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Transient Thermal Analysis for Heat Dissipation from Engine Cylinder Block with Different Shaped Holes in Fins using CFD

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ABSTRACT

The cost of fuel and materials in all sectors is rising day by day. In the IC engine, the engine fails primarily because the heat transfer from the cylinder wall to the ambient air is inadequate. Heat is derived from the cylinder wall in the engine by means of convection heat transfer through the fins. In this study, a 3-dimensional numerical (3-D) transient thermal state simulation was used to investigate the heat dissipation of the engine cylinder fin with holes of different shapes (hexagonal and an elliptical). ANSYS 17.0 simulation software was used to research the physiognomy of the heat transfer physiognomies of an engine cylinder fin with and without hole. The results indicate that, the fin with an elliptic hole attain a temperature of 797.94 °C at 14 seconds in comparison to other where with hexagonal hole 798.02 °C, and without hole 798.14°C. So above values clearly shows that fin with an elliptic hole dissipates more heat as compare to fin with hexagonal hole or without hole. Fin with an elliptic hole have a total heat flux of 56122 W/m^2 comparison to other where with hexagonal hole 49967 W/m^2, and without hole 46704 W/m^2. From the above results it is clearly shows that, the new proposed shape fin or fin configuration will greatly improve the heat transfer rate and increase the fin efficiency. Optimum results are obtained when we provide an elliptic hole in an engine cylinder fin.

KEYWORDS: *Convective heat transfer, Fins, Hole, Numerical analysis, Fluid flow, Temperature distribution, Heat flux, and CFD*

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1. INTRODUCTION

In order to prevent degradation and overheating of IC engines, unnecessary heat from the system is removed by means of air-cooling. Fins are also best used to improve convective heat transfer without overuse of the primary surface. To achieve optimum effectiveness, the option of fin configuration is very critical. The heat transfer from surfaces is typically increased by increasing the surface's heat transfer region or the heat transfer coefficient. Extended fins are popular for optimizing the heat transfer of IC engines. For this reason, it is important to use the fins more efficiently by an air-cooled engine to ensure that the temperature on the cylinder periphery is constant.

1.1. Cooling system for I.C. Engines

We know that in case of Internal Combustion engines, combustion of air and fuel takes place inside the engine cylinder and hot gases are generated. The temperature of gases will be around 2300-2500°C. This is a very high temperature and may result into burning of oil film between the moving parts and may result into seizing or welding of the same. So, this temperature must be reduced to about 150-200°C at which the engine will work most efficiently. Too much cooling is also not desirable since it reduces the thermal efficiency. So, the object of cooling system is to keep the engine running at its most efficient operating temperature. It is to be noted that the engine is quite inefficient when it is cold and hence the cooling system is designed in such a way that it prevents cooling when the engine is warming up and till it attains to maximum efficient operating temperature, then it starts cooling.

It is also to be noted that:

A. About 20-25% of total heat generated is used for producing brake power (useful work).
B. Cooling system is designed to remove 30-35% of total heat.
C. Remaining heat is lost in friction and carried away by exhaust gases.

There are mainly two types of cooling systems: **(a) Air cooled system, and (b) Water cooled system.**

1.1.1. Air Cooled System

Air cooled system is generally used in small engines say up to 15-20 kW and in aero plane engines. In this system fins or extended surfaces are provided on the cylinder walls, cylinder head, etc. Heat generated due to combustion in the engine cylinder will be conducted to the fins and when the air flows over the fins, heat will be dissipated to air. The amount of heat dissipated to air depends upon:

A. Amount of air flowing through the fins.
B. Fin surface area.
C. Thermal conductivity of metal used for fins.

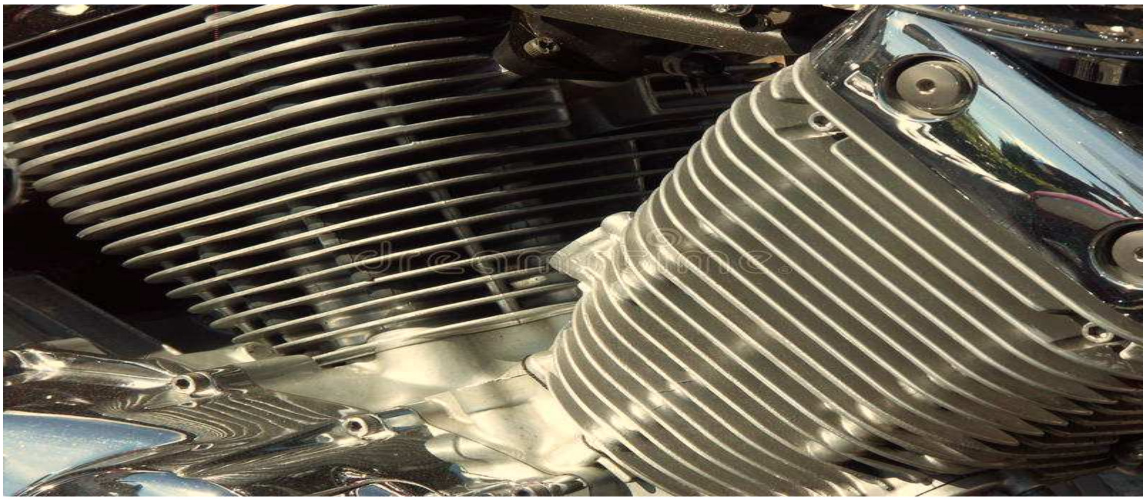


Figure 1 Cylinder with fins

Advantages of air Cooled System

A. Radiator/pump is absent hence the system is light.
B. In case of water cooling system there are leakages, but in this case there are no leakages.
C. Coolant and antifreeze solutions are not required.
D. This system can be used in cold climates, where if water is used it may freeze.

Disadvantages of air Cooled System

A. Comparatively it is less efficient.
B. It is used in aero planes and motorcycle engines where the engines are exposed to air directly.

1.1.2. Water Cooled System

In this method, cooling water jackets are provided around the cylinder, cylinder head, valve seats etc. The water when circulated through the jackets, it absorbs heat of combustion. This hot water will then be cooling in the radiator partially by a fan and partially by the flow developed by the forward motion of the vehicle. The cooled water is again recirculated through the water jackets.

1.1.2.1. Types of Water Cooling System

There are two types of water cooling system:

Thermo Siphon System

In this system the circulation of water is due to difference in temperature (i.e. difference in densities) of water. So in this system pump is not required but water is circulated because of density difference only.

Pump Circulation System

In this system circulation of water is obtained by a pump. This pump is driven by means of engine output shaft through V-belts.

