Experimental and Computational Analysis of Various Types of Fins

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Abstract

Fins are the extended surfaces which are used to dissipate the heat by means of conduction and convection mode of heat transfer. Fins are the cheapest mode of heat transfer compared to heat exchanger. Mostly rectangular fins are designed and used as heat transfer equipments where as when there is requirement of less heat transfer and material reduction. We can switch over to other type of fins instead of rectangular design. In this project rectangular, circular and pin fins are attached to circular rod separately. Then, these three models were subjected to experimental, analytical and computational analysis. In experimental analysis three models were heated to 100c then they were allowed for natural convection at room temperature. The temperature distributions were measured and viewed using thermocouple. In analytical method, the amount of heat transfer is calculated and plotted graphically. In computational analysis, these three models were analyzed ANSYS 14.0. The temperature distribution will be compared by both experimental and computationally.

1. INTRODUCTION

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. These notes provide an introduction to engineering heat transfer. Heat transfer processes set limits to the performance of aerospace components and systems and the subject is one of an enormous range of application. The notes are intended to describe the three types of heat transfer and provide basic tools to enable the readers to estimate the magnitude of heat transfer rates in realistic aerospace applications. There are also a number of excellent texts on the subject; some accessible references which expand the discussion in the notes are listening in the bibliography. The purpose of extended surfaces (commonly known as fins) is to enhance convective heat transfer from surfaces. The primary mechanism behind the operation of fins is to increase the effective heat transfer area of a surface. They are commonly used in situations in which cooling is attained via free (or natural) convection – for which the heat transfer coefficients h are relatively small. Typically fins are much longer than they are thick. Because of this it is common, and fairly accurate, to assume that the temperature varies only in the lengthwise direction. That is, at any point x along the length of the fin the temperature is essentially uniform across the cross section of the fin. What results from this assumption is a one–dimensional heat transfer problem – yet the 1–D DE from the previous section cannot be directly applied to analyze the fin. Rather, an energy conservation equation specific to the fin must be derived.

Consider the arbitrary fin illustrated. The heat flow direction is x, and the cross sectional area of the fin (the area exposed to the heat flow) is taken to be a function of x. Consider the small volume element of the fin of length. An energy balance is performed on this element, in which it is assumed that the element is at a constant and uniform temperature of T. Fins are used to enhance convective heat transfer in a wide range of engineering applications, and offer a practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area. Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. Other applications include engine cooling, condensers in refrigeration and air-conditioning. It IS important to predict the temperature distribution within the fin in order to choose the configuration that offers maximum effectiveness. The removal of excessive heat from system components is essential to avoid the damaging effects of burning or overheating. Therefore, the enhancement of heat transfer is an important subject in thermal engineering. The heat transfer from surfaces in general is enhanced by increasing the heat transfer coefficient between surface and its surroundings, or by increasing the heat transfer area of the surface. In most cases, the area of heat transfer is increased by utilizing the extended surfaces in the form of fins attached to walls and surfaces. Fins are used to enhance convective heat transfer in a wide range of engineering application and offer a practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area. Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. Other applications include IC engine cooling, such as fins in a car radiator. It is important to predict the temperature distribution within the fin in order to choose the configuration that offers maximum effectiveness this exercise serves as a visualization tool for evaluating the effect of shape on fin effectiveness, efficiency, and temperature distribution

