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Enhancing the Thermal Performance of Radiators using Nanofluids- A CFD Approach

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ABSTRACT

In the present study, the thermal performance of a simple car radiator has been investigated for different conditions such as coolant type and coolant inlet velocity. Different types of nanofluids have been used as coolants such as Al_2O_3, CuO, and TiO_2 nanofluids. The base fluids taken are water and 50-50 volume percentage of water and ethylene glycol (EG) mixture. The volume percentage of 1%, 2%, and 3% of nanoparticles has been used for all the cases. The lowest outlet temperature and highest heat transfer rate are found for Water-EG based nanofluids. The lowest coolant outlet temperature (355.91 K) is found for 3 vol% of Water-EG based TiO_2 nanofluid and the highest heat transfer rate (67.87 W) is found for 3 vol% of Water-EG based CuO nanofluid. The highest outlet temperature and the lowest heat transfer rate are found to be 358.50 K and 51.73 W respectively for water-based CuO nanofluid. Nonetheless, the Water-EG based nanofluids showed better results than water-based nanofluids showing a low coolant outlet temperature and a high heat transfer rate.

Keywords: Radiator, Nanofluid, Heat Transfer, CFD.

1 Introduction

Radiators are heat exchangers used for cooling internal parts of the engine, mainly automobiles through conduction and convection. It can also be used for cooling operations such as in motorcycles, railway locomotives, power plants, etc. The radiator transfers the heat from the fluid inside to the air outside, thereby cooling the fluid, which in turn cools the engine.

There are two types of the cooling system. The first one is a direct or air-cooling system and the second one is an indirect cooling system or water-cooling system. Engine cooling generally relies on an indirect cooling system, where liquid coolant circulates through the radiator tubes and a crossflow of atmospheric air takes away excessive heat from the coolant. Liquid coolant is circulated using a pump because of a very slow flow rate of natural circulation. All automobiles are using centrifugal pumps for many years for circulating coolants.

Car radiators are mainly fin and tube type heat exchangers. Fin is used to increase the surface area of the radiator thus increasing the heat transfer through the fin and tubes. The material mainly used in radiator tubes and fins is aluminum. Aluminum is used for its high thermal conductivity and ease of cost; some alloy metals are also being used for special purposes as well.

Heat transfer rate also depends on the geometry of the radiator, the flow rate of the coolant, the speed of the vehicle, etc.

For superior thermal performance, nanofluids are increasingly being used as a coolant instead of water. Nanoparticles (diameters less than 100 nm) having highly conductive materials are being suspended at a low ratio for increasing the heat transfer rate of a radiator, nanofluids possess higher density which results in requiring more pump energy to be used. Taking this into account, a suitable proportion of nanoparticles is used. Alumina (Al_2O_3), copper oxide (CuO), titanium dioxide (TiO_2), etc. nanoparticles are used alongside with water-alcohol/graphene mixture to enhance the performance of the radiator. By controlling the coolant flow rate and the airflow rate the thermal performance can be enhanced either.

Trivedi and Vasava [1] have analyzed a shell and tube type radiator in Ansys. They've used a 644 mm by 360 mm radiator with a 7 mm diameter tube. The result of this analysis is that the heat transfer rate and effectiveness of a radiator increase with increasing mass flow rate/ increasing the speed of the vehicle. Gautam et al. [2] analyzed the performance of a radiator using nanofluids. They've worked with a fin and tube type radiator and the finding is that the heat transfer rate of a radiator increases with an increasing volume percentage of nanoparticles. This analysis says Ag/Water nanofluid gives better performance over Fe_2O_3/water nanofluid. Al-Rashed et al. [3] have investigated the performance of nanofluid in CPU cooling and found that the addition of 2.25 vol% CuO nanoparticles with water dissipates the heat of 130W. Sathyan [4] finds the efficiency of a radiator increases up to 13% when the tubes of the radiator are helical instead of straight, which can reduce the size of the radiator by 204×60mm for the same performance as the straight one. Krishna has analyzed the heat transfer performance of graphene-based hybrid coolant in the radiator. Here the result shows that the thermal performance of a radiator increases with the addition of nanoparticles through a slight increase of pimping power is found as friction factor increases Devireddy et al. [5] worked with ethylene glycol water-based TiO_2 nanofluids experimentally. For 40% ethylene glycol in water and 0.5% TiO_2 nanoparticles dispersed, the heat transfer rate was enhanced by about 35%.

Another analysis is on heat transfer of radiator with and without louver fins and finds louver fins more effective [6]. Patel et al. [7] have found that a methanol-water mixture gives better thermal results than an ethanol-water mixture.

Peyghambarzadeh et al. [8] found that 1 vol% of Al_2O_3 nanofluid enhanced heat transfer rate by 45%. Tijani and Sudirman [9] analyzed both Al_2O_3 and CuO nanofluids. The thermal conductivity of the base fluid is found to be 0.415 W/mK. With the addition of 0.3% of Al_2O_3 and CuO nanoparticles, the thermal conductivity increased to 1.287 W/mK and 1.241 W/mK respectively. The heat transfer coefficient also changes in the same way.

