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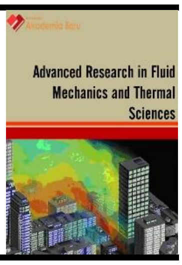

Study of Heat Transfer Attributes of Custom Fins for Crank-Rocker Engine Block using ANSYS

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Adeel Tariq[1], Khurram Altaf[1,*], Ahmad Majdi Abdul Rani[1], Masri Baharom[2], Abd Rashid Abd Aziz[2]

[1] Department of Mechanical Engineering, Universiti Teknologi Petronas, Perak, Malaysia
[2] Centre for Automotive Research and Electric Mobility – CAREM, Perak, Malaysia

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ABSTRACT

Crank-rocker engine (CRE) is an internal combustion (IC) engine with a curved piston and cylinder, developed at Universiti Teknologi PETRONAS (UTP) Malaysia. Heat is generated during combustion in an IC engine, some portion of which is converted into the mechanical energy. Almost 30 % of the generated heat needs to be dissipated through engine walls. Fins are used to provide additional surface area to engine block for dissipation of excess heat. Transient thermal analysis of existing 3-fins model of CRE is performed at different engine speeds, using 'ANSYS Transient Thermal' module. With the understanding of thermal behavior of the existing 3-fins model, new straight and curved conformal fin models, with increased surface area and better fin effectiveness, are proposed. Thermal performance of both, straight and curved fin models, is compared with existing 3-fins model of crank-rocker engine.

Keywords:
Crank-Rocker engine; curved fins; straight fins; Transient thermal analysis

1. Introduction

The energy transmitted as mechanical power is less than the energy generated during combustion in an IC engine. Only 25 % of the power generated, is converted into useful work. Energy lost due to friction (during transmission of power as mechanical energy) and via exhaust gases are 10 % and 35 % of the power produced, respectively. Remaining 30 % is excess heat, which needs to be dissipated through cylinder walls [1]. Mohammed *et al.,* [1] proposed a new four-bar mechanism for an engine called crank-rocker engine (CRE), in 2017. CRE is a 120 cc, 4-stroke gasoline engine that consists of a curved piston and cylinder. Like other IC engines, CRE also needs to dissipate the excess heat, effectively. Various kinds of fins are used for heat dissipation through engine cylinder block. Basic purpose of using bluff plates/fins is to provide more surface area for heat to be convected away from engine walls.

Heat transfer rate is often affected by air velocity, ambient temperature, surface of fin and fin geometry. Using Al 6061, at convection coefficient of 22 W/m2K, three geometries of fins, having different surface areas, were analyzed by Sagar *et al.,* [2]. Among plain, convex and concave

* *Corresponding author.*
E-mail address: Khurram.altaf@utp.edu.my (Khurram Altaf)

geometries, convex fins were found to have more heat transfer rate. Kumar enhanced the heat transfer rate of fins by 5-13 %, by making extensions on them [3]. To increase the heat transfer rate through fins of the Bajaj Caliber engine cylinder, Dubey *et al.,* [4] increased the fin tip thickness by 3mm and used different materials and slots sizes of 50 mm, 75 mm and 100 mm. To increase the surface area of fins, Natrayan thermally analyzed different geometries of fins for an engine [5]. Using aluminum, Yadav and Pandey numerically modelled fins of different shapes (elliptical, sprocket, channeled, kite and triangular). It was observed that kite and elliptical shapes were the most efficient [6]. Transient thermal analysis of 100 cc Hero Honda motorcycle engine was done in 'ANSYS Transient Thermal' by Ahirwar *et al.,* [7]. The existing design of this engine had rectangular fins, which was replaced by circular fins design, and analysis was performed. Results showed that using circular fins enhanced heat transfer rate and performance of ICE. Cooling efficiency of 150 cc Honda Unicorn engine was improved by varying geometry of fins by Tekhre and Saini. Holes of 4 mm, 6 mm and 10 mm were created in fins. Comparison showed that creating 10mm hole in fins could decrease the minimum temperature of 741^{o}C to 707^{o}C [8]. Original engine model of Bajaj Discover was analyzed in CFD and a couple of improved models were proposed by Ali and Kherde. Non-uniformity in in geometry enhanced heat transfer rate [9]. Combustion temperature in ICE is usually of the order of 2100^{o}C -2200^{o}C and needs to be lowered to 200-300^{o}C [11]. For a maximum temperature of 1500^{o}C, transient thermal analysis was performed on circular and rectangular geometries of fins by Chaitanya *et al.,* [10]. It was found that circular fins performed better thermally.

