort by the designers to determine the optimum fin that will maximize the rate of heat transfer for a specified fin volume or minimize the fin volume for a given heat duty.

The heat transfer rate can be increased by choice of a material of higher thermal conductivity. Therefore, the fins are made from metals, with copper, aluminium and iron. But aluminium is the best choice due to its low cost and the weight and its resistance to corrosion. The fin effectiveness is also enhanced by increasing the ratio of the perimeter to cross sectional area of the fin. For this reason, aluminium or copper thin fins, or slender pin fin closely spaced are preferred in most engineering applications. The use of the fins can be justified under conditions for which the convection heat transfer coefficient is small. Therefore, fins are placed on a surface on gas side, where the heat transfer is by natural convection instead of forced convection.

Fins are generally used for increasing heat transfer in many engineering application. Some common applications of finned surface are with:

1. Air cooled cylinder of I.C. engines, air compressors, aircraft engines, etc.
2. Electrical transformer and the motors.
3. Convectors for steam and hot water heating of system.
4. Economizer for steam power plants.
5. Cooling coils and condenser coils in refrigerators and air conditioners.
6. Electronic equipment, etc.

2. Methodology

2.1 Sample Preparation

This is very important part of the project. The chapter discusses about of sample preparation techniques, thin film coating technique and surface characterization techniques. The surface preparation is very important part of this experiment as it requires proper shape and size to achieve this it can be done into following sections: Machining, polishing and cleaning.

2.2 Machining

Machining is process of removing of unwanted materials from raw material to get desired shape and size. It has been performed on Lathe Machine in Govt. Engineering College Jagdalpur machine shop. The machining can be done in three steps: (a) Turning operation will be done on aluminium and mild steel rod having dimensions with the diameter of 20 mm and length of 160 mm to obtain the ø16mm diameter throughout the length. (b) Turning operation is to be done for getting the step of ø12 mm and length 25 mm for thread cutting.

2.3 Cleaning

'Clean' means 'good enough so that the next stage is not messed up. Cleaning of sample means the removing entrapped oil, grease and dirt particle.

2.4 Surface Coating Method

It describes the procedure adopted in the present study for the CuO and brass thin film coating over the aluminium and mild steel surface. It was done by electroplating coating technique.

2.5 Electroplating is the process of applying metal coating on metallic or non-metallic surface through electro chemical process. It is passing the electric current into the metal through the aqueous solution of metal to be deposited. The metal acts as anode whereas the part that is to be plated acts as cathode. It is also called electrodepositing as another metal is deposited by electrolysis. Different metal can be coated on the surface of metals depending upon the metal to be coated for example; iron is electroplated with metals such as copper by carrying out electrolysis in copper sulphate solution.

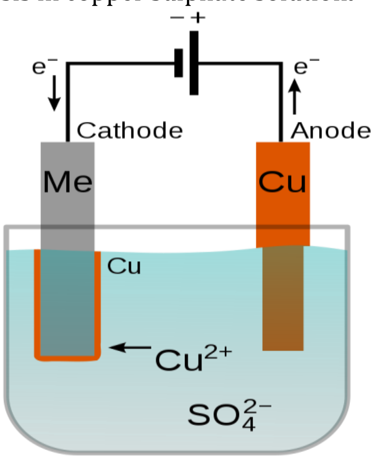


Fig 2.5: Diagram of the Electroplating System

2.6 Experimental Setup

Figure shows a schematic diagram of the experimental apparatus consists of a simple or circular cross section pin fin which is fitted in a rectangular duct. The other end of the duct is attached to suction end 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 an electrical 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 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. Thermocouples are mounted along the length of fin and a thermocouple notes the duct fluid temperature. When top cover the fin is opened and heating started, performance of fin with natural convection can be evaluated and with top cover closed and blower started, fin can be tested in forced convection.

