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Analysis of heat transfer coefficient in radiator cooling system using TiO_2/CuO hybrid fluid

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Abstract: The automotive industry is growing, encouraging more efficient car cooling systems, especially radiators. Innovations are constantly being made to improve the performance of radiators. Choosing the correct fluid is one of the ways to increase heat transfer. This study aimed to compare the performance of coolant OBC and TiO_2/CuO hybrid fluid mixed with coolant OBC to investigate the increase in heat transfer in the car's radiator. The first step is to make TiO_2/CuO hybrid fluid with a two-step method, with volume fraction variations of 1.0, 2.0, 3.0, 4.0, and 5.0%, and observe stability for 30 days. Viscosity and thermal conductivity tests are used to assess the thermophysical properties of the sample. Hybrid fluid samples of TiO_2 / CuO with a volume fraction of 5.0% showed the best stability and thermal conductivity, then were added to the coolant brand OBC (1:4). The results showed an increase in heat transfer rate of 23% and a heat transfer coefficient of 20% in the TiO_2/CuO hybrid fluid added to the coolant OBC.

Keywords: Heat transfer; thermophysical properties; TiO_2/CuO hybrid fluid

1. INTRODUCTION

Automotive technology advancements have resulted in higher thermal loads. Consequently, a more ideal cooling level is required [1]. A common technique for enhancing a radiator's cooling system is to add a fan [2]. Recently, the automotive industry has focused on lighting vehicles in an effort to reduce running costs and improve fuel efficiency [3]. The weight of the engine cooling system can be decreased. Low thermal conductivity and poor heat transfer characteristics are hallmarks of conventional cooling systems [4]. Heat transfer is an important factor in automobile engine performance [5][6]. So the coolant in an innovative radiator system is needed to optimize heat transfer [7]. The best fluid to improve radiators' thermal properties is nanofluid [8].

The outstanding ability of nanofluids to increase the complexity of thermal management systems for radiators [9]. Nanofluids are more stable and have a higher heat transfer coefficient than conventional fluids [10]. As a result, specialists have improved and altered nanofluids in a number of ways. The purpose of this study is to determine which fluid components are best for increasing heat transfer in the radiator. Put another way, it is essential to use prudence while choosing the base fluid and the particles that are used to create it. Because of their benefits and reasonable cost, metal oxides make excellent nanoparticles for use in nanofluids [11]. Additional advantages for nanofluid applications come from metal oxide nanoparticles enhanced homogeneity and non-clogging characteristics [12]. A variety of metal oxides have been converted into nanofluids for use in radiators, including Al_2O_3 [13], CuO [14], MgO [15], SiO_2 [16], TiO_2 [17], and ZnO [18]. TiO_2 and CuO are the two nanoparticles that are attracting the most interest because of their special qualities. TiO_2 has the properties of a thermal solid, is readily soluble, and breaks down gradually into sedimentation. [19]. Meanwhile, CuO has good heat conductor properties [20]. The application of TiO_2 and CuO in radiator cooling systems has been the subject of numerous studies. TiO_2 nanofluid at a concentration of 0.03% can boost heat transfer in the radiator by 29.5%. [21]. Heat transfer might be increased by up to 5%, and thermal characteristics could be improved by adding 0.9% copper oxide (CuO) nanoparticles. [22]. Adding 0.012% TiO_2/CuO hybrid

