This study aims to improve the performance of the vehicle's cooling system called the radiator, which is part of increasing energy efficiency. Research has been done to investigate the convective heat transfer of hybrid nanofluid, using CuO and TiO$_2$ nanoparticles and water-ethylene glycol (RC) as base fluids on a radiator. The mass concentration of the hybrid nanoparticles varied from 0.25 %, 0.30 %, and 0.35 %. For the preparation of the hybrid nanofluid through a two-step method, by mixing dry samples of CuO and TiO$_2$ nanoparticles (50:50) and then the mixture of radiator coolant, RC (60 % water and 40 % ethylene glycol). The fluid flow varies from 20 liters per minute to 28 liters per minute. Temperature variations range from 70 °C to 90 °C by using controlled heating. Four thermocouples measure the inlet and outlet hot fluid flow and the airflow before and after the radiator. The experiment showed that the overall heat transfer coefficient increases remarkably with the increase of the hybrid nanoparticle concentration under various flow rate values. The maximum overall heat transfer coefficient increases by about 83 % compared to pure radiator coolant under 0.35 % mass concentration at a flow rate of 22 liters per minute and a temperature of 70 °C. It has also been found that the heat transfer rate is highly dependent on the radiator's mass fraction and flow rate. Increasing the mass concentration shows maximum enhancement in heat transfer rate. Inlet temperature also enhances the heat transfer rate, but its effect is small compared to nanofluid's mass concentration and flow rate. This study reveals that hybrid nanofluids can be suitable as a working fluid, especially in small-scale heat transfer devices

Keywords: hybrid nanofluid, overall heat transfer coefficient, radiator coolant, cooling fluids

THE EFFECT OF HYBRID NANOFLUID CuO-TiO$_2$ ON RADIATOR PERFORMANCE

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1. Introduction

Nowadays, people need automotive vehicles, making their work simpler, faster, and more comfortable. With the increasing car demand, the automotive industry is constantly evolving to make it highly fuel-efficient to attract customers. Energy efficiency is aimed at reducing the size of vehicle components. A smaller size has an impact on the weight of the vehicle. The lighter the importance of the car, the less fuel consumption. There are various ways to increase engine efficiency, including an optimized engine design and an efficient engine cooling system that improves vehicle performance. The vehicle's engine cooling system keeps the engine cool and warm enough to ensure efficient and clean operation. The easiest way to enhance radiator performance is to increase the convection surface area, but this will increase the radiator's dimensions, which is undesirable. Besides that, increasing the radiator's performance can also increase the convection heat transfer. One way to improve its performance is to change the thermal properties of the radiator cooling fluid.

The conventional fluids being used today are based on a mixture of distilled water (DW) and ethylene glycol (EG), namely radiator coolant (RC), which widens the operational temperature range but at the same time limits the heat removal. Therefore, the use of nanofluids for improving heat transfer performance has soared over the past few years. One of the main drawbacks of using nanofluids as a heat transfer media, which limits its application in industries, is a higher pressure drop than conventional fluids. The problem is that most of the reports highlight the short-term heat transfer results, which may not be accurate over time. This paper presents, a suggest best practice for analyzing the usage of nanofluids in heat transfer applications, specifically for an actual car radiator.

Nanofluids, stable dispersions of nanometer-sized solid particles with high thermal conductivity in base fluids, have been proposed as potential heat transfer fluids in recent decades [1]. The results showed that the thermal conductivity of nanofluids was higher compare than base fluid [2, 3] which was described in the literature by several mechanisms. The definition of nanofluid is a mixture of liquid fluids (water, ethylene glycol, oil) with solid particles of nanometer size (<100 nm). Nanoparticles are solid particles generally made of metal, oxide, carbide, or carbon nanotubes with high thermal conductivity compared to liquid fluids.

Initially, nanofluids were only used to increase the thermal conductivity of fluids. Over time, researchers used nanofluids to increase the heat transfer rate by convection in heat exchangers with various flows and methods at constant temperature conditions or heat flux or constant heat flux [4–6]. Experimentally investigation developed a theoretical correlation to predict the heat transfer performance of nanofluids as single-phase fluids and double-phase mixtures, obtaining more accurate results [7]. The experiment used Al$_2$O$_3$ nanoparticles mixed with water in forced convection heat transfer in a double-pipe heat exchanger. The results showed an increase in heat transfer by 40.5 % at

a volume concentration of 0.5 % [8]. They have investigated the performance of the total heat transfer coefficient using a radiator coolant (a mixture of water and fluid) as a cooling fluid using Al_2O_3 and CuO nanoparticles with volume concentrations of 0.05 %, 0.15 %, and 0.3 %, respectively. This research results in the most significant improvement using Al_2O_3 nanoparticles compared to CuO nanoparticles Al_2O_3 nanoparticles compared to CuO nanoparticles [9]. The performance of the total heat transfer coefficient using a radiator coolant (a mixture of water and fluid) is investigated as a cooling fluid using Al_2O_3 and CuO nanoparticles with volume concentrations of 0.05 %, 0.15 %, and 0.3 %, respectively. The result of this research is the greatest improvement using Al_2O_3 nanoparticles compared to CuO nanoparticles [10].

