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Heat Transfer Characteristics of Aluminium Oxide-Based Ethylene Gycol/Water Nanofluids as a Coolant for Car Radiator

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ABSTRACT

An automotive radiator acts as a cooling system for a car engine by dissipating excessive heat generated in the engine to the surrounding. The pump for the coolant and the fan extract obtain their power from the car engine. Although the use of nanofluid has the potential to increase heat transfer performance, its presence in the coolants increases the pressure drop penalty and pumping power. This study was conducted to analyse the thermal characteristics of nanofluid coolants. The coolant was made of Alumina Oxide (Al_2O_3) based Ethylene Glycol, which flowed inside the radiator tubes to enhance the car radiator's heat transfer. A vortex generator fins with a flat tube was selected and numerically studied using ANSYS fluent software with the Al_2O_3 combination of 20:80 EG:water. The thermal performance of the car radiator was analysed using four different volume concentrations: 1vol%, 3vol%, 6vol% and 9vol%. Enhancement of the Nusselt number was observed with an increase in nanofluid concentration. For example, at 0.09 concentration, the Nusselt number equal to 33.3425, heat transfer coefficient of 441.857 W/m^{2}K, and thermal conductivity of 0.7156 W/m K were obtained. At 0.09% concentration, the highest heat transfer rate of 121.95W was obtained while the lowest rate of heat transfer corresponding to the base fluid was 48.42W. This shows an increase in heat transfer of about 39.7% with the increase of nanofluid concentration.

Keywords: nanofluid, car radiator, alumina oxide, computational fluid dynamics (CFD)

Nomenclature

Nu	*Nusselt number*
Re	*Reynold's number*
h	*Heat transfer coefficient*
Pr	*Prandtl number*
d	*Hydraulic diameter*
$\dot{Q}$	*Rate of heat transfer*
$\dot{m}$	*Mass flow rate*
T	*Temperature*
ρ	*Density*
φ	*Particle sphericity*
Cp	*Specific heat capacity*
Φ	*Thermal conductivity*
μ	*Viscosity*
Subscript	
nf	*Nanofluid*
bf	*Base fluid*
p	*Nanoparticle*
EG	*Ethylene glycol*

1.0 INTRODUCTION

The new fuel economy has become a central issue for high-efficiency car engines [1]. To reduce fuel consumption usage, weight reduction of automotive vehicles has become one of the significant challenges in the car manufacturing industry. The thermal performance of compact heat exchangers such as car radiators has the potential for thermal management of the engine block. [2]. However, achieving effective cooling of the car radiator is very challenging. Three significant factors can increase the thermal performance of radiators: the design of tube and fins and the coolant used. The fin and tube play a significant role in deciding the airflow through the fin and

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dissipate heat to the surrounding. Nanofluid is the combination of metallic or non-metallic particles mixed with the base fluid. Widely used base fluids are water, Ethylene glycol or a combination of both liquids [3-6]. The nanoparticles have different thermal characteristics that can influence the car radiator's whole thermal performance.

Car radiators are designed to transfer heat from the hot coolant that flows through it to the air flowing by the fan. These radiators are made by brazing fins to flattened tubes at the right and left sides. According to experimental study by M'hamed et al. [7], they found that flat-tube radiator with nano-coolant by using water ethylene glycol-based MWCNT nano-coolant with different nano particle concentrations between 0.1% – 0.5 % achieved a maximum heat transfer enhancement of 19% with 0.5% nanoparticle volume. Experimental study of flat-tube radiator by other researchers such as Naraki et al. [8] indicated that by using Water-CuO as a nano-coolant with laminar flow and Raynolds number between 100-1000, the heat transfer coefficient enhancements of 6–8% were measured. Another design and geometry of curved tube have also been conducted in a numerical study by Akbarinia and Behzadmehr [9]. Circular tubes have also been investigated in a numerical study by Maiga et al. [10].

The function of the fins is to absorb heat released by the coolant, which flows through the tube and dissipates the heat into the surrounding [11] and [12]. A numerical study by Manglik et al. [8] proved that the wavy plate-fin channel could considerably transfer heat in the recirculation zones. The variables used for the study consisted of 10–1000 Reynolds number. Experimental study of fins with a wavy plate design by Wang et al. [13] found that the heat transfer characteristics were strongly dependent on the corrugation angle, waffle height, and length. Other designs, such as louvered plate-fin channel, have been studied by Hsieh et al., Nuntaphan et al., and Sanders and Thole [10–12]. Another study related to different fins, which was delta-winglet vortex fins by Allison and Dally [17], showed that 46% reduction in airside pumping power was achieved with DWVG fins compared to louver fins.