2. LITERATURE SURVEY

Aurbur (2008) has done Finite element analysis and experimental study of convective heat transfer augmentation from horizontal rectangular fin by triangular perforations**.** Due to the high demand for lightweight, compact, and economical fins, the optimization of the fin size is of great importance. Therefore, fins must be designed to achieve maximum heat removal. Other studies have introduced shape modifications by cutting some materials from fins to make cavities, holes, slots, grooves or channels through the fin body to increase the heat transfer area and/or the heat transfer coefficient. One popular heat transfer augmentation technique involves the use of rough interrupted surfaces of different configurations. The surface roughness or interruption aims at promoting surface turbulence that is mainly intended to increase the heat transfer coefficient rather than the surface area. In another experimental study on the forced heat transfer enhancement over a flat surface equipped with square cross-sectional perforated pin fins in a rectangular channel was conducted. The experimental results showed that the use of the square pin fins with the circular perforations lead to the heat transfer enhancement. In an experimental study was conducted to investigate the heat transfer and friction loss characteristics of a horizontal rectangular channel with hollow rectangular profile fins attached over one of its heated surfaces. The study showed a significant enhancement of the heat transfer due to the hollow fins. The present study involves studying the effect of triangular perforations on rectangular fin. The study investigates the comparison of perforated fin with solid fin for temperature distribution along the fin and heat transfer rate. The analysis is done using ANSYS 14.0 version & also by experimentation analysis by ANSYS. Fins are used to enhance convective heat transfer in a wide range of engineering applications and offer a practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area. Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. Other applications include IC engine cooling, such as fins in a car radiator. It is important to predict the temperature distribution within the fin in order to choose the configuration that offers maximum effectiveness .This exercise serves as a visualization tool for evaluating the effect of shape on fin effectiveness, efficiency, and temperature distribution. The computational domain is represented in two dimensions. The procedure for solving the problem is (1) Create the geometry (2) Set the material properties and boundary conditions.(3) Mesh the domain geometry we take the rectangular shape shown in the figure.1 It is assumed that both fins have the same dimensions (the fin length is L = 50 mm and its width is W = 100 mm, no of perforations n=12, t=1.85mm, thickness of fin), same thermal conductivities, and same base and ambient temperatures. The analysis is done for three different materials such as MS, SS, and AL.

Daniel w. mackowski (2002) has done Conduction heat transfer. The temperature distribution along the perforated fin is examined in terms of perforation Parameters, where the perforation dimensions are different. The temperature distribution along the fin length with and without perforations for different materials is plotted. From the fin analysis we knew that the high fin temperatures mean high fin efficiency and effectiveness. Higher fin temperatures-exist as long as low fin thermal conduction resistance exists. As indicated in tis obvious that the temperature distributions show non-uniform curves caused by perforations. The perforations create a variation in the sectional area along the fin length and then lead to a variation in the fin thermal resistance. The variation effect of the perforated area on its thermal resistance decreases as the thermal conductivity increases. So the curves become more uniform. The temperature is at tip is maximum for the fin without perforations as compared to fins with perforations. It is seen that the temperature drop increases with the addition of perforations. : t is also seen that temperature decrease along the length of the solid fins and perforated fins varies with respect to thermal conductivity of materials. To compare the temperature distribution of the perforated fin with that of the solid one. The temperature difference distribution of the solid fin and the perforated fin *(Tsf -Tpf)* is plotted in. As shown in the figure it is obvious that the temperatures along the solid fin are always higher than those of the perforated one in all cases. This is because the thermal conduction resistance of the perforated fin is always higher than that of the corresponding non-perforate done. As the thermal conductivity increases, the difference *(Tsf - Tpf)* decreases and approaches zero as the thermal conductivity approaches infinity.

Raseelo j moitsheki et al (2005) has done Transient heat transfer in longitudinal fins of various profiles with temperature-dependent thermal conductivity and heat transfer coefficient. Harley In this exercise, heat transfer through various fin geometries is modeled. Geometry configurations such as rectangular, trapezoidal, triangular, cylindrical, and parabolic profiles are available. The length, base thickness, and end thickness of the fin can be specified. Coarse, medium, and the mesh types are available. Thermal conductivity of the fin material can be specified. Constant temperature or uniform heat flux boundary conditions can be applied at the base of the fin. Fully insulated or convective boundary conditions can be applied at the tip of the fin. The exercise reports base wall temperature, total area for heat convection, heat dissipation rate, efficiency, and electiveness. Contours of temperature can be displayed. The following thermal boundary conditions may be specified at the base of the fin. Temperature Heat flux either fully insulated or convective type boundary conditions may be applied at the tip of the fin. For non-cylindrical fins, the fin is assumed to be infinitely wide and side surfaces of the fin are assumed to be fully insulated. A convective type boundary condition is applied at all other walls. The mesh is exported to FLUENT along with the physical properties and the specified initial conditions. The material properties and the initial conditions are read through the case file, and the journal file provides instructions for the solver to start the solution. FLUENT solves the problem until either the convergence limit is met or the number of iterations specified by the user is achieved. Upon completion, FLUENT exports the data to a neutral file and to .xyplot files. GAMBIT reads the neutral file for post-processing activities.