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nanofluid to the radiator results in a 5% increase in thermal conductivity [23]. This justification suggests that this research should inspire creativity and innovation while advancing fluid development in radiator systems. The main objective of this work is to evaluate the characteristics of TiO_2/CuO hybrid fluids with volume fractions of 1.0, 2.0, 3.0, 4.0, and 5.0%, using water as the base fluid in a 50:50 (1:1) ratio. Fluid attributes include stability, viscosity, and thermal conductivity. These characteristics are the fundamental properties fluids must have for radiator cooling applications [9]. For radiator performance, the fluid must have long-term stability and high thermal conductivity [24]. This research investigates how adding TiO_2/CuO hybrid fluid to the OBC coolant can affect a car radiator's heat transfer flow rate and heat transfer coefficient. The stability of the TiO_2/CuO hybrid fluid volume fractions at 1.0, 2.0, 3.0, 4.0, and 5.0% for 30 days was examined using the visual technique. The best TiO_2/CuO hybrid fluid samples were obtained based on stability, viscosity, and thermal conductivity. The best samples are mixed with coolant in a ratio of 1:4. A similar mixing method was used in research on radiators with a fluid mixture of 80% water and 20% radiator coolant, with a significant level of heat transfer reaching 5% [25]. The heat transfer coefficient and rate of the mixed fluid are compared to the OBC coolant. The parameters of heat transfer are regarded as indicators of the radiator cooling system's efficiency in an automobile. To investigate the radiator's heat transfer efficiency, experiments were conducted at volume flow rates of 100, 150, and 200 lph and with inlet fluid temperatures varied at 80, 85, and 90°C. The advantageous characteristics of incorporating TiO_2/CuO hybrid fluids into coolants for heat transfer and associated applications are also confirmed by these findings.

2. METHOD

2.1 Preparation of TiO_2/CuO hybrid fluid

TiO_2/CuO hybrid fluid preparation is demonstrated in Figure 1. The preparation method has a significant impact on the stability of the nanofluid [26]. In this study, a two-step method was used for fluid preparation. This method can cause robust Van der Waals attractions between the particles and the base fluid, resulting in a phenomenon known as agglomeration [27]. The first step is to prepare TiO_2 and CuO fluids by dissolving TiO_2 and CuO into the base fluid. Then, a Thermo Scientific Cimarex+ magnetic stirrer was used to mix the TiO_2 and CuO fluids for 60 minutes at 600 rpm. TiO_2/CuO hybrid fluid was ultrasonicated using a Daihan Scientific Ultrasonicator for 70 minutes. The purpose of ultrasonication is to break down agglomeration and strengthen stability [28].

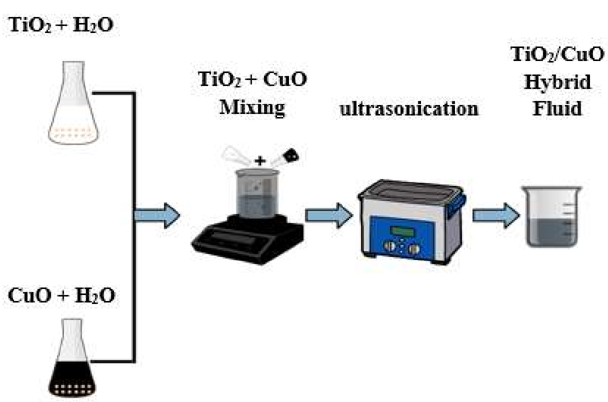

Figure 1. Process for making TiO_2/CuO hybrid fluid

In this research, a TiO_2/CuO hybrid fluid was made with a ratio of TiO_2/CuO = 50/50 (1/1) and using water as a base fluid. The volume fraction was varied, namely 1.0, 2.0, 3.0, 4.0, and 5.0%. The volume fraction is obtained from the sum of the volume concentrations of each fluid, and in this study, TiO_2 and CuO fluids [29]. Calculations of volume concentration were performed using Equation 1 [30]. The TiO_2 particles utilized in this study are white, and the material size is 0.03µm, boasting a particle purity of 99.9% with a density of 4.23 gr/cm^3. The CuO particles utilized in this study are black, and the material size is ≤ 160 µm, boasting a particle purity of ≥ 99% with a density of 6,31 gr/cm^3. The characteristics of the particles used in this research are shown in Table 1. The TiO_2 and CuO particles used were obtained from Merck KGaA, Germany.

$$\emptyset = \left(\frac{\left(\frac{w}{\rho}\right)_{Particle}}{\left(\frac{w}{\rho}\right)_{Particle} + \left(\frac{w}{\rho}\right)_{Basefluid}} \right) \times 100 \quad (1)$$

Ø is the volume fraction percentage (%), ρ is the density (gr/cm^3), w is the mass of the particle (gr), and the mass of the base fluid (ml).