1.2. Extended surfaces

The heat conducted through solids, walls or boundaries has to be continuously dissipated to the surroundings or to environment to maintain the system in steady state condition. In many engineering applications large quantities of heat have to be dissipated from small areas. Heat Transfer by convection between the surface and the fluid surrounding can be increased by attaching to the surface thin strips of metals called ns. Whenever available surface is found inadequate to transfer the required quantity of heat with available temperature drop and convective heat transfer coefficient, extended surfaces or fins are used. The fins increase effective area of surface thereby increasing the heat transfer by convection. The fins are also referred as extended surfaces. Fins are manufactured in different geometries depending upon practical applications. Fins may be of uniform or variable cross section.

Fins are used for cooling of electrical components, cooling of motor cycles, compressors, electrical motors, refrigerators, and radiators for automobiles.

Types of fins used based on their shape are: Straight fins, annular fins, longitudinal fins, rectangular fins, conical fins, Trapezoidal fins, parabolic fins, cylindrical fins, truncated conical fins, and triangular fins.

2. LITERATURE REVIEW

During several research projects in recent years, the heat transfer performance of the engine cylinder fin was the object of computational, theoretical and experimental work. Most work has been performed to increase the resulting heat dissipation in order to improve the heat transfer of engine fin.

Several studies on engine cylinder fin have been performed and their thermal and hydraulic characterization data are available in open literature. In these recorded similarities, however, there is a widespread difference and it was appropriate to examine the experimental facilities and procedures, methods of data reduction, findings and assumptions of some of the relevant past works before starting the present research.

2.1. Previous work

Denpong Soodphakdee et.al (2001) compared the heat transfer performance of various fin geometries. These consist of plate fins or pin fins, which can be round, elliptical, or square. The plate fins can be continuous (parallel plates) or staggered. The basis of comparison was chosen to be a circular array of 1mm diameter pin fins with a 2mm pitch. The ratio of solid to fluid thermal conductivity for aluminium and air is quite high, around 7000, permitting the fins to be modelled as isothermal surfaces rather than conjugate solids. The CFD simulations were carried out on a two-dimensional computational domain bounded by planes of symmetry parallel to the flow. The air approach velocity was in the range of 0.5 to 5m/s. the staggered plate fin geometry showed the highest heat transfer for a given combination of pressure gradient and flow rate [1].

Bassam A and K Abu Hijleh (2003) investigated the problem of cross-flow forced convection heat transfer from a horizontal cylinder with multiple, equally spaced, high conductivity permeable fins on its outer surface numerically. Permeable fins provided much higher heat transfer rates compared to the more traditional solid fins for a similar cylinder configuration. The ratio between the permeable to solid Nusselt numbers increased with Reynolds number and fin height but tended to decrease with number of fins. Permeable fins resulted in much larger aerodynamic and thermals wakes which significantly reduced the effectiveness of the downstream fins, especially at $\theta < 90°$. A single long permeable fin tended to offer the best convection heat transfer from a cylinder [2].

Han-Taw Chen and Wei Lun Hsu (2006) used the finite difference method in conjunction with the least-squares scheme and experimental temperature data to predict the average heat transfer coefficient and fin efficiency on the fin of annular-finned tube heat exchangers in natural convection for various fin spacing. The results show that the h value increases with increasing the fin spacing S, and the fin efficiency decreases with increasing the fin spacing S. However, these two values respectively approach their corresponding asymptotical values obtained from a single fin as $S \rightarrow \infty$ [3].

A. Mohammadi et.al. (2008) applied computational fluid dynamics (CFD) code to simulate fluid flow, heat transfer and combustion in a four-stroke single cylinder engine with pent roof combustion chamber geometry, having two inlet valves and two exhaust valves. Heat flux and heat transfer coefficient on the cylinder head, cylinder wall, piston, intake and exhaust valves are determined with respect to crank angle position. It was found that the local value of heat transfer coefficient varies considerably in different parts of the cylinder, but they have equivalent trend with crank angle. Based on the results, new correlations are suggested to predict maximum and minimum convective heat transfer coefficient in the combustion chamber of a SI engine [4].

N. Nagarani et.al. (2010) analyzed the heat transfer rate and efficiency for circular and elliptical annular fins for different environmental conditions. Elliptical fin efficiency is more than circular fin. If space restriction is there along one particular direction while the perpendicular direction is relatively unrestricted elliptical fins could be a good choice. Normally heat transfer co-efficient depends upon the space, time, flow conditions and fluid properties. If there are changes in environmental conditions, there is changes in heat transfer co-efficient and efficiency also [5].

Pulkit Agarwal et.al (2011) simulated the heat transfer in motor-cycle engine fins using CFD analysis. It is observed that when the ambient temperature reduces to a very low value, it results in overcooling and poor efficiency of the engine. It is observed that when the ambient temperature reduces to a very low value, it results in overcooling and poor efficiency of the engine. They have concluded that overcooling also affects the engine efficiency because of overcooling excess fuel consumption occurs. This necessitates the need for reducing air velocity striking the engine surface to reduce the fuel consumption. It can be done placing a diffuser in front of the engine which will reduce the relative velocity [6].

G. Raju et.al. (2012) investigated maximization of heat transfer through fin arrays of an internal combustion engine cylinder, under one dimensional, steady state condition with conduction and free convection modes. They used non-traditional optimization technique, namely, binary coded Genetic Algorithm to obtain maximum heat transfer and their corresponding optimum dimensions of rectangular and triangular profile fin arrays. They concluded [7]:
- Heat transfer through triangular fin array per unit mass is more than that of heat transfer through rectangular fin array. Therefore the triangular fins are preferred than the rectangular fins for automobiles where weight is the main criteria.
- At wider spacing, shorter fins are more preferred than longer fins.

S. M. Wange and R. M. Metkar (2013) have done, experimental and computational analysis of fin array and shown that the heat transfer coefficient is more in notch fin array than without notch fin array. Geometric parameters of fin effects on the performance of fins, so proper selection of geometric parameter such as length of fin, height of fin, spacing between fins, depth of notch is needed [8].

N. Phani Raja Rao et.al. (2014) analyzed the thermal properties by varying geometry, material and thickness of cylinder fins. Different material used for cylinder fin were Aluminum Alloy A204, Aluminum alloy 6061 and Magnesium alloy which have higher thermal conductivities and shown that by reducing the thickness and also by changing the shape of the fin to circular shaped, the weight of the fin body reduces thereby increasing the heat transfer rate and efficiency of the fin. The results shows, by using circular fin with material Aluminum Alloy 6061 is better since heat transfer rate, Efficiency and Effectiveness of the fin is more [9].

