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Numerical Simulation of Thermophysical Properties and Heat Transfer Characteristics of Al_2O_3/CuO Nanofluid with Water/Ethylene Glycol as Coolant in a Flat Tube of Car Radiator

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ABSTRACT

Thermal energy management in the automobile industry has been a growing challenge to ensure effective engine cooling and increase performance. The objective of this study is to investigate the heat transfer characteristics of nanofluids with different concentrations. The study focuses on the effect of thermophysical properties such as density, viscosity, and thermal conductivity on the thermal performance of the flat tube. Al_2O_3 and CuO nanoparticles concentrations of 0.05 to 0.3 per cent by volume were added into the mixture of the base fluid. CATIA V5 was used to design the flat tube, and the model was further simulated using ANSYS Fluent, a computational fluid dynamics (CFD) software. The base fluid consisting of 20% ethylene glycol and 80% water was observed to have a thermal conductivity of 0.415 W/m.K. The thermal conductivity, however, increases with the addition of 0.3% volume concentration of Al_2O_3 and CuO nanofluid, which are 0.9285 W/m.K and 0.9042 W/m.K, respectively. Under the same operating condition, the Nusselt number was observed to increase from 94.514 for the base fluid to 101.36 and 130.46 for both Al_2O_3 and CuO nanofluid, respectively. It can thus be concluded that CuO with a 0.3% concentration has the highest heat transfer rate compared to others. The heat transfer coefficient was recorded

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at 22052.200 W/m^{2}K, and the thermal conductivity obtained was 0.9042 W/mK, Nusselt number was 130.459, and the rate of heat transfer was at 66.71 W. There was a 10% increase in heat transfer coefficient at 0.3% nanofluid concentration when compared to 0.05%.

Keywords: Car radiator, computational Fluid Dynamic (CFD), nanofluid

INTRODUCTION

Recent developments in the advanced complexity of car engine systems have heightened the need for a good cooling system and a higher technology engine performance. This new development in engine technologies has led to increasing thermal load. The development of an efficient thermal management system is therefore very important. Throughout these past decades, a lot of research effort has been considered to examine how to improve the heat removal in a car cooling system such as a radiator. Recently, researchers have shown an increased interest in increasing the performance of car radiators by way of innovative design and application of new cooling fluids such as nanofluids.

The issue of engine overheating, reducing vehicular weight and increasing engine power output has recently received considerable critical attention (Ahmadi et al., 2020; Huminic & Huminic, 2013; Kole & Dey, 2010; Tsai & Chein, 2007). In addition, there is an urgent need to address the safety problems caused by thermal stress in car radiators, Kaska et al., 2019 argued that if the thermal energy in a car engine is not quickly removed, it may cause a significant increase in temperature of the engine above its operating temperature. It can cause losses of viscosity of the lubrication fluids; the metallurgical properties of the parts may be affected. Consequently, the engine parts may suffer from wear and tear.

According to Hong et al. (2018), inefficient thermal management of automotive engines can result in engine failure, and the metallurgical properties of the engine block can be badly affected, and this can also cause damage to the engine parts, thus resulting in a fatal accident. Therefore, there is an urgent need to address the overheating problems caused by the poor thermal management of car radiators. The demand for using high-efficiency engine increase as the technologies continues to develop. Nowadays, the issue that relates to the rising petroleum process and energy-saving awareness has been focused on enhancing the vehicle’s fuel performance efficiency. In order for solving the issues related, many experts have developed a new type of engine to increase the performance of heat dissipation by reducing the weight of cooling equipment (Esfe et al., 2019; Huminic & Huminic, 2018; Kaska et al., 2019; Zainal et al., 2016). There is a high level of heat transfer limitation imposed on conventional liquids such as water, and this is due to their low thermal characteristics. In recent years, there has been increasing interest in nanofluids and their application in enhancing heat transfer. Thermal management of heat dissipation in car radiators is crucial to ensure high performance and less fuel consumption of the vehicle

(Hayat & Nadeem, 2017; Kannaiyan et al., 2017; Karimi & Afrand, 2018; Hong et al., 2018). According to Babar & Ali (2019), heat transfer can be increased by adding fins to increase the surface area. Another way to increase the heat removal is by using an efficient coolant, which usually consists of the base fluid and a small percentage concentration of nanofluids. The base fluid of the coolant typically consists of some percentage of distilled water and ethylene glycol. The role of Ethylene glycol is to reduce the freezing point and increase the boiling point of water. The main advantage of adding nanofluids to the coolant is to enhancement the thermal properties. A number of authors have considered the effects of performance characteristics of nanofluids in car radiators (Awais et al., 2021; Kumar et al., 2020). These studies report that increase in the concentration of nanoparticles in the base fluid enhances the convection heat transfer in a car radiator. Three-dimensional thermal characteristics of car radiator with integrated louvre fins and nanofluid coolant were model by Kumar et al. (2020), the coolant properties consist of 60% ethylglycol, 40% distilled water, and Al_2O_3 and CuO as nanoparticles, they reported that the heat transfer coefficient of the working fluid was enhanced by about 42.4% and 47.4% with the addition of 2% concentration of nanoparticles to Al_2O_3 and CuO respectively.

According to Wen & Ding (2004), nanofluids are nanometre size particle fluids called nanoparticles with sizes significantly smaller than 100 nm. These fluids have a higher magnitude of bulk solids of thermal conductivity compared to the base fluid. When the nanofluids are properly engineered, the thermal conductivity is enhanced (Elsaid, 2019; Said et al., 2019). Conventional ethylene glycol and distilled water were used as the working fluid in the mechanical equipment, including heat exchangers such as car radiators (Soltanimehr & Afrand, 2015). Developing a high thermal performance working fluid could decrease the operating cost, such as the pumping power (Sundar et al., 2014a). A combination of nanoparticles with a base fluid, such as water and ethylene glycol, can be used as a coolant for car radiators for many years due to enhance the thermal conductivity of the working fluid (Ibrahim et al., 2019). In the past decades, researchers have been finding fluids that could offer higher thermal conductivity. Ahmed et al. (2018) investigated the improvement of car radiator performance by using varying volume concentrations of TiO_2/Water nanofluids with flow rates in the laminar region, where the Reynold number ranges from 560 to 1650. The research indicates that the friction factor decreases when the Reynold number and the volume concentration increase. In addition, the nanofluid promoted heat transfer dissipation by about 30% compared to the base fluid.

