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# Design and Thermal Analysis of Heat Transfer Through an Ellipsoidal Pin Fin

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***ABSTRACT***

***In order to obtain an increased thrust levels and decreased fuel consumption rates for gas turbine engines, a higher level of turbine inlet temperatures are necessary. So it need for higher temperatures results in a demand for effective internal and external cooling techniques for the high pressure turbine blades. In-line and staggered arrays of short cylindrical pin fins with circular cross-sections are one of the most common types of cooling devices used in turbine blades. These pin fin arrays enhance the heat transfer levels both by increasing the pin fin wetted surface area and the passage thermal transport downstream of the pin fin. Extended surfaces of 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. 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 paper presents thermal analysis carried out by the pin fin apparatus using different metals and their parameters are found and compared with each other.***

***Index terms:* *Heat transfer, Ellipsoidal pin fin apparatus, copper.***

## INTRODUCTION

Heat transfer describes the exchange of thermal energy, between physical systems depending on the temperature and pressure, by dissipating heat. Heat transfer always occurs from a region of high temperature to another region of lower temperature. The fundamental modes of heat transfer are conduction or diffusion, convection and radiation.

**Conduction:** Conduction is a mode of heat transfer of energy within and between bodies of matter, due to temperature gradient. Conduction means collisional and diffusive transfer of kinetic energy of particles of matter. Conduction takes place in all forms of matter, i.e. solids, liquids, gases.

**Convection:** Conduction is movement of molecules within fluids i.e. liquids, gases. It cannot takes place in solids, as neither bulk current flows nor significant diffusion can takes place in solids. Convection is one of the major modes of heat transfer and mass transfer. In the context of heat transfer convection refers to sum of advective (transport mechanism of a fluid substance or conserved property from one location to another, depending on motion and momentum.) and diffusive transfer.

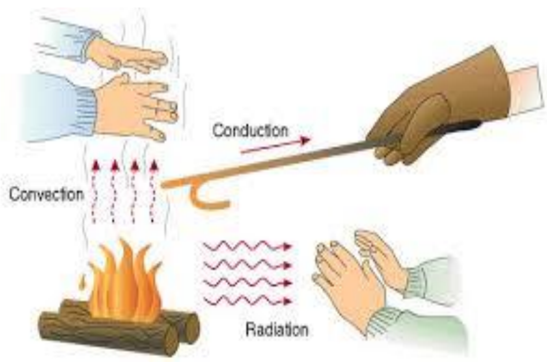


**Fig 1: Image of modes of heat transfer**

**Radiation:** Radiation is energy emitted by matter as electromagnetic waves due to the storage of thermal energy that all matter possesses that has a temperature

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above absolute zero. Thermal radiation propagates through the vacuum of space

Convection is further divided two types
- Natural convection
- Forced convection

**Natural convection-** Natural convection is a type of heat transfer , in which the fluid motion is not generated by any external source (i.e. pump. Fan, Blower etc.) But only by density differences in the fluid occurring due to temperature gradients

**Forced convection-** Forced convection is a type of heat transfer in which the fluid movement results from external surface forces such as a fan or blower or pump. Forced convection is typically used to increase the rate of heat exchange

**Fins (extended surface):** In the study of heat transfer, a fin is a surface that extends from an object to increase the rate of heat transfer to or from the environment by increasing convection.

The amount of conduction, convection, or radiation of an object determines the amount of heat it transfers. Increasing the temperature difference between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer. Sometimes it is not economical or it is not feasible to change the first two options. Adding a fin to an object, however, increases the surface area and can sometimes be an economical solution to heat transfer problems.

### (i) Fin efficiency

Fin efficiency is one of the parameters which makes a higher thermal conductivity material important. A fin of a heat sink may be considered to be a flat plate with heat flowing in one end and being dissipated into the surrounding fluid as it travels to the other. As heat flows through the fin, the combination of the thermal resistance of the heat sink impeding the flow and the heat lost due to convection, the temperature of the fin and, therefore, the heat transfer to the fluid, will decrease from the base to the end of the fin. Fin efficiency is defined as the actual heat transferred by the fin, divided by the heat transfer were the fin to be isothermal (hypothetically the fin having infinite thermal conductivity).