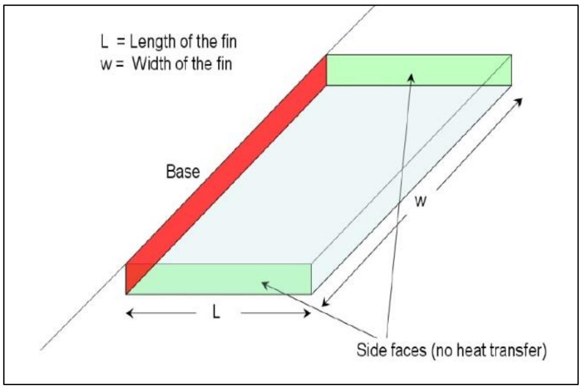

Fig.1 Non cylindrical fin

The maximum temperature allowed by FLUENT (hence Flow Lab as well) is 5000 K. If the temperature exceeds this limit, the temperature will be artificially restricted to 5000 K. Hence, the results obtained for cases where the temperature exceeds this limit may not be correct. Difficulty in obtaining convergence or poor accuracy may result if input values are used outside the upper and lower limits suggested in the problem overview. Ajay paul.J et al (2001) Experimental and parametric study of extended fins in the optimization of internal combustion engine cooling using CFD .In this experiment the single cylinder air cooled engines was assumed to be a set of annular fins mounted on a cylinder. Numerical simulations were carried out to determine the heat transfer characteristics of different fin parameters namely, number of fins, fin thickness at varying air velocities. A cylinder with a single fin mounted on it was tested experimentally. The numerical simulation of the same setup was done using CFD. The results validated with close accuracy with the experimental results. Cylinders with fins of 4 mm and 6 mm thickness were simulated for 1, 3, 4 & 6 fin configurations.

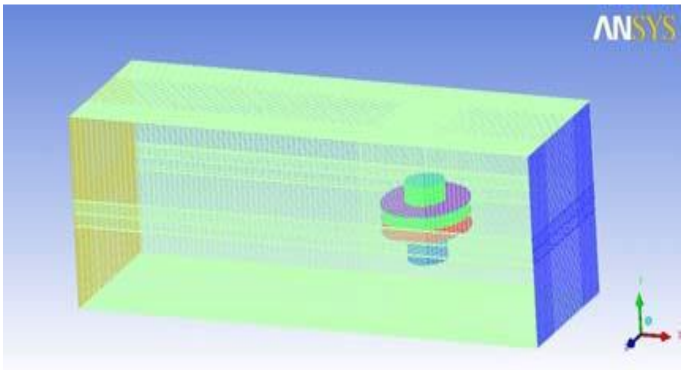

Fig.2 Extended Fins

Some of the following assumptions are made for the analysis of the fins.
1. The heat flow through the fin is considered as in steady state, so that the temperature of the fin does not vary with time.
2. The contact thermal resistance between the cylinder the fin is not considered.
3. The temperature of the fin does not vary along the thickness of the fin.
4. The thermal conductivity of the fin material is uniform and constant.
5. The radiation heat transfer of the fin is neglected.
6. Uniform ambient temperature of 306 K is considered

Both the fluids SAE 40 oil and air are assumed to be incompressible fluids. Ambient temperature and pressure are assumed as 306 K and 101325 Pa respectively. The values of the boundary conditions like operating temperature, velocity of air are taken from the experimental work. Other boundary conditions like density, specific heat, thermal conductivity and other material properties are considered as constants throughout the analysis. The mesh is imported to ANSYS-FLUENT and then the domains are initialized. The boundary conditions and the interface cylinder, fins, oil and air are set in the solver. The top and bottom of the cylinder surface are assumed to be adiabatic as it is insulated as per the experiment. The oil domain is initialized at a temperature of 423 K as the initial temperature of the domain as per the experiment. The heat transfer takes place due to natural convection and conduction up to 393 K so that the fins and cylinder can be initialized with some higher temperature value than ambient temperature. After the temperature reaches 393K air at inlet velocity of 0 km/hr. is passed over the cylinder and fins. The heat release from ethylene glycol from 393K after a time period of 10 minutes is calculated.