Huminic & Huminic (2013) studied the heat transfer performance of nanofluids that flows through a different cross-sectional tube in a laminar flow regime with constant heat flux. They used copper oxide nanofluids with a concentration between 0 to 4 per cent and ethylene glycol as the base fluid. The study result has shown that when the concentration of the nanofluid increases, the heat transfer coefficient also increases. Furthermore, the result shows that the heat transfer enhancement of 82% is achieved by the flattened tube compared to the circular and elliptic tube.

Devireddy et al. (2016) performed an experiment to study the performance of TiO_2 nanofluids with ethylene and water as the base fluid. They used 40% of ethylene glycol and 60% of water, with the volume concentration of nanofluids being between 0.1% and 0.5%. The experimental result shows that with a 0.5% volume concentration of TiO_2, the heat transfer increased by 35% compared to the base fluid.

According to the above discussion, it can be concluded that the heat transfer can be enhanced by using nanofluids as the coolant in the car radiator. Also, the above literature indicates relatively scant literature on the numerical simulation of nanofluid, especially (Al_2O_3 and CuO) in a flat tube car radiator. Therefore, this study makes a major contribution by numerically investigating the heat transfer characteristics of nanofluids with different concentrations. This study will focus on the effect of thermophysical properties such as density, viscosity, and thermal conductivity on the thermal performance of the flat tube. Different concentrations of nanofluids (Al_2O_3 and CuO) with 80% water and 20% ethylene glycol as the base fluid were adopted for this study. The concentration of nanofluids was varied from 0.05%, 0.15% to 0.3%. The investigation of this study only considers a portion of the flattened tube.

METHODOLOGY

This study focuses on determining the heat transfer characteristics of nanofluids (Al_2O_3 and CuO) in a flat tube of a car radiator. This study is completely based on numerical simulation. Firstly, CATIA V5 is used for modelling the flat tube. Then, the model is imported into Computational Fluid Dynamic (CFD) tool in ANSYS Fluent software for further simulation. Next, the numerical data is validated against other experimental results to prove that the data is qualified to produce accurate data. After validating the numerical data, the numerical simulation is carried out based on the chosen parameters.

Conceptual Modelling of the Radiator

Figure 1 illustrates the schematic representation of the operation of the radiator system, which consists of subsystems such as storage tank, electrical heater, feed pump, valve line, flow meter, fan, radiator, temperature indicator, and power source. This section aims to enhance the understanding of the operation of the car radiator cooling system. The heating coil placed inside the water tank acts as the car engine. The reflux line valve present is to prevent the backflow of the coolant. As a result, the hot coolant will flow into the feed pump, then to the flow meter and enter the flattened tube of the car radiator. At this stage, the hot coolant will release the heat to the surrounding by convection while the fan will induce air to the fins of the car radiator is to increase the heat transfer area. As a result,

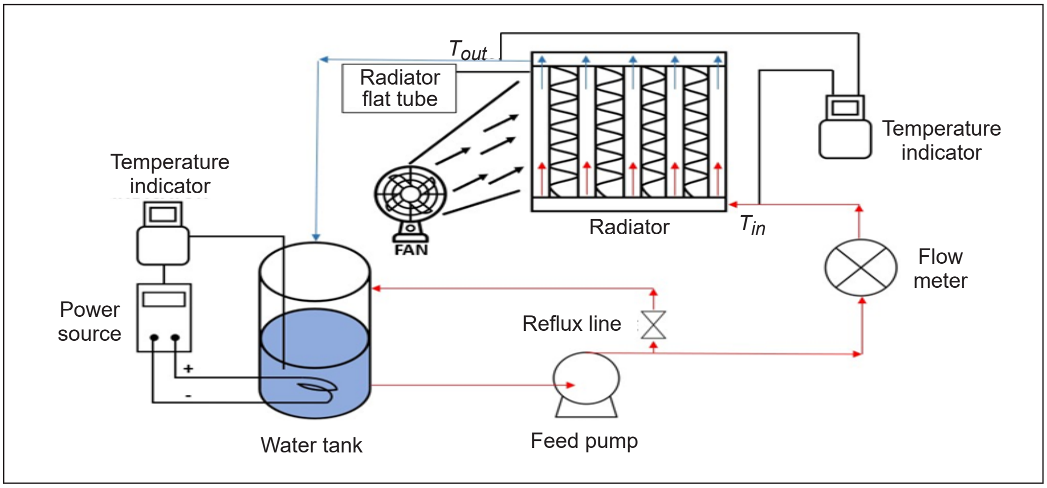


Figure 1. Mode of operation of the system

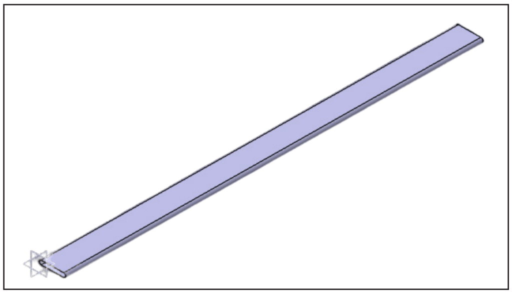
the coolant is cool to the desired temperature and flow back to the storage tank. The setup is an imitation of the actual operation condition of the cooling system of the car radiator (Delavari & Hashemabadi, 2014; Naraki et al., 2013; Oliveira et al., 2017).

Simulation Models

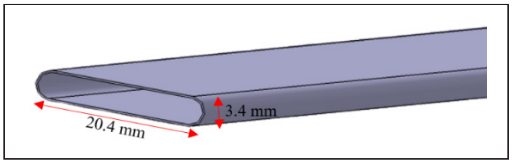
Table 1 shows the physical characteristics of the flat tube model used in this study. The geometric model of the flat tube was first designed by using (CATIA) tool. The flat tube car radiator with height (d), width (D) and length (L) are 3.4 mm, 20.4 mm and 315 mm, respectively, as shown in Table 1. The dimension of the flat tube was determined based on the previous literature studies. The hydraulic diameter of the flat tube is 5.349 mm. Figure 2(a) shows the isometric view of the flat tube, and Figure 2(b) shows the

Table 1
Geometrical configuration of the flat tube

Parameter	Specification (mm)
Tube length, L	315
Tube thickness	0.2
Tube height, d	3.4
Tube width, D	20.4
Tube hydraulic diameter, $\boldsymbol{D_h}$	5.349
Material used	Aluminium
Quality of mesh	212 173



(a)



(b)

Figure 2. (a) Isometric view of the flat tube; and (b) dimensions of the inlet

detailed dimension of the flat tube. The flat tube material is aluminium and was applied in the simulation setup. Only a section of the flat tube is analysed in the ANSYS software because of the limitation of the simulation tool and to reduce the computational time.