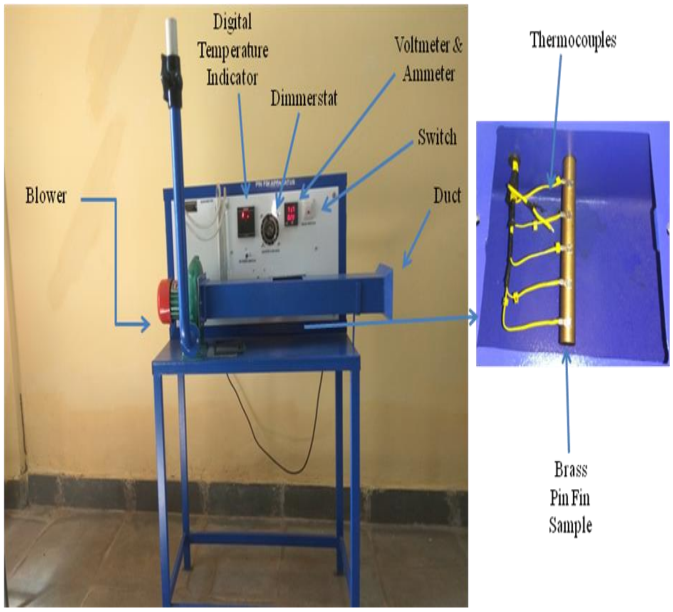


Fig 2.6: Diagram of the Experimental System

Fig 2.6 (a): Aluminium fin

Fig 2.6 (b): Brass fin

Fig 2.6 (c): Mild Steel fin

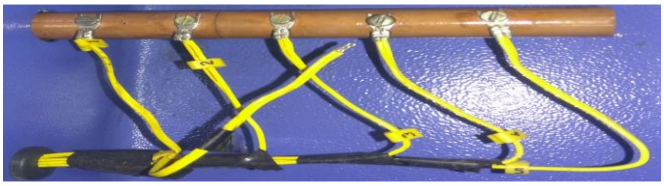


Fig 2.6 (d): Copper coated over Aluminium Pin Fin

Table-2: Experiment Readings under Natural Convection

S N	Fin Material	Fin Surface Temperature (°C)					Duct fluid Temp. (°C)
		T_1	T_2	T_3	T_4	T_5	T_6
1	Al	69.1	68.3	67.3	67.1	66.5	38.0
2	Al + Cu coating	59.7	59.1	58.4	57.8	55.2	31.0
3	Mild Steel	64.1	63.0	61.7	59.5	59.0	39.7
4	MS + Brass coating	57.8	57.4	55.7	55.6	55.3	37.3
5	MS + Cu coating	57.3	56.6	56.2	55.5	55.5	39.7
6	Brass	60.1	58.0	57.3	57.3	56.6	31.9

3.0 Results and Discussions

Table-3: Experiment Results

S N	Fin Material	Heat Transfer Coefficient (W/m^2-K)	Heat Transfer Rate (W)	Efficiency (%)
		h	q	η
1	Al	8.40	1.50	95.30
2	Al + Cu coating	8.60	1.80	95.65
3	Mild Steel	7.60	1.21	82.86
4	MS + Brass coating	7.65	1.52	92.24
5	MS + Cu coating	7.48	1.40	96.60
6	Brass	7.62	1.36	91.86

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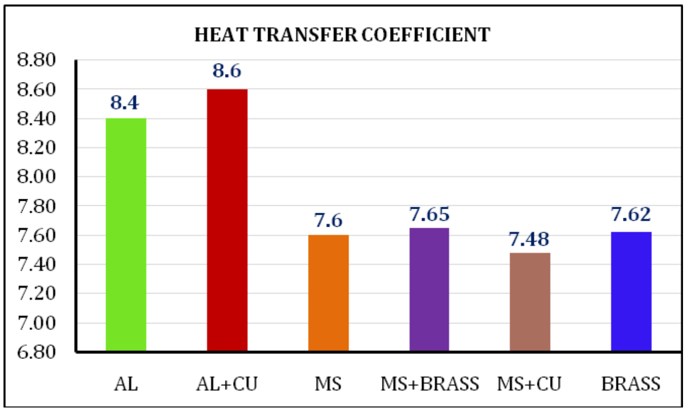
In the present work, a film with constant cross sectional area a and a finite length of 125mm is considered. From the results

- The efficiency of the composite material (Mild steel with Cu coated) shows the high value of **96.60 %.**
- The coated composite pin fin (Aluminium with Cu coating) shows high heat transfer rate of **1.80** Watts.
- The temperature gradient of a mild steel material is high along its length as it varies from **70 to 62.57 °C** but it attains high temperature at the starting stage due to its less thermal conductivity.