Investigated the performance of the total heat transfer coefficient using a radiator coolant (a mixture of water and fluid) as a cooling fluid using Al_2O_3 and CuO nanoparticles with volume concentrations of 0.05 %, 0.15 %, and 0.3 %, respectively. The result of this research is the greatest improvement using Al_2O_3 nanoparticles compared to CuO nanoparticles. The highest increase of 20 % with a volume concentration of 0.5 % [11]. Experimental using Al_2O_3 nanoparticles with water-Mono Ethylene Glycol as the base fluid in a car radiator. Overall heat transfer coefficient increased by 30 % at 0.2 % volume concentration [12]. A studied nanofluids with TiO_2 /water-EG (40:60) particles in a radiator and stated that using nanofluids affects the heat transfer process. At 0.5 % volume concentration has increased heat transfer by 35 %, while the inlet temperature effect has a smaller effect [13].

2. Literature review and problem statement

Paper [14] which investigated the combined effect of nanofluid and ultrasonic vibrations, showed a relatively small increase in the vibration effect. Even though the energy required for ultrasonic vibration is quite large, the energy efficiency system is not working correctly. An option to overcome this is to use two different particles called hybrid nanofluids. The increase in the Nusselt number of mono nanofluid is greater than that of hybrid nanofluid. Experiment by utilizing Al_2O_3-Cu/water nanofluids in circular copper pipes, the maximum increment of Nusselt number 13.56 % at Reynold number 1730 using hybrid nanofluid, and Al_2O_3-water nanofluid it is enhanced by 6.09 % [15].

Hybrid nanofluids are colloidal liquids containing a suspension of solid particles composed of two different particles. Hybrid nanofluids have higher thermal properties such as thermal conductivity and specific heat compared to pure fluids. This increase in heat transfer is due to the higher thermal conductivity of the hybrid nanofluids. Several researchers have improved the thermal properties of hybrid nanofluids, including using hybrid-nanoparticles TiO_2-SiO_2 with a volume concentration of 1.0 vol. % in a mixture of water-ethylene glycol (EG) increased thermal conductivity by 13.8 % and heat transfer coefficient increased by 35.32 % [16]. The thermal conductivity increased by 32 % in EG (ethylene glycol) at 50 °C for adding ZnO-TiO_2 hybrid nanoparticles with a percentage of 3.5 vol. % [17]. Research on increasing the thermal conductivity for MWCNT-SiO_2 nanoparticle hybrid with a volume percentage of 1.94 vol. % with ethylene glycol as a base fluid has been carried out by [18] increasing heat transfer by 22.2 %. While research on hybrid nanofluid used in radiators has been carried using aluminum oxide doped with silicon carbide (Al_2O_3-SiCM) at a percentage of 0.8 % using a mixed base fluid of distilled water (DW) and ethylene glycol (EG) (50:50) increased the heat transfer coefficient by 28.34 % [19]. Investigation experimentally and theoretically using TiO_2 particles doped with Ag particles in a radiator. Heat transfer increased by 5.615 % and 11.094 % for volume percentages of 1 % and 2 %, respectively. Meanwhile, theoretically, the increase in the heat transfer coefficient is 26.15 % and 27.72 % [20].

In recent years, advanced fluids such as nanofluids have replaced conventional heat transfer fluids due to their better heat transfer and flow characteristics. The application of nanofluids in thermal management systems brings out better heat transfer and reduces the heat exchangers' size and weight. Nevertheless, very recently, little work has been carried out on nanofluids with two types of nanoparticles dispersed simultaneously in a base fluid called "hybrid nanofluids."

However, the use of metallic nanoparticles for nanofluid applications is limited due to their stability and reactivity. According to these features of metallic and nonmetallic nanoparticles (such as Cu), their addition into a nanofluid composed based on Al_2O_3 nanoparticles can enhance the thermophysical properties of this mixture. Recent studies have shown remarkable heat transfer improvement using hybrid nanofluid [21]. However, the application-oriented research on hybrid nanofluids is limited.

3. The aim and objectives of the study

The aim of the study is to identify the effect of hybrid nanofluids in a radiator performance for a scientific and practical approach. This will make it possible to application of hybrid nanofluids as a new type of working fluids or cooling machining operations have some challenges in their development.

To achieve this aim the following objectives have been set:
– to analyze the effect of concentrations of hybrid nanofluid on the radiator's overall heat transfer coefficients;
– to analyze the effect of working temperature hybrid nanofluid on the best radiator's overall heat transfer coefficients.

4. Materials and methods

4. 1. Object and hypothesis of research
The object of this research is a radiator with dimensions, as shown in Table 1. The cooling medium uses a hybrid nanofluid with variations in mass concentrations of 0.25 %, 0.3 %, and 0.35 %, the base fluid of the radiator coolant is a mixture of water and ethylene glycol.

