Thermal Analysis of Extended Surfaces for Cooling of Heat Generated Devices

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Abstract-*Thermal analysis of heat generating device having different length of circular fins has been conducted in the present paper. 100 numbers of circular fins have been fitted over the heat generated device considered as base plate. Convective boundary conditions have been considered on all the surfaces of the assembly except the bottom surface on which a temperature boundary has been considered. Three different lengths of circular fins with 5, 10 and 15mm has been considered to study the effect of the length or available surface area on the heat transfer rate. From the study it has been found that the fin increases the heat transfer from the system where it has been fixed by raising the surface area presented for the releasing of heat and also increases the intensity of the flow near the heat generated device which further increases the heat dissipation rate. From the results it has been found that fins with largest length give highest cooling rate or heat transfer rate. Engine having circular fins of 10mm length shows 18°C more decrement in temperature compared to 5mm length circular fins. While engine having circular fins of 15mm length shows 112°C more decrement in temperature compared to 10mm length circular fins. But increasing the length of the fin also increases the weight of the engine assembly which one should have in mind while opting for a fin.*

I. INTRODUCTION

In engine, burning of air fuel mixture occur inside the cylinder and lots of heat produced in the moving and stationary parts of engine, if cooling mechanism are not provided to the engine it can damages the parts of engine. Heavy vehicles like four wheeler uses liquid cooling system while 2 wheeler engine uses air cooling system. Air cooling arrangement has some benefits for example lighter weight, easy maintenance and lesser space requirement. Air cooling is done by extended surfaces (fins) supplied at the outer surface of engine cylinder to release the heat. This is why the investigation of fin is essential.

Conduction Heat Transfer (Fourier's law of heat conduction)

The time of heat movement during a flat partition is directly proportional to the product of temperature difference across the wall and the region of heat transmit, and is inversely proportional to the width of the wall.

$$\text{Rate of heat conduction} \propto \frac{\text{Area} \times \text{Temperature difference}}{\text{Thickness}}$$

$$q'' = -k\frac{\partial T}{\partial x}$$

q'' = Heat flux W/m^2.
k = Thermal conductivity of the material, ability of a material to conduct heat. W/m-K
$\frac{\partial T}{\partial x}$Temperature gradient
Heat is flow towards fall of temperature gradient turns into negative while temperature reduces by rising of width x. The negative indications show that heat movement in the positive x direction.

Convection

In Convection, energy is transfer between solid surfaces to the adjacent gas (atmosphere) or liquid which is in action, and it engages the mutual effects of conduction and fluid motion. Heat transfer by convection based on the velocity of fluid. Convection is governed by Newton's law of cooling.
The rate of heat transfer from a surface at a temperature T_s to the surounding medium at T_∞ is given by Newtons law of cooling as

$$Q_{conv} = h\,A\,(T_s - T_\infty)$$

Where,
A =Heat transfer area, h = Convective heat dissipation coefficient.

Radiation

Radiation is the energy transfer in the form of waves through space without any medium other than conduction and convection. Conduction and convection require a medium like solid or gas but radiation only happen in space through electromagnetic waves. The velocity of radiation which can be emitted from an outside at an absolute temperature T is governed by the Stefan- Boltzmann law as

$$Q = \sigma A T^4$$

Where, σ =5.670 $\times 10^{-8}$ W/m^2 is the Stefan Boltzmann constant.
The black body is ideal surface for emits radiation at maximum rate, and the radiation transferred by a black body is called black body radiation.

Absorptivity α is another important property of a plane, is explained as the division of the radiation energy incident on a surface that is received by the surface. The entire radiation incident on it is absorbed by black body. That is, a blackbody is a perfect absorber (α=1) of radiation.

