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Performance analysis of single cylinder engines with enhanced heat dissipation fins using computational fluid dynamics

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ABSTRACT

Engine cooling plays a major role in engine performance. The expanded surfaces that aids to dissipate the engine's heat are called fins, but their length is limited, which constrains the heat dissipation rate. The automotive industry as a whole works to increase the rate of heat dissipation so that engine efficiency may be increased. Current work aims to increase heat dissipation rate through these extended surfaces by varying the shape of the fins. Here, four different fins are considered, namely circular fins, rectangular fins, aerodynamic fins and curved fins for the analysis. Firstly, finite volume method (FVM) analysis was carried to obtain convective heat transfer coefficient "h" value for each fin shape in FLUENT software. These "h" values are imported for FEA thermal analysis and the result of temperature distribution across the engine cylinder fins and heat flux values at three different vehicle speeds are examined. The heat dissipation rates were observed low for circular fins at all speeds.

INTRODUCTION

Internal combustion (IC) engines burn fuel (often a fossil fuel) and an oxidizer (usually air) in a combustion chamber. In an IC engine, some engine components are forced by the expansion of the high-temperature and high-pressure gases that are created during combustion. This force moves the component for over a distance by generating mechanical energy. Because of the internal combustion, the engine becomes hot under operation. In order to dissipate this generated heat, the fins are used if the engine is an air-cooled one. Figure 1 shows the components of the spark ignition single cylinder IC engine along with the fins. On the other hand, the other mode of the heat dissipation from the IC engine is by using liquid coolant which is not discussed in this paper as it falls out of the scope of this work.

Necessity of Cooling System in IC Engines

It is known that the amount of heat absorbed by the cylinder wall should be dissipated from it to the other medium to avoid the cylinder seizing. Additionally, the lubricant might also burn away because of this excess heat. Also, excess heating will damage the material of the cylinder. In light of all these variables, it is assumed that appropriate methods must be employed to remove extra heat from the cylinder walls so that

KEYWORDS

Engine performance, Circular fins, Rectangular fins, Aerodynamic fins, Curved fins

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the temperature remains within predetermined ranges. However, it is not advisable to cool beyond the acceptable limit since it reduces overall effectiveness for the following reasons: Thermal efficiency decreases due to more dissipation of heat to the cylinder walls; The vaporization of fuel will be less which results in a fall of combustion efficiency.

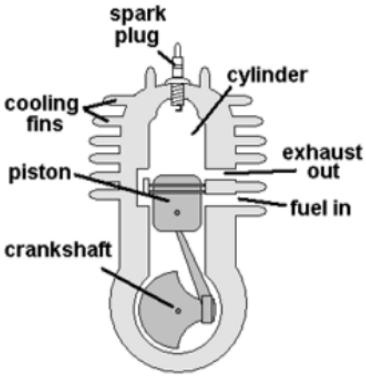

Figure 1: IC engine cylinder components.

Low temperatures cause lubricant to become more viscous, which results in higher piston friction and a reduction in mechanical efficiency. But, more cooling enhances volumetric efficiency, the above mentioned factors cause a decrease in overall efficiency.

Fins

A fin is an extended surface from an element that accelerates convection to speed up the heat that travels between the elements and its environment. The fins for the IC engine are shown in the figure 2. The quantity of heat that an item conducts is determined by its conduction, convection, and radiation properties.

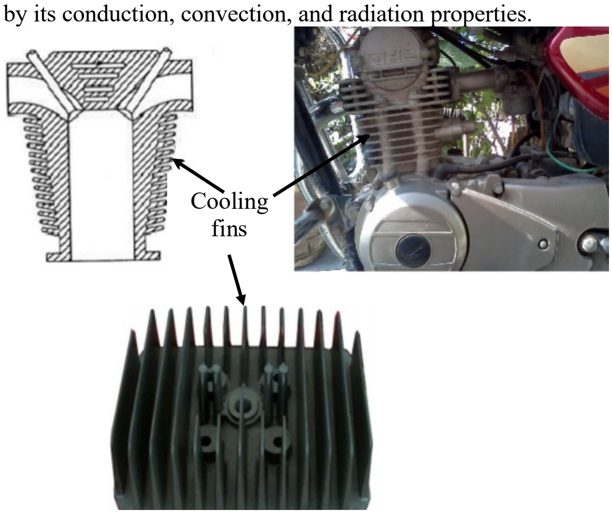

Figure 2: IC engine fins.