Table 1

Geometrical characteristics of the radiator

Description	Specification
Radiator Length	404 mm
Radiator Width	22 mm
Radiator Height	475 mm
Tube Width	21 mm
Tube Height	420 mm
Number of tubes	44 mm

The study's hypothesis is a difference in the radiator's overall heat transfer coefficient by using hybrid nanofluid. The null hypothesis assumes the overall heat transfer coefficient is the same for all concentration variations. The alternative hypothesis is that at least one mean of the overall heat transfer coefficient is not statistically equal. The assumption in this study is that the mixture between nanoparticles and the base fluid is considered homogeneous; to a simple calculation, the radiation heat transfer is ignored.

The experimental setup is shown in Fig. 1, consisting of a heating tank, pump, flow meter, and fan. The heating tank replaces the engine's heat with temperature variations ranging from 70 °C to 90 °C by using controlled heating (thermo control). The pump is used to circulate the coolant fluid, the flow meter to measure the flow of fluid flowing with a variation of 20 lpm to 28 lpm, and the fan to cool the radiator surface. Data were collected in steady state conditions, during the experiments, the inlet and outlet temperature of the nanofluid and air flow were measured and recorded using the thermocouple data acquisitions module (Omega TC-08).
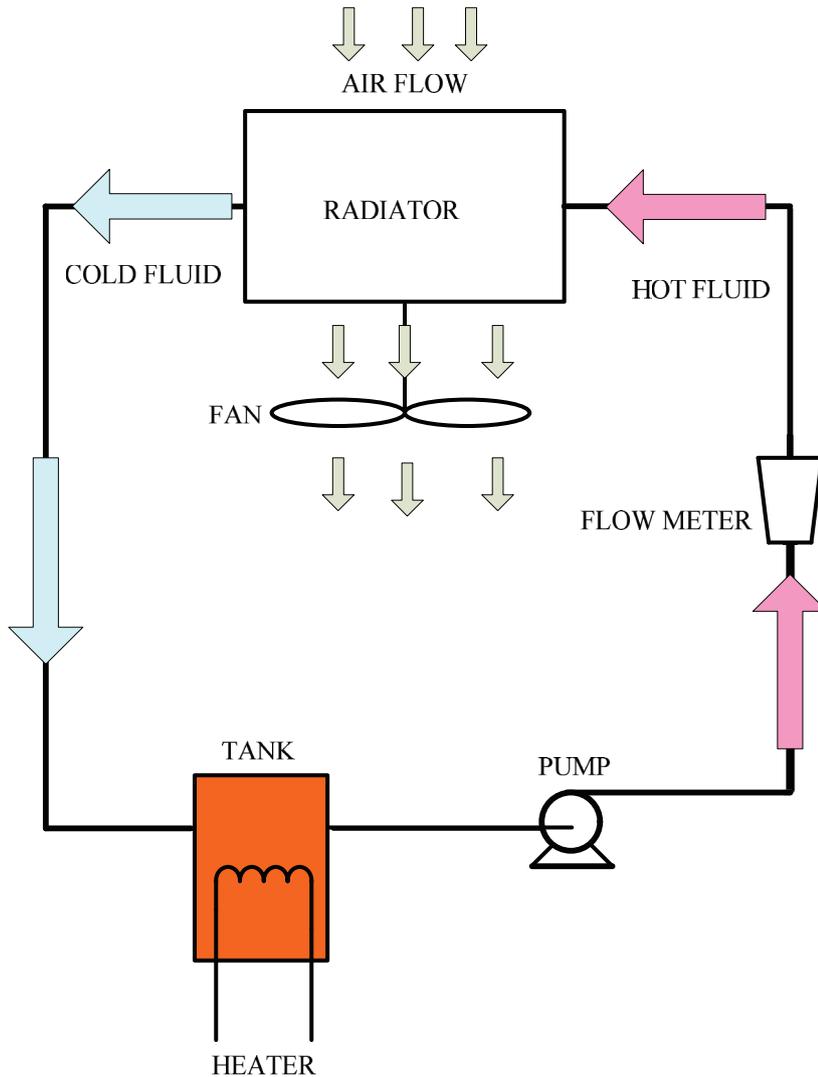
data logger. The overall heat transfer coefficient is calculated using (1).

$$U = \frac{Q_{avg}}{A \Delta_{LMTD}}. \tag{1}$$

The average heat flow of hot and colds fluids, calculated by (2)

$$Q_{avg} = \frac{Q_h + Q_c}{2}. \tag{2}$$

The heat released by hot fluids is calculated by (3)

$$Q_h = m_h C_h (T_{hi} - T_{ho}). \tag{3}$$

The heat received by cold fluids is calculated using equation (4)

$$Q_c = m_c C_c (T_{co} - T_{ci}). \tag{4}$$

The logarithmic mean temperature difference is calculated using equation (5)

$$\Delta_{LMTD} = \frac{(T_{hi} + T_{co}) - (T_{ho} - T_{ci})}{(T_{hi} + T_{co}) / (T_{ho} - T_{ci})}. \tag{5}$$