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

$$mL_c = \sqrt{\frac{2h_f}{kt_f}}L_f$$

Where:

- $h_f$ is the convection coefficient of the fin
  - Air: 10 to 100 W/(m$^2$K)
  - Water: 500 to 10,000 W/(m$^2$K)
- k is the thermal conductivity of the fin material
  - Aluminium: 120 to 240 W/(m·K)
- $L_f$ is the fin height (m)
- $t_f$ is the fin thickness (m)

Fin efficiency is increased by decreasing the fin aspect ratio (making them thicker or shorter), or by using more conductive material (copper instead of aluminium, for example).

### Application of fins in convection

For both modes of convective heat transfer i.e. natural and forced, fin is used to increase the rate of heat transfer from a surface to a fluid where heat transfer coefficient of surface and temperature difference between them is not possible to increase. Fins increase the surface area available for heat transfer. Fins are vastly used on the radiator surface, on the boiler water tubes, heat exchanger tubes and sometimes on electronic equipments.

## LITERATURE REVIEW:

The idea behind the proposed system is to design extended surfaces of fins that are used to increase the heat transfer rate from a surface to a fluid which can be used for variety of shapes. The analysis carried out by the pin fin apparatus using different metal of cylindrical

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and ellipsoidal shape of circular cross section are discussed.
The past pin fin research is mostly based on the determination of heat transfer and pressure loss characteristics of different array configurations with circular pin fins. Nevertheless, there has also been some effort in investigating different pin fin shapes and concepts. Steuber and Metzger investigated partial length circular pin fins as an alternate to full circular pin fins. Their results showed that the partial length pin fins did not outperform the full length fins in terms of heat transfer but when the heat transfer and pressure loss are both considered, some of their partial length pin fin arrays were superior. Arora and AbdelMesseh also investigated the partial length circular pin fin concept and found that both the array averaged heat transfer and friction factor decreases with increasing gap distance. Pin fins with oblong cross-sections are investigated by Metzger et al. For various pin orientations with respect to the main flow. Their results indicate that the use of elongated pin fins (oblong shape) increases endwall heat transfer but also causes higher levels of aerodynamic penalty than the circular pin fins when the main flow direction deviates from the direction of the major axis of the oblong pin fin. When the main flow approaches with zero incidence, the pressure loss levels become lower than that of circular pin fins. Wang and Ji experimentally investigated the heat transfer and pressure loss characteristics of tapered pin fin configurations and compared their results with full cross pin fins and shorter round pin fins.

For the preparation of materials, using thermal energy for turning, brazing, drilling and tapping operations were performed

### a. Turning

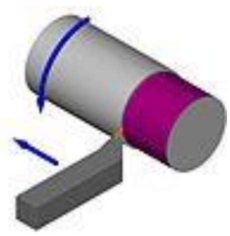

Fig 2: Image of turning operation

Turning is an engineering machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical tool path by moving more or less linearly while the work piece rotates. The tool's axes of movement may be literally a straight line, or they may be along some set of curves or angles, but they are essentially linear (in the nonmathematical sense). Usually the term "turning" is reserved for the generation of *external* surfaces by this cutting action, whereas this same essential cutting action when applied to *internal* surfaces (that is, holes, of one kind or another) is called "boring". Thus the phrase "turning and boring" categorizes the larger family of (essentially similar) processes. The cutting of faces on the work piece (that is, surfaces perpendicular to its rotating axis), whether with a turning or boring tool, is called "facing", and may be lumped into either category as a subset.