Convection is primarily responsible for heat transmission from the surface to adjacent fluids. The following are the three factors which have the greatest influence on the rate of heat transfer:

1) Convective heat transfer coefficient (h)
2) Accessible surface area
3) Temperature difference between the fluid around the surface.

Sometimes changing the first two possibilities is neither practical or affordable. However, increasing the surface area of the item by adding a fin might occasionally be a cost-effective way to solve heat transmission issues. A few noticeable examples include the circumferential fins that surround an engine's combustion chamber and the fins that link to a cooler's condenser containers.

IC Engine fins were designed and studied by Divyank et al. (2017) by altering the fins' inclined thickness. Fins' materials were changed as part of the analysis. They chose aluminium alloys in a variety of compositions with thermal conductivities ranging from 110 to 150 W/mk. They aimed to analyze the effect of thermal conductivity of fin body and fin geometry. Results have shown that Aluminum C443 shown the least heat transfer rates and Al 2014 had relatively better heat dissipation rates. In order to optimise geometries, mate/rial, and operating parameters, Mukesh et al. (2020) evaluated the efficiency of heat transmission through fins by making reference to earlier publications. In their investigation, K. Sathishkumar et al. (2017) initially investigated the heat dissipation rate and the variables affecting the rate at which heat transferred from the system to its surroundings. They modified the design of fins by placing different types of notches and performed the ANSYS-CFD Fluent software analysis. Thermal efficiency, combining pressure drop and transfer of heat via porous medium, was examined by Brijendra et al. (2017). They calculated and visually displayed many performance characteristics including efficiency, friction factor, Reynolds number, and Nusselt number using experimental data. Besides that, for the sake of comparison and optimization, the notches of various geometrical forms are also examined. CFD experiments were carried out on something like a rectangular fin engine by KM Sajesh et al. (2016). A single cylinder petrol engine was chosen, and the geometry was created in Ansys 16.0 design modeller. By adding holes to the fin, the engine's architecture was altered. The engine was subjected to a 400-second simulation of transient and steady-state heat transfer. Even more studies have been performed to examine the impact of temperature change on the development of perforations on fins of different sizes, including 2mm, 6mm, and 10mm. Heat transfer rates of rectangular fin arrays with perforations and extensions of various forms were examined by V. Karthikeyan et al. (2015). Extended and perforated fins were examined for efficiency. The fin arrays are perforated with holes of varying diameter and extensions of various shapes, including triangular, trapezoidal, rectangular, and circular segmental extensions. Using the Ansys workbench, L. Natrayan et al. (2016) examined the thermal characteristics of fins of various geometries. SolidWorks 2016 is used to generate the three - dimensional model of the configurations like angular, curved, rectangular, and circular fins. Ansys workbench R 2016 is used to study its thermal characteristics. In their study, Pradeep Singh et al. (2014) examined the heat transmission capabilities of fins by designing them in a variety of configurations, including circular segmental extension, rectangular extension, trapezium extension, and triangle extension. Comparisons are made between the heat transfer capabilities of fins with the same shape but different extension lengths. Using Ansys workbench, P. Sai Chaitanya et al. (2019) varied the shape, material, and thickness of cylinder fins to study the thermal characteristics. For a detailed investigation of temperature distribution, transient thermal analysis is highly useful in determining temperatures and other thermal parameters that change over time. The materials utilized are aluminium alloy 6061 and aluminium alloy A204. K. Angamuthu et al. (2021) used a wide range of materials to design and analyze a 100 cc IC engine cylinder with a groove and perforated fin design. In order to increase the heat transmission rate of cooling fins by modifying the configuration of cylinder fins and environmental factors, many types of study have been conducted in the past, according to Mohsin et al. (2014). Sachin et al. (2017) applied various materials and slot sizes to study the thermal characteristics of engine cylinder fins. Pulkit et al. (2017) examined how the surface finish affected the heat transmission rate (250 microns, 300 micron and 400 micron). The use of thermal analysis for various surface roughnesses is undertaken in an effort to replicate the rate of heat transmission. The parametric model is created to investigate the body's rate of heat transmission. The aluminium alloy 6061 is used to perform the body analysis. In the current work, CFD analysis was performed first to evaluate the heat transfer coefficient value, then the thermal FEA analysis was performed to evaluate the effect of fin profile on heat transfer rates at different operating speeds. Results of heat flux and surface temp of fins was presented for chosen operating conditions. Similarly, various researchers done the FEM analysis on IC engine components including the fins to enhance the efficiency of the engine (Jayakiran et al. (2021), Bill et al. (2022a), Bill et al. (2022b), Jayakiran et al. (2021), Jayakiran et al. (2016), Nikhil et al. (2021), Pranay et al. (2023), Bhavesh et al. (2023)). Though, all these studies are done on different geometries and various materials, none of them addressed and compared the use of the Aluminum 2014, Aluminum 6061, Aluminum 204, Aluminum C443 on the single cylinder petrol IC engine. Hence, the authors of this paper want to address these materials and study the CFD on different geometries of the engine.