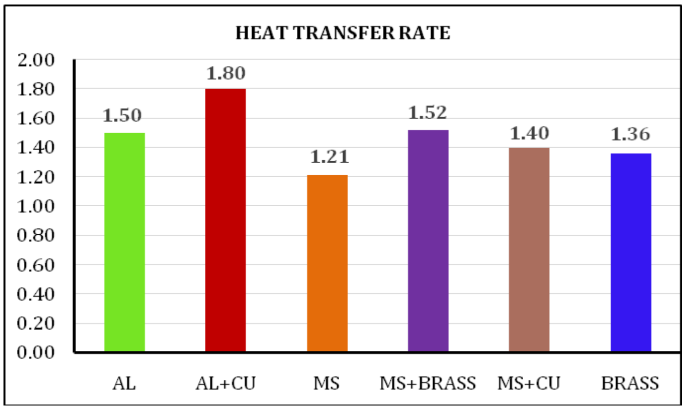
4.0 Graphs:

4.1 Heat Transfer Co-efficient (h):



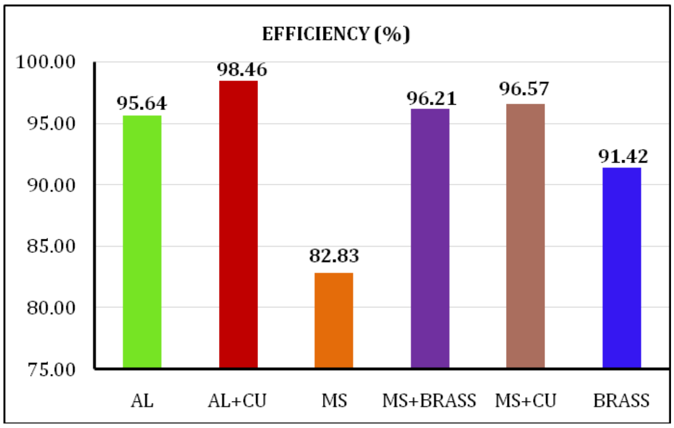
The coated pin fins show high heat transfer coefficient of 8.60 W/m2-K and low heat transfer coefficient of 7.48 W/m2-K Aluminium with Cu coating and Mild steel with Cu coatings are respectively.

4.2 Heat Transfer Rate (q):



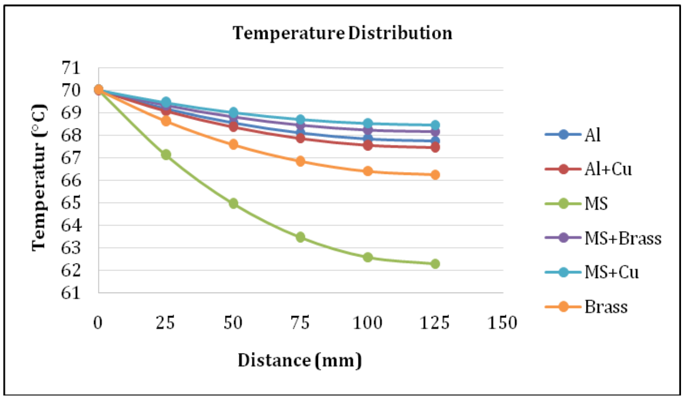
The coated pin fins show high heat transfer rate of 1.80 Watt and low heat transfer rate 1.21 Watt Aluminium with Cu coating and Mild steel are respectively.

4.3 Fin Efficiency (η_f):



The coated pin fins show high efficiency of **96.60 %** and low efficiency of **82.86 %** of Mild steel with Cu coating and Mild steel are respectively.

4.4 Temperature Distribution along the length of the fins (^{0}C):



The temperature gradient of a mild steel material is high along its length as it varies from **70 to 62.28 ºC** but it attains high temperature at the starting stage due to its less thermal conductivity.

5.0 Conclusions

In the present work, an attempt is made to find the fin efficiency, heat transfer rate, and temperature distribution and heat transfer coefficient for a solid and electroplating coated pin fins. From the results it is concluded that, the efficiency, heat transfer rate are higher for coated pin fins than that of solid pin fin.

- The efficiency for copper coated mild steel fin is improved by **16.60 %** and heat transfer rate for brass coated mild steel fin is improved by **25.62%** when compared to solid pin fin.

6.0 Acknowledgement

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