II. LITERATURE REVIEW

Tarvydas et al[1] in 2013 studied regarding the heat sink modelling and performance for an electronic element. They studied the result of the meshing processes on the time taken by COMSOL for completed solution of the heat Sink. Paul et al[2] in 2012 find out optimum solution of extended fins in the research of Internal burning of fuel in engine they found solution for top speed vehicles wider fins supplied improved efficiency. Results shows a huge number of fins with less width can be selected in high speed vehicles than wide fins with fewer numbers as it assists inducing better turbulence. Kumbhar et al[3] in 2009 find out the solution of heat transfer expansion from a horizontal rectangular fin by triangular perforations whose bases parallel and towards the fin base under natural convection has been calculated using ANSYS. The perforation of the fin enhance the heat removing rates at the same time reduces the expenses for fin equipment's also. Nagarani et al[4] in 2010 analyzed the heat removing rate and potency for circular and elliptical rounded fins for various environmental conditions. Elliptical fin efficiency is over than circular fin. If there are changes in ecological conditions, there are transform in heat transfer co-efficient and efficiency also.

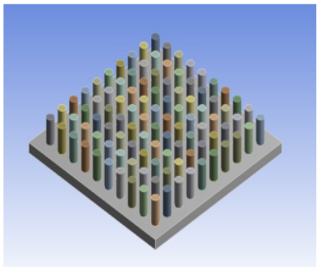
Pise et al[5] in 2010 investigated the research to evaluate the speed of heat transfer with solid and pervasive fins. It was found that permeable extruded surfaces block average heat removing velocity develops by about 5.63% and normal heat rejection coefficient 42.3% as evaluated to solid fins with decreasing of cost of the material 30%. Raju et al[6] in 2012 studied the finest plan of an IC engine cylinder fin array by a binary coded genetic algorithm. An outcome explains the benefit of triangular outline fin array. Heat transfer during triangular extruded surfaces array per unit mass is in excess of that the heat rejection by rectangular fin array. Patil et al[7] in 2013 find out CFD and investigational research of elliptical shaped fins for heat rejection parameters, heat rejection coefficient and tube effectiveness by artificial convection. The practical analysis is accepted for changed air stream speed with changing heat input. The CFD temperature division for all belongings confirms investigational results. At air moving rate of 3.7 m/s, the heat rejection speed decreases as heat participation increases. At air flow rate of 3.7 m/s the effectiveness, enhance as heat input increases.

Magarajan et al[8] in 2012 mathematically studied on heat rejection of I C Engine heat removing by extended surfaces on engine with the help of CFD. It is explained from the CFD consequence which it takes 174.08 seconds (pitch=10mm) and 163.17 sec (pitch =20mm) for ethylene glycol domain to achieve temperature of 423 K to 393 K for firstly. Wange et al[9] in 2013 conducted experimental and computational investigation of fin array and given that the heat removing coefficient is high in indentation fin array than not including notch fin array. Designing limitations of fin effects on the working of fins, so appropriate collection of geometric parameter. Nitnaware et al[10] in 2015 find out the result of fin designs. Also heat remove per unit mass of fin is higher for conical shape fin than rectangular shape therefore tapering fins are favoured over rectangular cross section fins. The speed of heat transfer increases with increase in h, linearly, for small values of h. Aluminium is the better material for designing fins for air-cooled IC engines due to low weight, high rate of heat transfer and lower cost.

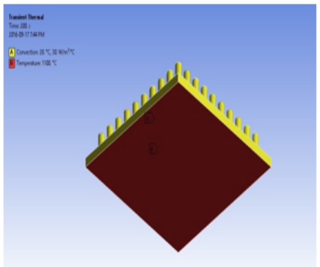
Ali et al[11] in 2012 find out the solution to improve heat transmit rate of cooling fins by over changing cylinder block fin form and size or climate condition. Inadequate deduction of heat from engine will guide to high thermal stresses and lower engine efficiency. The fin geometry and cross sectional area affects the heat movement capable. 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 larger heat transfer.