The hybrid nanofluid samples are prepared in three variations of mass concentrations which are 0.25 %, 0.3 %, and 0.35 %, using [22] in equation (6):

$$\varphi = \frac{m_{np.1} + m_{np.2}}{m_{np.1} + m_{bf.2} + m_{np.2} + m_{bf.2}}. \tag{6}$$

Subscript *h, c, hi, ho ci, co, np.1, np2, bf.1,* and, *bf.2* indicates hot, cold, hot inlet, hot outlet, cold inlet, cold outlet, nanoparticle 1, nanoparticle 2, base fluid 1, and base fluid 2 conditions, respectively.

4. 2. Preparation of Nanofluid

The first stage of conducting the experiments is to prepare the nanofluid. For a more detailed investigation, the nanofluids should be stable and homogeneous, and sedimentation not occur for a while. First, mixing dry samples of CuO and TiO_2 nanoparticles (50:50) and then the mixture of radiator coolant (60 % water and 40 % ethylene glycol) in the range of 0.25 %, 0.3 %, and 0.35 % of mass concentrations. Thermo-physical properties of both nanoparticles as shown in Table 2.

The base fluids were prepared in a certain amount of a mixture of water and ethylene glycol (60:40) called radiator coolant (RC). The ratio of ethylene glycol in water determines the thermal conductivity and density of the mixture. Table 3 shows the comparison of thermal properties between pure water and a mix of ethylene glycol and water or radiator coolant (RC), which are 20:80, 40:60, and 60:40 as base fluids.

Fig. 1. Experimental apparatus

Calculation of heat transfer coefficient by varying the radiator inlet flow rate and temperature. The temperature is measured using a type *K* thermocouple connected to the

The main disadvantage of nanofluids is agglomeration because the density of hybrid nanoparticles is greater than the density of the base fluid (RC). Hybrid nanoparticles consisting of CuO and TiO$_2$ nanoparticles and water-ethylene glycol (RC) were mixed into a 10-liter beaker. The solution mixes with a magnetic stirrer for 4 hours and eventually aggregates particle breakdown and becomes homogeneous. Fig. 2 shows hybrid nanofluids with mass concentrations of 0.25 %, 0.3 %, and 0.35 %.

Precipitation occurs over a while, ie in the first three hours, the hybrid nanoparticles have settled but can still be mixed with the base fluid, the radiator coolant, so that it still produces a turbid color. In the first six hours, the precipitated hybrid nanoparticles begin not to mix with the base liquid, resulting in a change in the color of the fluid. On the first day, the nanoparticles start to settle at the bottom so that the color of the base fluid i.e. the radiator coolant begins to return to its original color. On the third day, the Hybrid nanoparticles had settled and accumulated at the bottom and the radiator coolant color returned to its original color.

Tabel 2

Thermophysical property of nanoparticles

Thermo physical properties	ρ (kg/m^3)	C (J/kg·K)	k (W/kg·K)
TiO$_2$	4230	692	8.4
CuO	6320	531	32.9

Table 3

The physical property of water and mixture EG/W (RC) as base fluid

Base fluid	ρ (kg/m^3)	k (W/kg·K)
Water	998.5	0.602
20:80 % EG/W	1029.7	0.492
40:60 % EG/W	1059.6	0.404
60:40 % EG/W	1086.2	0.334

4. 3. Thermophysical Properties

The effective physical properties of the mixtures studied can be evaluated using some classical formulas usually used for two-phase fluids, like density, specific heat, viscosity, and thermal conductivity at different temperatures and concentrations

The following correlations were used to calculate the physical properties of nanofluid. The density of a nanofluid is estimated based on the principle of the mixture rule by the following equation:

$$\left(\frac{m}{V}\right)_{nf} = \frac{m_{bf}+m_{nf}}{V_{bf}+V_{nf}} = \frac{\rho_{bf}V_{bf}+\rho_{nf}V_{np}}{V_{bf}+V_{nf}}. \tag{7}$$

The density of mono nanofluid was estimated by [23] using equation (8):

$$\rho_{nf} = \varphi\rho_{np}+(1-\varphi)\rho_{bf}. \tag{8}$$

By extending the same mixture rule, the density of hybrid nanofluid was estimated by [24] using (9). This correlation had good agreement with their experimental outcomes

$$\rho_{nf} = \varphi_{np.1}\rho_{np.1}+\varphi_{np.2}\rho_{np.2}(1-\varphi_h)\rho_{bf}. \tag{9}$$