The following are the conclusions made
1. The difference of heat transfer between 4mm fins and 6mm fins are negligible same at zero velocity. So for stationary engines, fins of 4mm can be used with little difference in heat transfer, but helps in reducing the cost.
2. The heat transfer from 6mm fins is found to be the higher at high velocities. For high speed vehicles thicker fins provide better efficiency.
3. When fin thickness was increased, the reduced gap between the fins resulted in swirls being created which helped in increasing the heat transfer.
4. Large number of fins with less thickness can be preferred in high speed vehicles than thick fins with less numbers as it helps inducing greater turbulence and hence higher heat transfer.
5. The heat transfer from the outside portion of the finis found to be less. This is our future scope of our study, as we try to increase its convection by providing slits and holes.

3. 3-DIMENSIONAL MODELING

The rod is designed using ANSYS workbench. Three rods are attached with the circular rectangular and pin fins. The images are shown below.

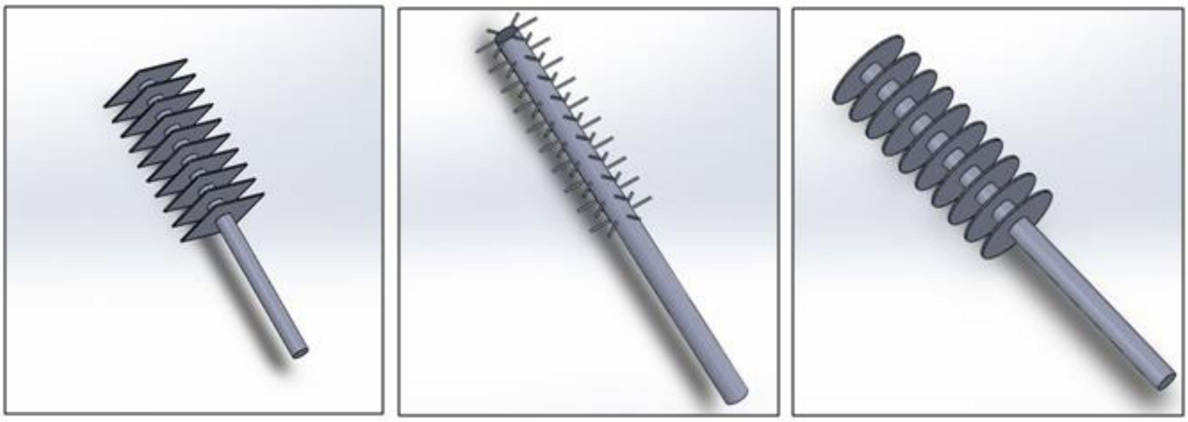

Fig.3 Three dimensional models of the different types of pins

4. EXPERIMENTAL WORK

4.1 Experimental Procedure

- The circular rod of 60 cm was taken.
- Three type of fins such as circular, rectangular and pin fins are joined to the circular rods by welding process for 30 cm
- Remaining 20cm of the rod is winded by the threads to prevent heat loss.
- The 10 cm of the rod is used for heating.
- The circular rod is heated at the end up to 100 c.
- Then it is left for natural convection process.
- The temperature at the various points of the rod is measured by the thermocouple.
- The amount of heat distributed is measured.
- Then the effectiveness is calculated separately.

- The temperature distribution along various fins is analyzed by the software ANSYS.

4.2 Fabricated Work

4.2.1 Circular rod with the circular fins

The circular MS rod of 60 cm was taken and they were divided into three parts. The first part 30 cm of the rod is attached with the fins. The second part of 20 cm was winded with the thread to prevent heat loss. The third part of the rod is used for heating.