Model Equation of the Thermophysical Properties of the Nanofluid

The thermal properties of the working fluid are determined by using the equation below. Those numerical data resulting from the previous equation will be analysed in the computational fluid dynamic simulation. The nanofluid used in this project is Al_2O_3 and CuO, forming a mixture with the base fluid containing 80% water and 20% ethylene glycol. In recent years, researchers have applied a few formulas to determine the thermophysical of the nanofluid. The density, specific heat capacity (Pak & Cho, 2013)s and the thermal conductivity (Hamilton, 1962) of the nanofluid can be calculated using Equations 1, 2 and 3s, respectively. Moreover, according to Ahmadi et al. (2020), the viscosity of nanofluid with based fluid as water and ethylene glycol can be estimated using Equation 4.

$$\rho nf = \varphi \rho p + 1 - \varphi\ \rho bf \tag{1}$$

$$(\rho Cp)_{nf} = (\rho Cp)_p + (1-\varphi)\left(\rho Cp\right)_{bf} \tag{2}$$

$$k_{nf} = \frac{k_p + (\Phi - 1)k_{bf} - \varphi(\Phi - 1)\left(k_{bf} - k_p\right)}{k_p + (\Phi - 1)k_{bf} + \varphi\left(k_{bf} - k_p\right)}\ k_{bf} \tag{3}$$

$$\mu_{nf} = \mu_{bf} + (1 + 2.5\varphi) \tag{4}$$

Where Φ is spherical particles of the shape factor of nanoparticles, which is Φ = 3 (Hamilton, 1962). $\boldsymbol{\rho}$ is the density, ***Cp*** is the specific heat capacity, ***k*** is the thermal conductivity, φ is the nanoparticles concentration, μ is the viscosity and the subscript “p”, “nf” and “bf” is referred to particle, nanofluid, and base fluid, respectively. Table 2 shows the properties of the nanofluid and based fluid.

Table 2
Thermophysical properties of based fluid and nanoparticles (Kole & Dey, 2010; Peyghambarzadeh et al., 2011; Tsai & Chein, 2007)

Material	Specific heat (J/kg.K)	Thermal conductivity (W/m.K)	Density (kg/m^3)	Viscosity (kg/m.s)
Base fluid (80%Water 20% EG)	3570	0.415	1027.01	0.00076
Al_2O_3	765	46	3970	-
CuO	535.6	20	6500	-

Model Equation for the Heat Transfer

In order to obtain the heat transfer characteristics of the nanofluid, the Prandtl number, Nusselt number, Reynold number and heat transfer coefficient were first estimated. The Prandtl number is obtained by using Equation 5. The Nusselt number for base fluid in this study is calculated using Equation 5, while for the nanofluid, the Nusselt number was calculated using Equation 7. Both of these equations were designed for the flat tube. The heat transfer coefficient obtained by Equation 8 and hydraulic diameter, D_h can be obtained by Equation 9, while the friction factor is calculated using the Blasius equation (Pak & Cho, 1998). The friction factor can be calculated using Equation 10, while the pressure drop can be calculated using Equation 11. Finally, the heat transfer rate, $\dot{Q}$ of the nanofluid is calculated using Equation 12.

Prandtl number equation:

$$Pr = \frac{v}{a} = \frac{C_p \mu}{k} \tag{5}$$

Reynold number Equation 6:

$$Re = \frac{pUD_h}{\mu} \tag{6}$$

The Nusselt number of the base fluid is a function of Reynold number, and Prandtl number is defined as in Equation 7:

$$Nu = 0.023 Re^{0.8} Pr^{0.3} \tag{7}$$

While the Nusselt number for nanofluid calculated in a function of Reynold number and Prandtl number is defined as in Equation 8:

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \tag{8}$$

Heat transfer coefficient, hydraulic diameter and friction factor Equations 9-11 are as follows:

$$h = \frac{Nu\, k}{D_h} \tag{9}$$

$$D_h = \frac{4\left(\frac{\pi}{4} d^2 + (D-d) \times d\right)}{\pi \times d + 2 \times (D-d)} \tag{10}$$

$$\text{f} = \frac{0.316}{Re^{0.25}} \tag{11}$$

Rate of heat transfer can be calculated using Equation 12:

$$\dot{Q} = hA_s(T_{inlet} - T_{outlet}) \tag{12}$$

Boundary Conditions

The flat tube was designed in the CATIA V5 and imported to ANSYS FLUENT to be analysed. The numerical calculation was done using all the stated formulas, and the data was tabulated in the excel spreadsheet. Before running the simulation, boundary condition was applied to the flat tube model, such as the inlet velocity, pressure outlet and boundary condition of the wall. The assumption included in this simulation is that the velocity at the inlet for the coolant was predefined at 0.0377 m/s, 0.0526 m/s, 0.054 m/s and 0.784 m/s. The coolant temperature was set to 369.15 K. Convection boundary condition was assumed on the wall of the flat tube with an air temperature of 35°C. The flow is also assumed to be steady, under turbulence and incompressible. The flow was assumed to be a steady-state because the thermophysical properties of the coolant were the same throughout the fluid flow section (Tijani & Sudirman, 2018). The continuity and momentum equations are the governing equations used to analyse the problem.

Continuity equation (Zainal et al., 2016):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{13}$$

Momentum equation (Zainal et al., 2016):

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial P}{\partial x} + \mu\left(\frac{\partial^2 u_x}{\partial x^2} + \frac{\partial^2 u_x}{\partial y^2} + \frac{\partial^2 u_x}{\partial z^2}\right) \tag{14}$$

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = -\frac{\partial P}{\partial y} + \mu\left(\frac{\partial^2 u_y}{\partial x^2} + \frac{\partial^2 u_y}{\partial y^2} + \frac{\partial^2 u_y}{\partial z^2}\right) \tag{15}$$

$$\rho\left(u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = -\frac{\partial P}{\partial z} + \mu\left(\frac{\partial^2 u_z}{\partial x^2} + \frac{\partial^2 u_z}{\partial y^2} + \frac{\partial^2 u_z}{\partial z^2}\right) \tag{16}$$

Energy Equation (Zainal et al., 2016):

$$\frac{\partial}{\partial x_i}(\rho u_i T) + \frac{\partial}{\partial \mathrm{t}}(\rho T) = k\frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial \mathrm{P} u_i}{\partial x_i} \tag{17}$$

Equations 13-17 are also based on the following assumptions (Sandhya et al., 2021):

(i) Steady-State

A steady-state indicates that all time-dependent terms in the governing equation can be cancelled or dropped; this reduces the complex equation to a simple form.

