Numerical Analysis of Different Configurations of Fins using CFD for Application in IC Engine

J. A. Gohil¹ M. M. Makwana²
1M.E. Student 2Assistant Professor
1,2Department of Mechanical Engineering
1,2L D College of Engineering, Ahmedabad, India

Abstract— Due to increasing demand of high power and efficiency, there is a need to improve internal combustion engine sub systems. The effective cooling system of IC engine can lead to reduction in average temperature of important engine parts like piston, valve, piston ring, injection system, etc. And saving in lubrication oil will reduce engine maintenance cost and increase engine life. Effectiveness of heat rejection systems by air cooling methods mainly depends on heat transferring area; more heat transfer area can be achieved by providing fins on cylinder block. The fin parameters like length, pitch, thickness, number of fins and materials have great influence on heat transfer rates, so if sole purpose is to increase heat transfer rates than shape of fin will play crucial role in increasing heat loss capacity of cylinder block of same size and same materials. In this paper, Ansys CFX 18.0 is used for CFD analysis. First of all, Results of CFD analysis is validated with past experimental work. Then CFD analysis is done for rectangular fins, trapezoidal fins, triangular fins, parabolic fins, elliptical fins, permeable fins, inclined fins for vertical engines. And results of these analyses are compared to see which type of fins give better heat transfer performance.

Keywords: Computational Fluid Dynamics (CFD), Cylinder fins, Air cooling system, Engine Cooling, Thermal Analysis

I. INTRODUCTION

In internal combustion engine, combustion of fuel happens inside engine cylinder and extremely high hot gases are produced, whose temperature is around 2300-2500K. Because of high temperature produced inside engine cylinder, burning of lubricating oil film between the parts occurs which leads towards seizing or welding of moving parts. Along these lines, decrease of temperature up to safe degree of 150-200°C at which engine can work viably should be required. Additional cooling likewise diminishes the thermal efficiency. Therefore, principle target of cooling system is to keep up the engine running at its most efficient working temperature. It is known to us that the engine is inefficient when it is cold and in this manner the cooling system is structured so that it forestalls cooling when the engine is heating up and when it achieves efficient working temperature, at that point it begins cooling. The heat generated in internal combustion engine …

1) 30 % of generated heat is used in generating brake power (useful work)
2) 30-35% of generated heat is removed by cooling system
3) Remaining heat is carried away by Friction and Exhaust gases

All the heat generated in internal combustion engine is because of friction and combustion of fuel inside engine cylinder will lead the temperature inside cylinder up to 1925°C (3500°F) and can have cataclysmic (tragic harm) impacts on engine working parts like Pistons, valves and cylinder head and so forth and these must be chilled off to decrease the danger of detonation. The excess cylinder temperatures should be chilled off, so lubricating oil can safeguard a defensive film on the cylinder surfaces and to guarantee cooling oil integrity. Notwithstanding overheating, overcooling can also adversely affect the engine.

Overcooling can diminish engine efficiency and decrease the engine's service life. Cooling systems are utilized to manage engine heat. Cooling systems must be fittingly structured, worked and kept up for optimum engine activity and service life.

A. Air Cooling System

A small capacity internal combustion engine and aero plane engine mostly utilizes air cooling system. In this system engine cylinder walls and cylinder head are given fins or extended surfaces. Heat created due to combustion in the engine cylinder will be directed to the fins and evacuated when the air flows over the fins, this heat will be dispersed to air. The amount of heat removed to air depends upon:

1) Flowing air amount
2) Surface area and
3) Material Used

Generally motor bike engines are air cooled due to the constraint of weight and space. In contrast with water cooling system, this system requires less space and there is no necessity of radiator, cooling fan and pump, so this system is light in weight. Additionally this system doesn't use cooling water. So there are no issues of spillages and freezing of cooling water.