METHOD

In the current study, four different fin profiles were taken for analysis. Figure 3 describes the methodology adopted, whereas figure 4 to figure 11 show the geometrical details of the current problem. Initially, a cylinder and fin were produced in Creo using Divyank Dubey et al. (2017)'s measurements, which took into account the 115cc Bajaj Caliber motorcycle's specs. Figure 4 to figure 11 depict fins with various geometries, including round, curved, aerodynamic, and rectangular. In the next stage, these models were meshed using the Ansys meshing tool. Figure 12 to figure 15 shows the meshed models. The total number of elements is about 20000 in each case. These number is achieved after the grid independence study. After meshing, the geometries are imported into fluent in finding convective heat transfer coefficient ‘h’. Here forced convective study is carried out for three different vehicle speeds and determined the heat transfer coefficient. In the next stage, thermal analysis was carried out using FEM. Here aluminium alloys were considered, and their heat dissipation rate was compared for different models considered. Thermal boundary conditions of constant wall temperature of 270°C, 550°C and 1020°C for 40 kmph, 60 kmph and 80 kmph respectively, were given to the inner cylinder of each model. Table 1 shows the validation of current results with that of literature (Divyank et al. 2017). Here the average surface temperature of the fin is compared in the case of the rectangular fin. Results are presented for four different fin materials; from the bar chart, the variation is less than 0.5 degrees centigrade in each case. Thus, further analysis is carried out for other geometries.

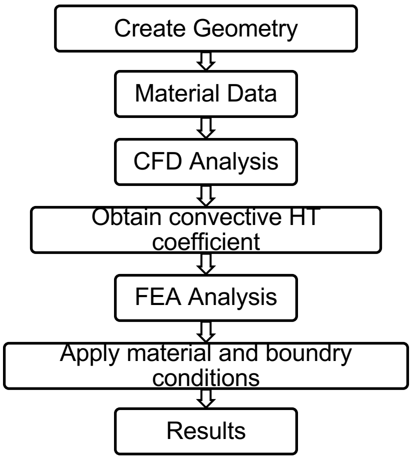

Figure 3: Flow chart of methodology.

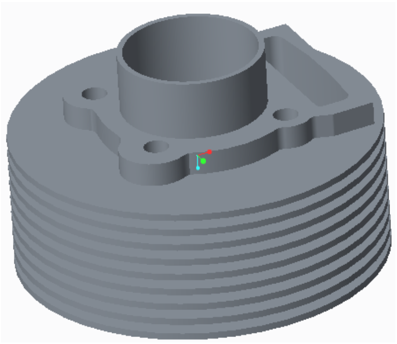

Figure 4: 3D models of IC engine with Circular Fins.

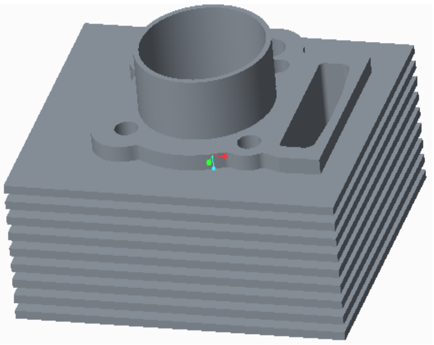

Figure 5: 3D models of IC engine with rectangular fins.