III. MODELLING AND BOUNDARY CONDITIONS

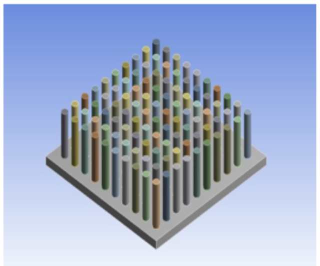
Three set of geometries have been considered. All geometries contain one base plate over which circular fins have been fitted. All the geometry has 100 numbers of fins. Figure 1(a-c) represents first, second and third geometry considered in the present study. First geometry has 5mm length circular fin, second geometry has 10mm length circular fin and third geometry has 15mm length circular fins. Base plate thickness is 2mm while its length and width are 38mm and 38mm respectively. Distance of 3.5mm in X-direction and Y-direction between two consecutive fins has been considered. Figure 2(a-c) represents the applied boundary conditions. Aluminium has been used in the present analysis table 1 shows its properties. On the base temperature (1100°C) has been applied while on all the other surfaces convective type boundary condition (30 $W/m^{2\circ}C$) has been considered.



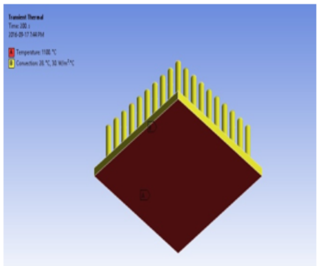
(a) 5mm length circular fins



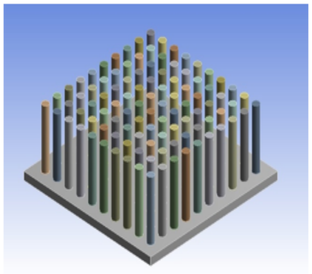
(a) 5mm length circular fins



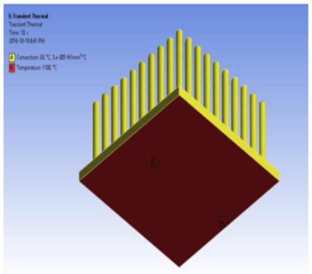
(b) 10mm length circular fins



(b) 10mm length circular fins



(c) 15mm length circular fins



(c) 15mm length circular fins

Figure 1(a-c): Circular fins with different length

Figure 2(a-c): Boundary conditions for corresponding geometry

Table 1: Thermal properties of Aluminium

S. N.	Property	Value
1	Thermal conductivity	170 W/m-K
2	Density	2800 Kg/m^3
3	Specific heat	870 J/kg-K

vehicles by their number plates without direct human intervention. The system work is generally framed into the steps: Number plate extraction, character segmentation and character recognition. From the entire input image, only the number plate is detected and processed further in the next step of character segmentation. In character segmentation phase each and every character is isolated and segmented. Based on the selection of prominent features of characters, each character is recognized, in the character recognition phase. This system is important in the area of traffic problems, highway toll collection, borders and custom security, premises where high security is needed. Previous works are Vehicle Number Plate Detection (VNPD) system algorithm based on template matching. They have devised an efficient method for recognition of Indian vehicle number plates.

IV. RESULT AND DISCUSSION

Figure 4, 5 and 6 represents the temperature distribution. Results for base plate having different length of circular fins have been presented here. It can be observed that maximum temperature is at the bottom of the base plate and minimum temperature is at the top surfaces of the fins. This concludes that fins helps in increasing the heat transfer by increasing the surface area available for releasing of the heat. It can also be observed that the base plate having 15mm length circular fins show low temperature at the outer surface when compared with circular fins of 5mm and 10mm length. This is because of the larger surface area available with increment in the length of the fins.