Table 1. Particle Characteristics

Particle characteristics	TiO_2	CuO
Purity (%)	99,9	≥ 99
Colour	White	Black
Particle size (μm)	0,03	≤ 160
Density (gr/cm^3)	4,23	6,31

2.2 Stability of TiO_2/CuO hybrid fluids

The stability of the TiO_2/CuO hybrid fluid was examined visually by taking images of the sample at the specified time. To see the sedimentation that happened in the sample, pictures were taken. This technique is regarded as one of the most simple ways to determine a nanofluid's stability. Research on the stability of TiO_2/water nanofluids was conducted using this technique. [31]. The photos obtained from each sample were compared to observe their stability [32]. TiO_2/CuO fluid is considered stable if the dispersion remains constant over time or sedimentation does not occur over a long period of time [33]. In this research, stability observations were carried out over 30 days, as seen in Figure 2.

2.3 Thermophysical properties of TiO_2/CuO fluids

Thermophysical properties of the TiO_2/CuO hybrid fluid confirm the heat transfer capability and overall thermal performance. Regarding nanofluids, thermal conductivity is the most crucial thermophysical characteristic to monitor. Thermal conductivity was measured by the Portable KS-3 Tempos Thermal Properties Analyzer Instrument (METRE Group, Inc., USA). Thermal conductivity testing begins by preparing the equipment and the TiO_2/CuO hybrid fluid sample. The next step is that the KS-3 sensor is inserted into the TiO_2 /CuO hybrid fluid; the needle on the KS-3 sensor must be immersed in the sample; the position of the KS-3 sensor needle is at the center point of the sample and is not attached to the container wall so that the thermal conductivity reading is accurate. The TiO_2/CuO hybrid fluid sample to be tested is placed in a water bath. Temperature ranges between 30 and 90°C were used to measure thermal conductivity. Viscosity measurements were carried out using the NDJ-5S Digital Viscometer measuring instrument. This device determines liquid viscosity at various temperatures [34]. Viscosity testing using the NDJ-5S viscometer begins by ensuring the tool's cleanliness and calibration. Then, the next step is selecting a rotor appropriate to the fluid's viscosity range to be tested. In testing the viscosity of TiO_2/CuO hybrid fluid using a zero rotor, because the viscosity value range for the TiO_2/CuO hybrid fluid is below 10 MPa.s. When testing the viscosity, the viscometer must be placed on a stable surface. Flatness measurements during testing are carried out using a water pass. Viscosity tests are performed at a temperature range of 30-90°C using sufficient fluid samples, at least at the rotor's boundary line. Adjust the rotor's rotational speed and rotate at 30 rpm to measure the viscosity of TiO_2/CuO. The viscosity value of the TiO_2/CuO hybrid fluid will be obtained from the test results. The viscosity test was carried out three times, showing the highest fluid viscosity value [34].

2.4 Process of determining the mixing of the TiO_2/CuO hybrid fluid with the coolant in the radiator

A car radiator was used to evaluate the TiO_2/CuO hybrid fluid that had the best thermal conductivity, stability, and viscosity when combined with the coolant. The radiator cooling system of an automobile has a 5 liters fluid capacity. Mixed fluid is a 20%:80% (1:4) mixture of TiO_2/CuO fluid and coolant. The heat transfer coefficient and mixed fluid heat transfer rate were measured by the radiator cooling system.