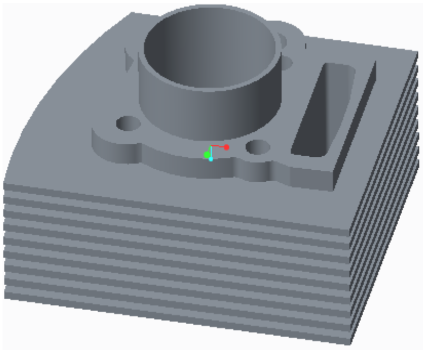

Figure 6: 3D models of IC engine with aerodynamic fins.

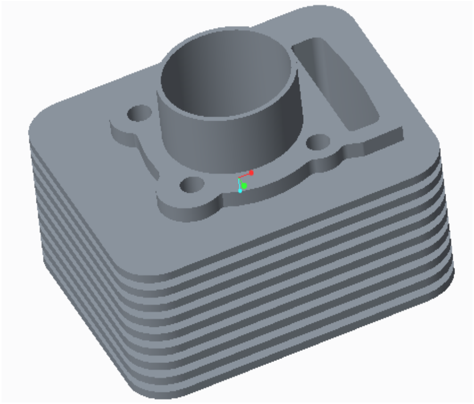

Figure 7: 3D models of IC engine with curved fins.

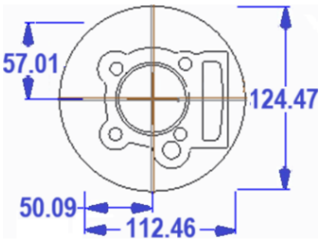

Figure 8: Drafted models of IC engine with Circular Fins.

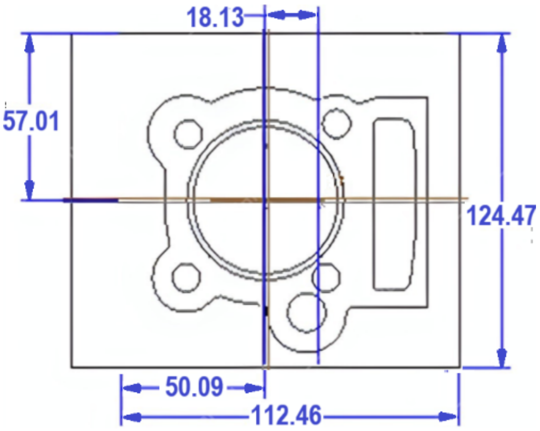

Figure 9: Drafted models of IC engine with Rectangular.

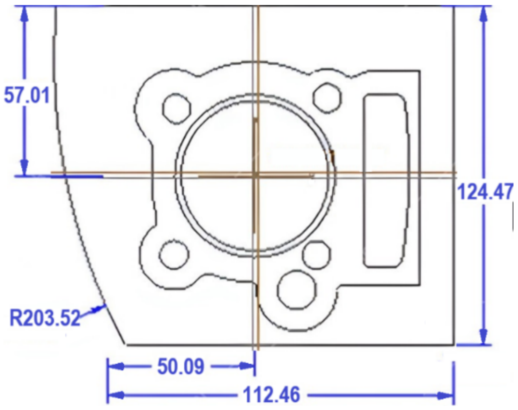

Figure 10: Drafted models of IC engine with Aerodynamic Fins.

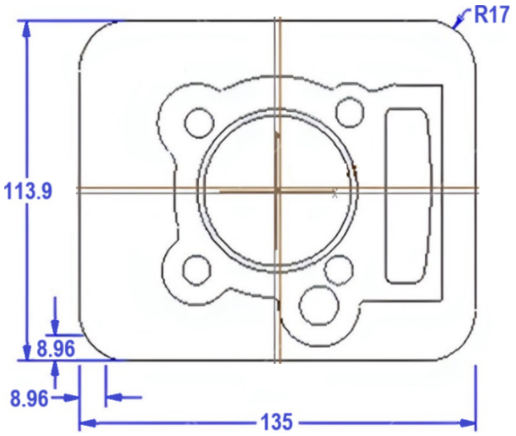

Figure 11: Drafted models of IC engine with Curved Fins.

