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 TiO₂ 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 TiO₂ nanoparticles (50:50) and then the mixture of radiator coolant, RC (60 % water and 40 % ethylene glycol). The flow fluid 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 85 % 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 working fluid, especially in small-scale heat transfer devices.

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

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 medium, 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 compared 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 Al₂O₃ 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
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 nanoparticles is enhanced by 6.09 % [15]. Experimental using Al2O3 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 TiO2/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].

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 machines. 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 Al2O3 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.

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.

| 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).

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 data logger. The overall heat transfer coefficient is calculated using (1).

\[ U = \frac{Q_{avg}}{A \Delta LMFD} \] (1)

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

\[ Q_{avg} = \frac{Q_h + Q_c}{2} \] (2)

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

\[ Q_h = m_h C_h (T_{hi} - T_{ho}) \] (3)

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

\[ Q_c = m_c C_c (T_{ci} - T_{co}) \] (4)

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

\[ \Delta LMFD = \frac{(T_{hi} + T_{ho}) - (T_{ho} - T_{hi})}{(T_{hi} + T_{ho}) / (T_{ho} - T_{hi})} \] (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):

\[ \phi = \frac{m_{np.1} + m_{np.2}}{m_{np.1} + m_{np.2} + m_{bf.1} + m_{bf.2}} \] (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 TiO2 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.
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 TiO₂ 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, i.e., 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.

### Table 2

| Thermophysical property of nanoparticles | \( \rho \) (kg/m³) | \( C \) (J/kg·K) | \( k \) (W/kg·K) |
|------------------------------------------|-----------------|-----------------|-----------------|
| TiO₂                                     | 4230            | 692             | 8.4             |
| CuO                                      | 6320            | 531             | 32.9            |

### Table 3

| Base fluid | \( \rho \) (kg/m³) | \( k \) (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 nano-fluid is estimated based on the principle of the mixture rule by the following equation:

\[
\left( \frac{m_{nf}}{\rho_{nf}} \right) = \left( \frac{m_{bf}}{\rho_{bf}} \right) + \left( \frac{m_{np}}{\rho_{np}} \right)
\]

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

\[
\rho_{nf} = \phi \rho_{np} + (1-\phi) \rho_{bf}.
\]

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

\[
\rho_{nf} = \phi_{np,1} \rho_{np,1} + \phi_{np,2} \rho_{np,2} (1-\phi) \rho_{bf}.
\]

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

\[
\rho_{nf} C_{nf} = \phi \rho_{np} C_{np} + (1-\phi) \rho_{bf} C_{bf}.
\]

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

\[
\mu_{nf} = \mu_{bf} + \left(1 + 7.3\phi + 123\phi^3\right).
\]

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 nano-fluid was estimated by [26] using equation (13):

\[
\frac{k_{nf}}{k_{np}} = \frac{k_{np} + 2k_{bf} + 2(k_{np} - k_{bf})(1 + \beta)^3 \varphi}{k_{np} + 2k_{bf} - (k_{np} - k_{bf})(1 + \beta)^3 \varphi}
\]  

(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/m² °C to 727.8 W/m² °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/m² °C to 613.6 W/m² °C) to pure radiator coolant at a particles mass concentration of 0.35 % at a flow rate of 20 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.

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/m² °C to 503.3 W/m² °C) as shown in Fig. 5.

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/m² °C, 439.5 W/m² °C, and 434.8 W/m² °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/m² °C and 554.8 W/m² °C, respectively. While at 90 °C the overall heat transfer coefficient is 436.7 W/m² °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/m²·°C, 533.3 W/m²·°C, and 449.5 W/m²·°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.
According to the two-way ANOVA analysis, the effect of temperature not affected changes the overall heat transfer coefficient, which shows that calculated $F_{\text{calculate}}$ is less than $F_{\text{critical}}$ (2.925 < 4.4589) (Table 4). The $H_0$ 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 $F_{\text{calculate}}$ is greater than $F_{\text{critical}}$ (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

### Table 4

| 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 | –      | –      | –         | –      |

![Fig. 9. Effect of temperature on overall heat transfer coefficient ($U$) in hybrid nanofluid of 0.35 %](image-url)
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/m² °C to 727.8 W/m² °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.

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