2. Methodology

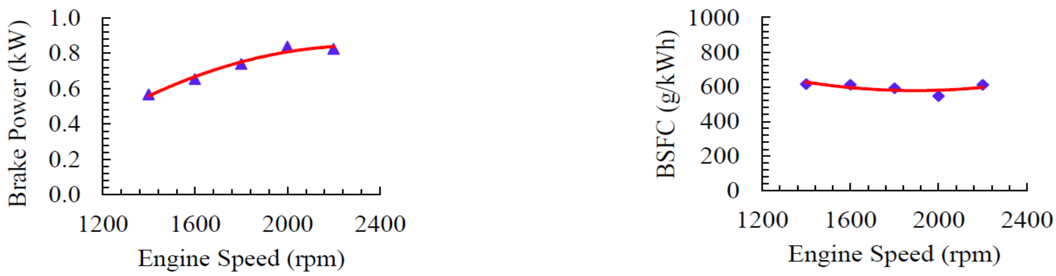
2.1 Heat Load Calculation

Heat generated by combustion of fuel can be calculated, using the calorific value of fuel and rate of fuel consumption, as shown by the relation in Eq. (1). Fuel consumption rate depends on the brake power and brake specific fuel consumption of an engine, as shown in Eq. (2).

$$Qg = CV \times r \tag{1}$$

$$r = BSFC \times BP \tag{2}$$

'Qg' is the heat generated by fuel combustion. 'CV' indicates calorific value of the fuel (gasoline in this case) and 'r' is the fuel consumption rate of engine. 'BSFC' is the brake specific fuel consumption and 'BP' indicates the brake power of engine. CV of gasoline is 45.8 MJ/kg [12]. BP and BSFC of CRE are plotted against engine speed (rpm) in Figure 1(a) and Figure 1(b), respectively [13]. The values of heat generated at different engine speeds are given in Table 1. The excess heat/heat load (Qd), that needs to be dissipated through CRE cylinder walls, is 30 % of the heat generated (Qg), as shown in the Table 1.



(a) (b)

Fig. 1. (a) BP and (b) BSFC of CRE at different rpm [13]

Table 1
Excess heat calculated at different engine speeds

Engine speed (rpm)	Q_g (watt)	Q_d (watt)
1400	4274.7	1282.4
1600	4885.3	1465.6
1800	5129.6	1538.8
2000	5292.4	1587.7
2200	5954	1786.2

2.2 Convection Coefficient

Convective heat transfer coefficient depends on the fluid, that is responsible for convection, and its speed. In the case of CRE cooling, the fluid is air, and its speed is the relative velocity of engine and air. The convection coefficient for air is plotted against air speed, in Figure 2 [14].

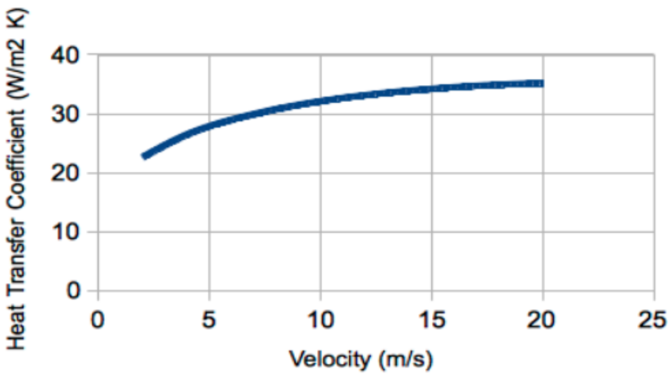


Fig. 2. Convection coefficient at different air speeds [14]