Turning can be done manually, in a traditional form of lathe, When turning, a piece of relatively rigid material (such as wood, metal, plastic, or stone) is rotated and a cutting tool is traversed along 1, 2, or 3 axes of motion to produce precise diameters and depths. Turning can be either on the outside of the cylinder or on the inside (also known as boring) to produce tubular components to various geometries. A 12mm diameter and 150mm long rods were selected, for which 44mm was made turning in order to obtain 11.9mm diameter (to insert in the heater)

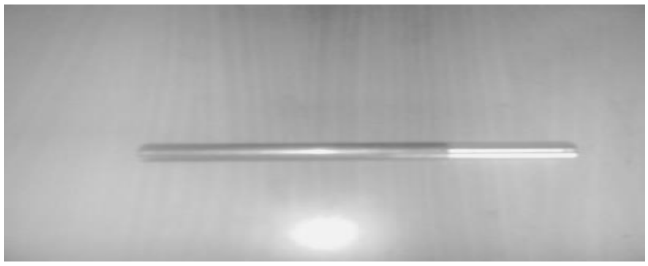

Fig 2: Image of finished rod

### b. Brazing

Brazing is a metal joining process whereby a filler metal is heated above melting point and distributed between two or more close-fitting parts by capillary action. The filler metal is brought slightly above its melting (liquid us) temperature while protected by a suitable

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atmosphere, usually a flux. It then flows over the base metal (known as wetting) and is then cooled to join the work pieces together. It is similar to soldering, except the temperatures used to melt the filler metal are higher for brazing.

Nuts were brazed on the surface of the materials in order to join the thermocouples with the help of screws

a. nut on rod

b. brazing work on rod

c. brazed rod

### c. Drilling and tapping

Drilling is a cutting process that uses a **drill** bit to cut or enlarge a hole of circular cross-section in solid materials. The **drill** bit is a rotary cutting tool, often multipoint. The bit is pressed against the work piece and rotated at rates from hundreds to thousands of revolutions per minute. **Taps** and **dies** are tools used to create screw threads, which is called threading. Many are cutting tools; others are forming tools. A tap is used to cut or form the female portion of the mating pair (e.g., a nut). A die is used to cut or form the male portion of the mating pair (e.g., a bolt). The process of cutting or forming threads using a tap is called tapping, whereas the process using a die is called threading. Both tools can be used to clean up a thread, which is called chasin. Since aluminum was unable to braze, the operation of drill and tap was performed.

## HARDWARE DESIGN OF PROPOSED SYSTEM

In this paper we presented an analysis of heat transfer suing Ellipsoidal pin fin apparatus.

The apparatus consists of the following features:

- Pin type fin of diameter 12mm and 150mm long with suitable temperature points.
- Heater of 250w capacity.
- Heater regulator to supply the regulated power input to the heater.
- Digital voltmeter and Ammeter to measure power input to the heater.
- Thermocouples at suitable position to measure the surface temperatures of the fin.
- Digital temperature indicator with channel selector to measure the temperatures.
- Blower unit to blow air through the duct with orifice meter and acrylic manometer to measure the air flow rate from the blower. A control valve is provided to regulate the air flow.

Control panel to house all the instrumentation. With this the whole arrangement is mounted on an aesthetically designed self sustained MS powder coated frame with a separate control panel.

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Fig 3: Image of PIN FIN apparatus

**Working Procedure:**

- Switch on the MCB and then console ON switch to activate the control panel.
- Switch on the heater and regulate the power input using the heater regulator.
- Switch on the blower unit and adjust the flow of air using gate valve to a desired difference in manometer (for forced flow only otherwise skip to step 4).
- Wait for reasonable time to allow temperatures to reach steady state.
- Measure the voltage, current and temperatures from T1 to T6 at known time interval.
- Calculate the effectiveness & efficiency of the fin using the procedure given.
- Repeat the experiment for different values of power input to the heater and blower air flow rates.

**Usage of Formulas for apparatus:**

1. For free convection condition,

$Nu = 1.1 \ (Gr. Pr)^{1/6}$ . . $10^{-1} < Gr. Pr. < 10^4$ }
$Nu = 0.53 \ (Gr. Pr)^{1/4}$ . . $10^4 < Gr. Pr. < 10^9$ } 4
$Nu = 0.13 \ (Gr. Pr)^{1/4}$ . . $10^9 < Gr. Pr. < 10^{12}$ }

2. For forced convection,

$Nu = 0.615 \ (R_e)^{0.466}$ . . $40 < R_e < 4000$
$Nu = 0.174 \ (R_e)^{0.618}$ . . $4000 < R_e < 40000$

$R_e = \frac{\rho VD}{\mu}$ =Reynold's Number

$G_r = \frac{\rho^2 . \beta . L^3 \Delta T}{\mu^2}$ = Grashoff Number.