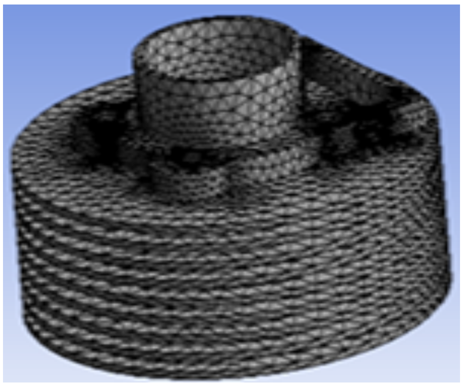

Figure 12: Meshing models of engine cylinder with circular fins.

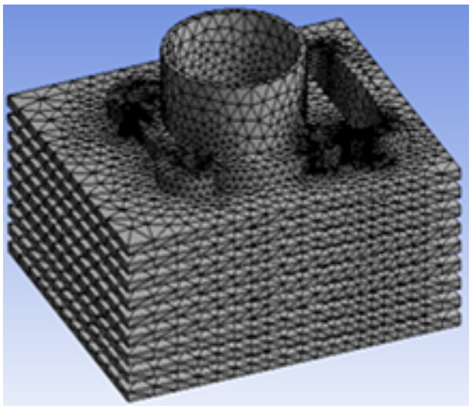

Figure 13: Meshing models of engine cylinder with rectangular fins.

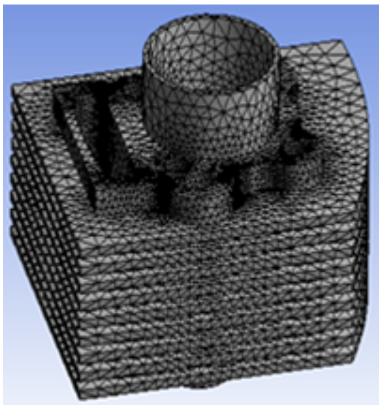

Figure 14: Meshing models of engine cylinder with aerodynamic fins.

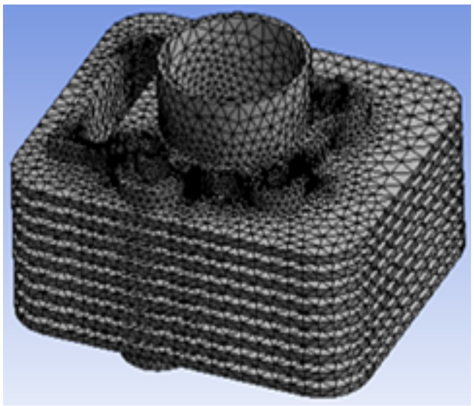

Figure 15: Meshing models of engine cylinder with curved fins.

Table 1: Comparison of the present average surface temperatures with literature (Divyank et al. 2017), when the inner surface of the cylinder is at 558 K.

		Aluminum 2014	Aluminum 6061	Aluminum 204	Aluminum C443
Temperature	Literature value	285.01	285.03	285.04	285.07
	Validated value	285.04	285.05	285.06	285.08

RESULTS AND DISCUSSION

CFD Analysis

In this study, the convective heat transfer coefficient was obtained from FVM analysis using a Fluent software. The ‘h’ values were obtained from the simulation and are presented in table 2. Here three different wind speeds were chosen, and the ‘h’ value is presented model wise. Results showed that h value increases with increased speed, and curved fins had generated dominant convective heat transfer characteristics.

Table 2: Heat Transfer Coefficient (W/m²K) Values from CFD analysis.

Speed (kmph)	Circular	Rectangular	Aerodynamic	Curved
40	42.85	43.85	43.58	44.00
60	58.88	60.18	59.75	60.37
80	74.01	75.59	75.06	75.82

Analysis of engine cylinder fins in a steady state

Later, thermal analysis was carried out for different fin models under different material conditions. The 'h' values obtained in the previous stage were used here as one of the boundary conditions. Thermal boundary conditions of constant wall temperature of 270oC, 550oC and 1020oC for 40kmph, 60kmph and 80kmph respectively were imposed on the inner cylinder of each engine and ‘h’ values is imposed for fins.