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One more analysis was on the performance of the Honda civic 2000 radiator under different atmospheric conditions in Kano, Nigeria [10]. The outlet temperature of the radiator was determined for 12 months of a year. The maximum outlet temperature was found in April and the minimum in August [10]. Heat transfer of a louver fin radiator with Water-EG based nanofluids was analyzed in one research. Here 0%, 1%, 3%, and 5% volume percentage of Al_2O_3 nanofluid was used and it was found that the outlet temperature decreased with an increasing volume percentage of nanoparticles [11]. Ali et al. [12] conducted an experimental investigation on forced convection heat transfer applied to a vehicle radiator filled with Al_2O_3 nanofluid with different concentrations: 0.1%, 0.5%, 1%, 1.5%, and 2% by volume. Results showed gradual enhancement in the heat transfer with concentrations 0.1%, 0.5%, and 1% by volume [12]. In this study effect of using Carboxyl-Graphene and Graphene-Oxide nanoparticles in automobile radiators at 1%, 2%, and 3% volume concentration of each of the nanoparticles for different flow rates of 4, 5, and 6 LPM was studied through a numerical approach. It was clear from the result that the addition of graphene oxide and carboxyl graphene enhances the heat transfer performance of the radiator by increasing the heat transfer [13]. The paper aimed to fulfill the parametric analysis of the heating performance of a compact automotive radiator using computational fluid dynamics. Another analysis was carried out at different air velocities with different fins modeled as real fins [14]. In this paper, the temperature variation across the tube length of a car radiator was studied using ANSYS. The effectiveness was calculated with GO and compared with conventional coolant (water). A comparison of the concentration of nanofluid (GO) particles (6, 8, 10% vol.) was examined [15]. In this research, four different water-based nanofluids ((Al_2O_3, TiO_2, ZnO, and SiO_2) were used in a horizontal flat tube radiator. CFD-based thermal analyses were performed to predict the heat transfer rate and pressure drop across the radiator. ZnO and Al_2O_3 showed better thermal properties with an increase of 4.9 to 15% [16].

As per a review of research papers, such parameters as; the shape of the radiator core, the direction flow of working fluid, the frontal area of the radiator, the space between fins, the space between tube, the fin & tube size, the coolant mass flow rate, the material of fins, the pitch of tube, the velocity of the fluid, the air inlet temperature were kept in mind to design a better automobile radiator. Using CFD is directed to comparing the heat transfer and the pressure drop of the heat exchanger with different parameters for optimum performance, and the CFD analysis also reduced the cost & time in the design and development of radiator as compared to conventional methods [17].

The automotive radiator is the key component that is also the last stage of heat dissipation to the environment. The proposed work relates to an improved heat exchanger as a radiator design for cooling a fluid [18]. A numerical analysis is carried out to investigate the change in heat transfer for various rib arrangements. Different rib types were used for evaluating Nusselt number and heat transfer rate [19].

This paper focuses on the performance of a radiator for different types of nanofluids (Al_2O_3, CuO, and TiO_2). The concentration of nanoparticles is taken at 1%, 2%, and 3%. The base fluid taken is simply water and a 50% mixture of ethylene glycol with water. The analysis has been conducted using CFD in ANSYS Fluent software. The outlet temperature and heat transfer rate for each nanofluid are compared, and the radiator's performance is optimized by utilizing the nanofluid with the best thermal performance.