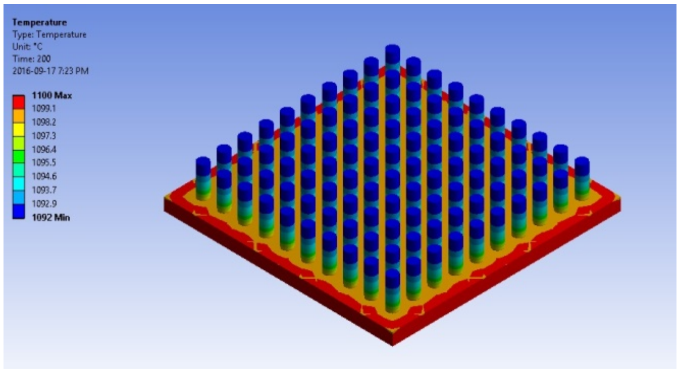


Figure 4: Temperature distribution for 5mm length circular fins

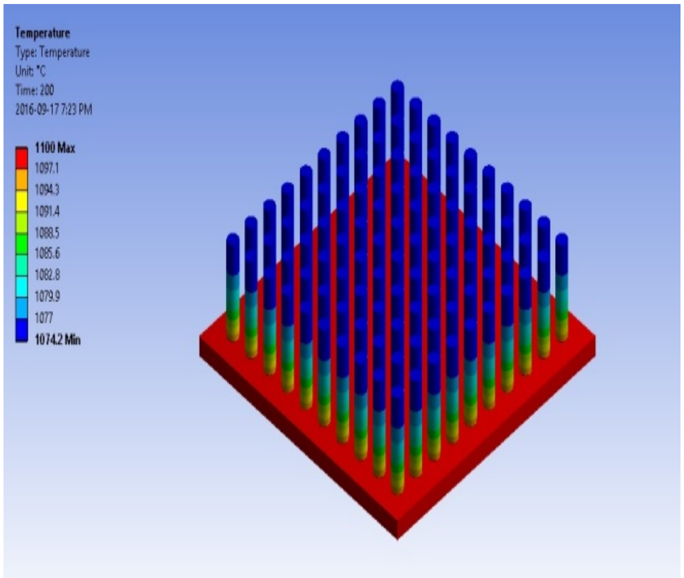


Figure 5: Temperature distribution for 10mm length circular fins

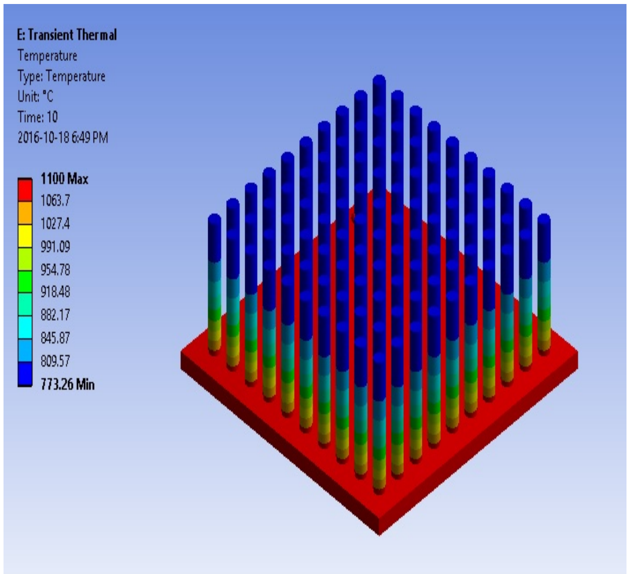


Figure 6: Temperature distribution for 15mm length circular fins

Figure 7, 8 and 9 represent the cooling curves between the time and temperature for all geometry considered in the present work. An end time of 10seconds has been considered for circular fins having length of 5mm and 10mm, while for third case (circular fins of 15mm length) an end time 40seconds has been considered. This is due to the reason that time-temperature curve for 5mm length circular fins shows no variation after a time of 1.5secons while time-temperature curve for 10mm length circular fins shows no variation after 5seconds. On the other hand time-temperature curve for 15mm length circular fins shows no variation after 37seconds. On the horizontal axis time has been considered while on the vertical axis temperature has been considered. One can easily observed from the time-temperature cooling curve that for fins with largest length (15mm) shows higher decrement in temperature when compared with time-temperature cooling curve for fins of 5mm length.