The results are presented for each case in the form of temperature contours, as shown in figures 16 to figure 19, and the summary data is tabulated in table 3.

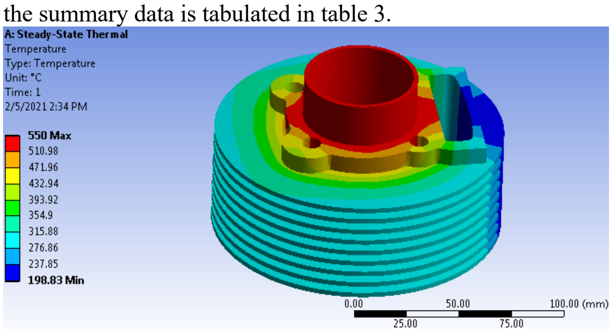

Figure 16: Temperature distribution at 60kmph for circular fins.

Figure 16 shows the thermal contour of circular fins corresponding to 60 kmph. According to the counter plot, the maximum temperature distribution is inside of the engine block and minimum temperature distribution at fins due to applied convection. The maximum temperature is 5500C and the minimum is 198.830C at a speed of 60kmph with circular fins.

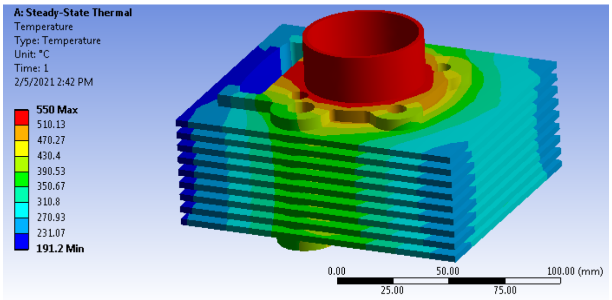

Figure 17: Temperature distribution at 60kmph for rectangular fins.

Figure 17 shows the temperature distribution on rectangular fins; the maximum temperature distribution is inside the engine block due to applied boundary conditions and minimum temperature distribution at fins due to applied convection. The maximum temperature is 5500C, and the minimum is 191.200C at a speed of 60kmph with rectangular fins.

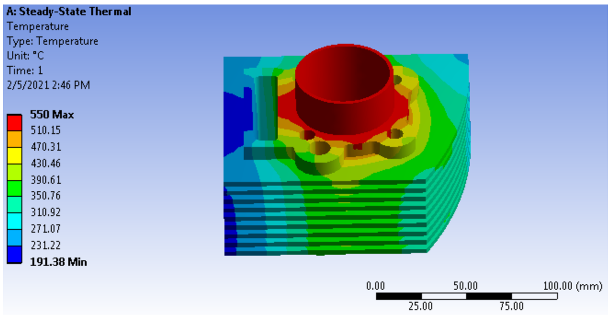

Figure 18: Temperature distribution at 60kmph for aerodynamic fins.

Figure 18 shows the temperature distribution on aerodynamic fins. According to the above counter plot, the maximum temperature distribution is inside of the engine block and minimum temperature distribution at fins due to applied convection. The maximum temperature is 5500C and the minimum is 191.380C at a speed of 60kmph with Aerodynamic fins.

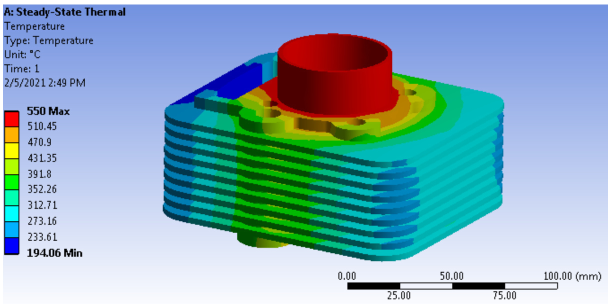

Figure 19: Temperature distribution at 60kmph for curved fins.

