Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Enhancing Heat Transfer in Compact Automotive Engines using Hybrid Nano Coolants

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ARTICLE INFO

Article history:
Received 18 May 2023
Received in revised form 20 August 2023
Accepted 28 August 2023
Available online 17 September 2023

Keywords:
Nano coolant; automobile radiator; compact engines

ABSTRACT

This research aimed to compare the performance of a reduced-scale automotive radiator using single nano coolant (CNC and CuO) and its hybrid nano coolant (CNC and CuO nanoparticles) to enhance heat transmission. Three ratios of 70:30, 80:20, and 90:10 of hybrid nano coolants was tested. UV Vis stability characterization of the nanofluids showed that all samples were highly stable for up to 30 days. A modest concentration (0.01 vol per cent) of the hybrid nano coolant was shown to efficiently increase the heat transfer rate of a reduced-size automobile radiator, demonstrating that the heat transfer behaviour of the nano coolant was reliant on the particle volume percentage. The results show the potential use of hybrid nano coolants in increasing heat transfer efficiency, decreasing cooling system size by up to 71 percent, and thus lowering fuel consumption; these benefits have significant implications for developing more efficient cooling systems in various industrial applications. The experimental findings showed that 80:20 exhibited a significant amount of improvement in thermal properties. The consistency of the low volume concentration of hybrid nano coolants throughout the experiment is further evidence of their promise as a practical substitute for conventional cooling media in the compact size of an automotive engine cooling system.

1. Introduction

A nano coolant is a revolutionary cooling fluid consisting of a base fluid in which tiny particles are scattered [1]. Nanoparticles, usually made of metal or metal oxide, may significantly improve the conduction and convection coefficients and, therefore, heat transmission efficiency [2]. Due to their

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https://doi.org/10.37934/araset.32.2.314326

superior thermal conductivity, nanoparticles are a top choice for vehicles' thermal management systems. Nanoparticles are ideal for heat transfer exchange systems due to their huge surface area. Many nanoparticles have been investigated for their potential as heat transfer materials; these include metal nanoparticles, metal oxides, metal carbides, metal nitrides, semiconductors, carbon nanotubes (both single- and multi-walled), graphene, diamond, graphite, and organic nanocrystals like cellulose and Malay apple. Researchers have discovered that hybrid nanofluids outperform individual nanofluids in heat transfer and thermal conductivity. Recent research indicates that by carefully choosing and hybridising two distinct nanoparticles, significantly improved heat transfer may be obtained. Using nano coolant can reduce vehicle weight since it improves heat transfer efficiency while allowing for smaller heat exchangers. Adding fins and changing the geometric design of the tubes, both tried and proper methods for increasing the radiator's cooling rate, have reached their limitations. Water and ethylene glycol, two standard air- and fluid-side heat transfer fluids, have poor thermal conductivity. New heat transfer fluids are required to increase the efficiency of automobile radiators. The current research intends to enhance heat transfer behaviour and address overheating difficulties in automobile engines by creating a hybrid nano coolant composed of an organic source (cellulose nanocrystal CNC) and an inorganic source (CuO). In this research, a smaller radiator is employed as the heat transmission system, resulting in less frontal area, reducing drag force and fuel consumption. This research investigates using hybrid nano coolants to improve heat transfer efficiency in car cooling systems, with potential benefits including lower energy consumption and operating costs.

