Chapter 9
Effect of Rectangular Fins on the Heat Transfer Performance of an Automotive Radiator

Faiza M. Nasir

Abstract The automotive radiator is a type of a compact heat exchanger with the main role to reduce the temperature of the coolant from the engine. The radiator is fitted with many types of fins with the purpose to enhance the heat transfer while reducing the overall size of the radiator. In this simulation study, the effect of using rectangular fins on the radiator heat transfer performance is investigated. Two radiator models were created, one without fins and the other one with rectangular fins. The effect of varying the convection heat transfer coefficient and the coolant's flowrate on the radiator's performance were also studied. It is observed that by adding fins, the coolant's temperature drop increases by 560% and the heat transfer rate increases by 283%. The results also show that as the convection heat transfer coefficient increases, the thermal performance of the radiator improves but remains constant as the coolant flowrate increases.

Keywords Automotive radiator · Compact heat exchanger · Thermal simulation · Thermal resistance

9.1 Introduction

In order to meet the increased demand for more powerful engines, there is a need for automotive radiators with enhanced thermal transport capacity. Many researches have been conducted to improve the radiator's thermal transport by manipulating its design or its coolant (Tran and Wang 2020; Kumar et al. 2020; Shariff et al. 2018; Sahoo et al. 2017; Mohamed et al. 2019). Oliet et al. (2007) conducted parametric studies on automotive radiator and discovered that air and coolant flowrate have a substantial impact on the radiator's heat transfer performance. Experimental parametric study of the fin geometry was also performed by Ismael et al. (2016). They fabricated five

F. M. Nasir (✉)
Universiti Kuala Lumpur, Malaysian Spanish Institute, Kulim Hi-Tech Park, 09000 Kulim, Kedah, Malaysia
e-mail: faiza@unikl.edu.my

M. H. Abu Bakar et al. (eds.), *Progress in Engineering Technology V*, Advanced Structured Materials 183, https://doi.org/10.1007/978-3-031-29348-1_9

different radiators with different fin pitch wave distance and tested their performance under a wind tunnel.

In an experimental numerical study conducted by Yadav and Singh (2015), the effect of different radiator operating parameters such as coolant mass flowrate, inlet coolant temperature, and the addition of antifreeze on the radiator's thermal performance was investigated. They found a direct relationship between the cooling capacity and the coolant's flowrate and its inlet temperature. A numerical study by Shariff et al. (2018) that focused on the thermal performance of car radiator in Kano State of Nigeria demonstrated that by adding fins, a 25% decrease in the outlet temperature and 33.2% increase in heat removal capacity can be attained. Sakthivel et al. (2021) numerically investigated the effect of using different fin materials (copper and aluminum) and shape of fins (rectangular and curved edge) on the thermal performance of the radiator.

Several studies have been conducted to compare the thermal performance of various shapes of fins for fin and tube heat exchanger. In a study by Wen and Ho (2009), it was shown that compounded fins have the highest effectiveness than plain and wavy fins. Comparing performance of heat exchangers with plain, wavy, and louvered fins under constant fan power, Yan and Sheen (2000) proved that louvered fins have the greatest impact on the heat transfer coefficient of the heat exchanger. Similar superior performance of louvered fins was also found in studies by Carija et al. (2014) and Okbaz et al. (2018).

The main goal of this study is to use SolidWorks to investigate the influence of rectangular-shaped fins on the thermal performance of an automotive radiator. The temperature decrease of the coolant, the total heat transfer rate, and the thermal resistance all contribute to the overall performance.

9.2 Simulation Setup

9.2.1 Simulation Models

The specification for the radiator with the rectangular fins is shown in Table 9.1. The material for the radiator is the aluminum alloy 6061, and the coolant used is water. There are two models simulated in this study: the base model and the fin model. The base model is basically the radiator tube without any fins attached to it, whereas for the fin model, the radiator is fitted with rectangular-shaped fins. The models were created using SolidWorks (see Fig. 9.1).