4.2.2 Circular rod with rectangular fins

The circular MS rod of 60 cm was bought in 3 numbers and they were divided into three parts. The first part 30 cm of the rod is attached with the rectangular fins. The second part of 20 cm was winded with the thread to prevent heat loss. The third part of the rod is used for heating.

4.2.3 Circular rod with pin fins.

The circular MS rod of 60 cm was bought in 3 numbers and they were divided into three parts. The first part 30 cm of the rod is attached with the pin fins. The second part of 20 cm was winded with the thread to prevent heat loss. The third part of the rod is used for heating.

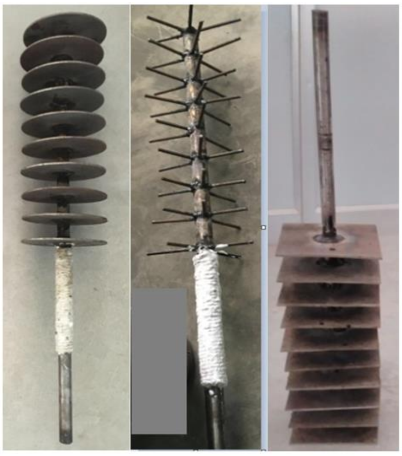

Fig.4 Different configuration of fabricated fins

4.2.4 Experimental procedure

- The circular rod is heated at the end up to 100 c.
- Then the heating process is stopped and allowed for the natural cooling.
- After the time span of 5 min the temperature is measured at the various fins using thermocouple.
- The temperature is tabulated for circular, rectangular, and pin fins. The temperature is compared.
- The experimental photos are shown below.

The main requirement of the natural convection heat transfer experiment is controlled environmental conditions. The experiment must be away from fans and flow of outside air. Hence to provide natural convection conditions, the experiments were conducted and windows were closed so that readings should not affect by the outside atmosphere and to provide similar atmospheric conditions for all experiments.