Hybrid nano coolants provide several potential advantages in the automotive industry, including enhanced engine performance, reduced fuel consumption, and reduced emissions. Numerous studies have been published on the use of nano coolant in automotive engines. Abbas *et al.,* [3] discovered that maximum of heat transfer rate enhancement up to 26.7% for Fe_2O_3-TiO_2 (50:50) hybrid nano coolant in water base fluid with low concentrations of 0.005 vol.%, 0.007 vol.% and 0.009 vol.%. Cardenas *et al.,* [4] performed investigation on the heat transfer performance of multiwalled carbon nanotube nanoparticles (MWCNT) dispersed in base fluid of water-Ethylene Glycol at a low volumetric ratio of 0.025%, 0.05% and 0.1% and obtained 4.6% of heat transfer improvement for 0.1% concentration. In a recent experimental investigation conducted by Ruey *et al.*, [5] the focus was on exploring the heat transfer performance of SiO_2 nano coolant within a water-Ethylene Glycol mixture. The study specifically examined the effects of different volume concentrations of SiO_2 nanoparticles, ranging from 0 to 1 vol%. The results revealed that the SiO_2 nanofluid with a volume concentration of 1.0 vol% displayed the most superior heat transfer performance among the tested concentrations. Developing efficient cooling systems is crucial to maximising engine performance, and nano coolants offer a promising option. Introducing nano coolants into automotive cooling systems presents novel stability and performance problems. Nano coolant stability testing is essential for avoiding sedimentation or blockage in the cooling system by ensuring that the particles stay evenly disseminated in the base fluid. Sedimentation and UV-Vis spectrophotometer measurement are two methods for determining a nano coolant's stability. Innovative radiator designs that increase heat transmission efficiency while minimising weight and space can be achieved using nano coolants. The demand for high-efficiency engines has risen because of recent developments in automobile technology, and nano coolants provide a practical way to satisfy these needs.

In sum, our work demonstrates how hybrid nano coolants may be used to boost the performance of automobile cooling systems by enhancing heat transfer. The results of this study give valuable insights for creating more efficient and sustainable automotive cooling systems, but additional research is needed to improve the design and application of nano coolants.

2. Methodology

The CNC nanoparticles used in this paper were purchased from Blue Goose Biorefineries Inc with a 7.4% of CNC w/w suspension. Information provided by the respective manufacturer; the CNC produced does not contain sulphate half ester moiety, which is a bioactive ingredient that is capable of steering the oxidation process. Therefore, these CNC are suitable for improving an automotive heat exchanger system's heat transfer performance and wear performance. Copper (II) Oxide (CuO) nanoparticles were commercially purchased from US Research Nanomaterials, Inc. (USA). Copper oxide nanoparticles physically appear as a brownish-black powder. The process flow for this research is illustrated as in Figure 1. The nano coolant was prepared by adopting the two-step preparation method as suggested by previous researchers [3-10] and at volume concentrations of 0.01%. The preparation of the nano coolant was considered under the variation of one volume concentration (0.01%) of two single nano coolants of CNC and CuO with three other hybrid nano coolants of CNC:CuO ratio at 90:10, 80:20 and 70:30. The characterization of the CNC and CuO nanoparticles is investigated with Field Emission Scanning Electron Microscope (FESEM) equipped with Energy Dispersive X-ray (EDX) from Jeol Japan, and model number JSM-7800F was used with magnification from ×25 up to ×1,000,000 (SEM).