By using nanofluid instead of conventional fluid, the heat transfer enhancement from the engine to the ambient increases the engine efficiency, which causes a reduction of fuel consumption. Also, more powerful engines could be designed for different climatic conditions. Siraj Ali Ahmed's [17] research has shown that TiO_2 nanofluids with 0.2% concentration can enhance the effectiveness of car radiator by 47% as compared to 0.1 and 0.3% concentration and pure water as a coolant. The variable parameters used for the study were 0.09 and 0.68m^3/h as a flow rate in laminar flow region. Another study on different nanofluids by Hussein et al. [18] used 1–2.5 vol% volume concentration of nanofluids and different flow rate between 2-8LPM which indicated that from the simulation result, SiO2 nanofluid with low concentrations can enhance heat transfer rate up to 50% as a comparison with pure water.

The literature review shows that compared to conventional fluids such as ionized water, there is a growing interest in using nanofluid as a coolant in thermal management of car radiators. However, the influence of different nanofluid concentrations on thermal characterization of car radiators has received less critical attention. Therefore, this manuscript makes a significant contribution by investigating the effect of (Al_2O_3) based Ethylene Glycol nanofluids on thermal characteristics of car radiators. In addition, the effects of the geometrical configuration of the car radiator with respect to fins (solid and perforated fin) were analysed. This project used Computational Fluid Dynamics (CFD) simulation in ANSYS software to determine the nanofluid's outlet temperature.

2.0 METHODOLOGY

2.1 Modelling and simulation

To simulate the car radiator model using Ansys Fluent (R18.1) software, several parameters were gathered from literature for designing flat tube and vortex generator fins as part of car radiator in Catia V5 software. Regarding the design, only one part of tube and fins was simulated because of the limitations imposed on Ansys Fluent software. However, based on Table 1, some parameters were used to design the tube and fins, while Figure 1 shows an isometric view of the car radiator in Catia VR5 and meshed car radiator in Ansys Fluent.

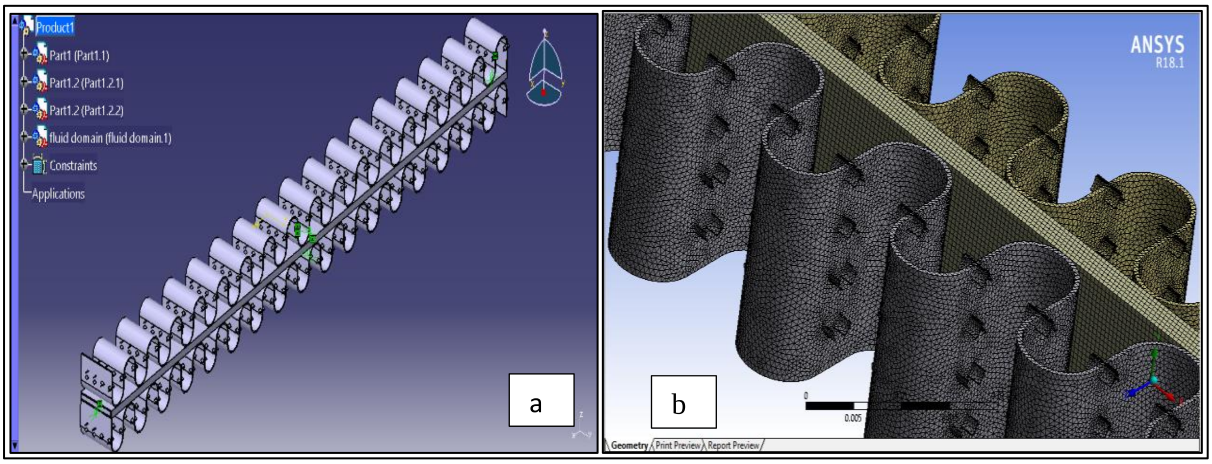


Figure 1. a) Isometric view of car radiator b) Mesh of the car radiator

Table 1: Parameters of car radiator model[19-21]

Parameters	Value
Tube length (cm)	31.5
Tube thickness(cm)	0.5
Tube width (cm)	20
Tube height (cm)	3
Space between tubes (cm)	1.5
Tube hydraulic diameter (cm)	0.5
Number of vortex generator (cm)	144
Vortex generator angle (^{o})	30
Vortex generator radius (cm)	1.35
Vortex generator thickness (cm)	1.55
Vortex generator horizontal distance	0.1
Distance between vortex generator	5
Material	Aluminium

2.2 Theoretical background

2.2.1 Mathematical modelling of the nanofluid thermophysical properties

The nanofluids' thermophysical properties can be solved after the properties of base fluid and nanoparticles are calculated first. The base fluid consists of water mixed with ethylene glycol (20:80 EG: water), and Al_2O_3 nanoparticles will combine and flow through the fluid domain in the flat tube. As shown in the equation below, some researchers have collected various data from the journal to get the exact equations in calculating nanofluid's thermophysical properties. Nanofluid's density, specific heat capacity, thermal conductivity, and viscosity can be determined based on the equation [22]–[24].

$$\rho_{nanofluid} = \phi\rho_{particle} + (1-\phi)\rho_{basefluid} \tag{1}$$

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

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

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

From equation 3, $\Phi=3/\psi$, Φ is defined as the empirical shape factor which is being assumed to be 3, ψ is known as the particle sphericity. Particle sphericity is characterized as the proportion of the surface territory of a circle having a similar volume as the nanoparticles to the surface region of the molecule [25].