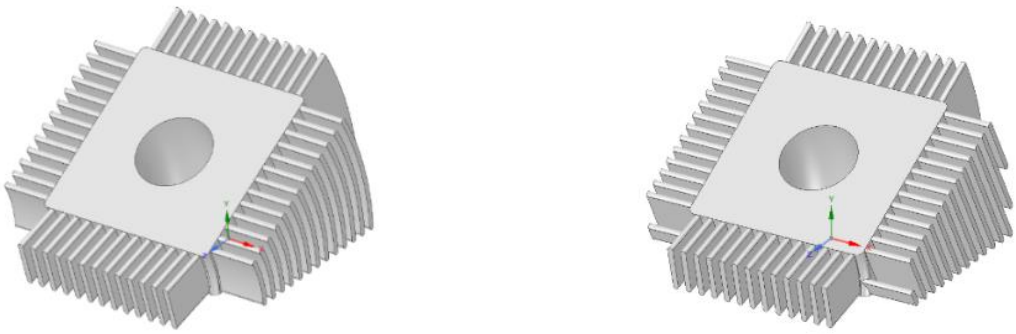
2.3 Transient Thermal Analysis

Existing design of CRE has 3 fins with nonuniform thickness. CAD model of this 3-fins design is shown in Figure 3(a). This design is analyzed at calculated heat loads and relevant convection coefficient values for 12000 seconds. The material used during analysis is made up of aluminum. At maximum engine speed, the minimum temperature achieved by existing 3-fin design is 87°C. Temperature distribution in the cylinder block at maximum engine speed is shown in Figure 3(b).

(a) (b)

Fig. 3. CAD model of 3-fins design [13] and (b)Temperature distribution in 3-fins model, at maximum engine speed

The fins of Curved-fins model are curved along the curvature of CRE cylinder, as shown in the Figure 4(a). Straight-fins model has fins that are straight and parallel to the flow of air. CAD model of straight fins design is shown in the Figure 4(b). Both models have uniform fin thickness of 4mm, and height of fins is assumed 35mm while distance between two consecutive fins is 6 mm.



(a) (b)

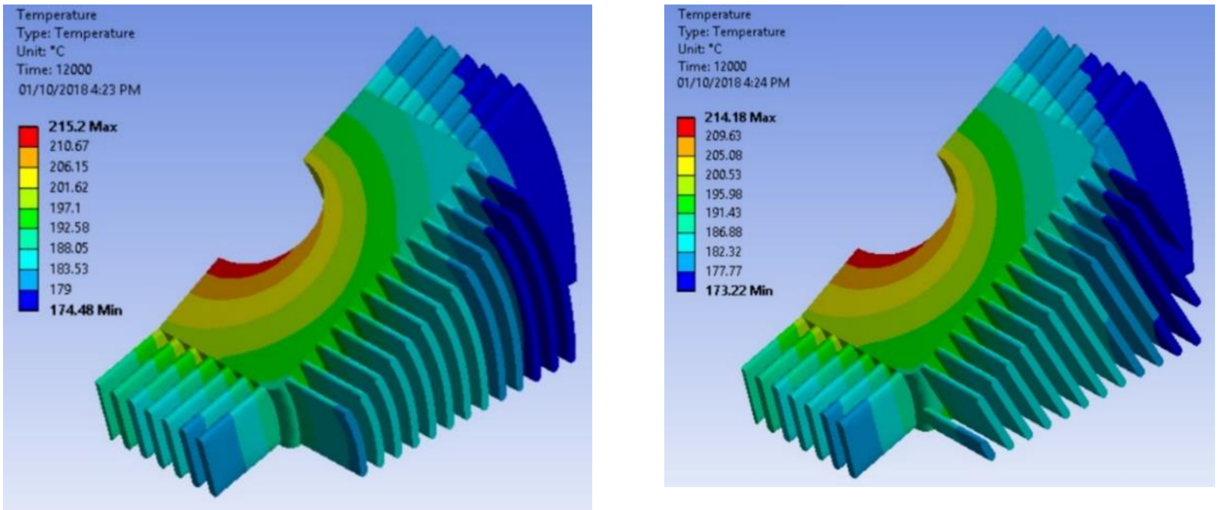
Fig. 4. CAD model of (a) Curved-fins model and (b) Straight-fins model of CRE cylinder

Straight-fins model of CRE has the largest surface area for heat convection. Surface areas of all three models are compared in the Table 2.