2.5 Testing of coolant and mixed fluid in the radiator cooling system

During the initial testing, the heat transfer rate was measured using the radiator's mixed fluid and coolant. The test scheme on the radiator is shown in Figure 2. In this study, three distinct flow discharge variations (100, 150, and 200 lph) were used. The temperature of the fluid inlet (T_{in}) fluctuated between 80, 85, and 90°C. Once the engine temperature reaches operating temperature, the test is run. When the temperature reaches 80°C, the thermostat on the car radiator opens and fluid begins to flow. The temperature indicator displays the information that the water temperature sensor sends of the fluid temperatures entering and leaving the system. The temperature of the fluid inlet (Tin) fluctuated between 80, 85, and 90°C. Once the engine temperature reaches operating temperature, the test is run. When the temperature reaches 80°C, the thermostat on the car radiator opens, and fluid begins to flow. The temperature indicator displays the information that the water temperature sensor sends of the fluid temperatures entering and leaving the system. To calculate the heat transfer rate using Equation 2 [34][35]. After obtaining the heat transfer rate results from the coolant and mixed fluid, the heat transfer performance will be measured by calculating the heat transfer coefficient. Equation 3 is used to find the heat transfer coefficient [35]. During the test, the heat transfer coefficient values of the coolant and mixed fluid were calculated to produce an indicator of fluid performance in the radiator cooling system. The results of these tests are compared with one another, and it is determined either the mixed fluid's heat transfer rate and heat transfer coefficient have increased. Higher values for the heat transfer rate and heat transfer coefficient indicate that a fluid is more efficient in heat transfer. [36][37].

$$Q = \dot{m}.C_p\ (T_{in}-T_{Out}) \tag{2}$$

Q is the heat transfer rate (Watt), $\dot{m}$ is the mass fluid flow rate (Kg /s), C_p is the specific heat fluid (Kj/Kg °C), T_{in} and T_{Out} is the temperature of the inlet fluid (°C) and the temperature of the outlet fluid (°C).

$$h=\frac{Q}{nA_s\ (T_b - T_{wa})} \tag{3}$$

h is the heat transfer coefficient (W/m ^{2}°C), Q is the heat transfer rate (Watt), n is the number of radiator tubes, A_s is the surface area of the radiator tube (m ^{2}), T_b is the average temperature of the inlet fluid (°C) and outlet fluid (°C), T_{wa} is the average temperature of the radiator walls (°C).

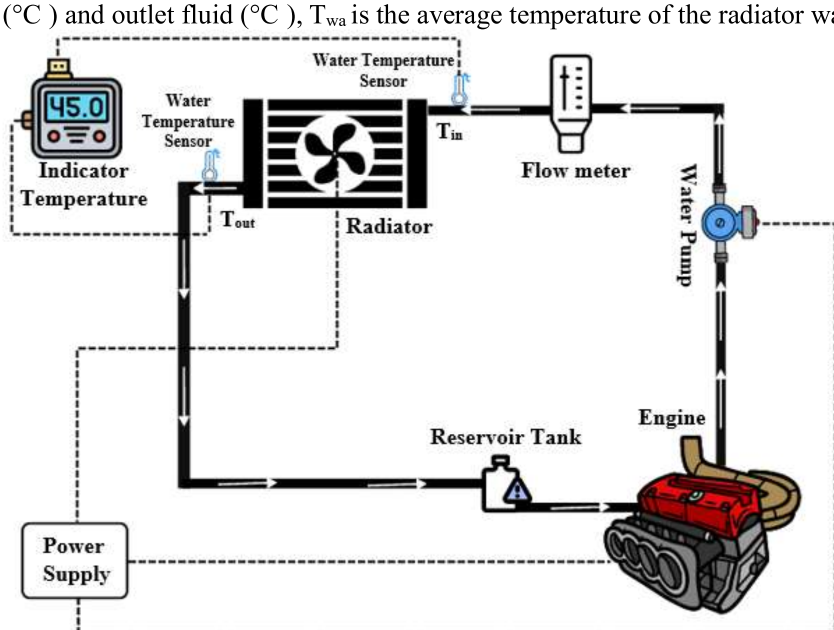

Figure 2. TiO_2/CuO hybrid fluid test scheme

3. RESULTS AND DISCUSSION

3.1 Stability of TiO_2/CuO hybrid fluid

Stability measurements were performed using observations on each TiO_2/CuO hybrid fluid sample over 30 days. This evaluation produces fluid stability information captured at various intervals of time.