Table 2: Aluminium oxide nanoparticle thermophysical properties [26]

Specification	Value
Purity	+99%
Grain size (nm)	20
Density (kg/m^3)	3970
Specific heat (J/kg.K)	370
Thermal conductivity (W/m.K)	40

2.2.2 Mathematical modelling for heat transfer performance

For studying the heat transfer performance of the base fluid and the nanofluid as the coolant for a car radiator, several heat transfer characteristics will be calculated: the Nusselt number, Prandtl number, and the heat transfer coefficient. The following equations show the mathematical modelling for the parameters of the heat transfer rate to be obtained [27]:

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

$$Nu = 0.023 Re^{0.8} Pr^{0.3} \tag{6}$$

$$h = \frac{Nu.k}{d_h} \tag{7}$$

The k for the heat transfer coefficient indicates the thermal conductivity of the fluid, while the d_h is the hydraulic diameter of the flat tube, which is equal to 0.0054m [27]:

$$\dot{Q} = hA\Delta \tag{8}$$

Where A is the cross-sectional area for the coolant entering the tube and ΔT is the difference between the inlet and outlet temperature of the coolant.

2.2.3 Boundary condition

To set up the boundary conditions, the thermophysical properties of the base fluid and the nanofluid are first calculated using a numerical method. Therefore, the boundary condition is listed as below:

- For the model of the simulation, k-epsilon is being used.
- The inlet velocity is varied starting from 0.024 m/s, 0.031 m/s, 0.038 m/s and 0.045 m/s which are equivalent to 7 l/min, 9 l/min, 11 l/min and 13 l/min while a constant coolant inlet temperature is kept at 95^o (368K) [28].
- The outlet pressure for the condition is set at 0 Pa as the pressure is being neglected through the whole flow inside the flat tube.
- For the convection boundary on the wall of the flat tube, a heat transfer coefficient of 10 W/m^2 is being set while the air temperature is 35 ^{o}C [29].

A few assumptions are made for flow to occur in the flat tube in the Ansys Fluent software. The following assumptions are being used for the numerical and simulation:

- A steady and incompressible flow is being assumed for the simulation
- The thermophysical properties of the base fluid and the nanofluid are assumed to be constant and do not change for the whole flow.

2.2.4 Grid independence test

In this paper, the grid independence study reduces the influence of the number of grids or grid size on the computational results by setting the mesh relevance within -75 until -100 to find the lowest number of elements. In this study, an outlet temperature was used as a parameter to select the suitable mesh relevance for the whole simulation. The importance of choosing the best mesh relevance is to have a better and more accurate result and lower the computing time. Table 3 shows the grid independence study result. The outlet temperature of each mesh relevance test has a slight difference for mesh relevance testing starting from -75 until -100. The highest number of elements recorded for the test is 3708674 when using -75 mesh relevance, which is different from other testing. On the other hand, the smallest observed number of an element is 1138422 for -100 mesh relevance. Table 3 clearly shows that at a mesh size of -75, the temperature significantly increases from 362.989 to 363.159, after which it remains constant within mesh relevance of -80 to -90. Hence, for this study, -90 of mesh relevance was selected as the outlet temperature which was the same as the number of elements for the smallest value of three mesh relevance.

Table 3: Grid independence study

Mesh Relevance	No of elements	Output Temperature (K)	Error
-75	3708674	362.989	-
-80	1224686	363.159	0.17
-85	1194858	363.159	-
-90	1164852	363.159	-
-95	1156260	363.16	0.001
-100	1138422	363.16	-

3.0 RESULTS AND DISCUSSION

3.1 Tabulated data for thermophysical properties of basedfluid and nanofluid

Before starting the Ansys Fluent solver simulation, the thermophysical properties for the base fluid and the nanofluids must first be determined. Therefore, the thermophysical properties of the base fluid were gathered from the literature. Meanwhile, for the nanofluid, thermophysical properties were being solved by using the numerical method of Excel at different volume concentrations: 0.01, 0.03, 0.06 and lastly, 0.09% was being set for the study. Tables 4 and 5 show the thermophysical properties of both coolants.