(ii) Incompressible flow
The assumption of incompressible flow means the density of the fluid is constant; this assumption enables the terms containing the density to be reduced to zero.
In this study, the k-epsilon model was chosen as the turbulent model. This model was chosen because the calculation of our Reynolds number suggests that the flow situation is turbulent. The following assumptions were, however, applied to the k-epsilon model (ANSYS, 2013; Elsaid, 2019):
(i) the flow is an isotropic and continuous phase
(ii) the flow is fully turbulent
(iii) the effects of molecular viscosity are negligible

Grid Independent Test

The purpose of the grid independence test for the flat tube model conducted in ANSYS Fluent is to ensure the accuracy and reliability of the simulation result (Zaidan et al., 2018). The number of elements will also affect the computing time of the simulation. This test was performed to reduce the number of elements of the mesh independent of the result obtained. The number of elements of the mesh also affected the value of the outlet temperature and velocity. In this simulation, the number of divisions of the edge sizing was varied, and the outlet temperature was observed with a different number of the edge sizing. Figure 3 shows the output characteristics of the outlet temperature with respect to the number of elements of the mesh model. The elements size obtain from the test include: 105 368, 121 529, 159 104, 212 173 and 280 662. The fourth and fifth mesh have the same output temperature, 368.002 K but with a bigger gap in the number of elements. Hence, the fourth mesh is chosen for further simulation. Figure 4 shows the detailed image of the meshed geometry of the flat tube.

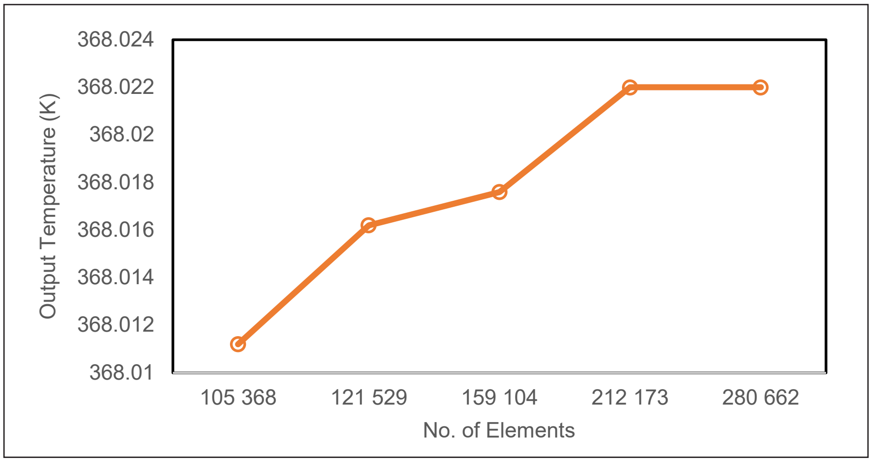


Figure 3. Grid independence data from the CFD simulation

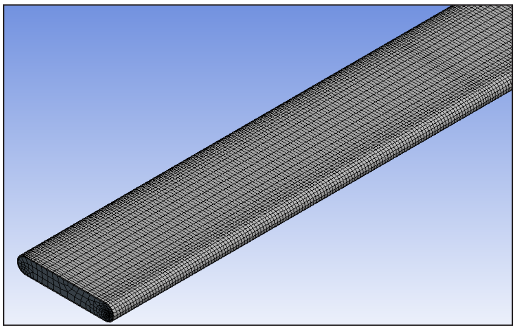


Figure 4. Meshed geometry of the flat tube

RESULTS AND DISCUSSION

In this section, the important findings of the research are discussed in detail. The heat transfer of the nanofluid was obtained after the simulation was done by using ANSYS Fluent with the data from the numerical calculation. In order to support the accuracy of the simulation results, experimental data from the literature (Peyghambarzadeh et al., 2011) was used to validate the numerical simulation.

Nanofluid Thermophysical Properties

First and foremost, the thermophysical properties of the nanofluid of Al_2O_3 and CuO need to be determined to obtain the heat transfer rate for both nanofluids. The thermophysical properties of the nanofluid include density, thermal conductivity, specific heat capacity, and viscosity need to be calculated before conducting the simulation. These thermophysical properties could be calculated by using Equations 1–4. With different concentrations, such as 0.05%, 0.15% and 0.3% of nanofluid, different thermophysical properties were obtained.

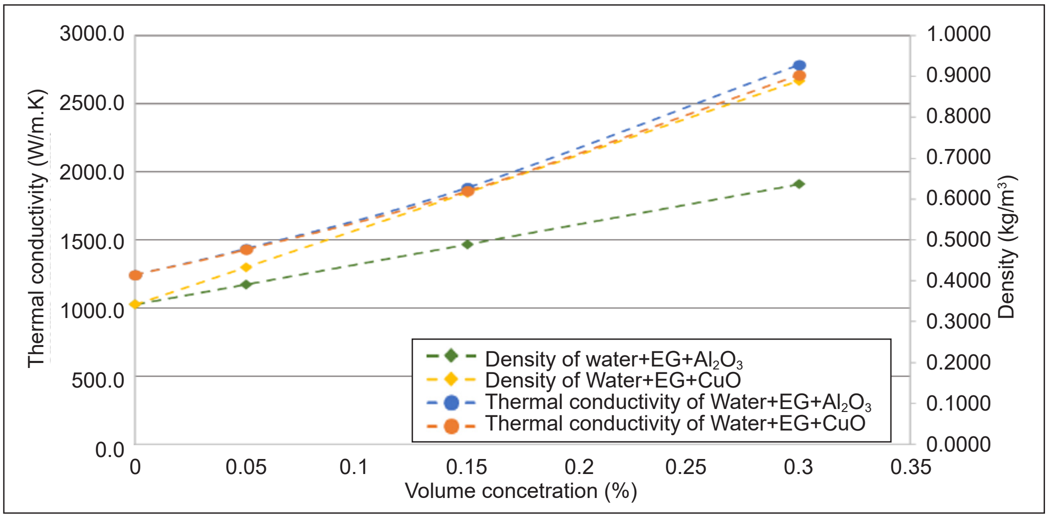
Table 3
Thermophysical properties of Al_2O_3 nanofluid

Volume concentration (%)	Density (kg/m^3)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Viscosity (kg/m.s)
0.05	1174.157	0.4787	3095.795	0.0008550
0.15	1468.459	0.6278	2432.496	0.0010450
0.3	1909.907	0.9285	1820.828	0.0013300