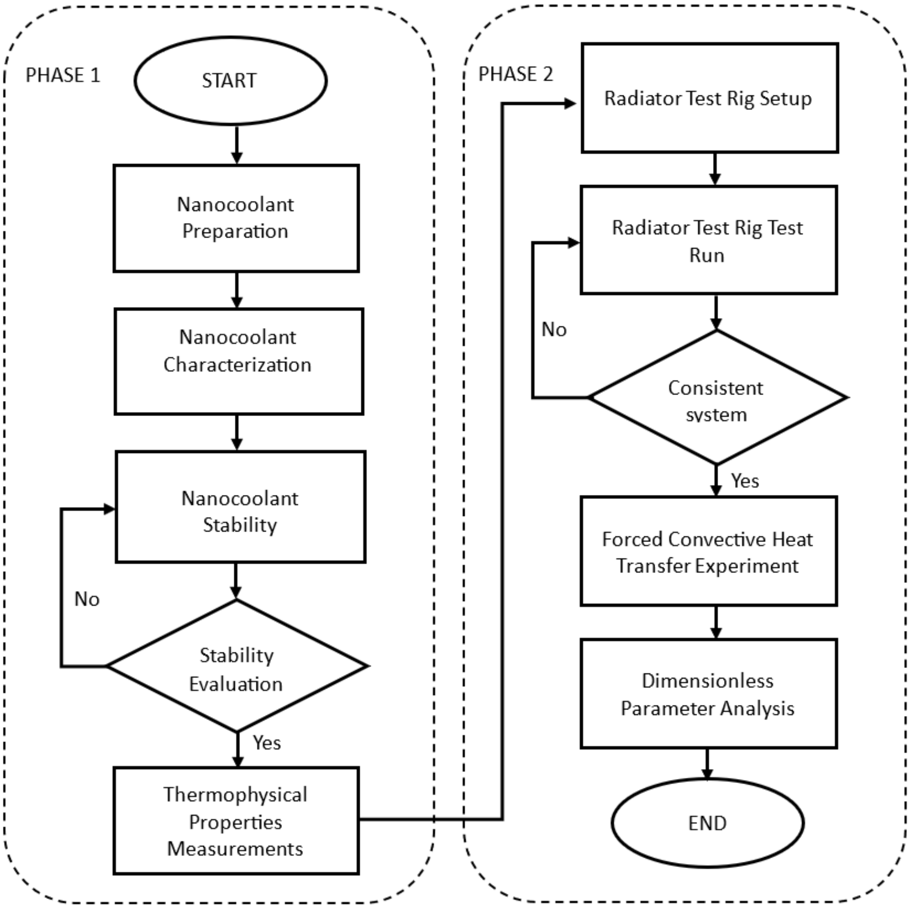


Fig. 1. Research framework for heat transfer in compact automotive engine

The preparation of nano coolant is crucial, beginning with weighing the nanoparticles and then adding the weighted nanoparticles to the base fluid. The single and hybrid nano coolants are prepared by adding predetermined CNC and/or CuO in Ethylene Glycol with a fixed volume fraction of 0.01% by using a magnetic stirrer and ultrasonic bath. In this research, the stability of the nano coolant is evaluated using qualitative and quantitative methods. The quantitative method is by visual inspection of sedimentation in a similar way as conducted by [11-13]. In the case of the quantitative method, a UV-Vis spectrophotometer analysis is performed. The Thermo Scientific™ GENESYS™ 50 UV-Visible Spectrophotometer, with a wavelength range of 190 nm to 1100 nm with an accuracy of ±0.5 nm, was utilized in this investigation. The 2ml transparent macro quartz cuvettes were used to contain all the nano coolants during the measurement. UV-vis is an efficient device for measuring the light absorbance of nanoparticles as the intensity of light becomes distinctive by absorption and dispersion of light passing through the nano coolant [14].

The thermal conductivity of applied nano coolant in the temperature range from 30°C to 90°C has been measured by KD2 Pro thermal property analyser. The KD2 Pro is equipped with a handheld controller and sensor, and the operating principle is based on the transient hot-wire method. The attached sensor is able to measure the thermal conductivity in the range of 0.002 and 2.00 W/m.K with an accuracy of ±5%. The KD2 Pro was calibrated by measuring the thermal conductivity of glycerine provided by the supplier at 20°C.

The measured density for this experiment uses the digital device, Anton Paar SVM 3001, able to compute the density at 40°C to 100 °C with repeatability of 0.00005 g/cm³ and reproducibility 0.0001 g/cm³. Compliances with ASTM D4052 and ISO 12185. This is to study the changes of density varies with the temperature change. Muneeshwaran *et al.,* [12] proposed equations for hybrid nanoparticles in determining their density by measuring the density, weight percentage, and volume fraction of individual nanoparticles.

The Cannon-Fenske Routine Viscometer measures the kinematic viscosity of any transparent Newtonian liquids and the specification according to ASTM D445 and ISO 3104. Standard testing method for kinematic viscosity of transparent and opaque liquids. Nano coolants are filled inside a glass capillary viscometer supplied by Cannon Instrument Company, United States of America. The requirement of minimum sample volume is 7 ml, and the minimum bath depth is limited to 230 mm (8 in). As a calibration step, a thermal oil sample was used to observe a stable temperature distribution inside the capillary tube. Each nano coolant sample at a different ratio is measured accordingly with the temperature range from 40°C to 100°C.