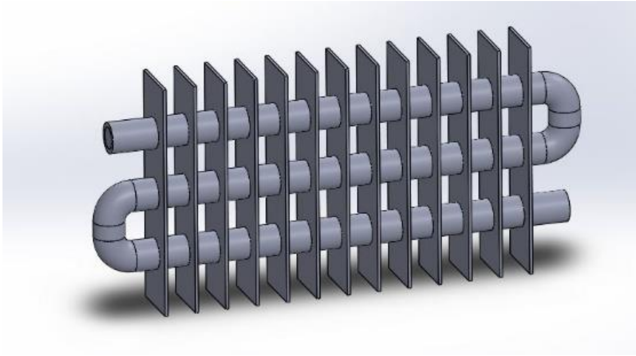


Fig. 1 CAD model of the radiator

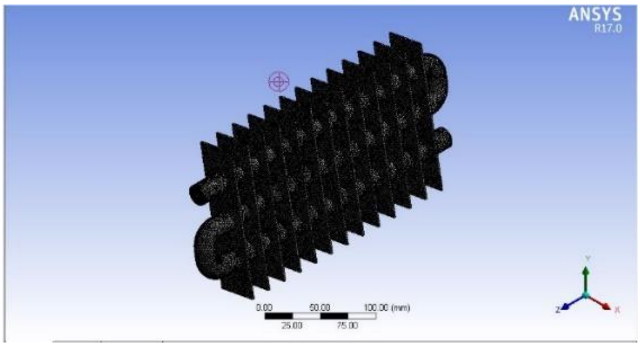


Fig. 2 Meshed geometry of the radiator

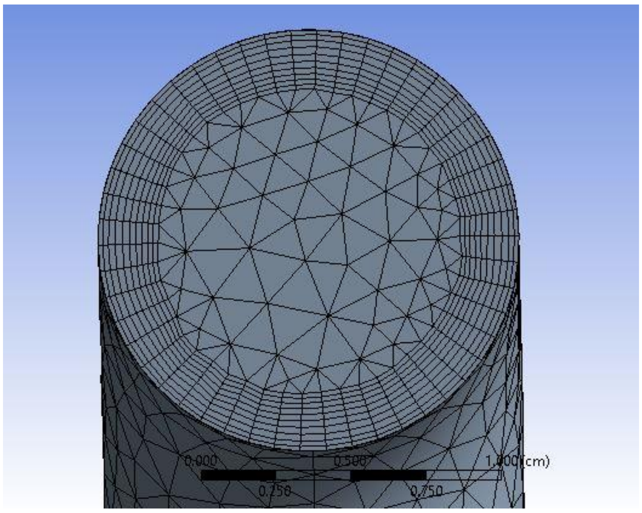


Fig. 3 Meshed geometry of coolant

Table 1 Dimensions of the radiator

Parameters	Values
Length of the tube	300 mm
Outside diameter of the tube	20 mm
Inside diameter of the tube	17 mm
Number of tubes	03
Height between centers of two tubes	40 mm
Height of the fin	150 mm
Width of the fin	40 mm
Thickness of the fin	2 mm
Number of fins	13

2 Modeling and Simulation

CAD model of the radiator is done in Solid Works 2018. The dimensions of the radiator are presented in Table 1. Fig. 1 shows the CAD model of the radiator. The CAD model is then imported to Ansys fluent 17. Meshing is performed in Ansys fluent mesh interface. Element size is taken at 1.8 mm at body sizing and 25 divisions at the circular edges. The meshing method used is tetrahedrons and 10 inflation layers are set. Fig. 2 and Fig. 3 show the meshed geometry of the radiator and the coolant respectively.

2.1 Materials

For investigating the performance of the radiator several nanofluids are used. These are water-based Al_2O_3, CuO, TiO_2 and 50%-50% water- ethylene glycol-based Al_2O_3, CuO, and TiO_2. Table 2 represents the properties of base fluids and nanoparticles. The nanofluid properties for various volume percentages are determined with the following equations:

Nanofluid density,

$$\rho_{n_f} = (1-\varphi)\rho_{bf} + \varphi\rho_{n_P} \tag{1}$$

Nano fluid's specific heat,

$$c_{P_{nf}} = \frac{(1-\varphi)\rho_{bf}Cp_{bf} + \varphi\rho_{np}Cp_{n_P}}{(1-\varphi)\rho_{bf} + \varphi\rho_{n_P}} \tag{2}$$

Nano fluid's thermal conductivity,

$$k_{n_f} = k_{bf}\left[\frac{k_\rho + 2k_{bf} + (kp - k_{bf}) \times 2\varphi}{k_P + 2k_{bf} - (k_P - k_{bf})\varphi}\right] \tag{3}$$

Nano fluid's viscosity,

$$u_{n_f} = (1 + 2\cdot 5\varphi + 6\cdot 5\varphi^2) \times u_{bf} \tag{4}$$

The rate of heat transfer, $\dot{Q}$ is calculated by the equation as follows:

$$\dot{Q} = \dot{m}C_p\,(T_{inlet} - T_{outlet}) \tag{5}$$

The thermal conductivity, K is calculated by the following equation,

$$K = Qd\,/\,A\,(T_{inlet} - T_{outlet}) \tag{6}$$

The heat transfer coefficient is calculated by the following equation,

$$q = h\,(T_{inlet} - T_{outlet}) \tag{7}$$

Table 2 Properties of base fluids and nanoparticles

Property	Water	EG	Al_2O_3	CuO	TiO_2
Density, **ρ** (kg/m^3)	997.5	1068.75	3970	6310	4260
Specific Heat, **c$_p$** (J/kgK)	4178	3319	880	550.5	690
Thermal Conductivity, **k** (W/mK)	0.628	0.3736	35	32.9	8.3
Dynamic Viscosity, **μ** (Pa s)	1.793 $\times10^{-3}$	2.05 $\times10^{-3}$			
Particle Diameter, (nm)			28	28	28

2.2 Setup

The model is simulated in ANSYS FLUENT 17. The numerical solutions are found using the mathematical models provided. Boundary conditions have been applied to the inlet, outlet, finned surface, and the side walls as follows-

- The model used for the simulation is scalable realizable k-epsilon
- Coolant inlet velocity is taken as velocity inlet and set at 0.01 m/s. And inlet temperature is set at 368 K
- Pressure outlet is taken as coolant outlet
- The finned surface or the outer surface of the radiator serves convection and radiation. The heat transfer coefficient is set at 5 W/m^{2}K and the external emissivity is 0.5. The free stream temperature is set at 300K
- Thermal condition of the walls is set via system coupling

3 Results and Discussion

To evaluate the thermal performance of the radiator some thermophysical properties are simulated using ANSYS FLUENT. Grid dependency is tested by altering body sizing, edge sizing, and inflations to produce various numbers of mesh elements and the number of elements used is 723151 (Fig. 4).