The volume concentration of two individual nanoparticles suspended in the hybrid nanofluid and it can be calculated from (10)

$$\varphi_h = \varphi_{np.1}+\varphi_{np.1}. \tag{10}$$

Specific heat of mono nanofluid was estimated by [7] using equation (11):

$$(\rho C)_{nf} = (1-\varphi)(\rho C)_{bf}+\varphi(\rho C)_{np}. \tag{11}$$

Dynamic viscosity of mono nanofluid was estimated by [25] using equation (12):

$$\mu_{nf} = \mu_b+(1+7.3\varphi+123\varphi^2). \tag{12}$$

a

b
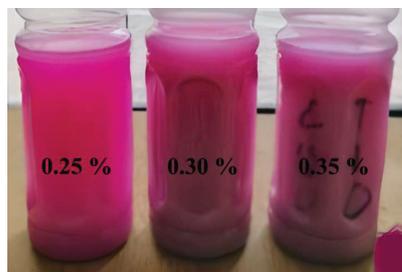
c
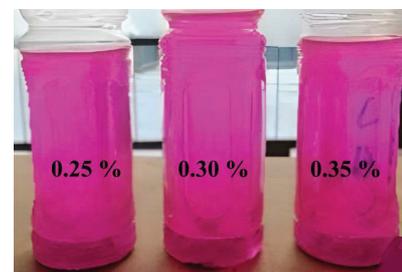
d

Fig. 2. Stability photographs of hybrid nanofluids at different times: a – three hours; b – six hours; c – one day; d – three days

The thermal conductivity of mono nanofluid was estimated by [26] using equation (13):

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{np} + 2k_{bf} + 2\left(k_{np} - k_b\right)(1+\beta)^3 \varphi}{k_{np} + 2k_{bf} - \left(k_{np} - k_b\right)(1+\beta)^3 \varphi}. \quad (13)$$

5. Results of studying the effect of hybrid nanofluid in the radiator

5. 1. The effect of particle concentration

As shown in Fig. 3, a graph of the total heat transfer coefficient (U) versus flow rate variation between 20 lpm and 28 lpm at 70 °C. The highest overall heat transfer increase of 83 % (from 496.3 W/m^2 °C to 727.8 W/m^2 °C) to pure radiator coolant at a particles mass concentration of 0.35 % at a flow rate of 22 Lpm. Meanwhile, at concentrations of 0.25 % and 0.30 % mass concentration of hybrid nanofluid, the overall heat transfer coefficient values are almost the same.

The influence of flow rate affects the value of the heat transfer coefficient for all concentrations, in general, the greater the fluid flow, the higher the heat transfer rate.

Fig. 4 shows a graph of the total heat transfer coefficient (U) versus flowrate variation between 20 lpm to 28 lpm at 80 °C. The highest overall heat transfer increase of 55.8 % (from 393.7 W/m^2 °C to 613.6 W/m^2 °C) to pure radiator coolant at a particles mass concentration of 0.35 % at a flow rate of 20 Lpm. As shown in Fig. 4, the bigger of mass concentration, the higher the overall heat transfer coefficient.

As shown in Fig. 5 the total heat transfer coefficient (U) versus flowrate variation between 20 lpm to 28 lpm at 90 °C. The higher the particle concentration, the greater the increase in heat transfer, as well as the flow rate.