Table 4: Properties of Basedfluid [30]

Coolant	Temp. inlet (°C)	Density (kg/m^3)	Specific heat capacity, (J/kg.K)	Thermal conductivity (W/m.K)	Viscosity (kg/m.s)
Basefluid	95	1008	3977	0.5568	0.0006

Table 5: Properties of Nanofluids

Coolant	Properties			
Water + EG + Al_2O_3	Density (kg/m^3)	Specific heat capacity, (J/kg.K)	Thermal conductivity (W/m.K)	Viscosity (kg/m.s)
0.01%	1037.62	3854.4129	0.5731	0.0006
0.03%	1096.86	3629.1011	0.6066	0.0006
0.06%	1185.72	3333.3465	0.6594	0.0007
0.09%	1274.58	3078.8302	0.7156	0.0007

Table 6: Heat transfer performance of base fluid as coolant

Material	Prandtl Number	Velocity (m/s)	Reynolds Number	Nusselt Number	Heat transfer coefficient ($W/m^2.K$)
Water + EG	4.28	0.0240	2177.28	16.65	171.78
	4.28	0.0310	2812.32	20.44	210.81
	4.28	0.0380	3447.36	24.06	248.1
	4.28	0.0450	4082.40	27.54	284.03

Table 7: Heat transfer performance of Nanofluids as coolant

Material Water + EG + Al_2O_3	Velocity (m/s)	Prandtl number	Reynolds Number	Nusselt Number	Heat transfer coefficient ($W/m^2.K$)
0.01	0.024	4.13	2186.59	19.72	209.34
0.03		3.85	2203.92	19.85	222.98
0.06		3.48	2227.09	20.01	244.45
0.09		3.16	2247.42	20.16	267.22
0.01	0.031	4.13	2824.35	24.20	256.91
0.03		3.85	2846.73	24.36	273.65
0.06		3.48	2876.65	24.56	299.99
0.09		3.16	2902.92	24.74	327.94
0.01	0.038	4.13	3462.10	28.49	302.36
0.03		3.85	3489.54	28.67	322.06
0.06		3.48	3526.22	28.91	353.05
0.09		3.16	3558.41	29.12	385.95
0.01	0.045	4.13	4099.86	32.61	346.15
0.03		3.85	4132.356	32.82	368.70
0.06		3.48	4175.79	33.10	404.19
0.09		3.16	4213.91	33.34	441.85

3.2 Tabulated data for heat transfer performance

As the thermophysical properties of the coolants have been obtained, the heat transfer characteristics such as Prandtl number, Nusselt number and heat transfer coefficient can be calculated by using the mathematical modelling equation discussed earlier. The table shows that the heat transfer performance of the nanofluid of alumina oxide is better than mixture of the water and ethylene glycol as a coolant for car radiator. From the table also, both coolants have a better heat transfer characteristic when the inlet velocity is being increased starting from 0.024 m/s until 0.045 m/s. However, for nanofluid, the volume concentration and the velocity inlet play a significant role in deciding the thermal performance of the nanofluid.

From table 6, the highest Nusselt number is 27.5463 when using 0.045 m/s flow rate for the basefluid which also results into 284.0325 $W/m^2.K$ of heat transfer coefficient. Meanwhile, for the nanofluid, the highest recorded and exhibited value for the Nusselt number and the heat transfer coefficient is 33.3425 and 441.8577 $W/m^2.K$, respectively, when using the same flow rate as the basefluid, which is 0.04 5m/s.

3.3 Validation of work

In this study, validation of the simulation results was conducted with experimental data from Heris et al. [1]. The parameter compared with the study was the Nusselt number. Table 8 indicates the Nusselt number for the literature and from the study. Based on the comparison of the data, an average error of 14.74% was recorded. The average error may be due to the different dimensions of the car radiator, which will affect some of the parameters and influence the result obtained.

Table 8: Validation of work

Flow rate	Literature Nanoparticle concentration					Flow rate	My work Nanoparticle concentration				
l/min	0	0.01	0.03	0.06	0.09	l/min	0	0.01	0.03	0.06	0.09
7	19.21	22.36	23.58	24.61	25.12	7	16.65	19.72	19.85	20.01	20.16
9	24.23	29.17	29.68	29.99	30.13	9	20.44	24.21	24.36	24.57	24.75
11	27.62	30.46	31.67	32.16	33.69	11	24.06	28.49	28.67	28.91	29.12
13	31.26	37.89	38.43	40.12	40.89	13	27.54	32.62	32.83	33.10	33.34

Table 9: Error of work

	Nanoparticle concentration				
	0	0.01	0.03	0.06	0.09
	13.30	11.80	15.82	18.73	19.74
Average error (%)	15.64	17.03	17.92	18.01	17.85
Total average error (%)	12.89	6.51	9.47	10.11	13.56
	11.90	13.91	14.57	17.49	18.46
	13.43	12.31	14.45	16.09	17.40
	14.74				