Table 2
Surface areas of CRE models

CRE Model	Surface Area (cm^2)
3-fin model	361
Curved fins model	1564
Straight fins model	1574

Both models are simulated under calculated heat load and convection coefficient values, at different engine speeds, for 12000 seconds. Temperature distributions in both models at maximum engine speed are shown in Figure 5. Material for both models is assumed to be aluminum, during simulation. At maximum engine speed, the minimum temperatures achieved by curved-fins model and straight-fins model are 174°C and 173°C, respectively.



(a) (b)

Fig. 5. Temperature distribution in (a) Curved-fins model and (b) Straight-fins model CRE model, at maximum engine speed

2.4 Fin Effectiveness

Fin effectiveness (∈) of all three models of CRE, at maximum engine speed, is calculated using the Eq. (3) [15] and is plotted in Figure 6.

$$\in = \frac{Q_{total,fin}}{Q_{total,no\ fin}} \tag{3}$$

'$Q_{total,fin}$' is the total heat transfer through fins. While '$Q_{total,no\ fin}$' is the total heat transfer rate through surface of CRE cylinder with no fins.

In steady state, the values of and are calculated using the total heat fluxes (watt/m2) obtained from ANSYS, as shown in Figure 7.

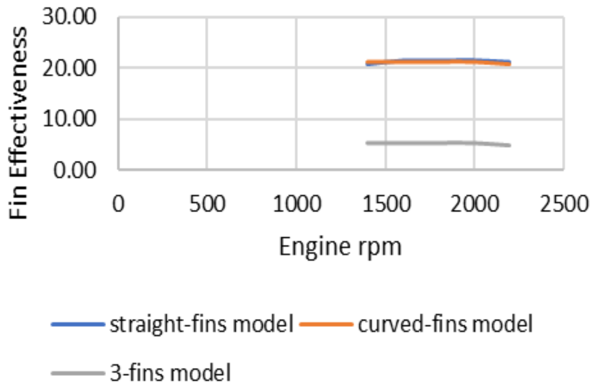


Fig. 6. Fin effectiveness of the three CRE cylinder models at different engine speeds