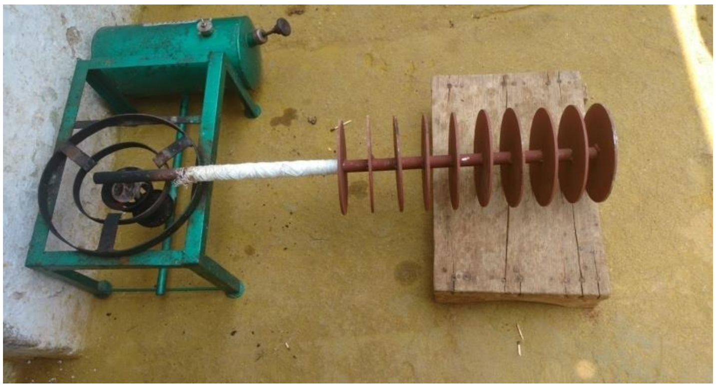

Fig.5 Circular rod attached with circular disc fins

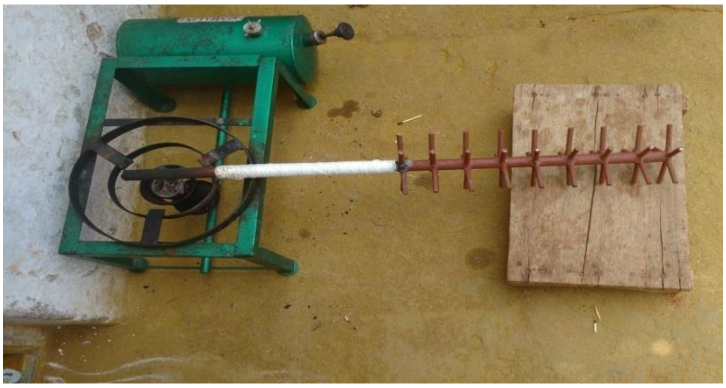

Fig.6 Circular rod attached with circular rod pin fins

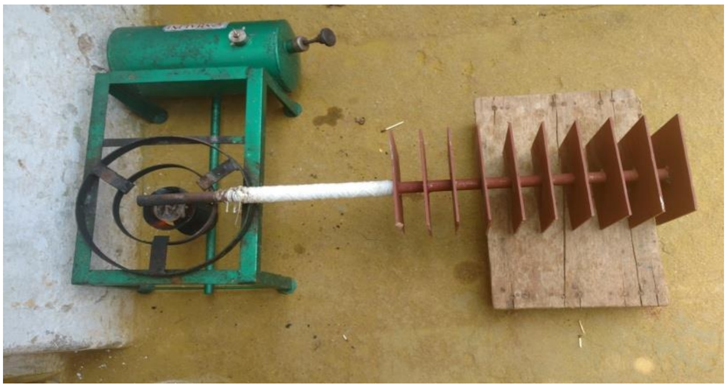

Fig.7 Circular rod attached with rectangular fins

4.2.5 Heat transfer rate

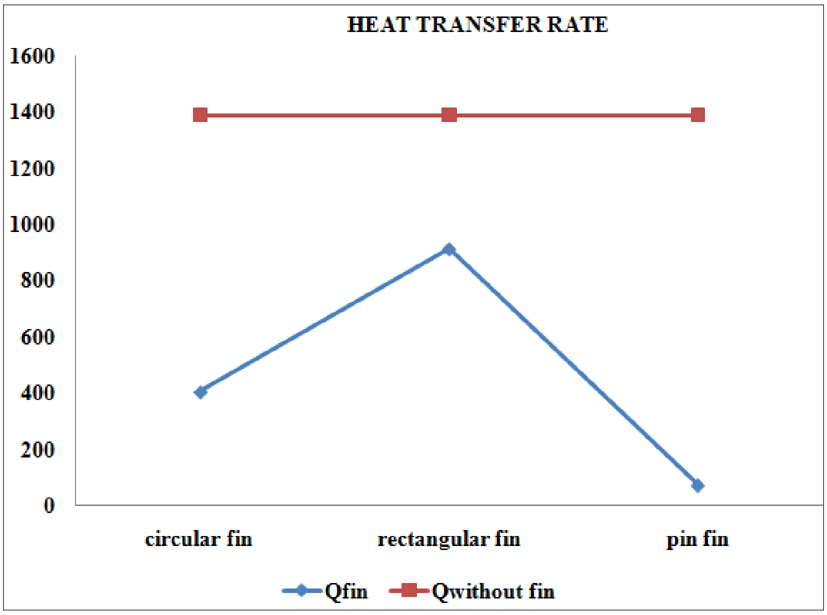

Fig.8 Heat transfer rate of fins

4.2.6 Fin effectiveness

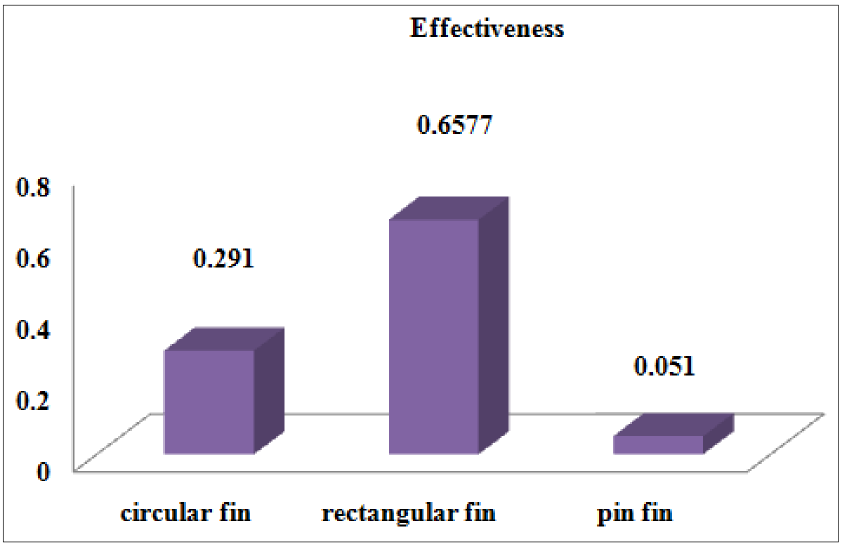

Fig.9 Effectiveness of fins

The figure.8 reveal that the amount of heat transferred by the circular fin is lower than the rectangular fin and higher than the pin fin, i.e., rectangular fin transfers more amount of heat when compared to the others. It is because that the rectangular fin has more amount of surface area when compared to circular and pin fin. The figure.9 shows the graph of effectiveness of various fins. The effectiveness is the ratio of the amount of heat transferred with fin to the amount of heat transferred without fin. It reveals that rectangular fin has more effectiveness than circular and pin fin. It is because that rectangular fin has more contact area with air, so the amount of heat transferred is higher for rectangular fins.