Figure 19 shows the temperature distribution on curved fins. The maximum temperature is 550°C, and the minimum is 194.06°C at a speed of 60 kmph with curved fins. The quantitative analysis of results of all four model chosen is presented in table 3. According to the table, the results of engine cylinder at various speeds 40, 60 and 80 kmph are compared with different fins with the maximum temperature distribution at a speed of 80 km/hr with fin geometry circular and maximum heat flux at a speed of 80 km/hr with aerodynamic fins. The results found that the heat dissipation rate was maximum with rectangular fins followed by aerodynamic at all the three speeds chosen. The circular fins showed maximum surface temperatures and minimum heat transfer rates in each case. Figure 20 gives the bar chart showing the clear difference in heat transfer rates for different fin models. From the results, it can be concluded that rectangular fins showed better performance and circular showed least.

Table 3: Comparison of heat flux and surface temperature.

Speed (Kmph)	Fin Geometry	Average surface temperature distribution (°C)	Heat flux (W / mm²)
40	Circular	200.05	0.35425
	Rectangular	198.715	0.39301
	Aerodynamic	198.195	0.39116
	Curved	198.775	0.38771

60	Circular	374.415	0.89968
	Rectangular	370.6	1.001
	Aerodynamic	370.69	0.98417
	Curved	372.03	0.97666
80	Circular	654.885	1.8875
	Rectangular	648.67	2.0867
	Aerodynamic	648.745	2.0486
	Curved	652.345	2.0291

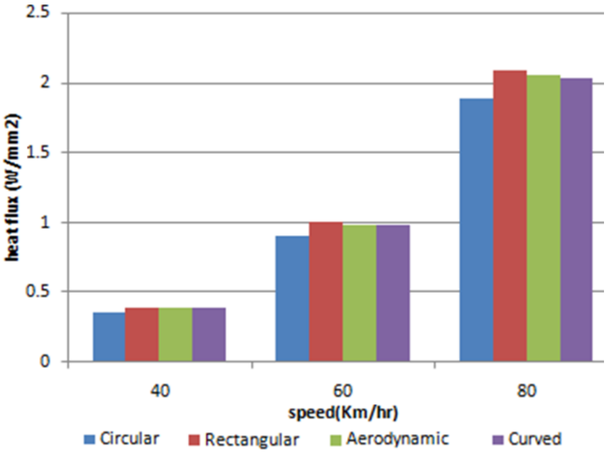

Figure 20: Wind speed versus outlet heat flux with four various fins.

CONCLUSION

In the present work, numerical analysis was carried out on heat dissipation rates through extended surfaces of the engine model. Here four different geometries of fins were chosen while maintaining surface area constant. Numerical analysis was carried in two stages: fluid flow was done using fluent software and static thermal analysis was carried out using Ansys workbench. Results showed that

- The heat transfer coefficient value increases with an increase in speed and decreases in the following order: Curved fins, Rectangular fins, Aerodynamic fins and Circular fins.
- FEA static thermal analysis shown that the heat transfer rate is maximum for rectangular-shaped fins compared to the remaining geometries.
- The average surface temperature on the fins was found high at high speeds and was maximum for circular fins irrespective of speed.
- Although the total surface area is the same for all four models, the heat dissipation rate is different, which suggest the need for proper design of fin blades.

REFERENCES

Angamuthu K, Gokul K, Gowrishankar M, Jibil GA. Modeling and simulation studies of 100 cc motor cycle engine cylinder with groove and perforated fin design using different materials. Mater Today: Proceedings 2021; 42 (2): 1447-1455. https://doi.org/10.1016/j.matpr.2021.01.249

Bhavesh P, Asfakahemad S, Nikul P, Vimal P. Review Analysis on CFD Techniques and Numerical Methods for IC Engines Fueled with Diesel and Biofuels. J Adv Res 2023; 110: 40–62. http://dx.doi.org/10.37934/arfmts.110.1.4062

Bill CS, Jayakiran RE. A basic automated CAD modelling approach for an IC engine piston. AIP Conference Proceedings 2022a; 2648: 020023-1–020023-10. https://doi.org/10.1063/5.0114356

Bill CS, Jayakiran RE. Automated CAD modelling approach and FEM analysis for an IC engine piston. AIP Conference Proceedings 2022b; 2648: 020029-1–020029-11. https://doi.org/10.1063/5.0114358

Brijendra SB and Choudhary SK. Experimental Investigation of Heat Transfer through Porous Material Heat Exchanger. Int Res J Eng Technol4 2017; 10: 51-60.