The specific heat capacity of nano coolant is decisive for heat storage and transfer applications [19]. Specific heat capacity is defined as the amount of heat energy required to raise the temperature of a substance per unit of mass. Differential Scanning Calorimeter Linseis DSC PT1000 was used to measure the specific heat capacity (Cp) of all the single and hybrid nano coolants at fixed volume concentrations and the base fluid. The Specific heat capacity was measured from 30°C to 90°C. Heat transfer rate calculated by:

$$Q = mC_p\,(Tout - Tin) \tag{1}$$

where m= mass flow rate; Cp = specific heat capacity; $Tout - Tin$ = temperature different at outlet and inlet

m= mass flow rate which is determined as:

$$m = \rho V \tag{2}$$

The heat transfer coefficient is calculated as:

$$h = \frac{mC(Tout-Tin)}{A_{s}\,(T_s - T_b} \tag{3}$$

The heat transfer performance of prepared single nano coolant and hybrid nano coolant was examined by performing a forced convective heat transfer experiment. The radiator test rig as on Figure 2 is one of the significant assemblies for testing the prepared nano coolant and recording the achieved temperature difference using six K-type thermocouples fixed at the radiator's fin and two thermocouple one located at the inlet and the other at the outlet of the radiator.

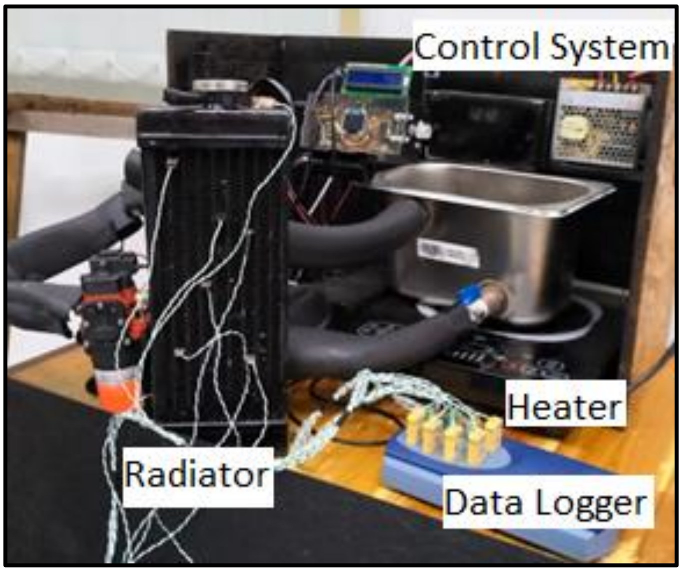


Fig. 2. Test rig for the experiment

Therefore, the design of the radiator test rig is crucial in obtaining an accurate result. The testing temperature was fixed at 80°C, which is the actual working temperature of the internal combustion engine, and the operating time was set at 60 minutes for every nano coolant. The temperature obtained is automatically recorded using Picolog 6 data logging software. A control system built using Arduino are used to control and monitor the flow rate and pump. A 2kW heater imitates the heat produced from an automobile system during its routine. The presented information in Table 1 provides the specifications of the reduced-size radiator used in the present experimental investigation.