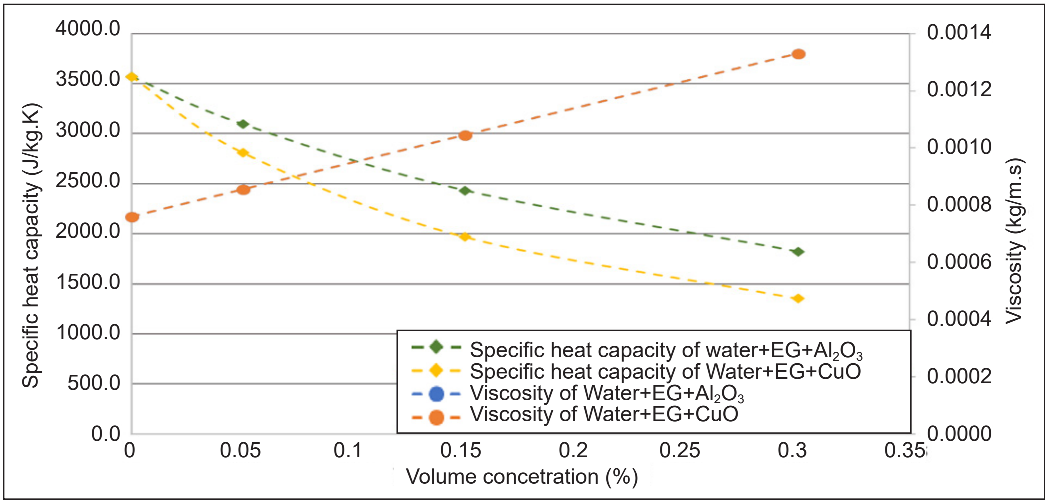
Table 4
Thermophysical properties of CuO nanofluid

Volume concentration (%)	Density (kg/m^3)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Viscosity (kg/m.s)
0.05	1300.660	0.4764	2811.785	0.0008550
0.15	1847.959	0.6194	1969.022	0.0010450
0.3	2668.907	0.9042	1352.958	0.0013300

Table 3 shows the thermophysical properties of Al_2O_3 nanofluid, while Table 4 shows the thermophysical properties of CuO nanofluid with water and ethylene glycol as the base fluid. The nanofluid density is vital in determining the thermophysical behaviour since it will affect the Reynold number, Nusselt number and heat transfer coefficient. Figure 5(a) shows that when the volume concentration of the nanofluid increase, the density of the nanofluid also increase. From Figure 5(a), as the volume concentration of the nanofluid increase, the thermal conductivity increase. Thermal conductivity is another important parameter in determining the heat transfer characteristic. The result shows that CuO nanofluid with 0.05% volume concentration has the lowest thermal conductivity of 0.4764 W/mK while



(a)



(b)

Figure 5. (a) Thermal conductivity (k) and density (ρ) versus concentration; (b) specific heat capacity (Cp) and viscosity (μ) versus concentration

Al_2O_3 nanofluid with 0.3% volume concentration has the highest thermal conductivity 0.9285 W/mK. Comparing the thermal conductivity of the base fluid in Table 2 and the thermal conductivity of the coolant with Al_2O_3 and CuO nanofluid, there were huge increases. While comparing the thermal conductivity between Al_2O_3 and CuO nanofluid, CuO nanofluid has lower thermal conductivity than Al_2O_3 nanofluid with 0.9042 W/mK for CuO nanofluid and 0.9285 W/mK for Al_2O_3 nanofluid with a volume concentration of 0.3%. One of the interesting findings of the research is that nanofluid concentration has a positive impact on the thermophysical properties of the nanofluid; as can be observed in Figure 5(a), the thermal conductivity of the nanofluid increases sharply with an increase in nanofluid concentration. Both Al_2O_3 and CuO nanofluid exhibited similar responses to increase in concentration except that the thermal conductivity of Al_2O_3 is slightly higher by about 4 %. The reason is that Al_2O_3 has a lower density as compared to CuO nanofluid (Sundar et al., 2014b). It can also be observed from Figure 5(b) that the specific heat capacity of each nanofluid decreases with an increase in nanofluid concentration. It is because the dispersion of nanoparticles in base fluids promotes the development of resistance between the fluid layers and helps to enhance the viscosity [Figure 5(b)] and density of the fluid; thus, the combination of these two effects reduces the specific heat capacity of the nanofluid (Ahmadi et al., 2020; Kumar et al., 2020; Plant & Saghir, 2021). The linear characteristics of viscosity of each nanofluid also show that the nanofluids are exhibiting similar Newtonian behaviour, which is why both nanofluids are overlapping, as shown in Figure 5(b). Many researchers have reported similar Newtonian characteristics (Delavari & Hashemabadi, 2014; Soylu et al., 2019; Nabil et al., 2017; Okonkwo et al., 2019).

Experimental Data Validation

Validation was carried out to verify the accuracy of the simulation model. In this study, validation was done by comparing the value of the Nusselt number in previous literature by Peyghambarzadeh et al. (2011) and the Nusselt number calculated in this work by using the equation. The inlet velocity of coolant, type of nanofluid, volume concentration of nanofluid and base fluid of the previous literature is adapted into this study. The average percentage error was 10.05%, as shown in Figure 6. The percentage error difference is because there may be a small variation in the dimension between experiment and simulation. Also, because of the limitation of the element size in Ansys Fluent, only a part of the whole radiator tube was simulated, while the whole radiator was used in the experiment.

Figure 7 shows the correlation between the Nusselt number and the volume concentration of the nanofluid with the change in velocity. Figure 7 depicts that as the volume concentration of nanofluid and the inlet velocity increase, the Nusselt number also increases. From both nanofluids, the highest Nusselt number was recorded at a velocity of 0.0774 m/s and 0.3% volume concentration. The highest Nusselt number for CuO and