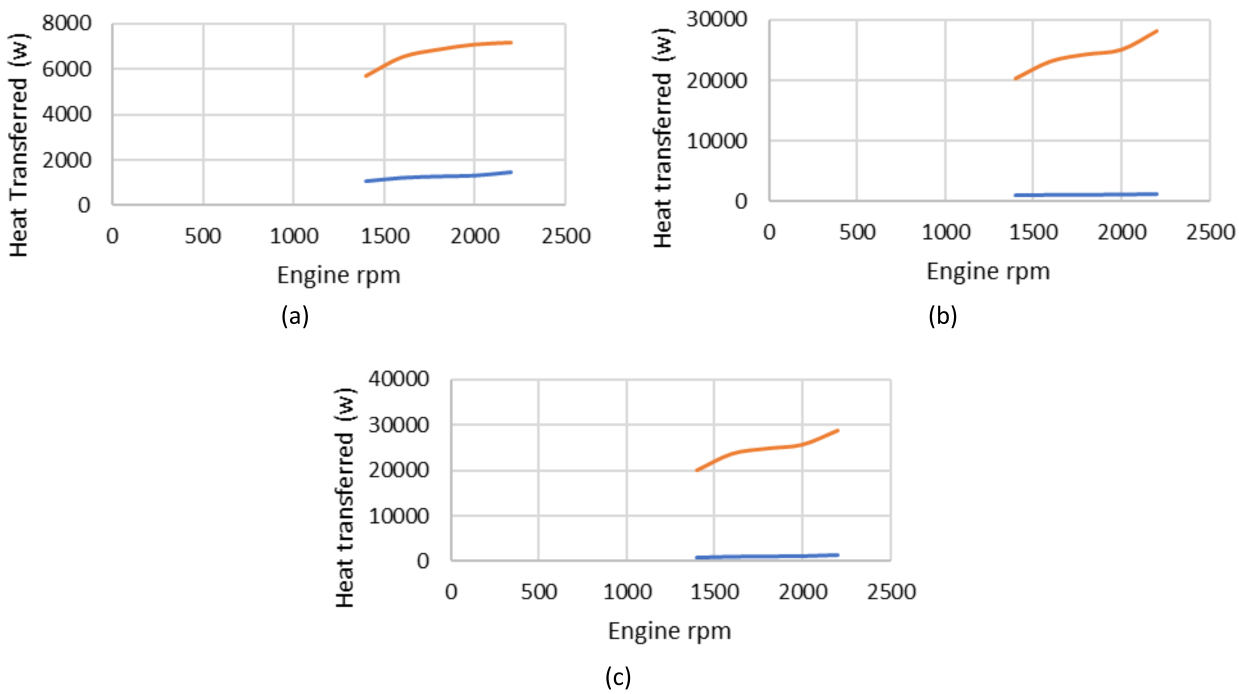
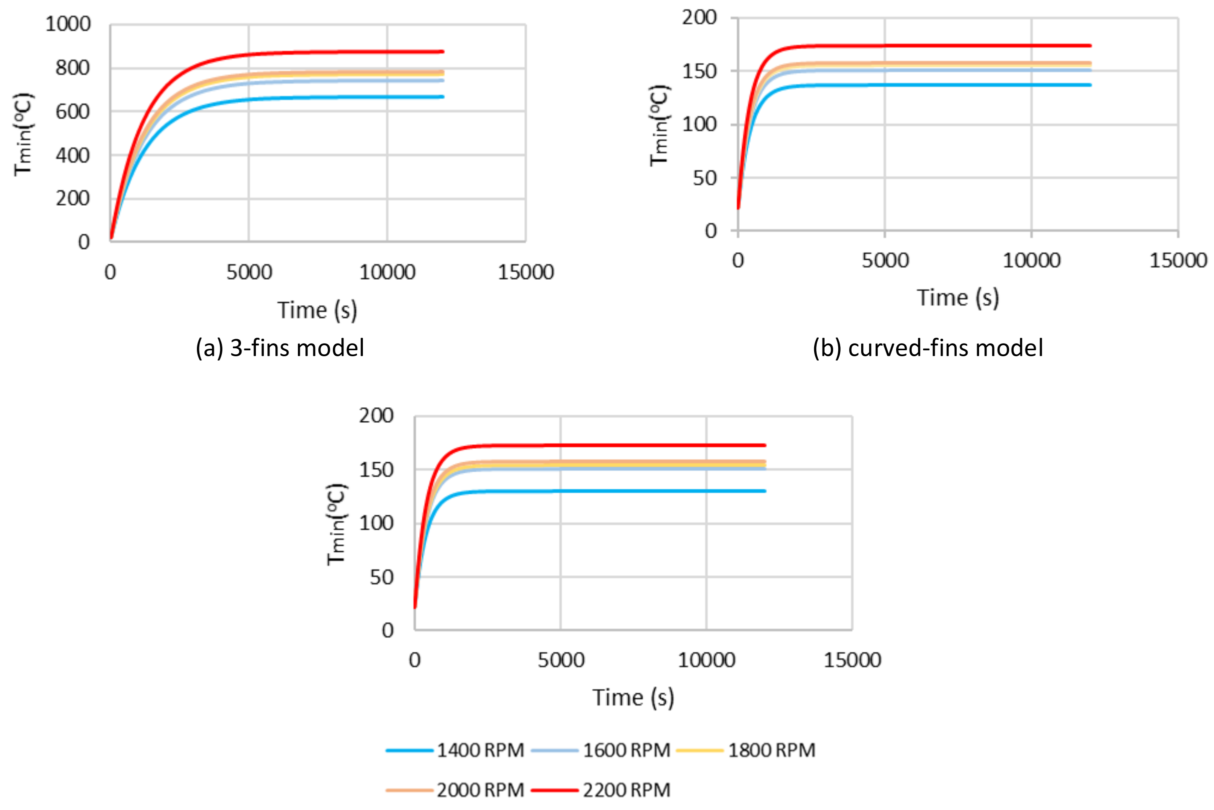