Table 1
Geometrical characteristics of the reduce size radiator

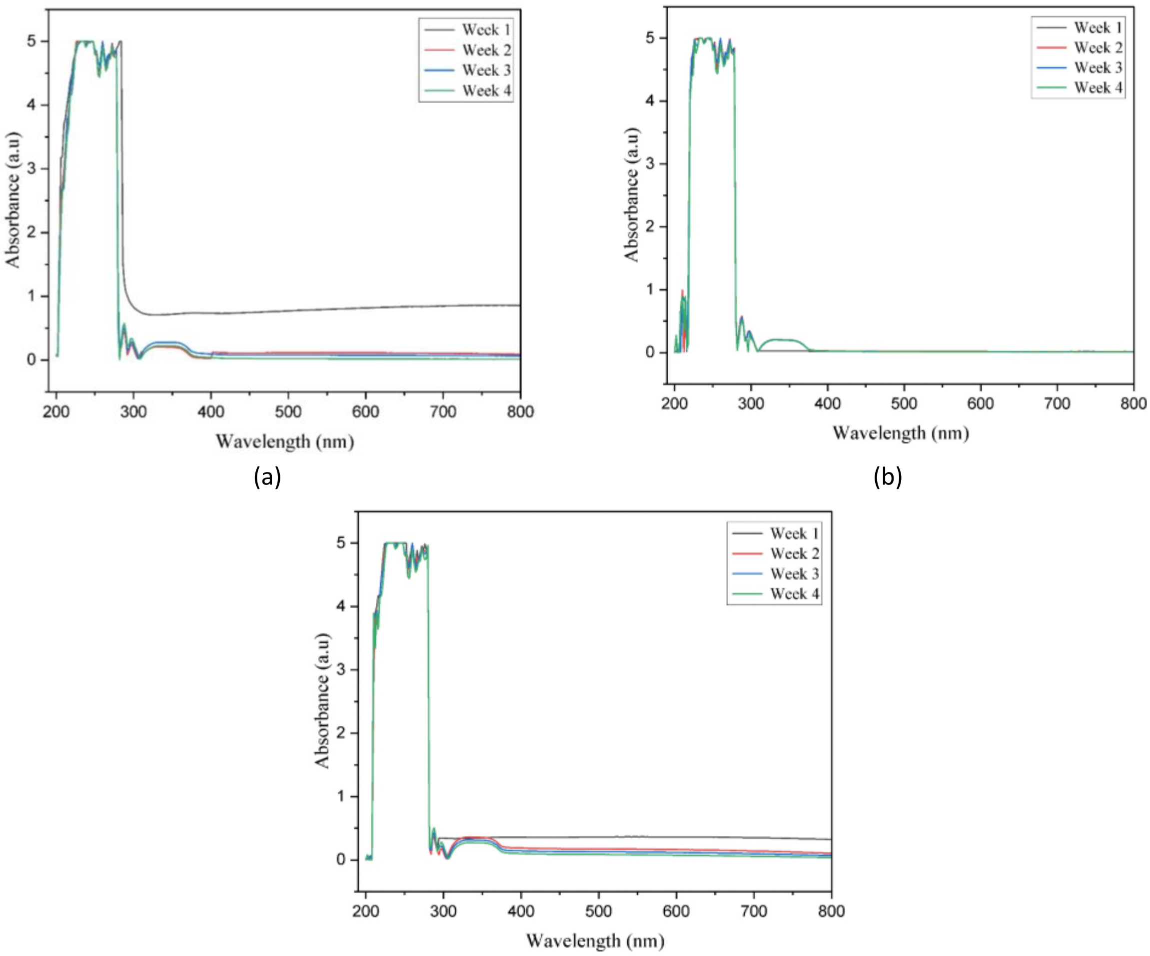
Feature	Configuration
Radiator length	123 mm
Radiator height	320 mm
Radiator width	36 mm
Tube length	2.2 mm
Tube height	25 mm
Tube width	2 mm
Number of tubes	16
Weight	800 g

3. Results and Discussion

3.1 Nano Coolant Suspension Stability of CNC-CuO in EG

As demonstrated in Figure 4, UV-Vis spectrophotometry was utilized to compare the absorption spectra of single nano coolant CNC and CuO, as well as three different ratio mixtures of hybrid nano coolant. The concentration of the samples was monitored from day one up to day 30 after sonification. The UV-Vis absorbance spectra of nano coolant solutions were recorded in the range of 200-1100 nm, and the wavelength peaks of each sample were detected at the range of 282-278 nm. The absorption peak of pure CuO was observed at 292 nm by Shah *et al*., [18] 295 nm by Jillani *et al.,* [19] and 270 nm by Kolahalam *et al.,* [20]. Rodrigues *et al.,* [21] studied CNC stability using UV-Vis and observed the peak wavelength at 254 nm.

In Figure 3(a) and (b), the mono nano coolant with CuO nanoparticles was obtained at 284 nm, and CNC was obtained at 278 nm, which is consistent with the literature reported by previous researchers. The stability of all nano coolants was found to be stable throughout the four-week duration, as depicted in Figure 2(a)-(c). The stability of the hybrid nano coolants with ratios of 70:30 and 90:10 exhibited similar peak absorbance results to the ones represent in Figure 3(c). The obtained stability is expected due to the low concentration of nano coolant particles.