In this study, TiO_2/CuO hybrid fluid was observed after 0, 10, 20, and 30 days. The observation results are shown in Figure 3. Figure 4 shows that the best stability of the TiO_2/CuO hybrid fluid occurs in the TiO_2/CuO hybrid fluid sample with a volume fraction of 5% and a stability level of 60% for 30 days. This shows that sedimentation occurred under these conditions, but the reaction behind the deposition process cannot be predicted. This happens because of the particle's robust Van Der Waals forces and gravity [38].

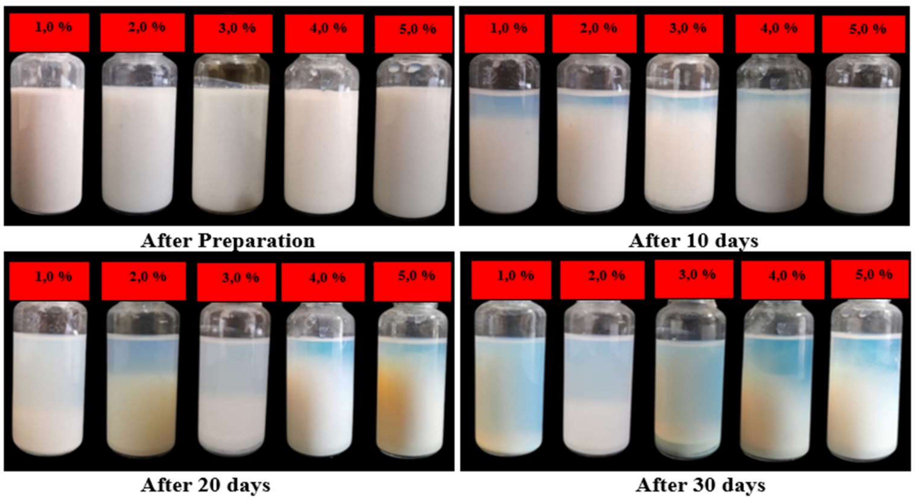

Figure 3. Photo of TiO_2/CuO hybrid fluid sedimentation

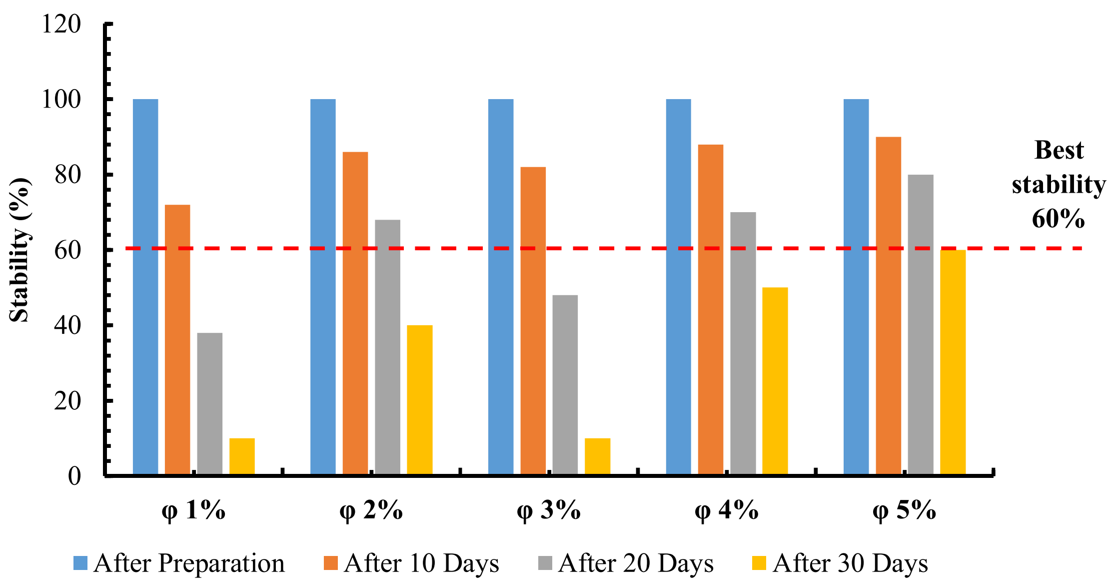

Figure 4. Decreased stability of the TiO_2/CuO hybrid fluid

3.2 Thermophysical properties of TiO_2/CuO fluids

Dynamic viscosity changes are shown in Figure 5 at temperatures between 30 -90°C. Investigations indicate that raising the temperature reduces the liquid viscosity of TiO_2/CuO hybrid fluids because the higher temperature and the force of attraction between molecules impact the liquid molecules. The Brownian motion effect of particles also affects fluid viscosity [27]. Increasing temperature also increases the distance between particle molecules and the base fluid, reducing the fluid's resistance to flow and viscosity. The highest viscosity results were obtained in the TiO_2/CuO hybrid fluid with a volume fraction of 5.0% and a viscosity value of 1.02 MPa.s at a temperature of 30°C. The viscosity