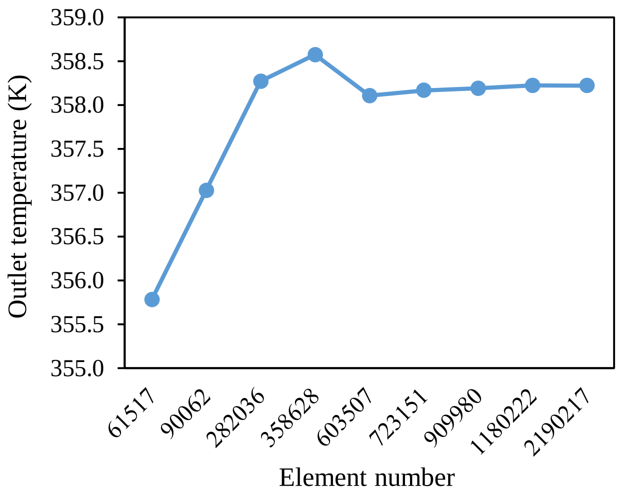


Fig. 4 Grid dependence test

3.1 Validation

Tijani et al. [9] investigated the thermal performance of a car radiator with 50-50% water-ethylene glycol-based Al_2O_3 and CuO nanofluids. In this research same procedures and boundary conditions are followed for the validation of the research. The boundary conditions for this validation are as follows:

- the model used for the simulation is k-epsilon
- coolant inlet velocity was set at 0.077 m/s
- coolant inlet temperature was set constant at 368.15K
- heat transfer coefficient was set at 10 W/m^{2}K
- free stream temperature fixed at 308.15 K

Table 3 shows the deviation between reference and tested values. Fig. 5 shows the results graphically. It is seen that the shapes of the reference curve and test curve for both Al_2O_3 and CuO nanofluids are close enough. The maximum deviation between reference outlet temperature and test outlet temperature is 0.469%. So, the simulation procedure is alright.

Table 3 The deviation between reference and tested outlet temperature for Al_2O_3 and CuO nanofluids

Nanofluid type	Vol%	Outlet temperature (K) (Tijani et al. [9])	Outlet temperature (K) (Present study)	Deviation
Al_2O_3 nanofluid	0.00	365.59	364.52	0.29%
	0.05	365.56	364.37	0.32%
	0.15	365.49	364.11	0.38%
	0.30	365.39	363.68	0.46%
CuO nanofluid	0.00	365.59	364.51	0.29%
	0.05	365.57	364.62	0.25%
	0.15	365.52	364.06	0.39%
	0.30	365.47	363.75	0.46%

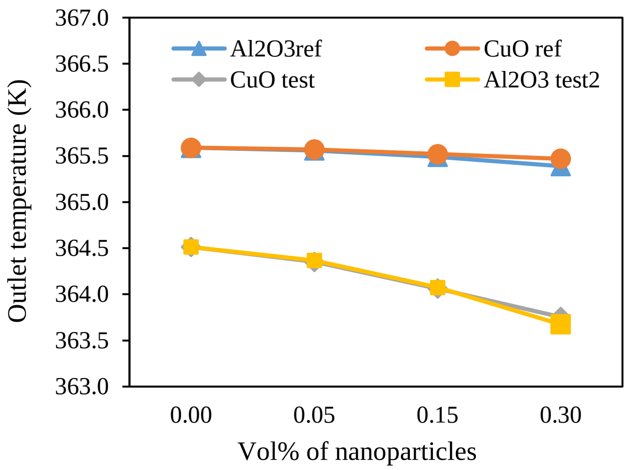


Fig. 5 Difference between the reference and analyzed values

Table 4 Results for water-based Al_2O_3, CuO, and TiO_2 nanofluids

Nanoparticles	Vol%	Inlet temperature (K)	Outlet temperature (K)	Heat transfer rate (W)	Heat transfer coefficient (W/m^2K)
Al_2O_3	1	368	358.11	63.20	62.98
	2		357.77	65.23	68.55
	3		357.38	67.46	75.72
CuO	1		358.50	51.73	60.15
	2		357.93	64.22	65.86
	3		357.42	67.38	75.42
TiO_2	1		357.77	65.24	68.51
	2		357.47	66.66	72.99
	3		357.38	67.52	76.35