(c)

Fig. 3. (a) Copper Oxide (CuO) (b) CNC nano coolant (c) 80:20 hybrid nano coolant

3.2 Thermal Conductivity

The thermal conductivity of all the studied nano coolants increased linearly with increasing temperature, as shown in Figure 4. The single CuO nano coolant displayed the highest thermal conductivity compared to all the studied nano coolants. The hybrid nano coolant with a ratio of 80:30 exhibited the highest thermal conductivity value, followed by the ratio mixtures of 70:30 and 90:10. The movement of nanoparticles in the nano coolant liquid was found to be random due to Brownian motion, resulting in continuous collisions between nanoparticles. The smaller size of CNC nanoparticles, compared to CuO, contributed to the enhancement of thermal conductivity in the hybrid nano coolant CNC:CuO (80:20). This behaviour has been previously reported by Abu-Hamdeh *et al.,* [22]. The thermal conductivity of nano coolants is a critical parameter determining their heat transfer efficiency. The results of the study provide valuable insights into the thermal conductivity of different nano coolants and their hybrid mixtures. The random movement of nanoparticles in the liquid and their collisions play a vital role in enhancing thermal conductivity, particularly in hybrid nano coolants. These findings can be utilized in designing and optimizing nano coolants for various heat transfer applications.

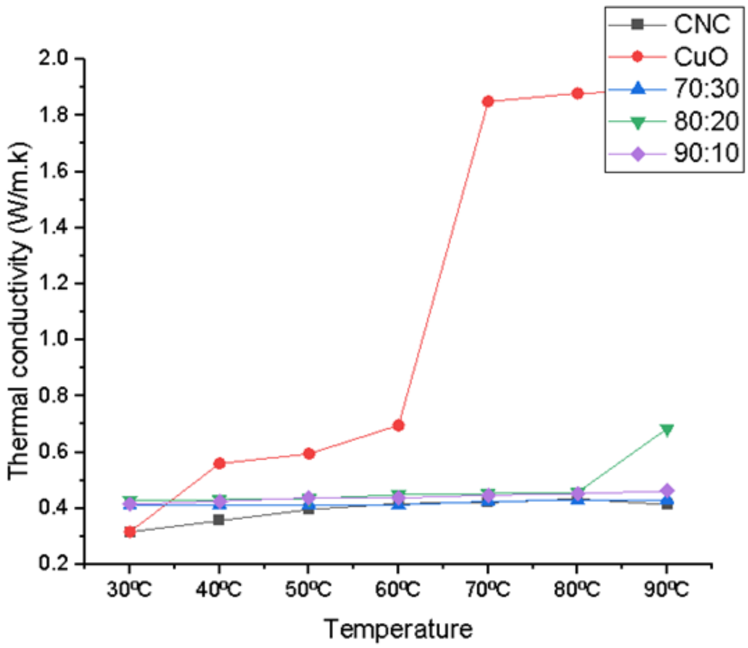


Fig. 4. Thermal conductivity for 30 °C to 90 °C

3.3 Density

The thermal conductivity of all the studied nano coolants increased linearly with increasing temperature, as shown in Figure 5. The single CuO nano coolant displayed the highest thermal conductivity compared to all the studied nano coolants. The hybrid nano coolant with a ratio of 80:30 exhibited the highest thermal conductivity value, followed by the ratio mixtures of 70:30 and 90:10. The movement of nanoparticles in the nano coolant liquid was found to be random due to Brownian motion, resulting in continuous collisions between nanoparticles. The smaller size of CNC nanoparticles, compared to CuO, contributed to the enhancement of thermal conductivity in the hybrid nano coolant CNC:CuO (80:20). This behaviour has been previously reported by Abu-Hamdeh *et al.,* [22]. The thermal conductivity of nano coolants is a critical parameter determining their heat transfer efficiency. The results of the study provide valuable insights into the thermal conductivity of different nano coolants and their hybrid mixtures. The random movement of nanoparticles in the liquid and their collisions play a vital role in enhancing thermal conductivity, particularly in hybrid nano coolants. These findings can be utilized in designing and optimizing nano coolants for various heat transfer applications. The density of the nano coolant relies on the densities of the constituent nanoparticles and the base fluid. The nano coolant's density is crucial since it influences the friction factor, pressure drop, and Reynolds and Nusselt numbers. Figure 4 presents a comparison of the densities at 40°C and 100°C for the CNC:CuO hybrid nano coolant against CNC and CuO single nano coolants, all at 0.01% volume concentrations. As per the referenced figure, despite an increasing trend, the density values of the CNC:CuO hybrid nanofluid at 70:30 and 80:20 ratios are marginally lower than those of the individual nano coolants at both temperatures. At a 90:10 ratio, the density is slightly greater than that of the CNC single nano coolant at both evaluated temperatures. Yet, it is moderately lower compared to the CuO single nano coolant. The conclusion can be drawn that as the proportion of CNC nanoparticles increases, the density rises due to the additional volume of CNC nanoparticles suspended within the base fluid.