5. NUMERICAL ANALYSIS

The designed part of the fins were converted into IGES format and imported to the ANSYS fluent. The boundary conditions were given and the thermal analyses were done.

5.1 CFD modeling and simulation

The CFD modeling, simulation and post processing are carried out in an ANSYS 14.0, Workbench environment with an ANSYS system of fluid flow. It has the capability of solving the convective transport of energy by fluid flow along with the conjugate heat transfer (CHT) capability to solve the thermal conduction in solids .The steps in performing fluid analysis are
1) Create or import geometry
2) Create a mesh
3) Set up the analysis that will be sent to the solver
4) Control and monitor the solver to achieve a solution
5) Visualize the results in a post-processor and create a report.
These steps are briefed below.

5.5.1 Create Geometry

Geometry was created using ANSYS Design Modeler software which is specifically designed for the creation and preparation of a geometry for simulation. A domain has to be built around the fin to study mass flow and thus the heat flow from the fin, because the area of interest is the outside of fin, which is the interface between the air and fin surface. Thus, connections are required between the solid fin surface and the fluid domain consisting of air. Initially the domain of fin including base was created and required domain of fluid of size 172x140x130mm created with the help of the 'Enclosure' option around the fin .The setup was modeled with full geometry so that maximum physics of experimental analysis can be included. Hence it is logical to assume that the behavior of the created system domains is similar to the behavior of the experimental system.

5.5.2 Create a Mesh for the Geometry

The standard volume Meshes in a CFX-Mesh is the Advancing Front Volume Meshes. It enables an automatic tetrahedral mesh generation using efficient mesh generation techniques, meshes were created with high contact sizing relevance (dense meshing near the fin surface), inflation growth rate 1.2 and total number of tetrahedral elements between 3.0 to 3.5 million.

5.5.3 Setup the Analysis that will be sent to the Solver

Under the ANSYS Workbench, selected Analysis type 'Steady State'. The appropriate boundary conditions were applied to the domains. Materials Aluminum and Air were assigned to the created solid and fluid domain respectively. The interface between solid fin surface and fluid was created by using the option 'Domain Interface', having chosen 'Fluid Solid' interface under the basic settings. Activated buoyancy in Y direction, chosen Turbulence model as Laminar. Through the use of the boundary condition of 'opening' to all sides of the enclosure faces except the bottom face (set to adiabatic) the size of the fluid domain can be reduced to a great extent and it can be assumed to be as the atmospheric conditions. Under fluid domain a layer adjacent to the bottom face of fin base was set to adiabatic. Under the domain fin and base, bottom surface of a base of the fin, set the boundary condition to 'Heat Flux'. The heat flux was applied equal to the QN/AB of the experimental readings. Other vertical sides of base plate set to boundary condition as adiabatic.