Table 9.1 Specification of the base model A

Tube depth	21.58 mm
Tube thickness	0.3 mm
Core width	635 mm
Fin pitch	2.5 mm
Fin length	8.59 mm
Tube height	2.4 mm
Core height	382 mm (actual) 50 mm (model)
Fin thickness	0.1 mm

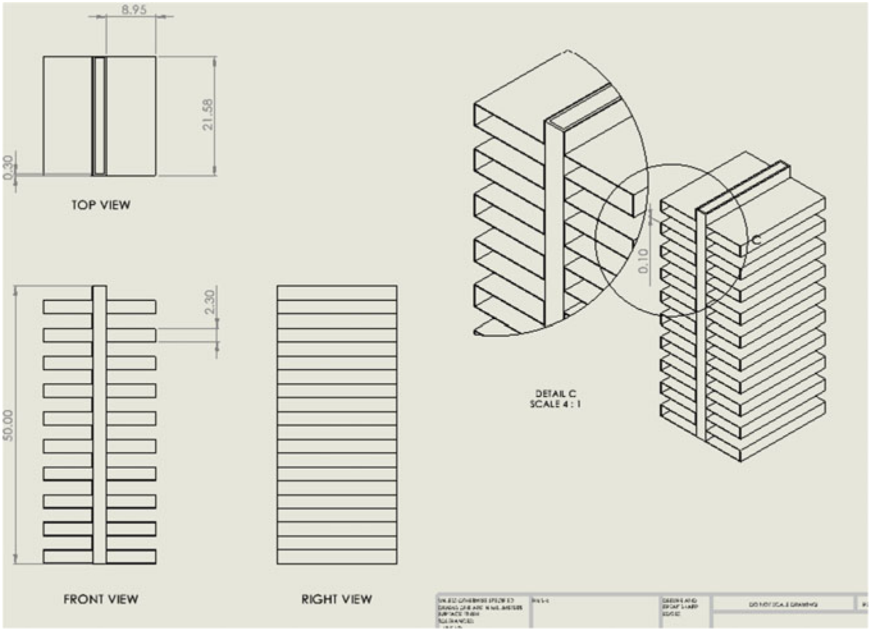

Fig. 9.1 Detailed drawings of the fin model

9.2.2 Boundary Conditions

The thermal simulation for the models was conducted by using the steady thermal-external flow simulation in SolidWorks. The coolant's inlet temperature is 85 °C, and the temperature of the inlet air is 28 °C. The external convection heat transfer coefficient is varied between 10 and 200 $W/m^2 \cdot K$, implying different speeds of the car. The coolant's inlet flowrate is varied between 5 and 60 LPM, with higher flowrate indicating higher pumping power requirement.

9.2.3 Data Analysis

The heat transfer performance of the radiator is measured by the coolant's temperature drop across the tube, the thermal resistance, and the total heat transfer rate. The temperature drop is defined by Eq. (9.1), and the thermal resistance is defined by Eq. (9.2).

$$\Delta T = T_{w,\text{in}} - T_{w,\text{out}} \tag{9.1}$$

$$R_t = \frac{T_{w,\text{in}} - T_{s,\text{min}}}{Q} \tag{9.2}$$

where T_w is the coolant's temperature, $T_{s,\text{min}}$ is the minimum temperature of the solid wall of the radiator, and Q is the total heat transfer rate of the radiator.

9.3 Results and Discussion

9.3.1 Effect of Fins

The addition of fins to the radiator will adversely affect its performance. The simulation results for the base model and the fin model are shown in Table 9.2.

As mentioned earlier, the base model is the radiator tube without any fins and the fin model is the radiator with fins. From the results, the total heat transfer rate for the fin model is 282.95% higher than that for the base model. The result shows that the heat transfer rate of the fin model is 38.51 W greater than the base model. The greater heat transfer is attributed to the greater surface area for heat exchange of the fin model that is fitted with the rectangular fins.