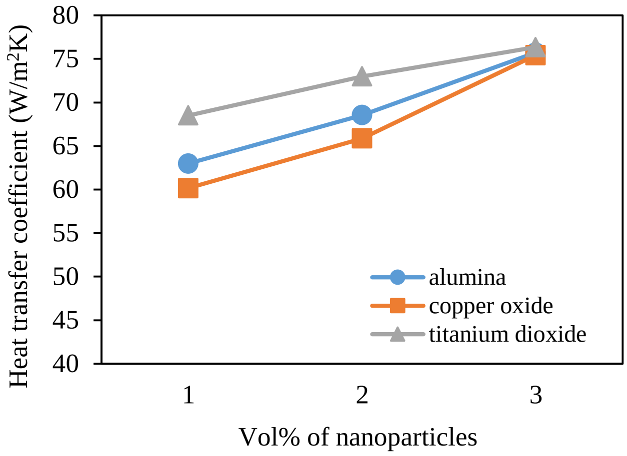


Fig. 6 Effect of vol% of nanoparticles on heat transfer coefficient

The simulated results for water-based nanofluids at different volume fractions are tabulated in Table 4. Fig. 6 and Fig. 7 represent the variation of heat transfer coefficient and outlet temperature with volume fraction of nanofluids respectively.

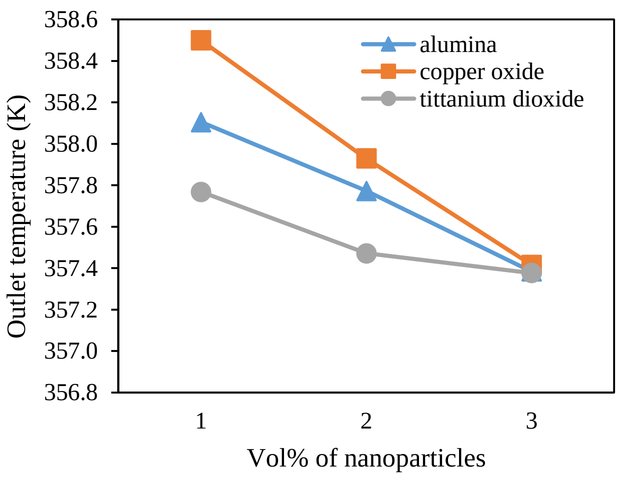


Fig. 7 Effect of vol% of nanoparticles on outlet temperature of the radiator.

Changes have been found in the outlet temperature of the radiator and heat transfer rate of the radiator with the change of volume percentage of nanoparticles as shown in Table 4 and Fig. 8. By increasing the volume fraction of Al_2O_3 from 1% to 3% outlet temperate reduces from 358.11 K to 357.38 K. Heat transfer rate increases from 63.19 to 67.46 Watt. By increasing the volume fraction of CuO from 1% to 3% outlet temperature reduces from 358.50 K to 357.42 K. Heat transfer rate increases from 51.73 to 67.38 Watt. By increasing the volume fraction of TiO_2 from 1% to 3% outlet temperate reduces from 357.77 K to 357.38 K. Heat transfer rate increases from 65.24 to 67.52 Watt. Thus, it is seen in Fig. 7 that with increasing volume fraction of nanoparticles outlet temperature decreases gradually. Here we can see TiO_2 gives the lowest outlet temperature among these three nanofluids. Al_2O_3 nanofluid gives a slightly better result than CuO nanofluid. The difference gap in outlet temperature is highest at 1 vol% of nanoparticles and the difference gradually decreases up to 3 vol% of nanoparticles.

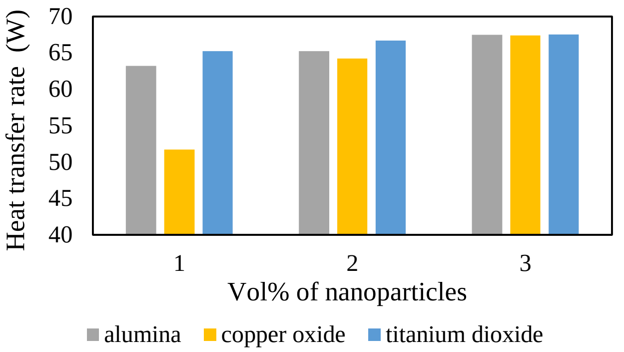


Fig. 8 Effect of different water-based nanofluids on the heat transfer rate of the radiator.

The heat transfer rate of the radiator is also seen increasing with increasing volume fraction of nanoparticles (Fig. 8). Here we can see that the TiO_2 nanofluid has the highest heat transfer rate among these three nanofluids. Al_2O_3 nanofluid gives a slightly better result than CuO nanofluid. The difference gap in heat transfer rate is highest at 1% vol. of nanoparticles and the difference gradually decreases up to 3% vol. of nanoparticles.

The simulated results for 50-50% Water-EG based nanofluids at different volume fractions are tabulated in Table 5. Fig. 9 and Fig. 10 represent the variation of heat transfer coefficient and outlet temperature with volume fraction of nanoparticles respectively.

Table 5 Results for Water-EG-based Al_2O_3, CuO, and TiO_2 nanofluids.