While at a temperature of 90 °C, the overall heat transfer coefficient (U) an increase of 25.1 % occurring at a mass concentration of 0.35 % for a flow rate of 26 lpm compare to pure coolant radiators under the same conditions (403.6 W/m^2 °C to 505.3 W/m^2 °C) as shown in Fig. 5.
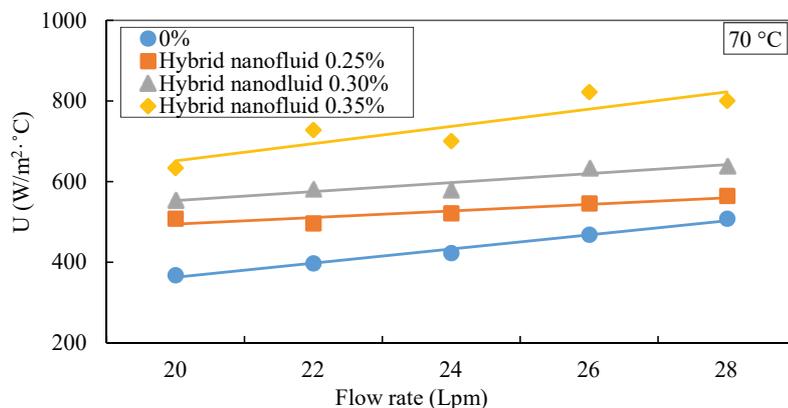
Fig. 3. The effect of mass concentration on the overall heat transfer coefficient (*U*) at a temperature of 70 °C
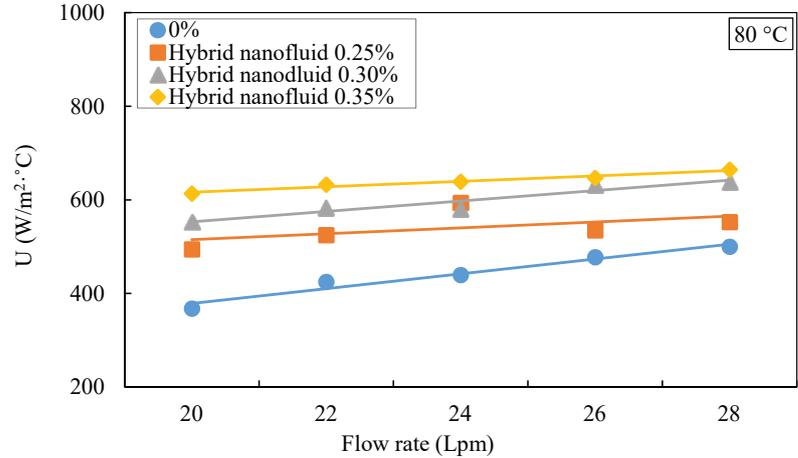
Fig. 4. The effect of mass concentration on the overall heat transfer coefficient (*U*) at a temperature of 80 °C
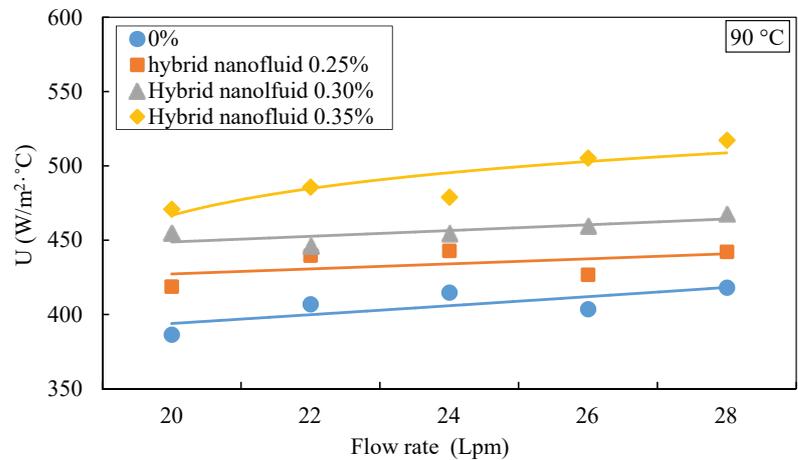
Fig. 5. The effect of mass concentration on the overall heat transfer coefficient (*U*) at a temperature of 90 °C

5. 2. The effects of temperature

Fig. 6–9 illustrate the overall heat transfer coefficient due to differences in temperature of the working fluid on pure RC and hybrid nanofluids with mass concentrations of 0.25–0.35 %. The effect of temperature in pure RC does not affect the performance of the radiator. The value of the overall heat transfer coefficient at temperatures of 70 °C, 80 °C and 90 °C, is almost the same for all temperatures, at a flowrate of 26 lpm are 422.5 W/m^2 °C, 439.5 W/m^2 °C, and 434.8 W/m^2 °C, respectively as shown in Fig. 6. The higher the percentage of nanoparticles, the higher the overall heat transfer coefficient value.

Fig. 7 shows the effect of temperature on the hybrid nanofluid at a mass concentration of 0.25 %. The total heat transfer coefficient value is relatively the same in the hybrid nanofluid with a mass concentration of 0.25 % at a temperature of 70 °C and 80 °C, and this means that both temperatures do not affect the radiator performance much, while at a temperature of 90 °C the overall transfer coefficient decrease. The overall heat transfer coefficients at 70 °C and 80 °C on 26 lpm are 545.4 W/m^2 °C and 554.8 W/m^2 °C, respectively. While at 90 °C the overall heat transfer coefficient is 436.7 W/m^2 °C.

Fig. 8 shows the effect of temperature on radiator performance hybrid nanofluid mass concentration of 0.30 %. The total heat transfer coefficient at a temperature of 80 °C is higher than the temperature of 70 °C and 90 °C, the lowest overall heat transfer coefficient at a temperature of 90 °C is 632.9 W/m^2 °C, 533.3 W/m^2 °C, and 449.5 W/m^2 °C, respectively.

From Fig. 9 below, it can be seen that in nanofluid hybrid 0.35 % of the temperature affects the radiator performance,

the overall heat transfer coefficient at 70 °C is higher than 80 °C and 90 °C, and the overall heat transfer coefficient is the lowest at 90 °C.

While at 80 °C the effect of fluid flow rate also does not affect the overall heat transfer coefficient. It means that the effect of fluid flow has no effect on increasing the total heat transfer coefficient.