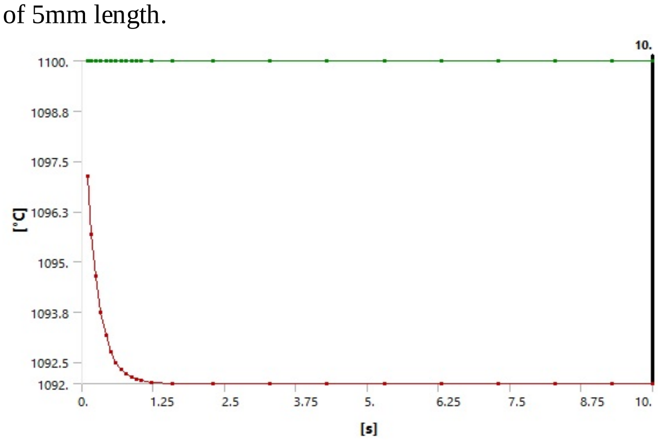


Figure 7: Time-temperature cooling curve for 5mm length circular fins

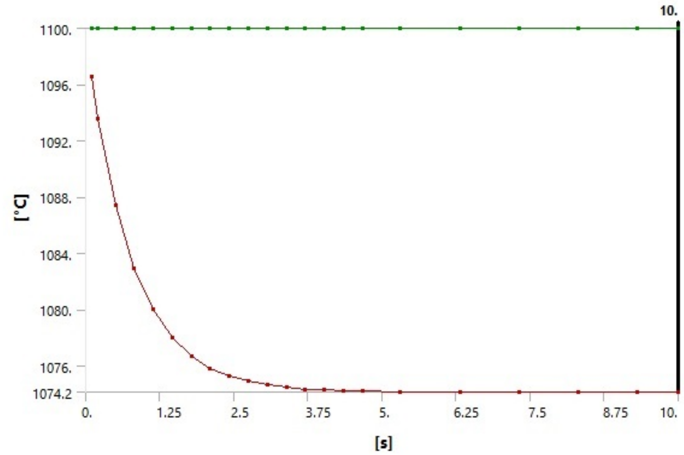


Figure 8: Time-temperature cooling curve for 10mm length circular fins

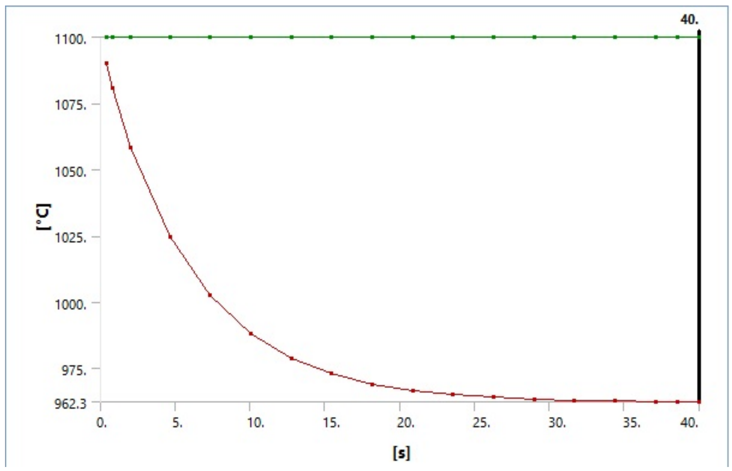


Figure 9: Time-temperature cooling curve for 15mm length circular fins

Table 2: Temperature for different length of fin

Length of circular fins	**5mm**	**10mm**	**15mm**
Initial temperature	1100°C	1100°C	1100°C
Final temperature	1092°C	1074.5°C	962.3°C
Decrement in number	8°C	25.5°C	137.7°C

Figure 10, 11 and 12 represents the heat flux for all the three assemblies considered in the present study. Heat flux physically represents the amount of heat generated per unit area. One can notice that for all the three assemblies considered in the present study larger heat flux is generating near the bottom portion of the fins. It can be noticed that with increment in the length of the fin amount of heat flux generating is increasingly continuously.