The addition of fins to the radiator tube has resulted in a significant rise in the temperature decrease of the coolant flowing through the tube. Without any fins, the radiator is only able to reduce the coolant's temperature by 0.52 °C for 50 mm length of the radiator tube. By adding the rectangular fins, the coolant's temperature reduces by 3.43 °C for 50 mm length of the radiator tube, indicating the significant contribution of the fins in dissipating excess heat from the coolant. The temperature

Table 9.2 Simulation results for base model and the fin model

Model	Temperature drop	Heat transfer rate (W)	Total surface area
Base model	0.52	13.61	0.0024
Fin model	3.43	52.12	0.0209
Absolute difference of fin model from base model (%)	559.62	282.95	770.83

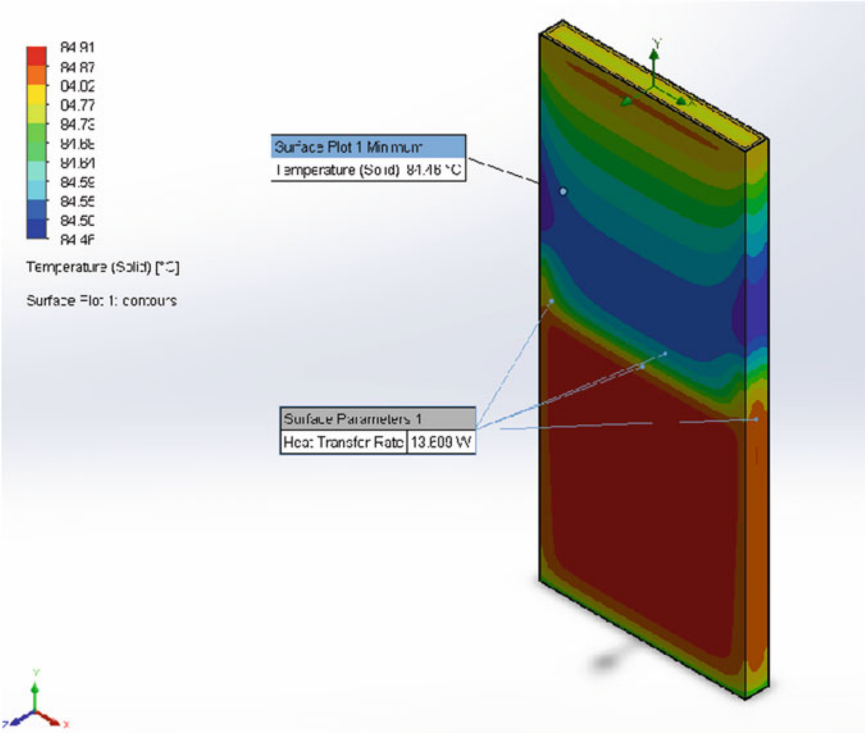

Fig. 9.2 Temperature contour plot for the base model

contour plot for both the base model and the fin model are shown in Figs. 9.2 and 9.3.

9.3.2 Effect of Convection Heat Transfer Coefficient

Oliet et al (2007) investigated a few factors that influence the performance of a radiator, including air and coolant flow, fin density, and air temperature. It has been demonstrated that the mass flow rates of the air and coolant have a significant impact on the heat transfer and performance of the radiator. The convection heat transfer coefficient is inextricably linked to the velocity of the air; the higher the velocity, the greater the value of the coefficient. Figure 9.4 shows the effect of the heat transfer coefficient, h on the thermal resistance and the temperature drop of the radiator with rectangular fins.

Figure 9.4 shows the positive relationship between h and the coolant's temperature drop. As the heat transfer coefficient increases, the coolant's temperature drop increases. When $h = 200$ W/m^2·K, the temperature drop of the coolant is 3.43 °C,