S. S. Chandrakant et.al.(2015) conducted experiments for rectangular and triangular fin profiles for air velocities ranging from 0 to 11 m/s. Experimental and CFD simulated result proves that annular fins with rectangular fin profiles are more suitable for heat transfer enhancement as compared to triangular fin profiles. Surface temperature of triangular fin profile is higher than rectangular fin profile at different air velocity. Heat transfer coefficient increase with increases with increases in velocity in both profiles. In comparison of both profile rectangular fin profile have higher heat transfer coefficient than triangular fin profile. In comparison of both profile rectangular fin profile transfer large amount of heat than triangular fin profile [10].

G. Babu and M. Lava Kumar (2016) analyzed the thermal properties by varying geometry, material and thickness of cylinder fins. The models were created by varying the geometry, rectangular, circular and curved shaped fins and also by varying thickness of the fins. Material used for manufacturing cylinder fin body was Aluminum Alloy 204 which has thermal conductivity of 110-150W/m-k and also using Aluminum alloy 6061 and Magnesium alloy which have higher thermal conductivities. They concluded that by reducing the thickness and also by changing the shape of the fin to curve shaped, the weight of the fin body reduces thereby increasing the efficiency. The weight of the fin body is reduced when Magnesium alloy is used and using circular fin, material Aluminum alloy 6061 and thickness of 2.5mm is better since heat transfer rate is more and using circular fins the heat lost is more, efficiency and effectiveness is also more [11].

M. Vidya Sagar et.al. (2017) analyzed the thermal properties like Directional Heat Flux, Total Heat Flux and Temperature Distribution by varying Geometry (Circular, Rectangular),material(Aluminium Alloy, Magnesium Alloy) and thickness of Fin (3mm,2mm) of an approximately square cylinder model prepared in SOLIDWORKS-2013 which is imported into ANSYS WORKBENCH-2016 for Transient Thermal analysis with an Average Internal Temperature and Stagnant Air-Simplified case as Cooling medium on Outer surface with reasonable Film Transfer Coefficient as Boundary Conditions. The results shows, by using circular fin with material Aluminum Alloy is better since heat transfer rate of the fin is more [12].

2.2. Problem finding of review

A great deal of research work in the area of engine cylinder fin has been undertaken. Design of fin plays an important role in heat transfer. There is a scope of improvement in heat transfer of air-cooled engine cylinder fin if mounted fin's shape varied from conventional one. Contact time between air flow and fin (time between air inlet and outlet flow through fin) is also important factor in such heat transfer. Circular fin are found to have the highest heat transfer dissipation capacity of all forms of fin.

Many researchers have explored different facets of engine cylinder fin to increase heat transfer, as summarized above. The heat transfer dissipation of engine cylinder fin with different shape holes has yet to be published, however.

3. METHODOLOGY

In this study, a 3-dimensional numerical (3-D) transient state simulation was used to investigate the heat dissipation of the engine cylinder fin with holes of different configurations in fins. ANSYS 17.0 simulation software was used to research the physiognomy of the heat transfer physiognomies of an engine cylinder fin, with different holes configurations.

The main objectives of the present work are as follows:

- To examine the thermal characteristics of an engine cylinder fin with holes of different configurations.
- To design fins with holes at different segments and carry out Transient Thermal analysis for heat transfer and find out best result of fin design.
- In order to build and test the engine cylinder fin model on a CFD model, comparisons will be made with the previous model.
- Thermal characteristics such as Temperature distribution, Heat Flux and Directional heat flux are evaluated in the effect of a hole in engine cylinder fin of different configurations.

3.1. Steps taken during the analysis

This chapter mentions the steps that have been taken place to achieve the objectives of the work.

- We first developed the CFD model of engine cylinder fin with holes of different configuration on ANSYS 17.0 for CFD research.
- Meshing of model is done on CFD pre-processor.
- The boundary conditions are applied on the model and numerical solutions are calculated by using solver.
- The FVM is used in solving the problem.
- The solution is calculated by giving iterations to the mathematical and energy equations applied on model.
- Validation will be carried on CFD model with previous model.
- Applying formulas for calculating Temperature distribution, Heat Flux and Directional heat flux.
- The results can be visualized in the form contours and graphs by CFD post processor.
- Result analysis.

4. COMPUTATIONAL MODEL AND NUMERICAL SIMULATION

The study uses the CFD model in this section to examine the heat transfer physiognomies of the engine cylinder fin with holes of different configurations. CFD analysis involves three major steps: (a) pre-processing, (b) solver execution, and (c) post-processing. The first step includes the creation of the geometry and mesh generation of the desired model, while the results are seen as expected in the last step. In the execution of the solver (medium) stage, the boundary conditions are fed into the model.

4.1. Geometry Setup

The geometry of engine cylinder fin performing the transient thermal simulation study is taken from the one of the research scholar's **M. Vidya Sagar et.al. (2017) [12]** with exact dimensions and after than in the proposed designs, the hexagonal hole and elliptical hole is provided in the fins of engine cylinder. The part of the model designed in ANSYS (fluent) workbench 17.0 software.

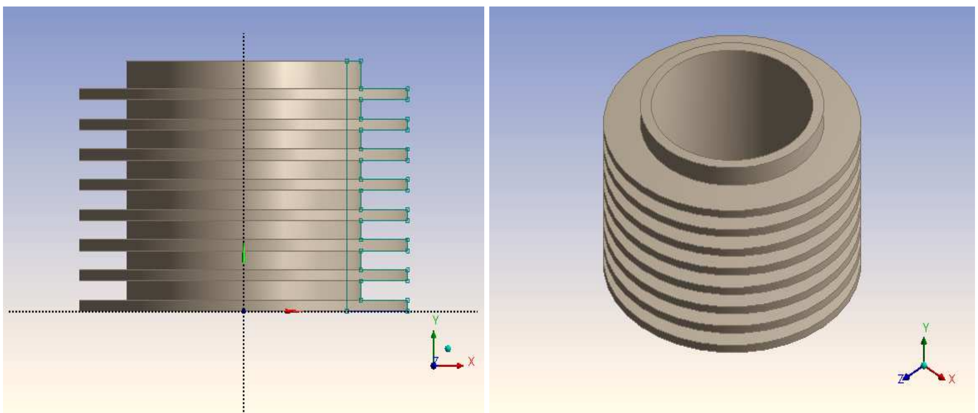


Figure 2.The geometrical model of engine cylinder with circular fin (conventional design).