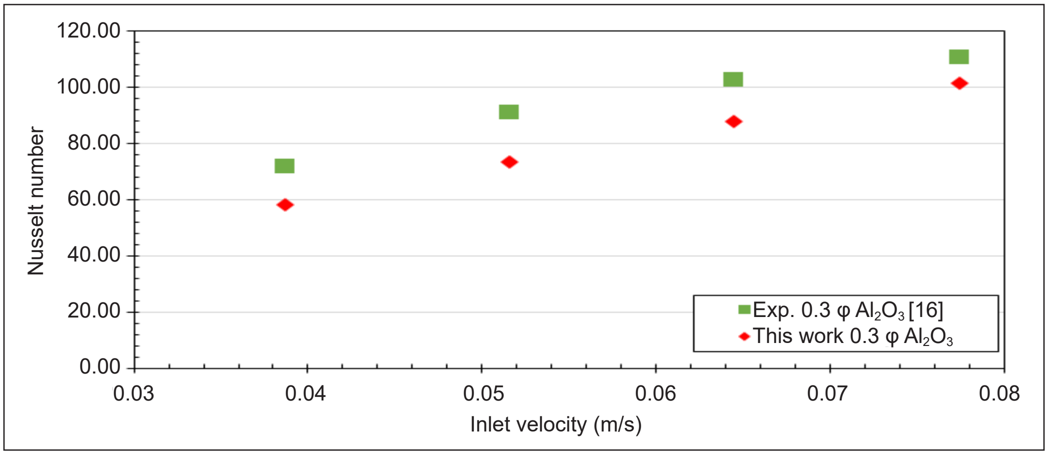
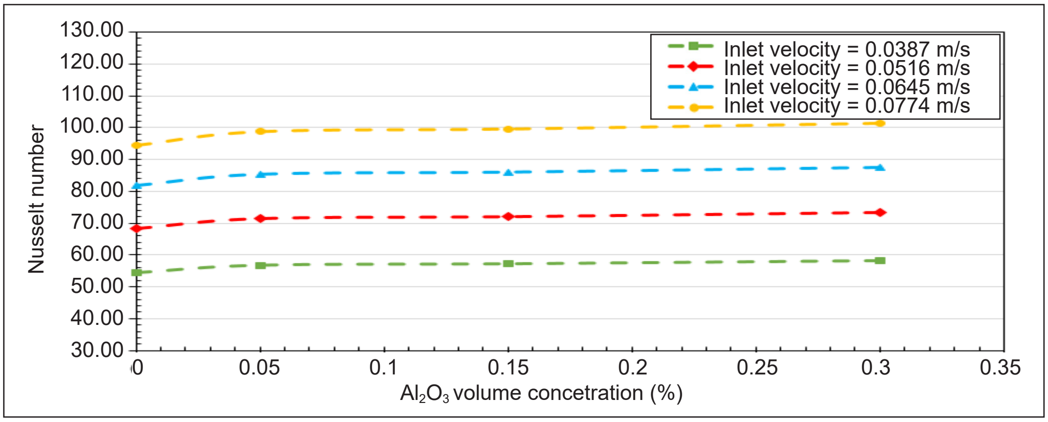
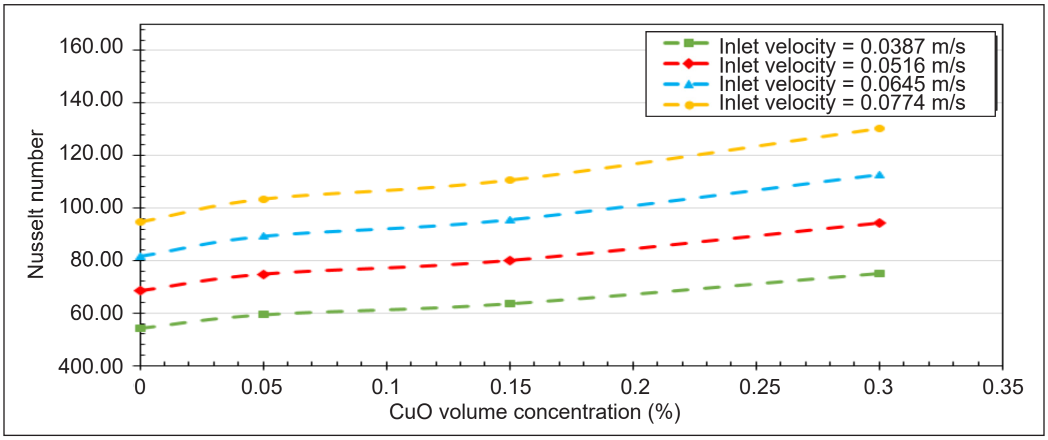


Figure 6. Validation of Nusselt number vs inlet velocity of experimental and this work



(a)



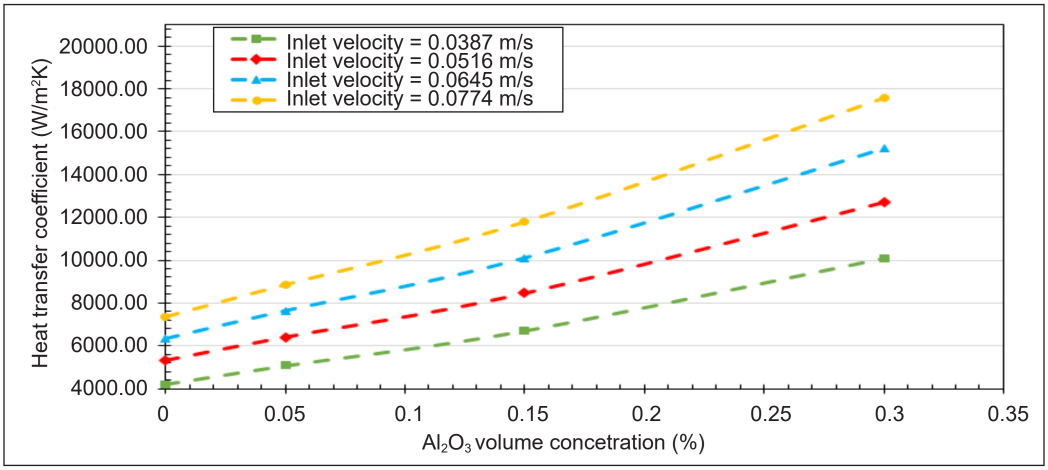
(b)

Figure 7. (a) Effect of nanofluid (Al_2O_3) concentrations on Nu (b) Effect of nanofluid (CuO) concentrations on Nu