B. Cylinder fins

A fin is a surface area that reaches out from an object to enlarge the rate of heat removal from the object to the environment by raising convection. The measure of conduction, convection, or radiation from object decides the measure of heat dissipation capacity. Raising the temperature difference between the heated surface and the environment, increasing the convection heat transfer coefficient, or expanding the surface area of the object raises the heat transfer coefficient. Generally it isn't cheap or it is not conceivable to change the initial two alternatives. Adding fins to cylinder, however, increases the surface area and can on occasion be a efficient answer for heat transfer problems. The fins are commonly used to expand the heat exchange rates from the system to the environment by expanding the heat transfer area. The fins are usually extended surfaces or projections of materials on the system. Small capacity engines (engine bicycle) and compressors and electric engines are utilizing fins for cooling purpose.
Fins are additionally utilized in numerous fridges (evaporators and condensers) for increasing the heat expulsion rates. The data of fin efficiency and effectiveness are necessary for proper design of fins. The main intention of present research is to choose the most effective cross section among the distinct cross sections available.

II. METHODOLOGY OF CFD ANALYSIS

In this section, method of CFD analysis is explained. For this, CFD analysis of finned cylinder from the experimental work of Yoshida et. al. [5] is done. And the results of this CFD analysis are validated with experimental results of Yoshida et. al. [5].

A. Modelling

CAD model of finned cylinder is created in the Solidworks 2016 software. Dimensions of finned cylinder are kept same as the dimensions of the finned cylinder used in Yoshida et. al. [5]. CAD model of finned cylinder is shown in Fig. 2.1 and its dimensions are shown in Table 2.1.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cylinder length</td>
<td>120mm</td>
</tr>
<tr>
<td>2</td>
<td>Cylinder Inside Dia.</td>
<td>62mm</td>
</tr>
<tr>
<td>3</td>
<td>Fin Root Dia.</td>
<td>78mm</td>
</tr>
<tr>
<td>4</td>
<td>Fin Tip dia.</td>
<td>148mm</td>
</tr>
<tr>
<td>5</td>
<td>No. of Fins</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Pitch</td>
<td>10mm</td>
</tr>
<tr>
<td>7</td>
<td>Thickness of Fin at Root</td>
<td>6mm</td>
</tr>
<tr>
<td>8</td>
<td>Thickness of Fin at Tip</td>
<td>2mm</td>
</tr>
</tbody>
</table>

Table 2.1 Dimensions of Finned cylinder

Since this is a Conjugate Heat transfer model both the Solid and fluid volume are required to be modelled independently. Fluid inside the Fin is not modelled as we are not interested in temperature distribution near the wall. Finned cylinder is defined as solid domain. This CAD model is imported in the Ansys CFX module of Ansys 18.0 software. To create the fluid domain a cylindrical enclosure is created around the finned cylinder. Dimensions of the cylindrical enclosure are kept same as the dimensions of wind tunnel used in Yoshida et. al. [5]. Diameter of enclosure is 400mm and length is 680mm. Length is kept this long to keep the fluid flow streamlined. Fluid domain is created by subtracting the solid domain from the cylindrical enclosure.

B. Meshing

ANSYS meshing software is used to generate unstructured mesh for all the domains. Both Solid and Fluid domains are meshed using same methodology. Inflation Layers are applied in the Fluid region near fin walls to effectively capture the heat transfer in boundary layer region.

C. Problem Setup

CFD analysis is done in Ansys CFX software. For this boundary conditions for solid and fluid domain are to be given in software. Here, type of analysis is steady state analysis. K-epsilon scalable turbulence model is used. Air ideal gas is used as fluid. Aluminum is used as fin material. Heat transfer model for solid domain is thermal energy model and total energy model for fluid domain. Heat transfer model at solid fluid interface is Conservative interface flux model. At the inlet of fluid domain, wind velocity of 0,20,40,60 kmph and temperature of 298K is given. At the outlet, 0 Pa pressure is given to prevent the backflow. The remaining wall of fluid domain is given Standard wall function. The upper and lower surface of finned cylinder is kept adiabatic. Temperature of 373K is given at the inside cylinder wall. Convergence criteria is kept as 0.00001. For that initially 300 iterations are done. If solutions do not converge at 0.00001 than more iterations are done. Fig. 2.4 shows the problem setup in Ansys CFX software.
D. Solution

Convergence criteria is kept as 0.00001. For that initially 300 iterations are done. If solutions do not converge at 0.00001 than more iterations are done.

E. Results

CFD analysis is done at different wind speeds of 0kmph, 20kmph, 40kmph, 60kmph. For each analysis we get temperature contours, wall heat flux contours, wall heat transfer coefficient contours as results. From these results minimum temperature on the fin surface, Total heat transfer rate and Avg. heat transfer coefficient can be calculated.