Fig. 7. Total heat transfer through CRE cylinder models at different engine speeds

3. Results and Discussion

Transient thermal analyses performed on existing 3-fins model and the new curved-fins and straight-fins models show the following results.

i. Figure 8(a)-(c) show that, time taken by 3-fins model to achieve steady state is 7700s, while curved-fins and straight-fins models take 2240 s and 2140 s, respectively, to reach steady state.
ii. At higher engine speeds, more heat needs to be dissipated, thus, minimum temperature achieved by every CRE models increase, as shown in Figure 8(a)-(c).
iii. Figure 9 shows that, at maximum engine speed, the minimum temperature achieved by existing 3-fins model is 402.1 % and 405.7 % higher than the minimum temperatures achieved by curved-fins and straight-fins models, respectively.
iv. Overall fin effectiveness of curved-fins and straight-fins model, is 3.93 times and 3.98 times more than that of existing 3-fins model of CRE, as shown in Figure 9. This shows that above mentioned curved-fins and straight-fins models are more efficient for proper dissipation of excess heat from CRE cylinder.
v. Performance of curved-fins model and straight-fins model is comparable. Minimum temperature achieved by straight-fins model is 1.26°C less than that achieved by curved-fins model, at maximum engine speed, as shown in Figure 9. However, at lower rpm of engine, this difference is more notable, as shown in Figure 10. This is because surface area provided by straight-fins model is greater than the surface area of curved-fins model, as stated in Table 2.



(a) 3-fins model
(b) curved-fins model
(c) straight-fins model

Fig. 8. Minimum-temperature profiles with respect to time, achieved by CRE models, at different engine speeds

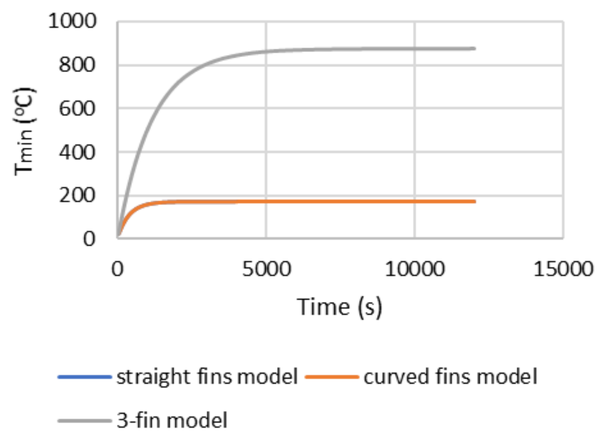


Fig. 9. Comparison of minimum temperatures, achieved by the three CRE cylinder models, at maximum engine speed

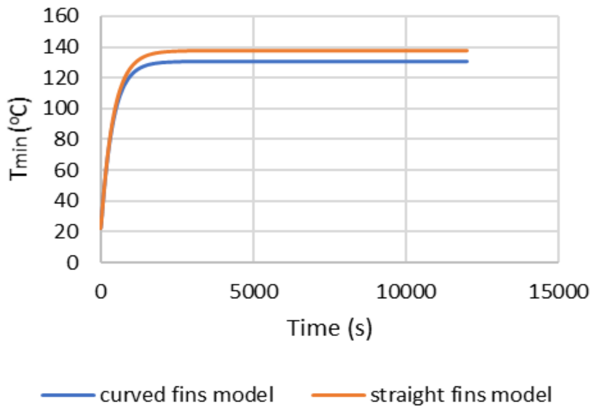


Fig. 10. Comparison of minimum temperatures, achieved by curved-fins and straight-fins models, at minimum engine speed

4. Conclusions

Transient thermal analysis of the existing 3-fin model of CRE cylinder shows that it is not capable of dissipating excess heat from engine, effectively. Two new models of CRE fins, with better heat dissipation capacity and higher overall fin effectiveness, are proposed and analyzed. The results show that straight-fins model is the most efficient and curved-fins model is not far behind with minimum temperature of 173.22oC and fin effectiveness of 21. The performance of curved-fins model and straight-fins model is comparable and far better than that of existing 3-fin design of CRE cylinder.