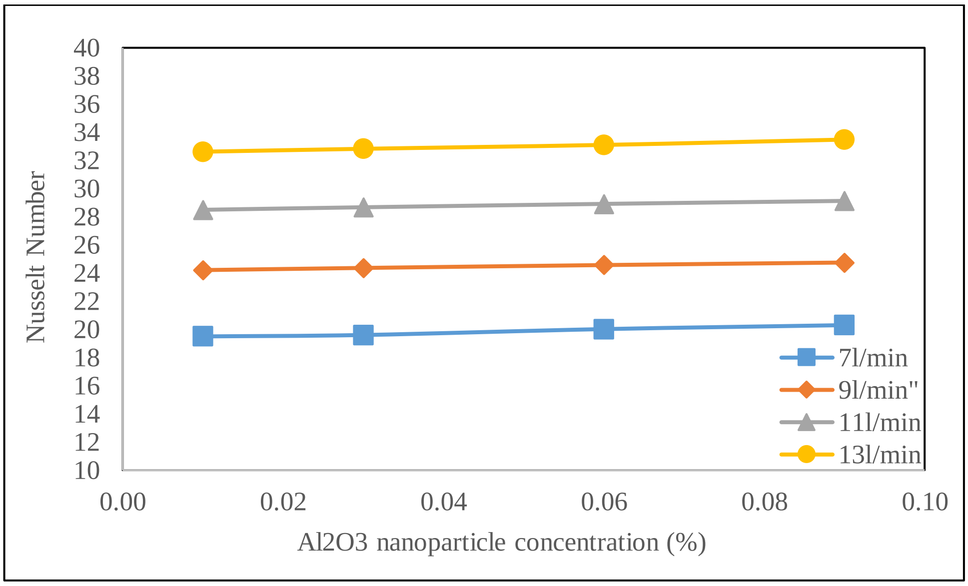


Figure 2: Nusselt Number versus Al2O3 for different volume flow rate

Based on Figure 2, it shows the correlation of nanoparticle concentration with the Nusselt number at different volume flow rates. As it can be seen from there, the highest volume concentration and flow rate will produce the highest Nusselt number and vice versa. For example, the highest recorded value for the Nusselt number is 33.34 and the lowest is 19.72.

Figure 3 shows the effect of nanoparticle concentration on the heat transfer coefficient. Same as the Nusselt number, the effect of the nanoparticle concentration will increase the heat transfer coefficient when the concentration is being added more into the mixture of the basefluid while having a high volume flow rate flowing inside the tube. The highest recorded data for the heat transfer coefficient is 441.8577 $W/m^2.K$ and the lowest is 209.3483 $W/m^2.K$.

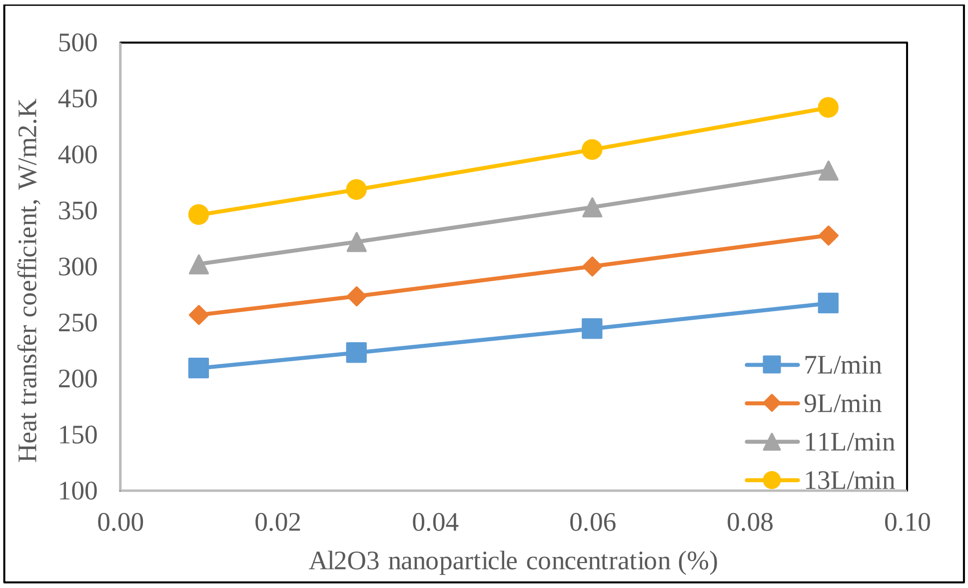


Figure 3: Al2O3 concentration against Heat Transfer Coefficient for various volume flow rate

Table 10 and Figure 4 show the rate of heat transfer rate for the four concentrations of nanofluids, which are 0.01, 0.03, 0.06 and 0.09% concentration, and the base fluid. Based on the result, a mixture of base fluid and nanoparticle concentration will produce a better rate of heat transfer than base fluid alone as it can be seen that the outlet temperature for the nanofluid is lower than the base fluid. Therefore, at 0.09% concentration, the highest rate of heat transfer of 121.95W is obtained and the lowest rate of heat transfer corresponding to the base fluid is 48.42W.