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results of the TiO_2/CuO hybrid fluid at various volume fractions are shown in Figure 5. At low concentrations, the fluid viscosity does not significantly increase due to the small number of particles; increasing volume fraction and adding particles increases the resistance to flow. Large numbers of particles prevent particle movement in the base fluid, thereby increasing viscosity [39]. This viscosity change is essential in heat transfer applications, where factors such as pump power and viscosity-relevant factors significantly contribute [27].

Figure 6 shows that the thermal conductivity of the TiO_2/CuO hybrid fluid increases with increasing temperature. The thermal conductivity of the TiO_2/CuO hybrid fluid is also enhanced with particle concentration. The highest thermal conductivity of the TiO_2/CuO hybrid fluid was found at a volume concentration of 5.0%, with 3.08 W/m.K at a temperature of 90°C. The thermal conductivity enhancement for the TiO_2/CuO hybrid fluid is more prominent at higher temperatures. Due to the influence of Brownian motion, the collision rate between suspended particles and fluid molecules increases as temperature rises, resulting in a significant increase in thermal conductivity. This finding is an advantage of the TiO_2/CuO hybrid fluid in car radiator cooling system applications.

This research then discovered several characteristics of TiO_2/CuO hybrid fluid properties, which may benefit future work innovations. Adjusting the volume fraction in TiO_2/CuO hybrid fluid is advised to perform better.