References

[1] Mohammed, Salah E., M. B. Baharom, and A. Rashid A. Aziz. "Performance and combustion characteristics of a novel crank-rocker engine." *Journal of Mechanical Science and Technology* 31, no. 7 (2017): 3563-3571.

[2] Sagar, Pulkit, Puneet Teotia, Akash Deep Sahlot, and H. C. Thakur. "Heat transfer analysis and optimization of engine fins of varying geometry." *Materials Today: Proceedings* 4, no. 8 (2017): 8558-8564.

[3] Ramesh Kumar, " Heat Transfer Analysis of Engine Cylinder Fin by Varying Extension Geometry." *Conference: Contemporary Approaches in Design and Manufacturing, Alagappa Chettiar College of Engineering and Technology, Karaikudi*, April (2016): 0–8.

[4] Dubey, Divyank, Dinesh Singh, and Harishchandra Thakur. "Thermal Analysis of Engine Cylinder having thick tip fin with varying slot sizes and material." *Materials Today: Proceedings* 4, no. 8 (2017): 7636-7642.

[5] Natrayan, L., G. Selvaraj, N. Alagirisamy, and M. S. Santhosh. "Thermal Analysis of Engine Fins with Different Geometries." *International Journal of Innovative Research in Science, Engineering and Technology* 5, no. 5 (2016): 6900-6906.

[6] Yadav, Saroj, and Krishna M. Pandey. "A comparative thermal analysis of pin fins for improved heat transfer in forced convection." *Materials Today: Proceedings* 5, no. 1 (2018): 1711-1717.

[7] Mahendra Kumar Ahirwar, Ravindra Mohan, and Jagdish Prasad. " I.C. Engine Cylinder Fins Transient Thermal Analysis by using ANSYS Software." *International Research Journal of Engineering and Technology* 5, no. 2 (2018): 1085-1091.

[8] Tekhre, Deepak, and Jagdeesh Saini. "Design Modification and Thermal Analysis of IC Engine Fin." *International Refereed Journal of Engineering and Science (IRJES) ISSN (Online)*: 2319-1821.

[9] Ali, Mohsin A., and S. M. Kherde. "Design Modification and Analysis of Two-Wheeler Cooling Fins-A Review." *International Journal of Advances in Engineering & Technology* 7, no. 3 (2014): 998.

[10] Chaitanya, P. Sai, B. Suneela Rani, and K. Vijaya Kumar. "Thermal Analysis of Engine Cylinder Fin by Varying Its Geometry and Material." *IOSR Journal of Mechanical and Civil* 11, no. 6 (2014): 37-44.

[11] Nitnaware, P. T., and Prachi S. Giri. "Design Optimization of An Air-Cooled Internal Combustion Engine Fin Using CFD." *Journal of Multidisciplinary Engineering Science and Technology* 2, no. 11 (2015): 3129-3131.

[12] "calorific value of gasoline." [Online]. Available: https://www.acea.be/news/article/differences-between-diesel-and-petrol. [Accessed: 30-Jan-2019].

[13] S. E. Mohammed. "Development, Performance and Emission Assessment of a Single-Cylinder Air-Cooled Gasoline Crank-Rocker Engine." Universiti Teknologi Petronas, Malaysia.
[14] "Convection coefficient values." [Online]. Available: https://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html. [Accessed: 30-Jan-2019].
[15] Yunus A. Cengel, (2002). *Heat Transfer: A Practical Approach*. 2^{nd} Edition. McGraw-Hill, New York.