Table 4 illustrate the analysis of variance results (two-way ANOVA) of the effect of hybrid nanofluid.
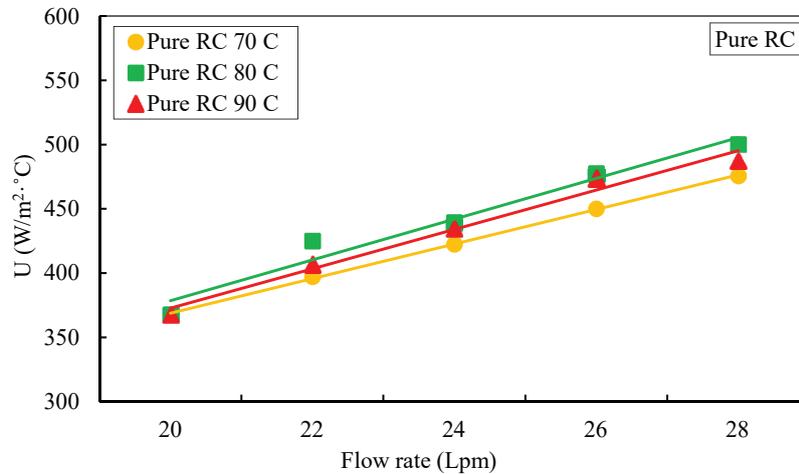
Fig. 6. Effect of temperature on overall heat transfer coefficient (U) in pure RC
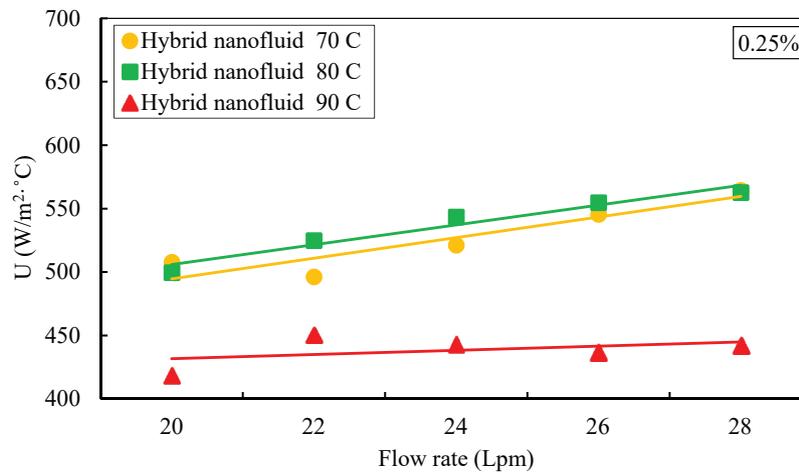
Fig. 7. Effect of temperature on overall heat transfer coefficient (U) in hybrid nanofluid of 0.25 %
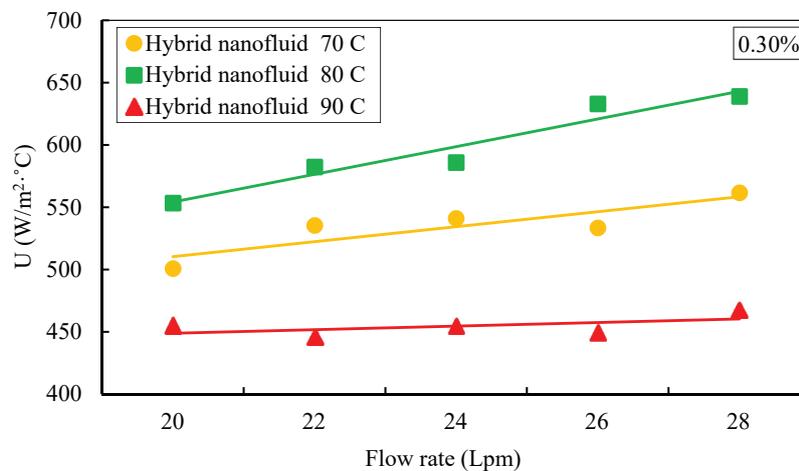
Fig. 8. Effect of temperature on overall heat transfer coefficient (U) in hybrid nanofluid of 0.30 %
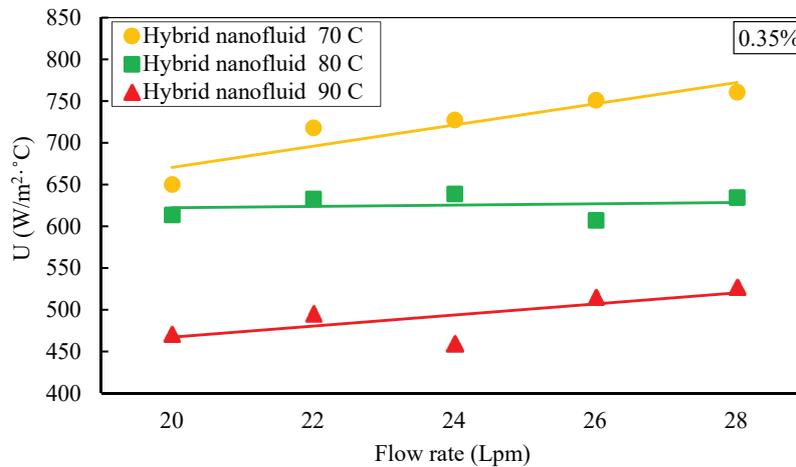
Fig. 9. Effect of temperature on overall heat transfer coefficient (*U*) in hybrid nanofluid of 0.35 %