1) Results for 0 Km/hr wind velocity

Minimum temperature on fin surface = 371K

Total heat transfer Q = 68W

Avg. heat transfer coefficient h = 6.18 W/m²K

<table>
<thead>
<tr>
<th>Wind Speed(Km/hr)</th>
<th>Min. Temperature(K)</th>
<th>Total Heat Transfer Q (W)</th>
<th>Avg. Heat transfer coefficient h (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>371</td>
<td>68</td>
<td>6.18</td>
</tr>
</tbody>
</table>

Fig. 2.4: Problem setup in Ansys CFX 18.0

Fig. 2.5: Residual plots of momentum and mass

Fig. 2.6: Residual plots of heat transfer energy

As it is shown in Fig. 2.5 and 2.6, all residual plots converge at 0.00001. So, the obtained solutions are accurate.

Fig. 2.7: (a) Temperature contours for finned cylinder at 0 km/hr wind velocity

Fig. 2.7: (b) Wall heat flux contours for finned cylinder at 0 km/hr wind velocity

Fig. 2.7: (c) Avg. heat transfer coefficient contours for finned cylinder at 0 km/hr wind velocity

In this way, results were obtained for wind velocity of 20, 40, 60 Km/hr.
Table 2.2: Results for different wind velocity

<table>
<thead>
<tr>
<th>Wind Speed (Km/hr)</th>
<th>Avg. Heat Transfer Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CFD</td>
</tr>
<tr>
<td>0</td>
<td>6.18</td>
</tr>
<tr>
<td>20</td>
<td>35.04</td>
</tr>
<tr>
<td>40</td>
<td>60.21</td>
</tr>
<tr>
<td>60</td>
<td>95.13</td>
</tr>
</tbody>
</table>

Table 2.3: Validation of CFD Results

From the above table, it can be said that CFD results comply accurately with experimental results. So, it can be stated that CFD method used in this paper will provide accurate results for other fin configurations.

III. CFD ANALYSIS OF DIFFERENT TYPES OF FINS

In this section, CFD analysis will be carried out for rectangular fins, trapezoidal fins, triangular fins, parabolic fins, elliptical fins, permeable fins, inclined fins etc. for vertical and horizontal engine. In inclined fins CFD analysis will be done for different angles of inclination. All the CFD analyses will be done at 40 Km/hr wind velocity and 423K temperature at the inside cylinder wall. All other boundary conditions will be same as mentioned in previous section.

A. Vertical Engine cylinders
Fig. 3.7: Inclined fins

B. Horizontal Engine cylinders

Fig. 3.8: Rectangular fins

Fig. 3.9: Trapezoidal fins

Fig. 3.10: Triangular fins

Fig. 3.11: Parabolic fins

Fig. 3.12: Elliptical fins

Fig. 3.13: Inclined fins

C. Results for CFD Analysis of Different types of fins for Vertical Engines

<table>
<thead>
<tr>
<th>Type of Fin</th>
<th>Min. Temperature (K)</th>
<th>Avg. heat transfer coefficient (W/m²K)</th>
<th>Total heat transfer (W)</th>
<th>Total Surface area A (mm²)</th>
<th>Volume V (mm³)</th>
<th>% reduction in weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>408</td>
<td>61.07</td>
<td>930.98</td>
<td>17220 9.55</td>
<td>55637</td>
<td>-</td>
</tr>
</tbody>
</table>
Trapezoidal fins gives the highest heat transfer rate and avg. heat transfer coefficient. Triangular and parabolic fins are better weight effective options of rectangular fins because they give similar heat transfer rate and reduces the weight by 34.98 and 43.65% respectively compared to rectangular fins. Elliptical fins decreases the heat transfer rates and avg. heat transfer coefficient. Triangular and parabolic fins are better weight effective options of rectangular fins because they give similar heat transfer rate and reduces the weight by 44.34% and 49.58% respectively compared to rectangular fins. Elliptical fins also increases the heat transfer rates and reduces weight by 20.15%. Permeable fins gives slightly reduced heat transfer rate and slightly reduced weight.