Table 10: Rate of heat transfer of various coolant

Materials	Outlet Temperature (K)	Temperature Difference	Rate of heat transfer, Q (W)
Basefluid	365.159	2.84	48.42
Basefluid + 0.01% Al2O3	363.527	4.47	92.90
Basefluid + 0.03% Al2O3	363.493	4.51	99.71
Basefluid + 0.06% Al2O3	363.450	4.55	110.35
Basefluid + 0.09% Al2O3	363.400	4.60	121.95

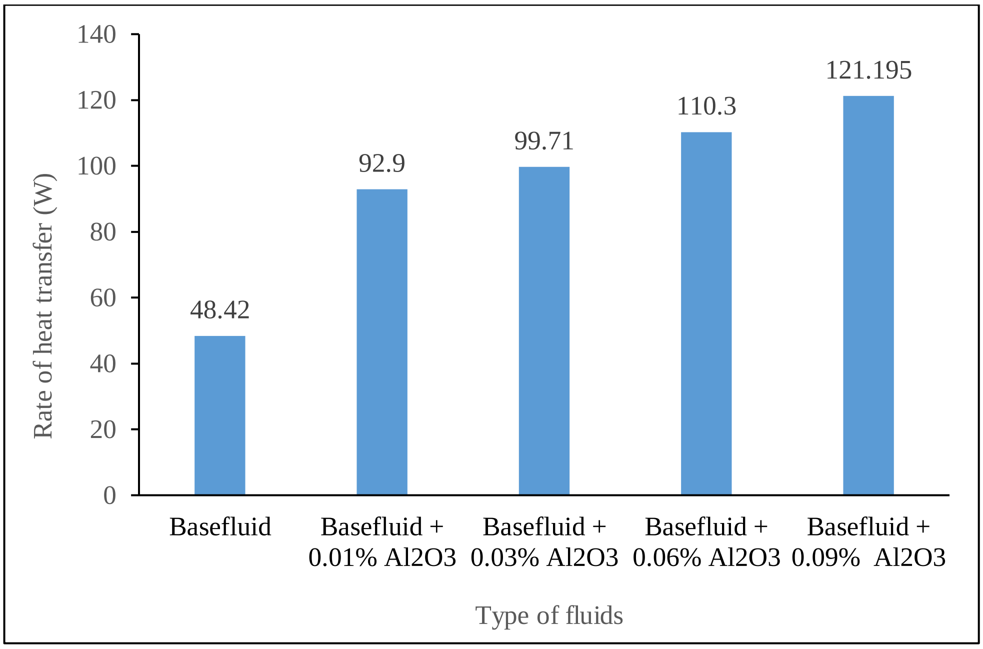
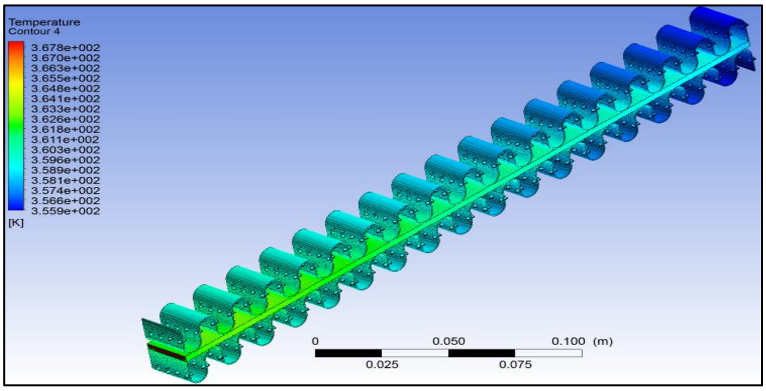


Figure 4: Rate of heat transfer of different nanofluid

Based on Table 11, the temperature profile for each concentration of the nanofluid and the base fluid is shown which was obtained from the Ansys CFD Post. Table 11 shows the temperature distribution along the flat tube and fins of the car radiator. Interesting observations and conclusions can be drawn from the results. Firstly, it can be seen from all cases studied that the temperature distribution was the highest at the inlet of the flat tube and it decreased gradually toward the outlet for both the flat tube and the fins. This shows that heat desipated from the working fluid to the fins. It was also observed that the design with (Basefluid + 0.09% Al2O3) had a much higher temperature distribution than the remaining model. Furthermore, the temperature profile shows the contour for the maximum flow rate of 13L/min. The reason for this is that with higher nanofluid concentration, the thermal conductivity of the fluid is enhanced and this eventually improves the heat transfer across the radiator flat tube and fins.