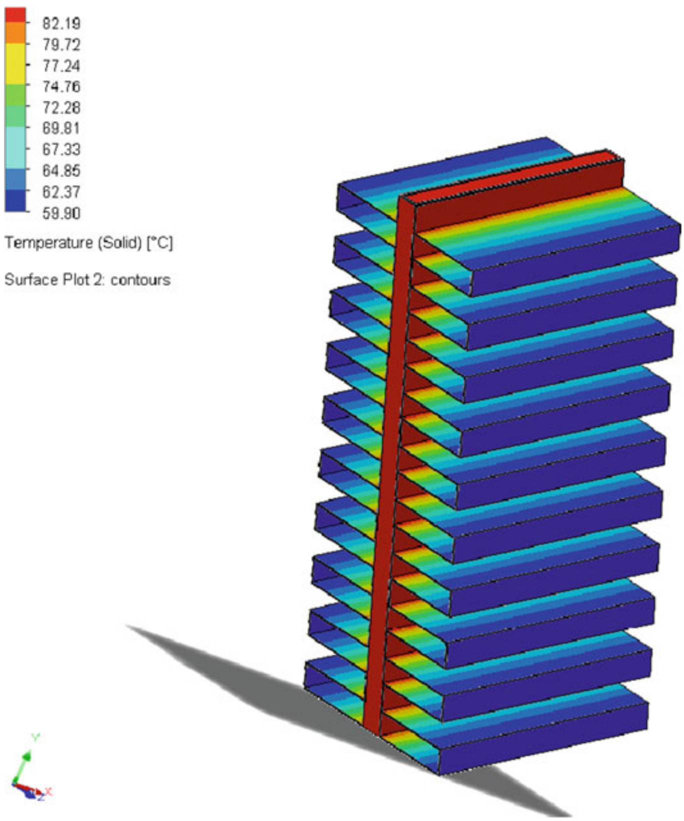

Fig. 9.3 Temperature contour plot for the fin model

and when $h = 50$ W/m^2·K, the drop reduces to 1.23 °C for 50 mm length of radiator's tube. The higher value of h indicates higher convection heat transfer occurring on the external surface of the radiator, thus promoting enhanced heat removal from the radiator to the surroundings. This is proven by Fig. 9.5 that shows the greater heat transfer rate produced when the convection heat transfer coefficient is the highest at 200 W/m^2·K.

There is a negative relationship between heat transfer coefficient and the thermal resistance (Fig. 9.4). The thermal resistance indicates the radiator's resistance to heat transfer, the lower the better, as lower resistance allows a greater amount of heat to be transferred rather than stored. At the highest heat transfer coefficient of 200 W/m^2·K, the radiator's thermal resistance is 0.571 °C/W, while when $h = 50$ W/m^2·K, the thermal resistance is 0.701 °C/W. This is translated to a reduction of 18.54% in thermal resistance when h increases by thrice.

Figure 9.5 shows the total of heat transfer of the radiator increasing from the minimum value of 5.03 W to the maximum value of 63.802 W as the heat transfer