Table 4

Analysis of variance (two-way ANOVA) of the effect of hybrid nanofluid

Source of Variation	SS	df	MS	F	P-v Value	F-crit
Temperature	18006.07	2	9003.03	2.925	0.11129	4.4589
Concentration	519824.46	4	129956.11	42.227	2E-05	3.8378
Error	24620.27	8	3077.53	–	–	–
Total	562450.82	14	–	–	–	–

According to the two-way ANOVA analysis, the effect of temperature not affected changes the overall heat transfer coefficient, which shows that calculated $F_{calculate}$ is less than $F_{critical}$ (2.925<4.4589) (Table 4). The Ho hypothesis is accepted; the hybrid nanofluid's overall heat transfer coefficient is the same at all temperatures. But the effect of Mass concentration significantly changes the overall heat transfer coefficient showing that calculated $F_{calculate}$ is greater than $F_{critical}$ (42.227>3.8378).

6. Discussion of the effect of hybrid nanofluid as a coolant on the engine radiator performance

The effect of hybrid nanofluid increases the overall heat transfer coefficient by 83 % compared to pure radiator coolants (RC). This improvement is because the thermal conductivity of hybrid nanofluids is significantly higher than that of base fluids and mono nanofluids. In hybrid nanofluids, the metal nanoparticles form a nanolayer on the surface of the metal oxide particles and create a thermal interface between the grain boundaries of the hybrid nanoparticles and the base fluid, resulting in a much more significant increase in thermal conductivity. The more nanoparticles in the base fluid, the greater the heat transfer rate because the more collisions between particles that serve as heat carriers [27] and also causes the reduction of boundary layer thickness. These reasons why the presence of hybrid nanoparticles affected a radiator's overall heat transfer coefficient. But the more mass concentration of nanoparticles, the higher the viscosity of the nanofluid, which is undesirable in the cooling system. Since it is related to the pumping power to circulate the coolant, the particle concentration should not be too high. Fig. 4, 5 shows that the particle mass concentration of 0.35 % is the highest, compared to the mass concentration of 0.25 and 0.3 %. The higher the particle concentration, the greater the overall heat transfer coefficient. The increase of

the overall heat transfer coefficient for hybrid nanofluids occurred because of Brownian motion between particles and a random movement of nanoparticles suspended in fluids (radiator coolant) resulting from the impact of molecules of the surrounding medium. The Brownian motion decreases when the particle size is significant because the movement of fluid molecules cannot push solid particles. But if the particle size is smaller, the Brownian motion increase.

Fig. 6 shows that the overall heat transfer coefficient in pure RC for temperatures of 70 °C, 80 °C and 90 °C is relatively the same. While in Fig. 8, 9 shows the different values of the overall heat transfer coefficient with the presence of hybrid particles. The highest overall heat transfer occurs at 70 °C, and the lowest occurs at 90 °C. This reason is the higher the temperature of the liquid, the thermal conductivity of nanofluid decreases with increasing temperature as the liquid expands and the molecules move apart. The lowest overall heat transfer coefficient occurs at a temperature of 90 °C at a mass concentration of 0.25 % and a flow rate of 24 lpm. Depict Fig. 7 for temperatures of 70 °C, 80 °C, and 90 °C the overall heat transfer coefficients are 521.2 W/m² °C, 543.5 W/m² °C and 442.9 W/m² °C, respectively.

The study of hybrid nanofluid SWCNT-MgO suspended in ethylene glycol as a base liquid at a temperature of 25 °C to 50 °C, the highest thermal conductivity at a temperature of 50 °C [28].

Hybrid nanofluids may possess better thermal network and rheological properties due to synergistic effect. Hybrid nanofluids for practical application as a new type of working fluids or cooling machining operations have some challenges in their development.

The limitation of this method to increase radiator performance lies in the stability of the nanofluid. The study of hybrid nanofluids is still at an early stage and requires further experimental analysis to better understand the mechanism of thermal properties. Necessary to develop more correlation to understand the heat transfer

enhancement as well as better stability enhancement methods before being used in practical applications in the automotive industry.

7. Conclusions

1. The heat transfer rate is highly dependent on the mass fraction. Increasing the mass concentration of 0.35 % shows the maximum overall heat transfer coefficients of 83 % (from 496.3 W/m^2 °C to 727.8 W/m^2 °C) to pure radiator coolant (RC).

2. Inlet temperature also increases the heat transfer rate; the effect is only at low temperatures, but its value gets smaller at high temperatures. Using hybrid nanofluid as a cooling fluid in the radiator increases the maximum heat transfer rate at a temperature of 70 °C, and the lowest increase occurs at a temperature of 90 by 5.7 %.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Acknowledgments

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