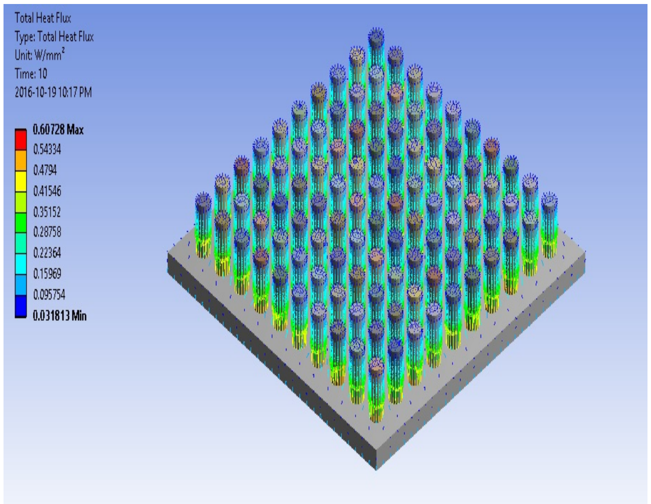


Figure 10: Heat flux distribution for 5mm length circular fins

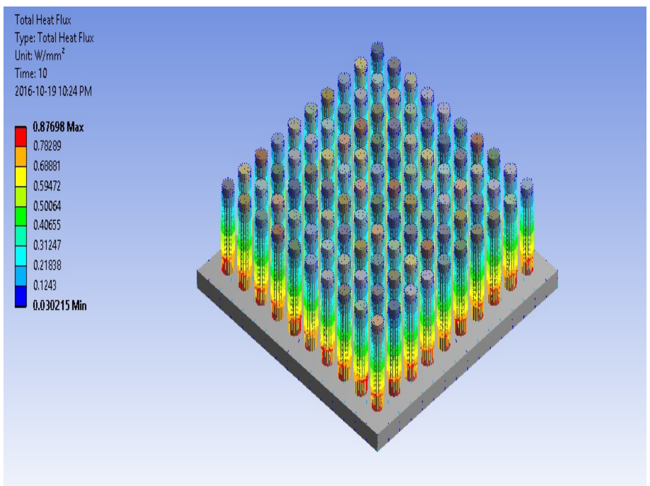


Figure 11: Heat flux distribution for 10mm length circular fins

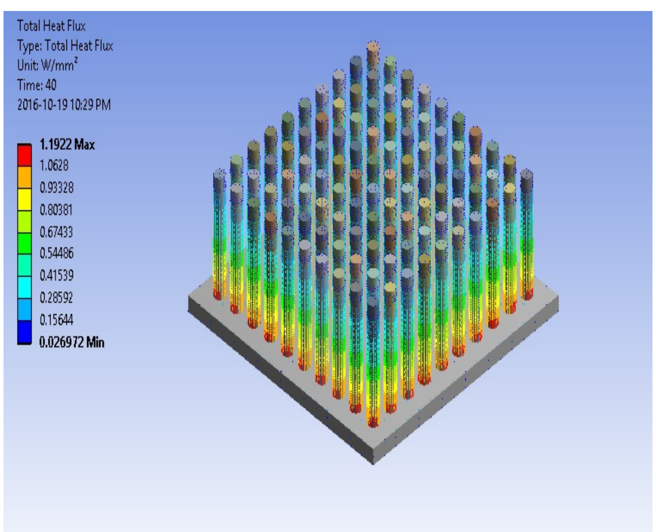


Figure 12: Heat flux distribution for 15mm length circular fins

Table 3 shows the weight comparison of the three different geometries considered in the present study. From the table it can be noticed that increasing the length of the circular fins from 5mm to 10mm increases the total weight of the assembly by 29.4% only. But third set in which length of the circular fins are 15mm increases the weight of the assembly by 244% when compared to 10mm length circular fins assembly. So, one should be specific while opting for fins size.

Table 3: Weight comparison

Length of circular fins	**5mm**	**10mm**	**15mm**
Weight	1.1454 kg	1.4821 kg	5.0993 kg
Volume	4090.6 mm³	5293.3 mm³	6495.9 mm³

V. CONCLUSION

- Fins increases the heat transfer by increasing the surface area and intensity of the fluid flow near the base plate
- Fins with largest length give highest cooling rate or heat transfer rate.
- Base plate having circular fins of 10mm length shows 18°C more decrement in temperature compared to 5mm length circular fins.
- Base plate having circular fins of 15mm length shows 112°C more decrement in temperature compared to 10mm length circular fins.
- Increasing the length of the fin also increases the weight of the assembly.

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