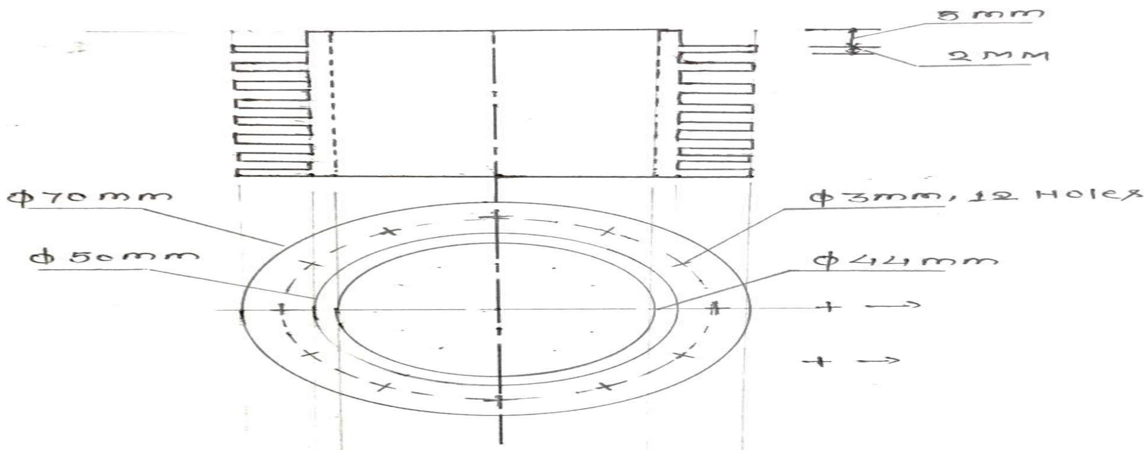


Figure 3 Geometrical specifications of engine cylinder fin with holes (Proposed model)

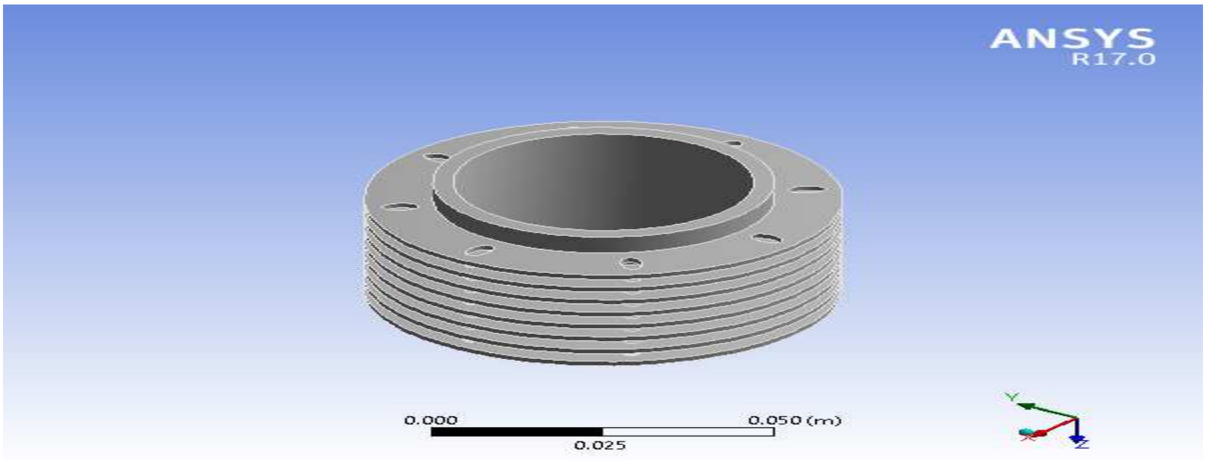


Figure 4 The geometrical model of engine cylinder fin with an elliptic hole (proposed design)

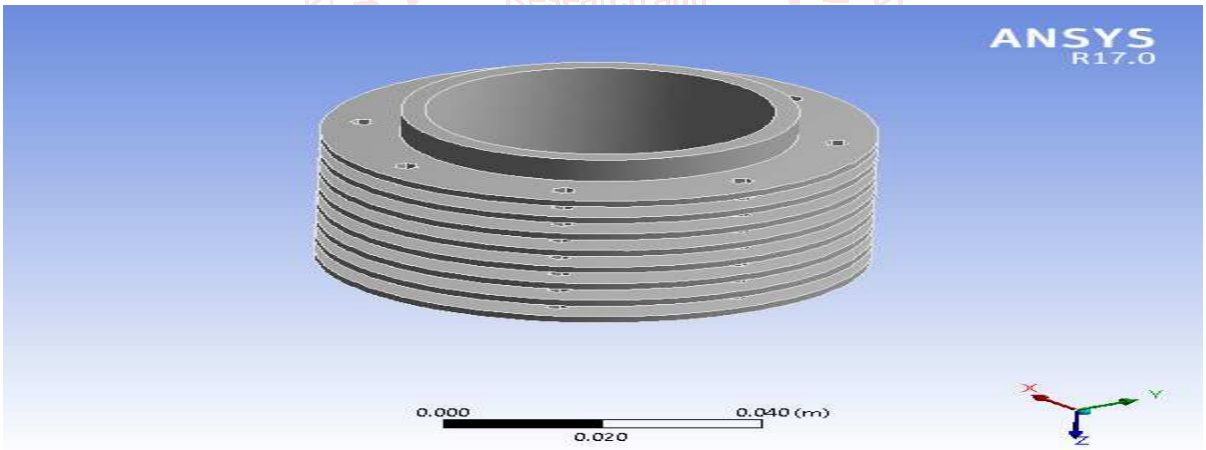


Figure 5 The geometrical model of engine cylinder fin with hexagonal hole (proposed design)

4.2. Meshing

In the pre-processor step of ANSYS FLUENT R 17.0, a three-dimensional discretized model of engine cylinder fin was developed. Although the styles of grids are connected to simulation performance, the entire structure is discretized in the finite volume by, default, a coarse mesh is generated by ANSYS software. Mesh contains mixed cells per unit area (ICEM Tetrahedral cells) having triangular faces at the boundaries. The meshing that has used in this transient thermal analysis is none mesh metric with medium smooth curvature. The mesh type generated tetrahedral meshing as shown in figure.