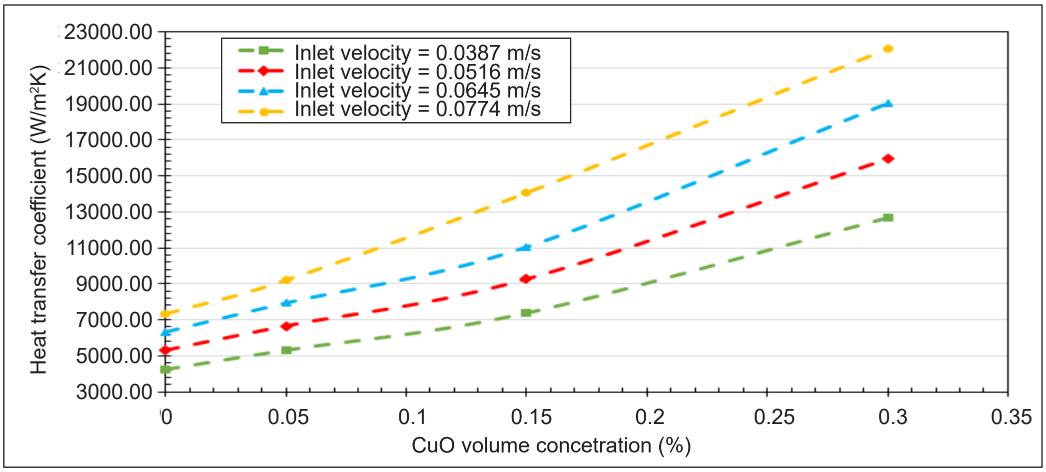
Al_2O_3 nanofluids were at 130.459 and 101.365, respectively, and these were observed at 0.3% volume concentration and velocity of 0.0774 m/s. It can be generally observed from Figures 7(a) and 7(b) that there is an enhancement in Nusselt number as the velocity of the nanofluid is increases. The reason is that increasing velocity promotes enhancement in the mixing of the nanoparticles, which also enhances the thermal transport characteristics and therefore increases the rate of heat transfer. Also, as the nanoparticle concentration increases, the thermal conductivity and Brownian motion of the nanoparticles is enhanced; it can therefore be concluded that the systematic motion of the nanoparticles due to increasing volume concentrations are the main reason for the improvement in Nusselt number. These results reflect those of (Sajid & Ali, 2019), who also found that increasing nanoparticle concentrations causes a reduction in boundary layer thickness and clustering of particles which play an important role in enhancing the Nusselt number. These results corroborate the findings of a great deal of the previous work (Ahmed et al., 2021; Almasri et al., 2022; Alsabery et al., 2021; Chompookham et al., 2022).

Heat transfer coefficient is an important parameter to describe the thermal performance of nanofluids. It can be observed from Figures 8(a) and 8(b) that the heat transfer coefficient increases significantly with respect to the increase in velocity of the fluid and the nanofluid concentration. It can also be observed that both nanofluids have the same pattern. Figures 8(a) and 8(b) recorded the highest heat transfer coefficient at a velocity of 0.0774 m/s and 0.3% volume concentration. The highest heat transfer coefficient for CuO and Al_2O_3 nanofluids was recorded at 22052.200 W/m^2K and 17596.353 W/m^2K, respectively. The contributing factor to the enhancement of heat transfer coefficient is that heat transfer coefficient is a parameter that is a function of both Nusselt number and Reynolds number; therefore, an increase in velocity of the fluid promotes a turbulent flow situation which eventually increases the Nusselt number of the fluid. Therefore, an increase in the Nusselt number indicates that the flow situation is dominated by convective heat transfer instead of conductive heat transfer in the fluid. The domination of the convective heat transfer is a result of an increase in the heat transfer coefficient. Comparison of the findings with those of other studies (Almasri et al., 2022; Chompookham et al., 2022) confirms a similar observation in the literature.

Figure 9 describes the effect of nanofluid concentration on the rate of heat transfer. It can be observed that the base fluid, which is a mixture of water and ethylene glycol, exhibits the lowest heat transfer rate of about 21.03 W. As the nanofluid concentration is gradually introduced into the base fluid, the heat transfer rate increase significantly for both nanofluids. For example, the heat transfer rate for Al_2O_3 and CuO nanofluid at 0.05% volume concentration and velocity of 0.0774 m/s was observed to be about 26W for each nanofluid. The reason is due to an increase in thermal conductivity of the nanofluid, and this is consistent with the findings of Kumar et al. (2020) and Tijani and Sudirman (2018).



(a)



(b)

Figure 8. (a) Effect of nanofluid (Al_2O_3) concentrations on Heat transfer coefficient (b) Effect of nanofluid (CuO) concentrations on Heat transfer coefficient

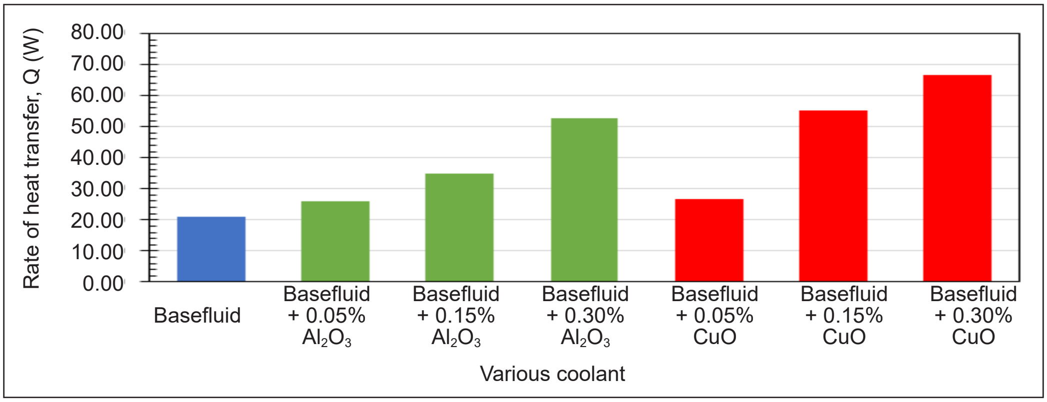
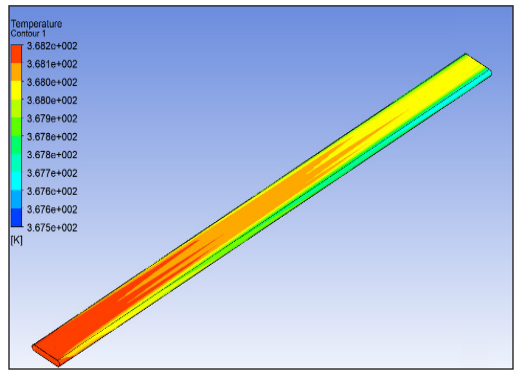


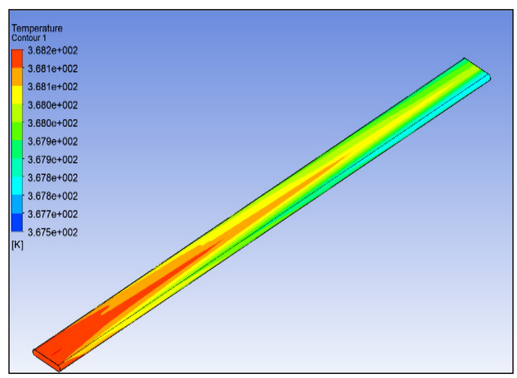
Figure 9. Heat transfer rate of various coolants

It can also be observed that at a nanofluid volume concentration of 0.3%, the CuO nanofluid with water and ethylene glycol has the highest heat transfer (66.71 W) compared with Al_2O_3 nanofluid (52.70 W). Generally, this enhancement in heat transfer may be due to the enhancement of thermo-physical properties and the increased effect of radiation around the internal wall of the flat tube.