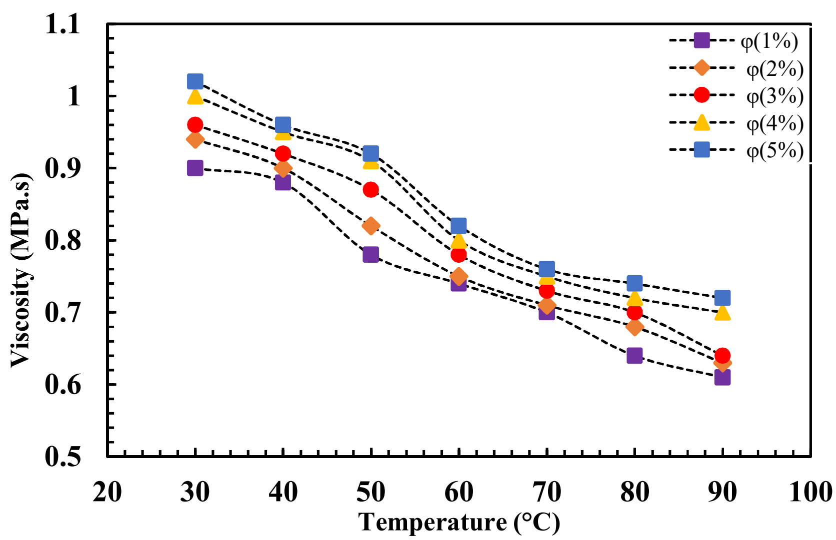

Figure 5. Viscosity of TiO_2/CuO hybrid fluid

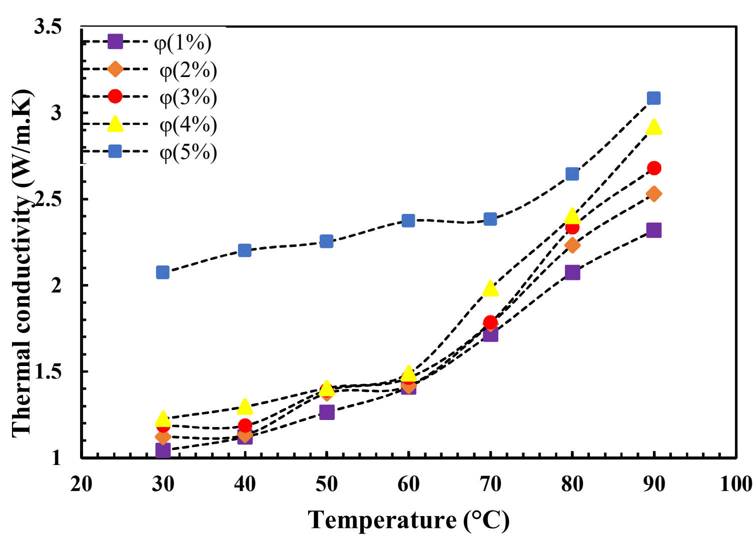

Figure 6. Thermal conductivity of TiO_2/CuO hybrid fluid

3.3 Calculation of heat transfer rate and heat transfer coefficient in radiators

Figure 7 illustrates the flow rate of heat transfer for the coolant and mixed fluid at various inlet fluid temperatures. Investigations show that the heat transfer rate in the mixed fluid at various flows produces a heat transfer rate more significant than the heat transfer rate in the cooling fluid. The maximum heat transfer rate value obtained in the coolant was 5207.57 Watts at a flow rate of 200 lph and Tin 90°C, in comparison to the highest rate of heat transfer value in the mixed fluid, which was 6385.35 Watts at a flow rate of 200 lph and Tin 90°C. These results show that the mixed fluid flow rate is more significant, and there is a percentage increase in the heat transfer flow rate of 23%.