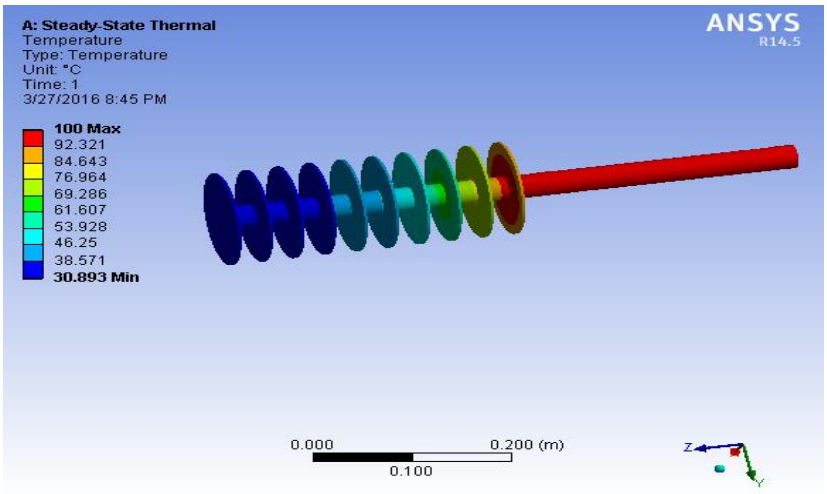

Fig.10 Temperature distribution of circular rod

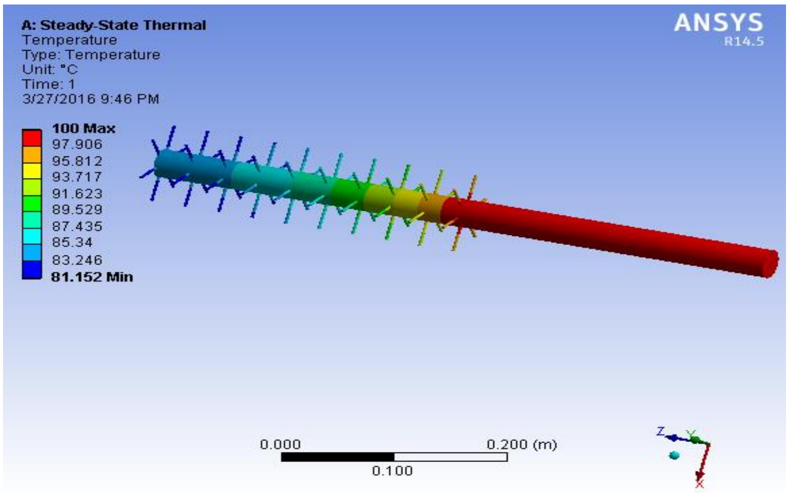

Fig.11 Temperature distribution of pin fins

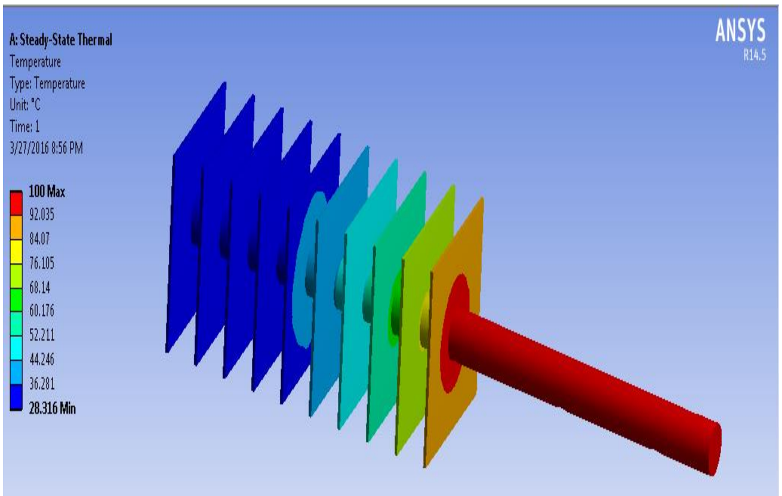

Fig.12 Temperature distribution of rectangular fins

5.5.4 Assumptions made in this analysis

- Homogenous and isotropic fin material. The thermal conductivity of the fin material is constant.
- Uniform heat transfer coefficient 'h' over the entire fin surface.
- No heat generation within the fin itself.
- Steady state heat dissipation.

6. RESULT AND DISCUSSION

Using the CFD software the fluid analysis is done with existing design. The dimensions of the cylinder length, cylinder thickness, cylinder inner and outer diameter are initialized by us to a certain value corresponding to the existing available design.
The parameters to be considered while designing are

- Heat transfer
- Effectiveness of fin.

The output parameters are efficiency and the effectiveness of the fin which are considered for the comparison of results of different cross sections of the fin.

S.No	Fins	Weight (kg)	Cost (Rs)
1	Pin	1.350	70
2	Circular	3.750	185
3	Rectangular	4.540	280

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