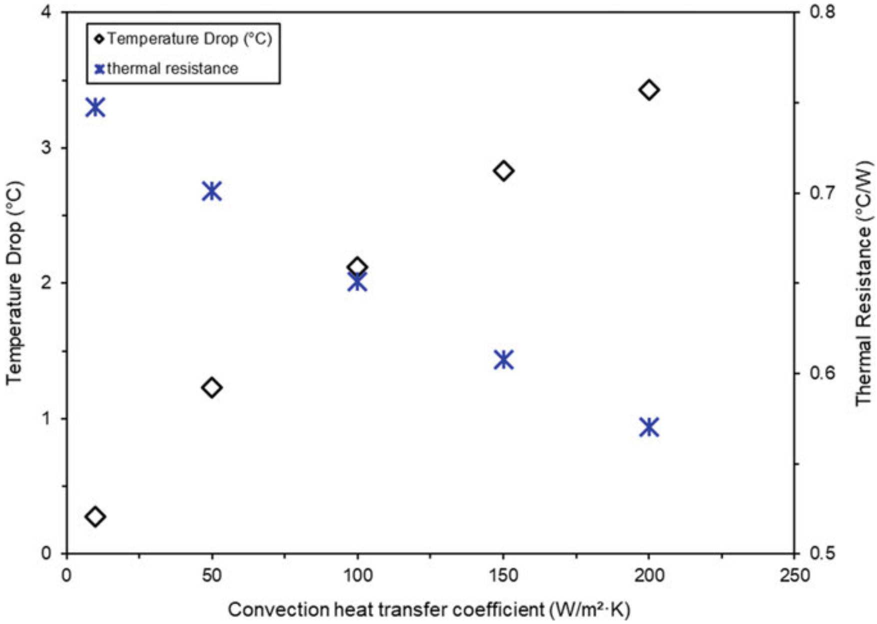

Fig. 9.4 The effect of *h* on the temperature drop and the thermal resistance

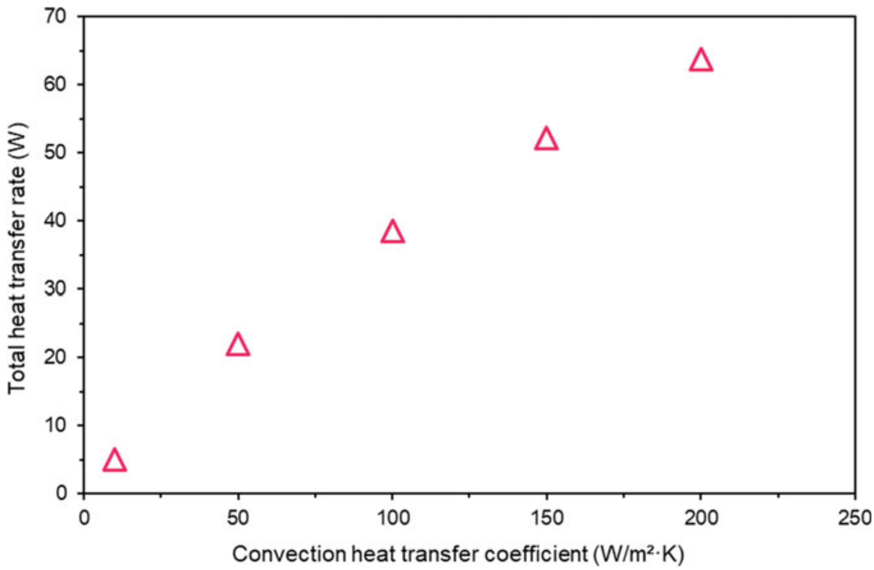

Fig. 9.5 The effect of *h* on the total heat transfer

increases from 3 to 200 W/m^2·K. The higher value of h indicates higher convection heat transfer occurring on the external surface of the radiator, thus promoting enhanced heat removal from the radiator to the surroundings.

9.3.3 Effect of Coolants' Flow Rate

Studies showed that one of the factors that strongly affect the radiator's performance is the coolant flow rate. In this work, the coolant flow rate is varied between 5 and 60 LPM. Figure 9.6 shows the effect of the coolant's flow rate on the temperature drop and the thermal resistance. At the lowest flowrate of 3 LPM, the temperature of the coolant reduces by 6.18 °C while at the highest flowrate of 60 LPM, the temperature reduces by 1.21 °C. The results indicate that as the flowrate increases, the temperature reduction of the coolant reduces, implying that for an effective operation of the radiator, it is better to control the coolant flowrate to the lowest possible. Similar relationship between the coolant's flowrate and the thermal resistance was also observed (Fig. 9.6). As the flowrate increases, the thermal resistance reduces to at least 0.031 °C/W when the coolant's flowrate is 60 LPM.

The effect on the coolant's flowrate on the total heat transfer is considered to be insignificant as the heat transfer varies between 36.23 and 38.98 W when the flowrate