Table 11: Temperature profile

COOLANT	TEMPERATURE PROFILE
Base fluid	

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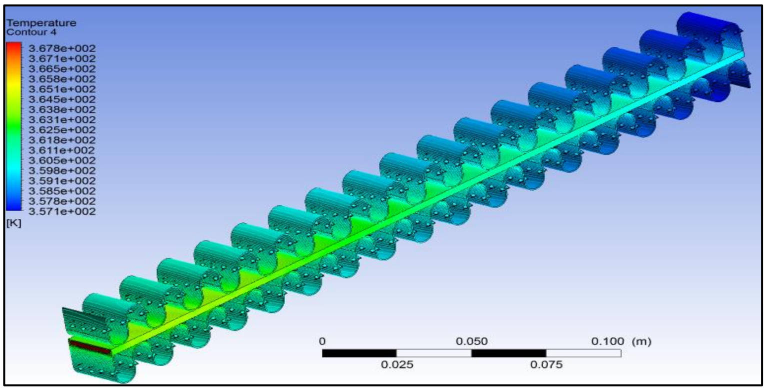

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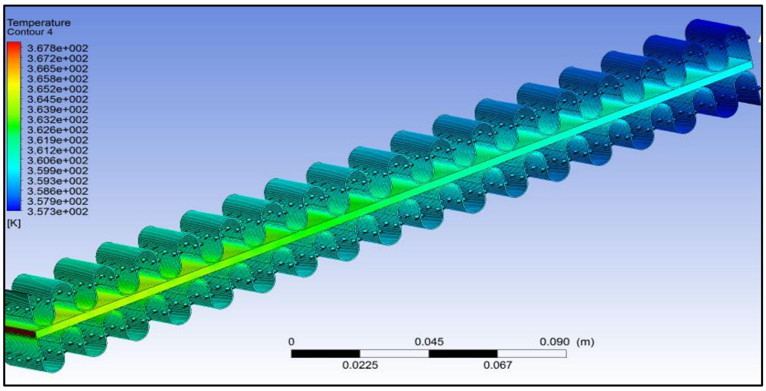
<tr><td>Basefluid + 0.03% Al2O3</td><td>


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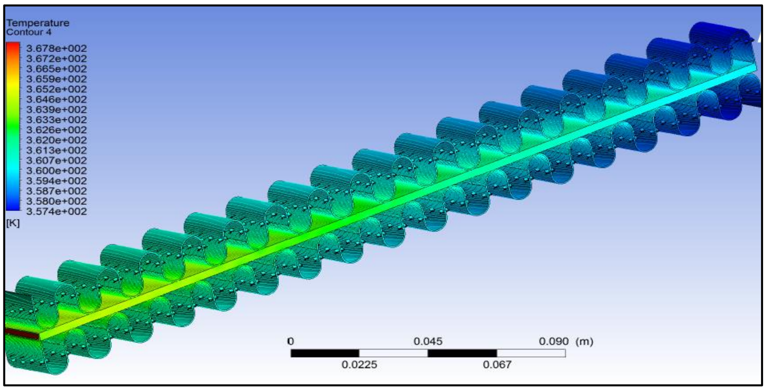

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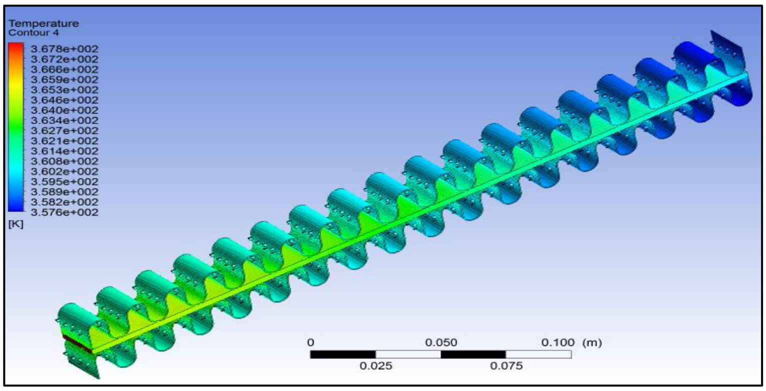
<tr><td>Basefluid + 0.09% Al2O3</td><td>


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Table 12: Streamline Profile