Table 1 Meshing detail of various models

S. No.	Parameters	Without hole	With an elliptic hole	With hexagonal hole
1	Curvature	On	On	On
2	Smooth	Medium	Medium	Medium
3	Number of nodes	8992	16666	15954
4	Number of elements	4656	8041	7856
5	Mesh metric	None	None	None
6d	Meshing type	Tetraheral	Tetrahedral	Tetrahedral

4.3. Model Selection and Solution Methods

Assumptions for analysis:

A. The temperature of the surrounding air does not change significantly.
B. Constant heat transfer coefficient is considered at the air side.
C. The heat generation is neglected.
D. Loads are constant.
E. Most of physical properties are constant

Table 2 Model Selection

Object Name	Transient Thermal (B5)
State	Solved
Definition	
Physics Type	Thermal
Analysis Type	Transient
Solver Target	Mechanical APDL
Options	
Generate Input Only	No

Table 3 Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	120. s
Auto Time Stepping	Off
Define By	Sub steps
Number Of Sub steps	120.
Time Integration	On
Solver Controls	
Solver Type	Program Controlled
Radiosity Controls	
Radiosity Solver	Program Controlled
Flux Convergence	1.e-004
Maximum Iteration	1000.
Solver Tolerance	0.1 W/m^2
Over Relaxation	0.1
Hemi cube Resolution	10.
Nonlinear Controls	
Heat Convergence	Program Controlled
Temperature Convergence	Program Controlled
Line Search	Program Controlled
Nonlinear Formulation	Program Controlled
Output Controls	
Calculate Thermal Flux	Yes
General Miscellaneous	No
Store Results At	All Time Points

4.4. Material Property

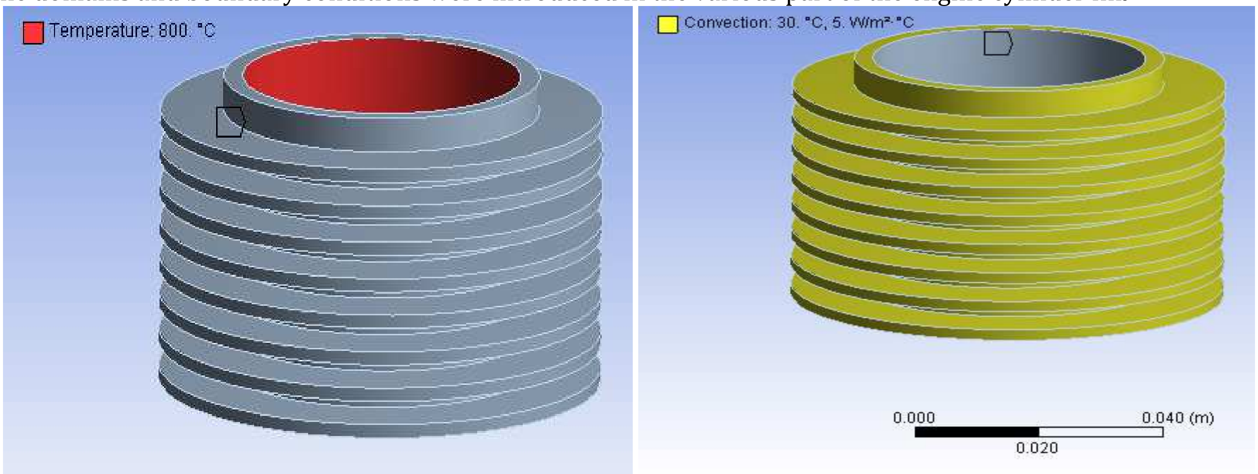
For any kind of analysis material property are the main things which must be defined before moving further analysis .There are thousands of materials available in the ANSYS environment and if required library is not available in ANSYS directory the new material directory can be created as per requirement. For the present work aluminum alloy used as a material.

Table 4 Thermophysical properties of Aluminium alloy

Material	Density (Kg/m^3)	Specific heat (J/Kg-K)	Thermal conductivity (W/m-K)
Aluminium Alloy	2770	880	202

4.5. Boundary Conditions

Machine domains and boundary conditions were introduced in the various part of the engine cylinder fin.



(a) (b)

Figure 6 Boundary condition of engine cylinder block (a) Inlet Temperature, (b) Ambient air temperature and convective heat transfer coefficient

Table 5 Boundary Conditions

Test conditions		
Type	**Temperature**	**Convection**
Magnitude	800. °C (step applied)	
Suppressed	No	
Film Coefficient		5. W/m²·°C (step applied)
Ambient Temperature		30. °C (step applied)

5. RESULTS AND DISCUSSIONS

This segment aims to evaluate the thermal performance of proposed designs i.e. effect of providing an elliptic and hexagonal hole on engine cylinder fin. To study the performance of engine cylinder fin with different configuration of holes in fin subject to flow, the variations in the Temperature distribution, Heat Flux and Directional heat flux are measured.

5.1. Validation of numerical computations

To validate the accuracy of developed numerical approach, comparison was made with the work reported in **M. Vidya Sagar et.al. (2017) [12].** The engine cylinder fin geometry that used for validation of numerical computations was considered to be as same as the geometry shown in Fig. 2. After using all boundary test condition we have acquired the next results which are shown in figure:

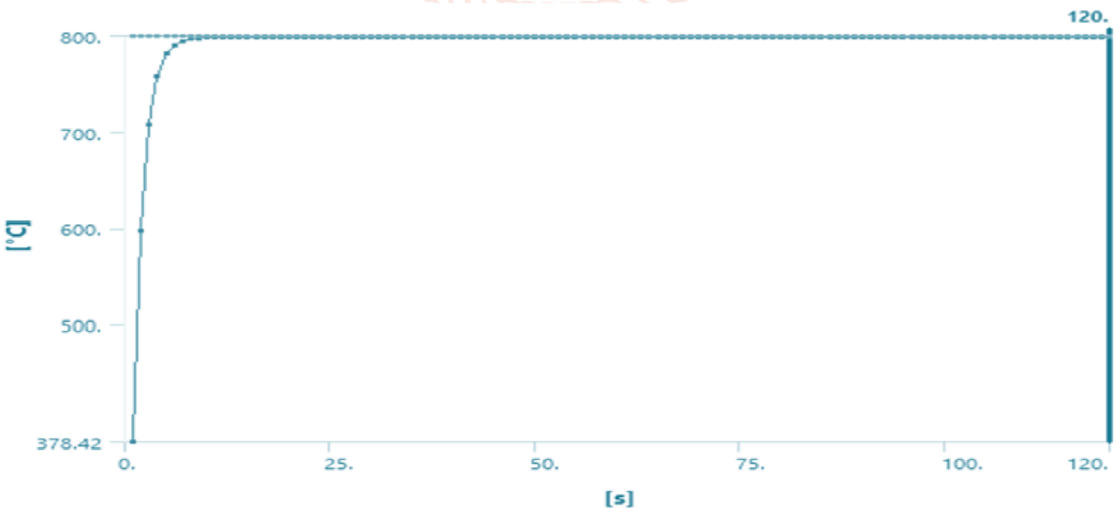


Figure 7 Temperature distribution over time for circular fin for step end time 120s

From the above result, we can observe that circular fin can attained maximum temperature of 798.13 °C and time taken to attained steady state condition is 14 seconds.