Divyank D, Dinesh S, Abhishek Y, Satyajeet P, Harish CT. Thermal Analysis of Engine Cylinder having thick tip fin with varying slot sizes and material. Mater Today: proceedings 2017; 4(8): 7636-7642. https://doi.org/10.1016/j.matpr.2017.07.097

Jayakiran RE, Bala TM. Developing a basic CAD model of a spur gear using an automated approach. Int J Tech Phys Probl Eng 2021; 13 (48): 20-24.

Jayakiran RE, Gondi KR, Rajendra D. Design of Lifting Tackle for Armor Plate of Sinter Machine. Int J Tech Phys Probl Eng 2021; 13(46): 23-28.

Jayakiran RE, Sridhar CNV, Pandu RV. Development of KBS for CAD modeling of a two wheeler IC Engine Connecting Rod: An approach. Adv Intell Syst Comput 2016; 530: 597-606. https://doi.org/10.1007/978-3-319-47952-1_48

Karthikeyan V, Suresh BR, Vignesh K G. Design and Analysis of Natural Convective Heat Transfer Coefficient Comparison between Rectangular Fin Arrays with Perforated and Fin Arrays with Extension. Int J Eng Sci Res Technol 2015; 4(2): 124-128.

Mohsin AA, Kherde SM. Design Modification and Analysis of Two Wheeler Cooling Fins-A Review. Int J Eng Adv Technol 2014; 7(3): 998-1002.

Mukesh KS, Sahu HS. A Review on Internal Combustion Engine Fins. Int J Eng Res Technol 2020; 9(8): 802-804.

Natrayan L, Selvaraj G, Alagirisamy N, Santhosh MS. Thermal Analysis of Engine Fins with Different Geometries. Int J Innov Res Technol Sci Eng 2016; 5(5): 6900-6906. https://doi.org/10.15680/ijirset.2016.0505040.

Nikhil T, Gurunandan J, Shubham A, Jayakiran RE. Development of a preliminary approach for automatic CAD model generation of the IC engine piston. Smart Innov Syst Technol 2021; 265: 227-237. https://doi.org/10.1007/978-981-16-6482-3_23

Pardeep S, Harvinder L, Baljit SU. Design and Analysis for Heat Transfer through Fin with Extensions. Int J Innov Res Technol Sci Eng 2014; 3(5): 12054-12061.

Pranay P, Rajan BS, Navanth P, Jayakiran RE. Development of an Automated CAD Modeling System for a Four Stroke Four Cylinder IC Engine Crankshaft. Smart Innov Syst Technol 2023; 334: 605–615. https://doi.org/10.1007/978-981-19-8497-6_55

Pulkit SP, Teotia ADS, Thakur HC. Heat transfer analysis and optimization of engine fins of varying surface roughness. Mater today: proceedings 2017; 4(8): 8565-8570. https://doi.org/10.1016/j.matpr.2017.07.203

Sachin KG, Harishchandra T, Divyank D. Analyzing Thermal Properties of Engine Cylinder Fins by Varying Slot Size and Material. HCTL Open Int J Technol Innov Res 2017; 14: 1-9.

Sai CP, Suneela RB, Vijaya KK. Thermal Analysis of Engine Cylinder Fin by Varying Its Geometry and Material. IOSR J Mech Civ Eng 2019; 11(6): 37-44.

Sajesh KM, Neelesh S, Siddhartha K. Design Modification and Heat Transfer Analysis of Air Cooled Rectangular Fin Engine. Int J Recent Sci Res 2016; 7(3): 9653-9656. https://doi.org/10.24327/ijrsr.7.3.9653

Sathishkumar K, Vignesh K, Ugesh N, Sanjeevaprasath PB and Balamurugan S. Computational Analysis of Heat Transfer through Fins with Different Types of Notches. Int J Adv Eng Res Sci 2017; 4(2): 175-183. https://dx.doi.org/10.22161/ijaers.4.2.35.