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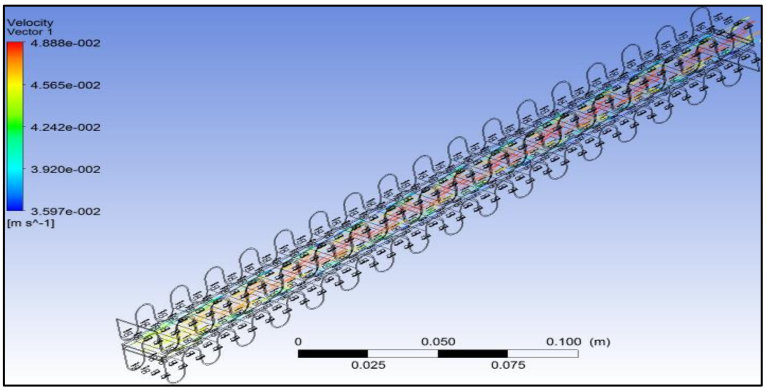
<tr><td>Basefluid</td><td>
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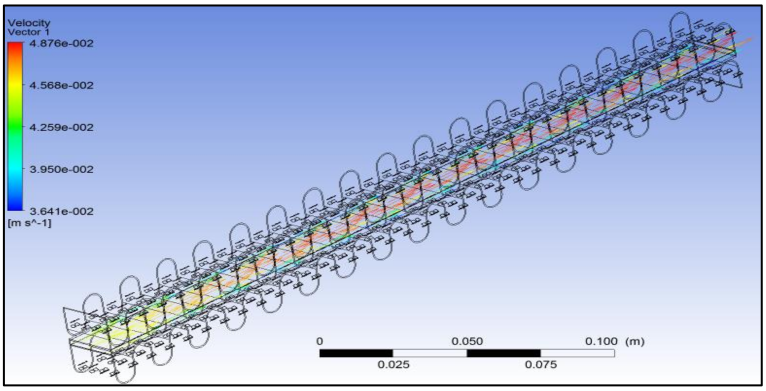
<tr><td>Basefluid + 0.01% Al2O3</td><td>
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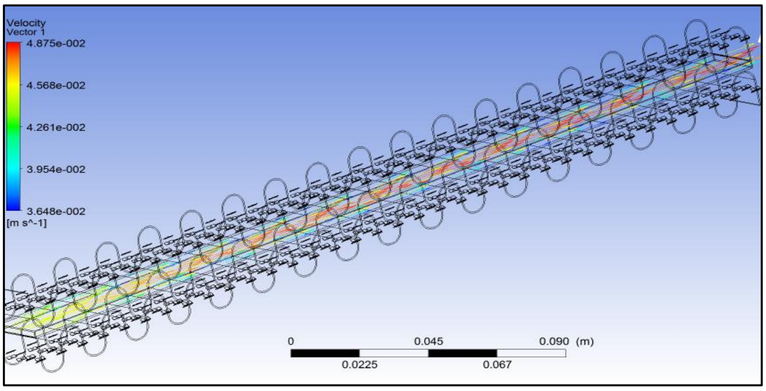
<tr><td>Basefluid + 0.03% Al2O3</td><td>
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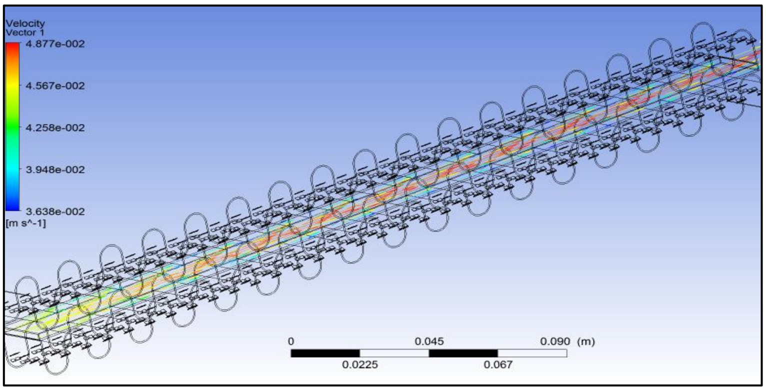
<tr><td>Basefluid + 0.06% Al2O3</td><td>
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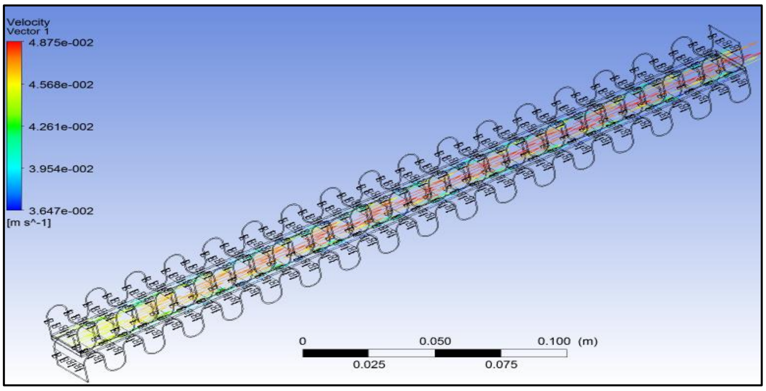
Basefluid + 0.09% Al2O3	

4.0 CONCLUSION

In conclusion, the study's objective was to investigate and analyse the addition of alumina particle to the mixture of water and ethylene glycol. By adding different volume of concentration into the base fluid, it can be observed that the heat transfer performance of the nanofluid as a coolant for a car radiator has increased. The heat transfer characteristics such as the Nusselt number, Prandtl number, and heat transfer coefficient increase when the volume concentration and the volume flow rate are increased. It can also be observed the enhancement of 50% of the Nusselt number when the alumina particle is being added. It can be concluded that the nanofluid's heat transfer parameters are highly dependent on the concentration of the particle and the flow conditions. Hence, this result shows that alumina oxide nanofluid is very suitable and has a great influence in increasing the heat transfer performance of the car radiator. The engine is very compact and small in size; thus, using nanofluid as the coolant is reliable for a heavy-duty engine cooling system.

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Conflict of interest

There is no conflict of interest associated with this research

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