Table 3.1 CFD results for different types of fins at 40 Km/hr wind velocity (Vertical engines)

<table>
<thead>
<tr>
<th>Type of Fin</th>
<th>Min. Temperature (K)</th>
<th>Avg. heat transfer coefficient (W/m²K)</th>
<th>Total heat transfer (W)</th>
<th>Total Surface Area (mm²)</th>
<th>Volume V (mm³)</th>
<th>% Reduction in weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incline 10°</td>
<td>400</td>
<td>66.47</td>
<td>105 2.19</td>
<td>17000 9.03</td>
<td>40627 6.93</td>
<td>26.9%</td>
</tr>
<tr>
<td>Incline 20°</td>
<td>398</td>
<td>67.81</td>
<td>109 2.07</td>
<td>17810 7.14</td>
<td>41668 6.29</td>
<td>25.1%</td>
</tr>
<tr>
<td>Incline 30°</td>
<td>400</td>
<td>67.25</td>
<td>112 9.23</td>
<td>18873 6.95</td>
<td>42960 5.12</td>
<td>22.7%</td>
</tr>
<tr>
<td>Incline 40°</td>
<td>397</td>
<td>67.10</td>
<td>116 4.11</td>
<td>20055 7.19</td>
<td>44356 1.90</td>
<td>20.2%</td>
</tr>
<tr>
<td>Incline 50°</td>
<td>397</td>
<td>65.97</td>
<td>114 7.19</td>
<td>21210 0.82</td>
<td>45696 4.71</td>
<td>17.8%</td>
</tr>
</tbody>
</table>

Table 3.2 CFD results for inclined fins at 40 Km/hr wind velocity (Vertical engines)

Table 3.2 shows CFD results for inclined fins with different angle of inclination for vertical engines. As we increase the angle of inclination, surface area of fin increases. So total heat transfer rate and avg. heat transfer coefficient increases. And minimum temperature on fin surface reduces. But when we increase angle from 40° to 50°, total heat transfer rate and avg. heat transfer coefficient decreases. So it can be said that heat transfer rate increases only up to a certain angle for certain fin configuration.

D. Results for CFD Analysis of Different types of fins for Horizontal Engines

In table 3.3, CFD results for different fins like rectangular fins, trapezoidal fins, triangular fins, parabolic fins, elliptical fins etc. for horizontal engines are given. Among these fins, trapezoidal fins gives the highest heat transfer rate and avg. heat transfer coefficient. Triangular and parabolic fins are better weight effective options of rectangular fins because they give similar heat transfer rate and reduces the weight by 34.98 and 43.65% respectively compared to rectangular fins. Elliptical fins decreases the heat transfer rates and avg. heat transfer coefficient. Triangular and parabolic fins are better weight effective options of rectangular fins because they give similar heat transfer rate and reduces the weight by 44.34% and 49.58% respectively compared to rectangular fins. Elliptical fins also increases the heat transfer rates and reduces weight by 20.15%. Permeable fins gives slightly reduced heat transfer rate and slightly reduced weight.

Table 3.3 CFD results for different types of fins at 40 Km/hr wind velocity (Horizontal engines)

Table 3.4 CFD results for different types of fins at 40 Km/hr wind velocity (Horizontal engines)
IV. CONCLUSIONS

- In this paper, CFD results were validated with experimental results of Yoshida et al. [5]. It showed that CFD results are in close approximation with experimental results.
- As the wind velocity increases from 0 to 60Km/hr, minimum temperature on fin surface decreases and total heat transfer rate and avg. heat transfer coefficient increases.
- In Vertical engines, Trapezoidal fins and inclined fins give best thermal performance. Triangular fins and parabolic fins are better weight effective options of rectangular fins as they reduce weight by 44.34% and 49.58% respectively. In inclined fins thermal performance improves up to 40° angle, after that performance degrades.
- In horizontal engines, Trapezoidal fins and inclined fins give best thermal performance. Triangular fins and parabolic fins are better weight effective options of rectangular fins as they reduce weight by 34.98% and 43.65% respectively. In inclined fins thermal performance improves up to 50° angle, after that performance degrades.

V. FUTURE SCOPE

In this research work, effect of different types of fins on thermal performance of cylinder fins was studied vertical and horizontal engines. Further effect of notches, perforations on fin performance can be studied. Effect of different cross section on inclined fins can be further evaluated. Effect of orientation of engine cylinder on heat transfer performance of fins can be researched. Effect of surface finish of fin surface can be checked.

REFERENCES