$P_r = \frac{Cp . \mu}{k}$ Prand tl Number

All the properties are to be evaluated at the mean film temperature

$$T_f = \frac{T_m + T_a}{2}$$

- 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
- N = Kinematic viscosity, $m^2$/Sec
- K= Thermal conductivity of air, W/m $^0$C
- g= Acceleration due to gravity, 9.81m/$sec^2$
- Tm= Average fin temperature

$= (T_1 + T_2 + T_3 + T_4 + T_5)5$
$\Delta T = T_m - T_a$
β = Coefficient of thermal expansion
$1/T_f + 273$

Velocity of air in the duct.

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

$$V = \frac{0.62 * (\pi/4) * (D_1^2) * \sqrt{2*g*H}}{(\pi/4)*(D_2^2)}$$

Where, H = Difference of levels in manometer,
V= Kinematic viscosity
Cd =Coefficient of discharge= 0.62
$D_1$ = Diameter of the orifice = 20mm.
$D_2$= flow diameter =50mm

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Use this velocity in the calculation of $R_e$ and find the value of Nu

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

$$Q = \sqrt{h.P.K_f.A} \times (T_m - T_a) \tanh mL$$

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

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

$$E = \frac{\tanh mL}{\sqrt{\frac{h.A}{kP}}}$$

**Apparatus Results:**

The analysis using various metals of cylinder and ellipsoidal shape in the pin fin apparatus and found the efficiencies & effectiveness of those metals and are compared with each other as show in the table

**Practical**

| MATERIALS | | NATURAL CONVECTION | FORCED CONVECTION |
|---|---|---|---|
| COPPER | cylindrical | Efficiency= 13% Effectiveness=7.31 | Efficiency= 16.34% Effectiveness=8.15 |
| | Ellipsoidal | Efficiency= 6.47% Effectiveness=8.92 | Efficiency= 6.73% Effectiveness=9.27 |
| ALUMINIUM | Cylindrical | Efficiency= 10.85% Effectiveness=5.58 | Efficiency= 11.43% Effectiveness=5.8817 |
| | Ellipsoidal | Efficiency= 4.59% Effectiveness=6.396 | Efficiency= 4.61% Effectiveness=6.366 |
| BRASS | Cylindrical | Efficiency= 5.34% Effectiveness=3.76 | Efficiency= 7.77% Effectiveness=3.986 |
| | Ellipsoidal | Efficiency= 3.01% Effectiveness=4.137 | Efficiency= 2.995% Effectiveness=4.128 |
| MS BRIGHT | Cylindrical | Efficiency= 4.50% Effectiveness=2.309 | Efficiency= 4.55% Effectiveness=2.323 |
| | Ellipsoidal | Efficiency= 1.909% Effectiveness=2.63 | Efficiency= 1.609% Effectiveness=2.725 |

## CONCLUSION

The presented paper of "**Design and thermal analaysiis of Heat transfer through Ellipsoidal Pin Fin**" was designed with different metals showing different results for cylindrical and ellipsoidal shape. The paper also presented an analysis using the table about that the efficiency of the ellipsoidal structure which is less compared to cylinder but the effectiveness is more in both natural and forced conditions. It is clearly presented the explanation that copper is the best choice for the selection, as the other materials are showing less values than copper as Copper has excellent heat sink properties in terms of its thermal conductivity, corrosion resistance, efficiency,. Copper has around twice the thermal conductivity of aluminum and faster, more efficient heat absorption. Its main applications are in industrial facilities, power plants, solar thermal water systems, HVAC systems, gas water heaters, forced air heating and cooling systems, geothermal heating and cooling, and electronic systems. In future the efficiency and effectiveness of the fins can be calculated using various cross sectional fins such as rectangle, square, elliptical, e.t.c.

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