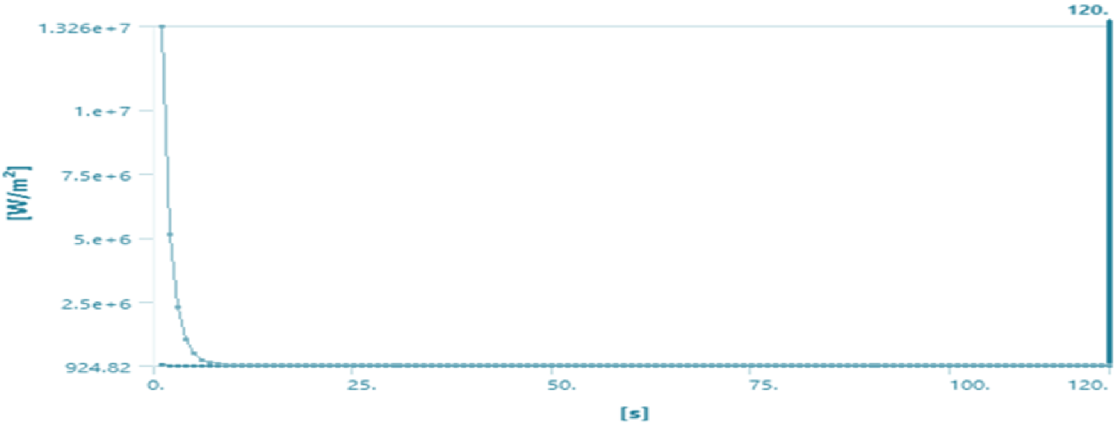


Figure 8 Total heat flux distribution over time for circular fin for step end time 120s

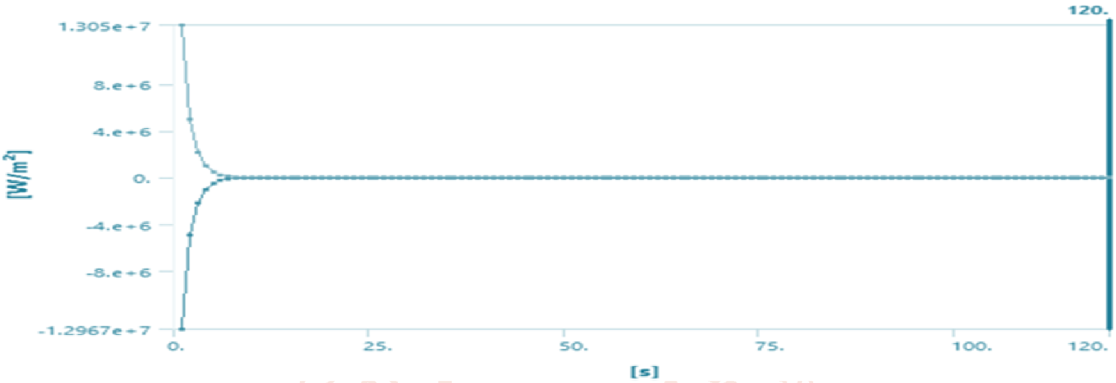


Figure 9 Directional heat flux distribution over time for circular fin for step end time 120s

Table 6 Maximum and minimum values of Temperature, total heat flux and directional heat flux obtained from numerical study

Results			
	Temperature	Total heat flux	Directional Heat flux
Minimum	798.14 °C	924.82 W/m^2	-44417 W/m^2
Maximum	800. °C	46704 W/m^2	45366 W/m^2

From the aforementioned validation study it is observed that the values of the temperature, total heat flux, and directional heat flux measured from CFD study are similar to the values of the temperature, total heat flux, and directional heat flux obtained from the base journal. So here we can claim the circular fin model is right.

5.2. Effect of an elliptic hole on engine cylinder fin

To investigate the heat dissipation characteristics of proposed designs using an elliptic hole in engine cylinder fin when subjected to flow, the temperature contours, total heat flux distribution, and directional heat flux distribution at after a 120 sec of operation and by the thermal transient analysis are presented below:

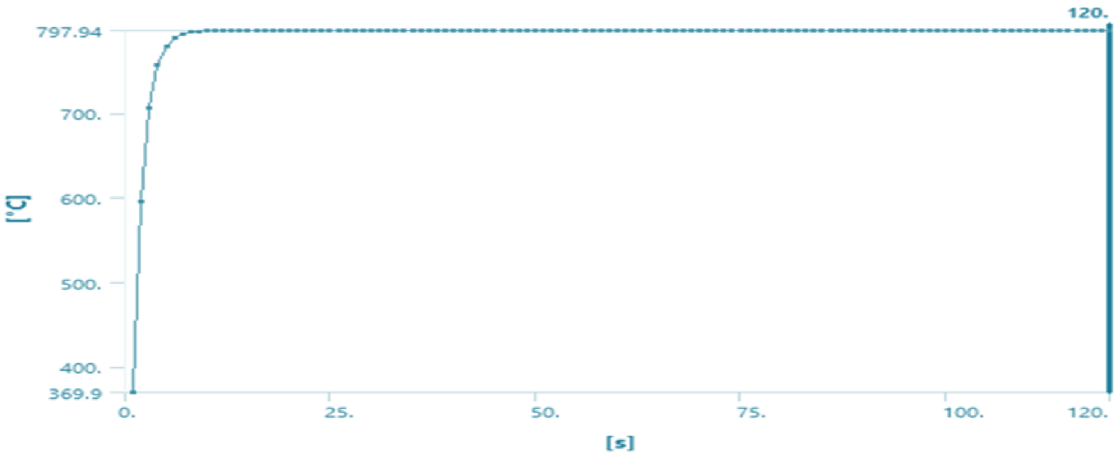


Figure 10 Temperature distribution over time for circular fin with an elliptic hole for step end time 120s

From the above result, we can observe that circular fin can attained maximum temperature of 797.93 °C and time taken to attained steady state condition is 14 seconds.