Nanoparticles	Vol%	Inlet temperature (K)	Outlet temperature (K)	Heat transfer rate (Watt)	Heat transfer Coefficient W/m^2K
Al_2O_3	1		356.41	65.91	73.72
	2		356.03	67.24	78.40
	3		355.94	67.78	80.48
CuO	1		356.24	66.16	74.61
	2	368	355.99	67.71	79.23
	3		355.93	67.87	80.91
TiO_2	1		356.10	66.61	76.13
	2		356.00	67.26	79.58
	3		355.91	67.65	81.08

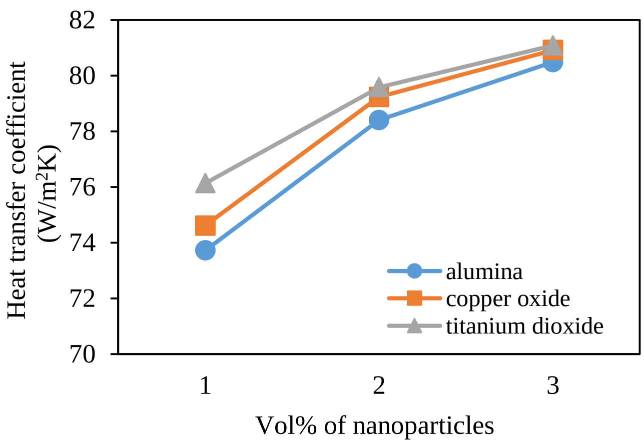


Fig. 9 Effect of vol% of nanoparticles on heat transfer coefficient of different Water-EG based nanofluids

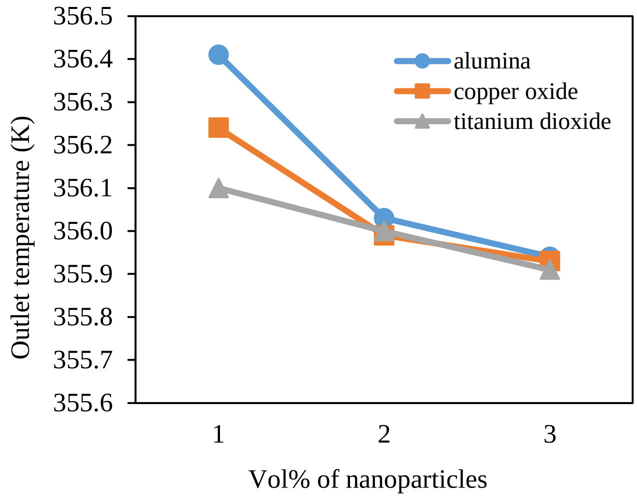


Fig. 10 Effect of vol% of nanoparticles on outlet temperature of different Water-EG based nanofluids

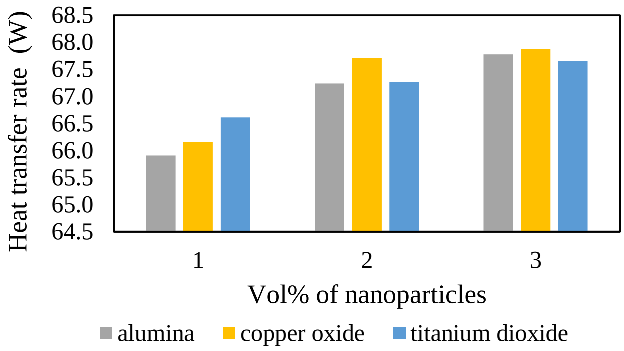
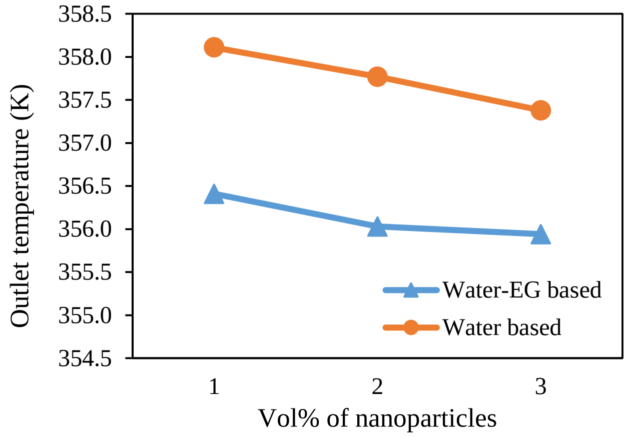


Fig. 11 Effect of vol% of nanoparticles on the heat transfer rate of the radiator for different Water-EG-based nanofluids.