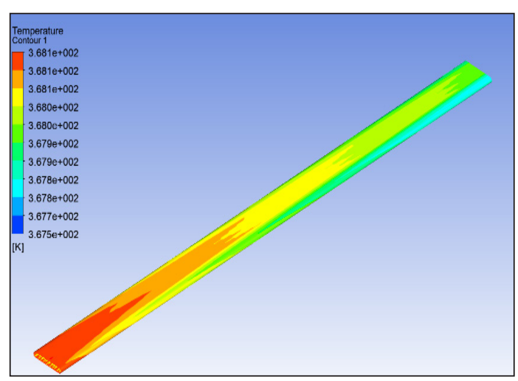
In this study, the temperature was one of the selected parameters to be used to determine the heat transfer distribution across the flat tube. The temperature contour describes the effect of nanofluid volume concentration on the heat transfer enhancement. Figure 10 shows the temperature contour for base fluid, 0.3% Al_2O_3 nanofluid and 0.3% CuO nanofluid at 0.774 m/s. From Figure 10, it can be observed that the temperature contours were covered by the entire region of the flat tube. Figure 10(b-c) indicates a better enhancement of heat transfer using nanofluids as compared with base fluid. It is due to the contribution of enhancing the nanofluid thermal conductivity. Figure 11(a-c) describes the velocity profile of the streamline of the working fluid coolant in the car radiator. We can conclude from Figure 11(a-c) that there was no significant change or decrease in the fluid velocity in each. As a result, constant pressure was observed between the inlet and outlet of the tube. Figure 11(a-c) also shows a more qualitative nature of the flow characteristics in the flat tube. It shows a high level of shear stress produced around the sidewall, which leads to the generation of vortex zones. This phenomenon of vortex formation promotes turbulence flow situation and eventually improves heat transfer. These results corroborate



(a)



(b)



(c)

Figure 10. Temperature contour of coolant at 0.0774 m/s (a) base fluid (Water+EG) (b) Water + EG + 0.30% Al_2O_3 nanofluid (c) Water + EG + 0.30% CuO nanofluid

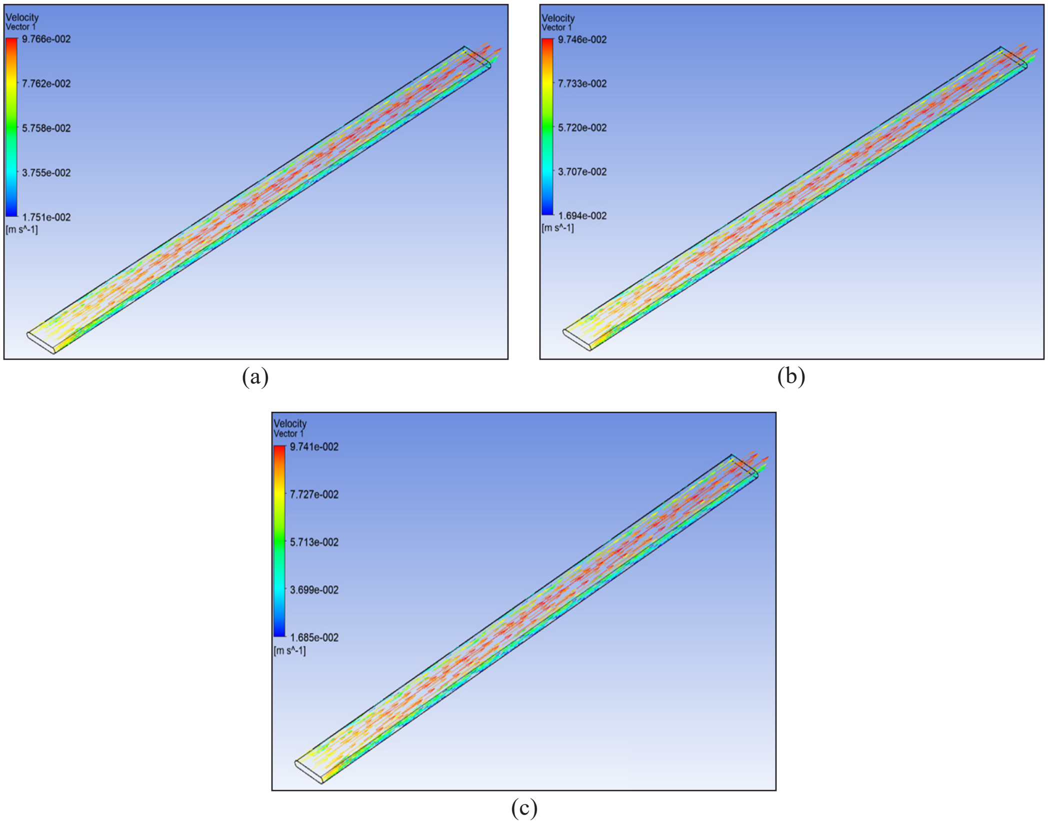


Figure 11. Velocity streamline of coolant at 0.0774 m/s (a) base fluid (Water+EG) (b) Water + EG + 0.30% Al_2O_3 nanofluid (c) Water + EG + 0.30% CuO nanofluid

the findings of a great deal of the previous work (Guo et al., 2018; Kaska et al., 2019; Vajjha et al., 2015; Zaidan et al., 2018).

CONCLUSION

This study aims to investigate the thermophysical properties of the nanofluids, which is Al_2O_3 and CuO, as well as to study the heat transfer characteristic of the nanofluids. The thermophysical of the base fluid and the nanofluids have been determined and compared. It can be concluded that the addition of nanofluids to the base fluid coolant of the car radiator showed a significant increase in the heat transfer rate. The thermophysical properties of the nanofluids, such as thermal conductivity, heat transfer coefficient and Nusselt number, enhanced the heat transfer performance of the car radiator. It was observed that the rate of heat transfer increase as the concentration of the nanofluid increases. It can be concluded that the CuO nanofluid with 0.3% of volume concentration at 0.774 m/s has the highest heat transfer rate, which was at 66.71 W compared to Al_2O_3 nanofluid with the same condition with the rate of heat transfer of 52.70 W and the base fluid with the rate of heat transfer of 21.03 W. This is due to the fact that CuO has greater thermal conductivity and Nusselt number compared to Al_2O_3 and base fluid.

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