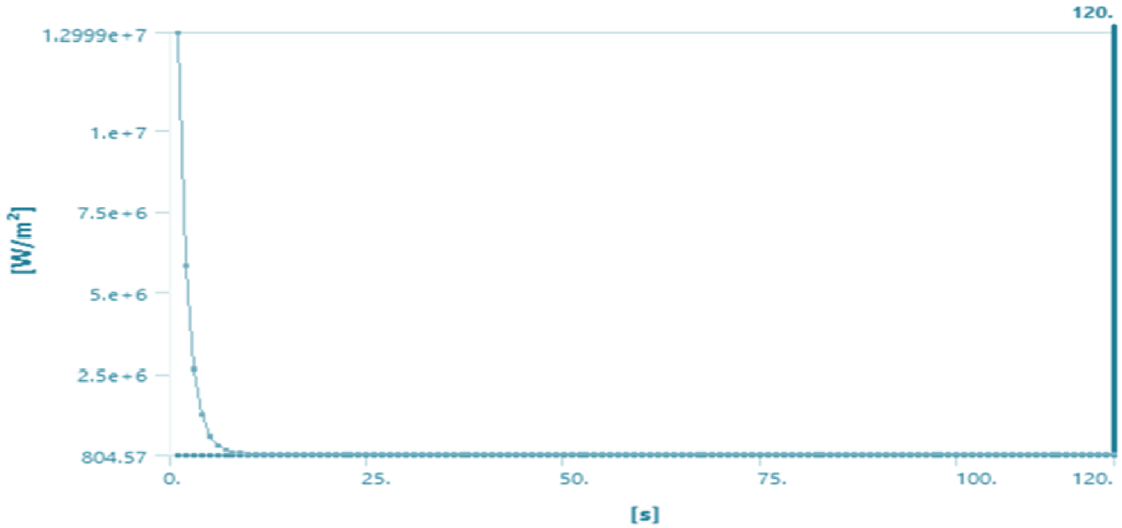


Figure 11 Total heat flux distribution over time for circular fin with an elliptic hole for step end time 120s

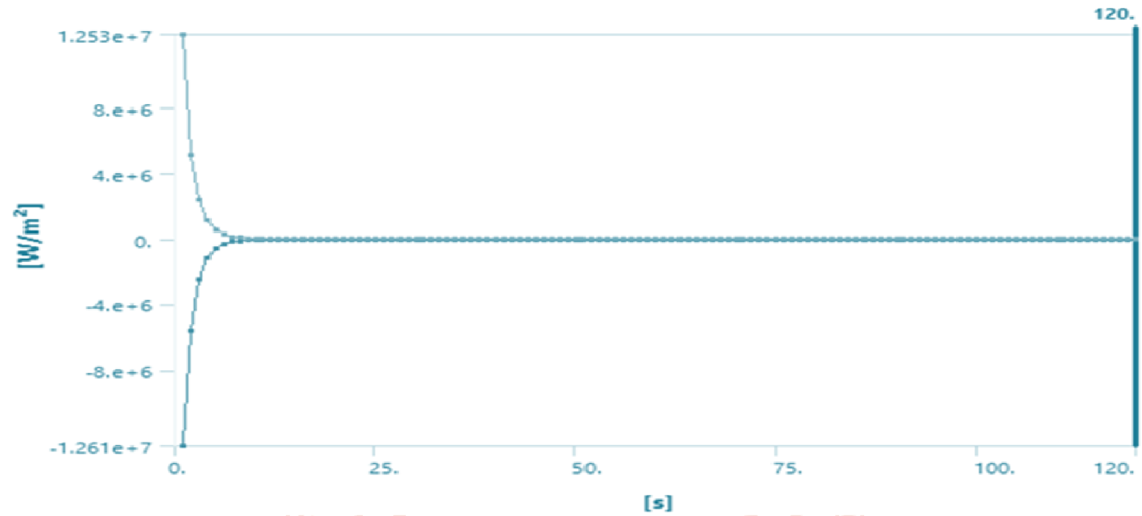


Figure 12 Directional heat flux distribution over time for circular fin with an elliptic hole for step end time 120s

5.3. Effect of hexagonal hole on engine cylinder fin

To investigate the heat dissipation characteristics of proposed designs using hexagonal hole in engine cylinder fin when subjected to flow, the temperature contours, total heat flux distribution, and directional heat flux distribution at after a 120 sec of operation and by the thermal transient analysis are presented below:

Figure 13 Temperature distribution over time for circular fin with hexagonal hole for step end time 120s

From the above result, we can observe that circular fin can attained maximum temperature of 798.01 °C and time taken to attained steady state condition is 14 seconds.

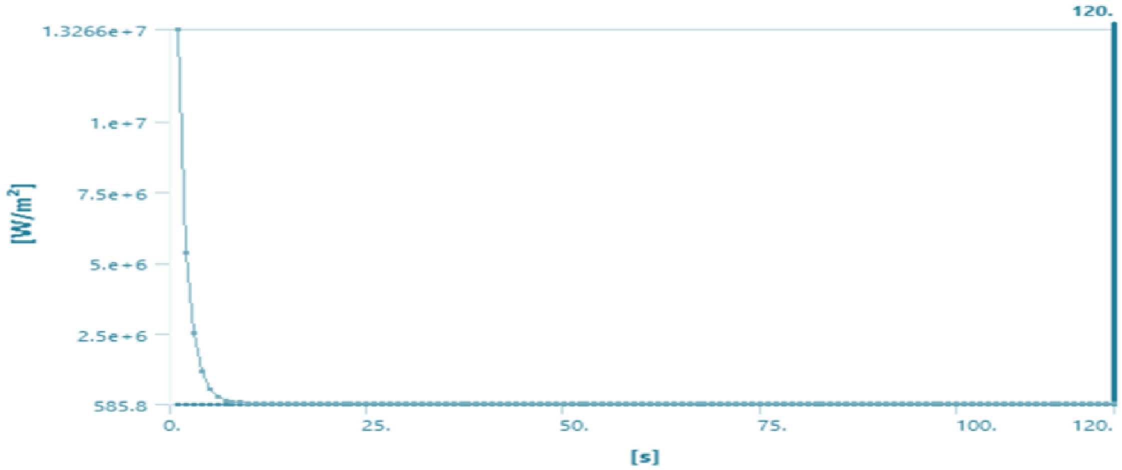


Figure 14 Total heat flux distribution over time for circular fin with hexagonal hole for step end time 120s