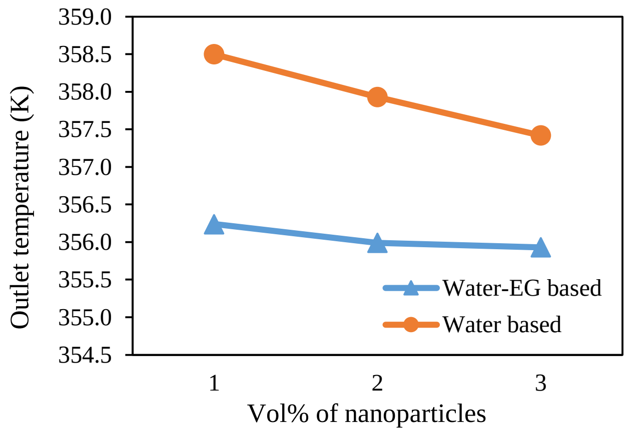
Just like water-based nanofluids, it is seen that thermal conductivity and heat transfer coefficient increase with an increasing volume percentage of Water-EG-based nanofluids. It is seen that for water-ethylene glycol-based Al_2O_3 nanofluids outlet temperature of the radiator decreases from 356.41 K to 355.94 K with an increasing volume fraction of 1% to 3%. a further increase in concentration has not given a significant change in outlet temperature and this higher concentration may cause issues regarding viscosity. Heat transfer rate increases from 65.91 to 67.78Watt with the increase in volume fraction of Al_2O_3 nanoparticles similarly. The outlet temperature of the radiator similarly decreases from 356.24 K to 355.93 K with an increasing volume fraction of 1% to 3%. The heat transfer rate increases from 66.16 to 67.87 Watt with the increase in volume fraction of CuO nanoparticles. The outlet temperature decreases from 356.10 K to 355.91 K with an increasing volume fraction of 1% to 3%. And heat transfer rate increases from 66.61 to 67.65 Watt with the increase in volume fraction of Water-EG-based TiO_2 nanoparticles. Thus, Fig. 10 and Fig. 11 say that Water-EG based TiO_2 nanofluid gives the best result. The outlet temperature of the radiator is the least and the heat transfer rate is highest for 3% TiO_2 nanoparticles. The outlet temperature differences among these three nanofluids are highest at 1 vol% and there is a slight difference at 2 vol% and 3 vol%.

Now we can compare the results for water and Water-EG-based nanofluids. Fig. 12 and Fig. 13 graphically represent the variations in outlet temperature and heat transfer rate for water and Water-EG-based nanofluids respectively for different volume percentages. It is seen that 50-50% Water-EG-based nanofluid gives better results than water-based nanofluids for all volume fractions of nanoparticles because the outlet temperature is less and the heat transfer rate is more for Water-EG based nanofluids.

Fig. 14 shows the contour of the finned tube of the radiator, Fig. 15 represents the contour of the coolant flowing through the tube, and Fig. 16 demonstrates the streamlines of coolants flowing inside the tube.



(a)



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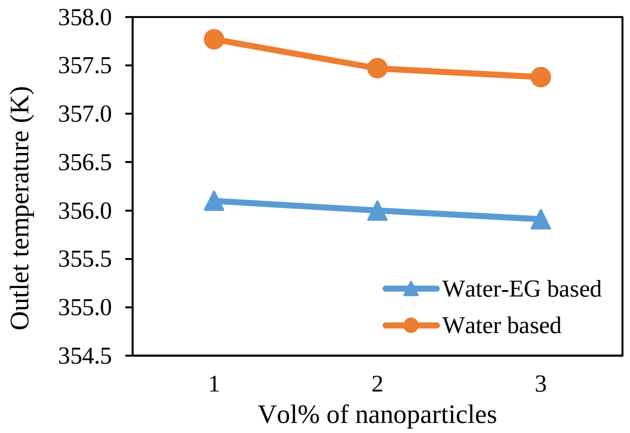
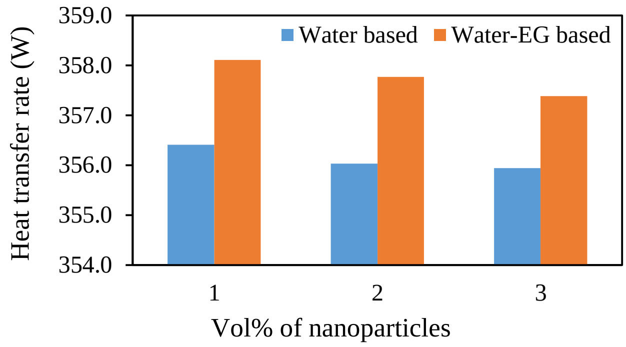
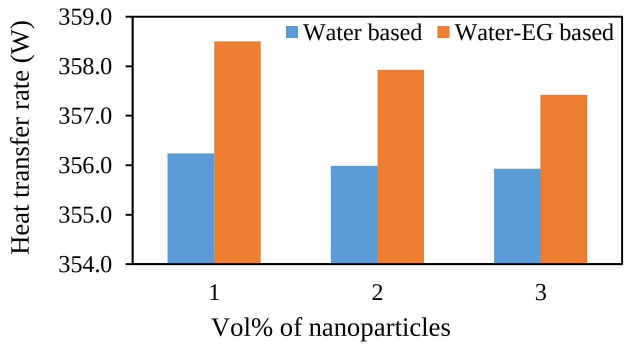


(c)

Fig. 12 Comparison of outlet temperature between water-based and Water-EG-based (a) Al_2O_3, (b) CuO and (c) TiO_2 nanofluids



(a)