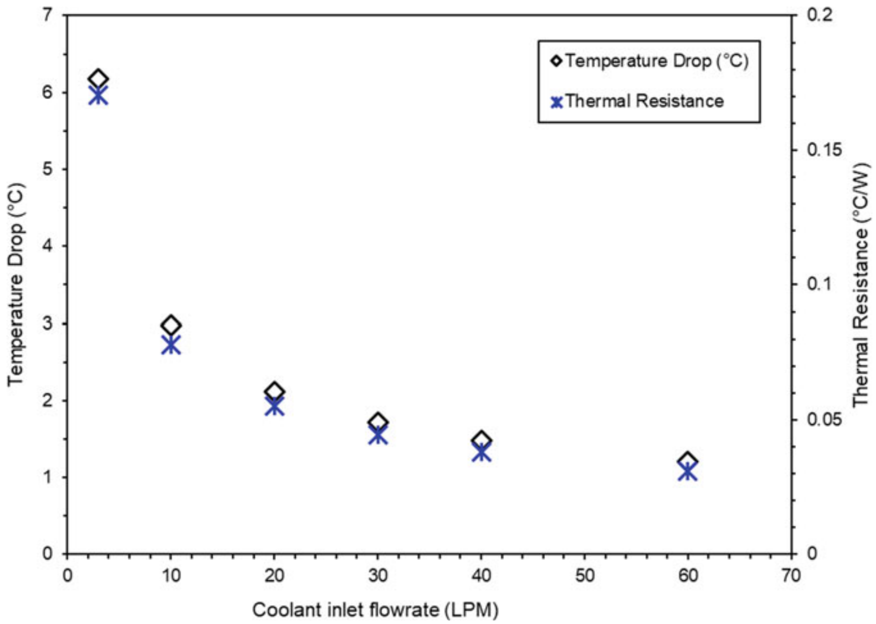

Fig. 9.6 The effect of coolant inlet flowrate on the temperature drop and the thermal resistance

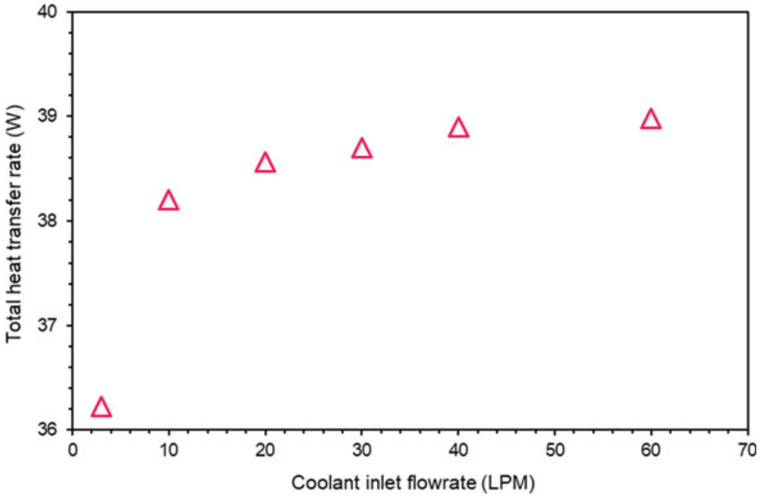

Fig. 9.7 The effect of coolant inlet flowrate on the total heat transfer rate of the radiator

changes from 3 to 60 LPM (Fig. 9.7). It can be observed that the effect is almost negligible when the coolant's flowrate is greater than 10 LPM.

The simulation results indicate that at low coolant's flowrate of 3 LPM, the temperature of the coolant can be reduced by at most 6.18 °C albeit at a higher thermal resistance of 0.17 °C/W. The resulted thermal resistance is considered to be within favorable value indicating low radiator's resistance to heat transfer. There is also an insignificant effect of the flowrate on the total heat transfer. Therefore, based on the results, it is best to operate the radiator with coolant's flowrate of 3 LPM, instead of a higher value.

9.4 Conclusion

The influence of rectangular fins on the heat transfer performance of an automobile radiator was the focus of this research. There were two types made: one without fins and one with rectangular fins. The effect of changing the convective heat transfer coefficient and the flowrate of the coolant on the coolant's temperature drop, thermal resistance, and overall heat transfer rate was studied. The results showed that the convection heat transfer coefficient must be as high as feasible to improve the radiator's performance in dissipating heat from the engine's coolant. The flowrate of the coolant has no effect on the radiator's thermal performance, suggesting that the coolant can flow with the lowest flowrate while still delivering comparable thermal performance with the greater flowrate.

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