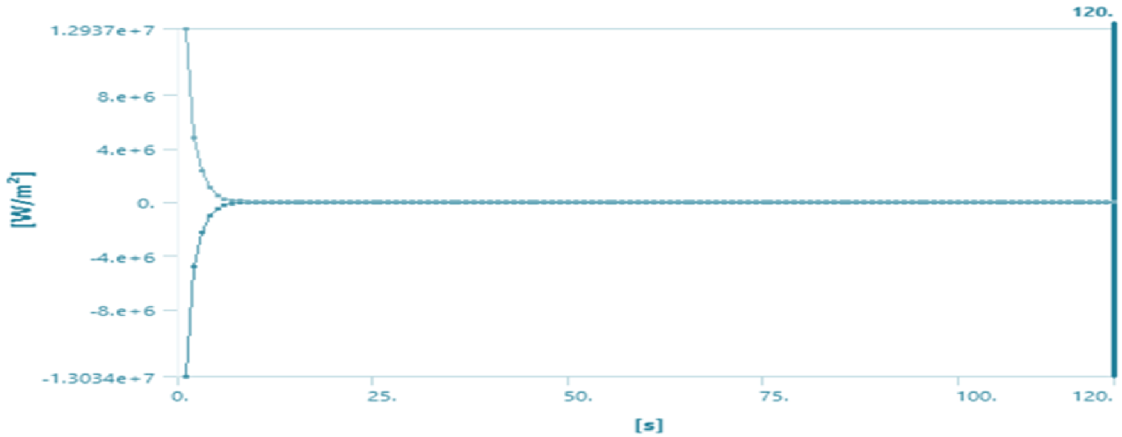


Figure 15 Directional heat flux distribution over time for circular fin with hexagonal hole for step end time 120s

5.4. Comparison of heat dissipation characteristics of engine cylinder fin with and without hole

Table 7 Distribution of temperature for engine cylinder fin with and without hole over time

Time [s]	Temperature [°C]		
	Without hole	With an elliptic hole	With hexagonal hole
1.	378.42	369.9	373.06
2.	598.07	594.97	597.08
3.	708.89	705.68	706.69
4.	758.75	756.45	756.9
5.	780.74	779.33	779.55
6.	790.46	789.6	789.73
7.	794.75	794.21	794.31
8.	796.65	796.27	796.36
9.	797.49	797.19	797.28
10.	797.86	797.6	797.69
11.	798.02	797.79	797.87
12.	798.09	797.87	797.95
13.	798.12	797.91	797.99
14.	798.13	797.93	798.01

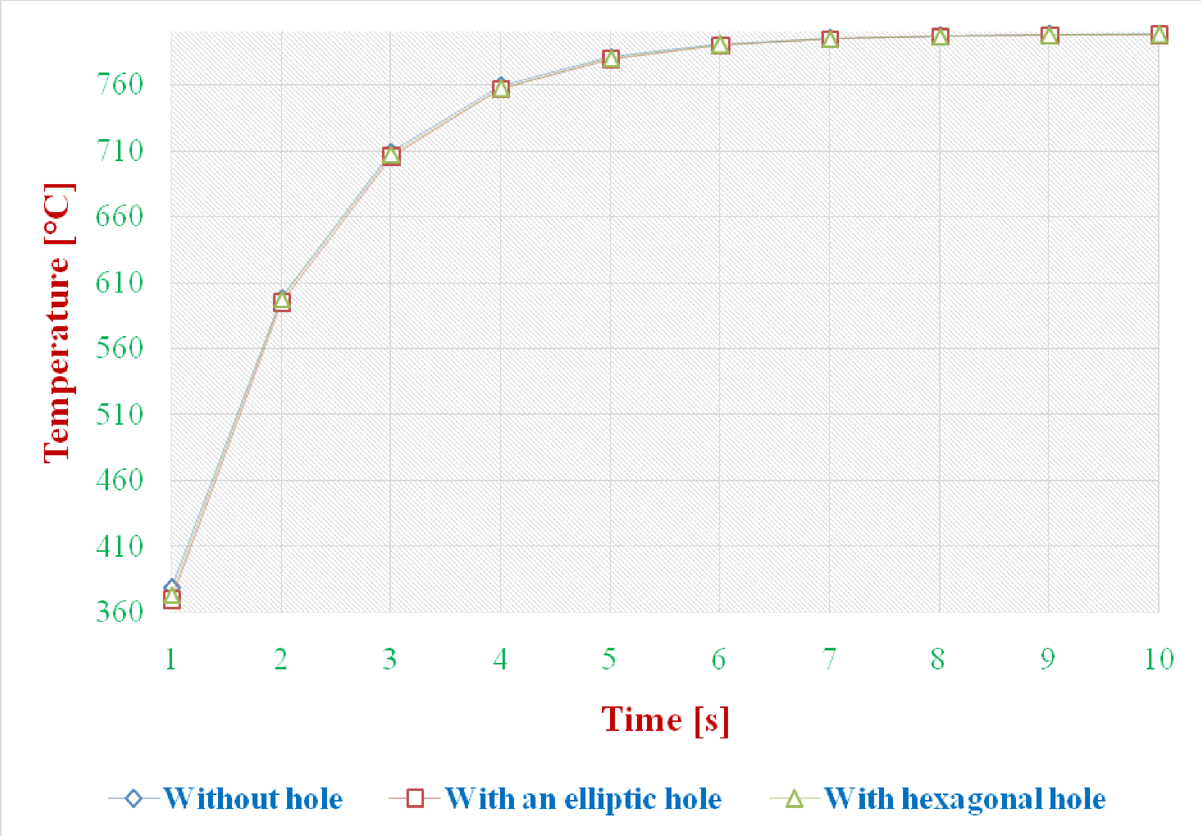


Figure 16 Distribution of temperature for engine cylinder fin with and without hole over time

Table 8 Maximum and minimum values of Temperature, total heat flux and directional heat flux for engine cylinder fin with and without hole

	Results			
	Fin	Temperature	Total heat flux	Directional Heat flux
Minimum	Without hole	798.14 °C	924.82 W/m²	-44417 W/m²
	With an elliptic hole	797.94 °C	1556.8 W/m²	-51973 W/m²
	With hexagonal hole	798.02 °C	1750.9 W/m²	-45333 W/m²
Maximum	Without hole	800. °C	46704 W/m²	45366 W/m²
	With an elliptic hole	800. °C	56122 W/m²	50751 W/m²
	With hexagonal hole	800 °C	49967 W/m²	45484 W/m²

6. CONCLUSIONS

New thermal designs for engine cylinder fin with hole of hexagonal and elliptical shapes have been established that enable the heat dissipation of system to be investigated using CFD codes. Analyzes of the tests give the following primary points:

- From the above results it is clearly shows that the fin with an elliptic hole attain a temperature of 797.94 °C at 14 seconds in comparison to other where with hexagonal hole 798.02 °C, and without hole 798.14°C. So above values clearly shows that fin with an elliptic hole dissipates more heat as compare to fin with hexagonal hole or without hole.
- Fin with an elliptic hole have a total heat flux of 56122 W/m² comparison to other where with hexagonal hole 49967 W/m², and without hole 46704 W/m².
- From the above results it is clearly shows that, the new proposed shape fin or fin configuration will greatly improve the heat transfer rate and increase the fin efficiency.
- Optimum results are obtained when we provide an elliptic hole in an engine cylinder fin.

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