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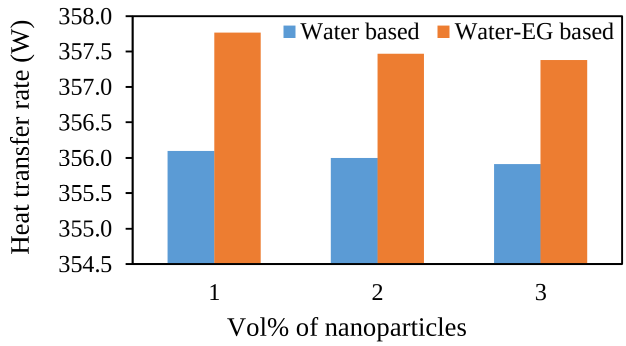

(c)

Fig. 13 Comparison of the heat transfer rate between water-based and Water-EG-based (a) Al_2O_3, (b) CuO, and (c) TiO_2 nanofluids

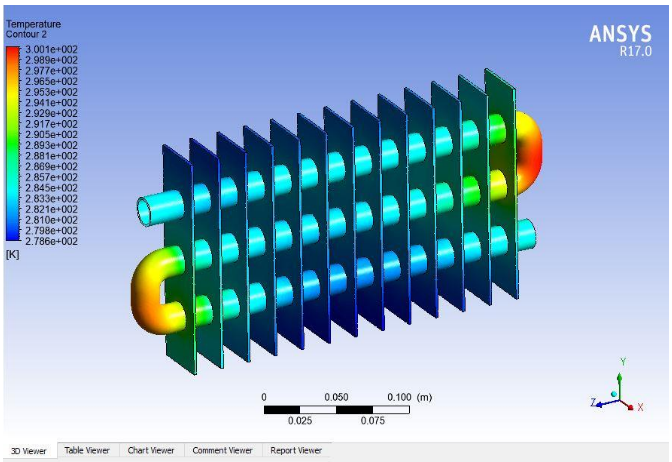

Fig. 14 Temperature contour of the finned tube

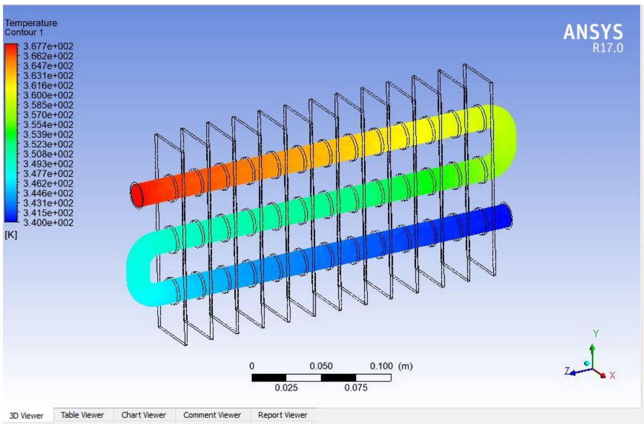

Fig. 15 Temperature contour of the coolant inside the tube

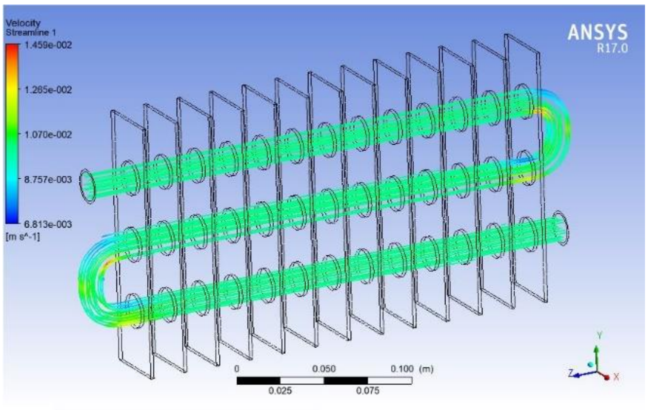

Fig. 16 Streamlines of coolant inside the tube

4 Conclusion

In this study, the thermal performance of a simple radiator is investigated for different types of nanofluids. The base fluid is taken from normal water and 50%-50% of water and ethylene glycol mixture. Nanoparticles used were 1%, 2%, and 3% volume percentage of Al_2O_3, CuO and TiO_2 respectively dispersed in base fluids. For all the nanofluids heat transfer rate increases with an increasing volume percentage of nanoparticles. A volume percentage of 3% of TiO_2 nanoparticles gives the best result among the water-based nanofluids. However, Water-EG-based nanofluids give better results than water-based ones for all three nanofluids. The heat transfer rate is more in Water-EG based nanofluids. For Water-EG based nanofluids, the minimum radiator outlet temperature is found for 3 vol% of TiO_2 fluids.

Nomenclature

Symbols	Description
φ	volume fraction
ρ_{n_f}	nanofluid density
ρ_{bf}	base fluid density
ρ_{n_p}	nanoparticle density
$c_{P_{nf}}$	specific heat of nanofluid
Cp_{bf}	specific heat of the base fluid
Cp_{n_p}	specific heat of nanoparticle
k_{n_f}	thermal conductivity of nanofluid
k_{bf}	thermal conductivity of the base fluid
k_P	thermal conductivity of nanoparticle
u_{n_f}	viscosity of nanofluid
u_{bf}	viscosity of the base fluid

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