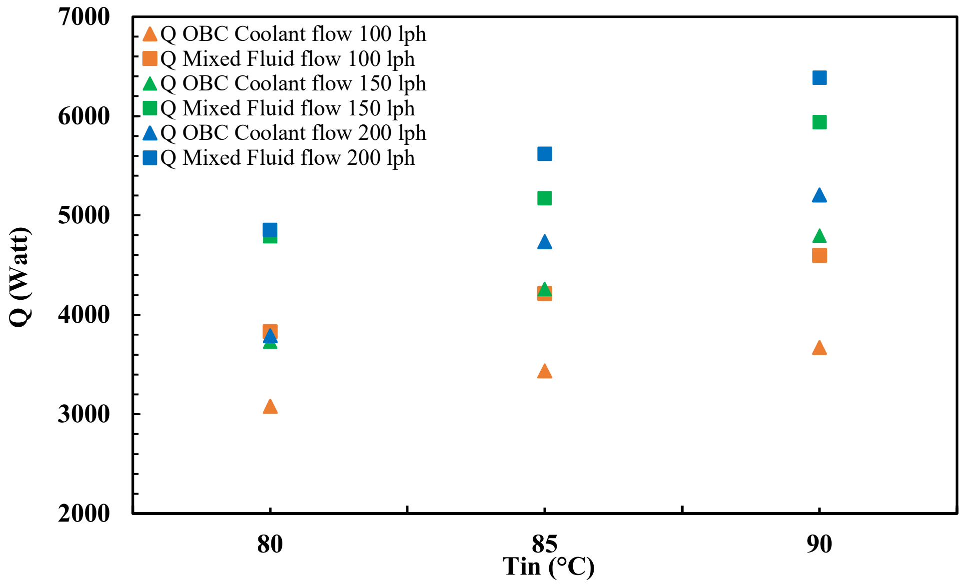

Figure 7. OBC coolant heat transfer rate vs mixed fluid

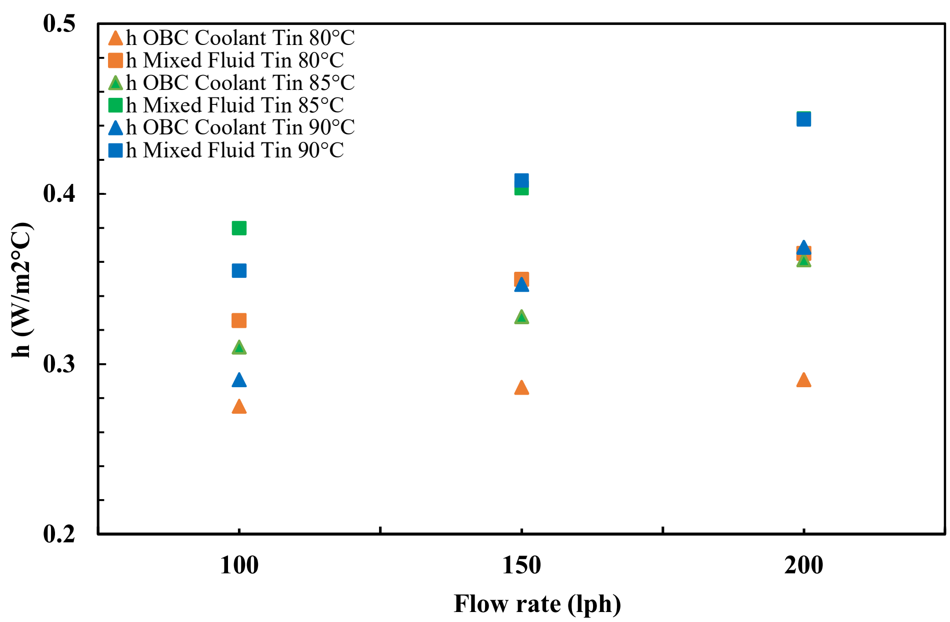

Figure 8. Heat transfer coefficient of OBC Coolant vs mixed fluid

Figure 8 shows the heat transfer coefficient values of the coolant and merged fluid in various fluid flows. According to the decisions, the heat transfer coefficient in the combined fluid at various flows produces a heat transfer coefficient value that is greater than that of the coolant. The maximum heat transfer coefficient value obtained for the OBC coolant is 0.37 W/m^2°C at a flow rate of 200 lph, while the maximum heat transfer coefficient value for the combined fluid is 0.45 W/m^2°C at a flow rate of 200 lph. According to the decisions, the combined fluid heat transfer coefficient value is more significant, with a percentage increase of 20%.

4. CONCLUSION

This research investigates how adding TiO_2/CuO hybrid fluid to the coolant affects a car radiator's heat transfer flow rate and heat transfer coefficient. TiO_2/CuO hybrid fluid stability volume fractions of 1.0, 2.0, 3.0, 4.0, and 5.0% were observed using visual methods for 30 days. The best stability is in TiO_2/CuO hybrid fluid with a volume fraction of 5.0%, which has up to 60% stability. The TiO_2/CuO hybrid fluid's thermal conductivity was investigated between 30°C and 90°C. At 90°C, the TiO_2/CuO hybrid fluid with a volume fraction of 5.0% and 3.08 W/m.K had the highest thermal conductivity value. The viscosity of TiO_2/CuO hybrid fluid was also observed, and the results showed that the most considerable viscosity was 1.02 MPa.s at a temperature of 30°C. The best TiO_2/CuO hybrid fluid samples were obtained based on stability, viscosity, and thermal conductivity. The best sample was a TiO_2/CuO hybrid fluid with a volume fraction of 5.0%, which was then mixed with coolant in a ratio of 1:4. Observation of heat transfer rate and heat transfer coefficient compared with OBC coolant. The results showed an increase in the heat transfer flow rate of 23% and a heat transfer coefficient of 20% in TiO_2/CuO hybrid fluid added to the OBC brand coolant. These results also validate the favorable properties of TiO_2/CuO hybrid fluids for heat transfer and related applications.

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