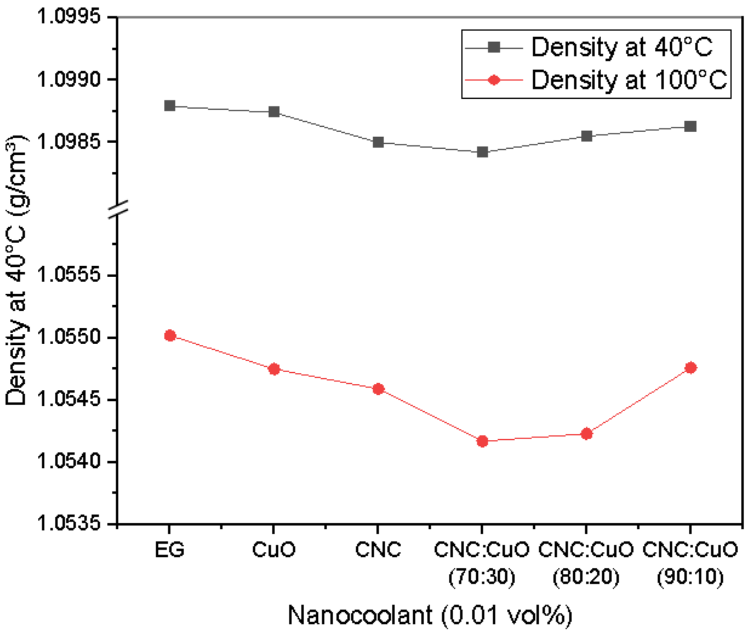


Fig. 5. Density for 0.01 vol% of nano coolant

3.4 Kinematic Viscosity and Viscosity Index (VI)

When subjected solely to gravitational forces, kinematic viscosity quantifies a fluid's intrinsic resistance to flow. Assessing kinematic viscosity offers insight into a fluid's lubricant resistance under gravity's influence and elevated temperatures impact on flow characteristics [23]. To investigate the variations in nano coolant viscosity in response to temperature changes, Figure 5 displays the viscosity deviation due to temperature effects at different ratios. The nano coolant's viscosity decreases as the temperature rises. This observation corresponds to the attenuation of attractive intermolecular forces, enabling faster nanoparticle movement within the suspension and reducing resistance to motion, resulting in lower viscosity values. Based on the experimental findings, the viscosity values at 100°C and 40°C consistently affect the base fluid viscosity across all nano coolants. Furthermore, it can be observed that the kinematic viscosity for all nano coolants exhibits a minimal reduction compared to the base fluid, Ethylene Glycol. The behaviour of the nano coolant viscosity concerning temperature change, as demonstrated in Figure 6, highlights the importance of understanding the fluid's thermophysical properties to optimize its performance in various applications [23]. The reduction in viscosity with increasing temperature can be attributed to the thermal agitation of the molecules, which consequently lowers the internal resistance to flow. This property has significant implications for the heat transfer efficiency and pumping power requirements in heat exchangers and cooling systems. Moreover, the relatively small decrease in kinematic viscosity for all nano coolants compared to the base fluid, Ethylene Glycol, suggests that adding nanoparticles does not significantly impair the flow characteristics.

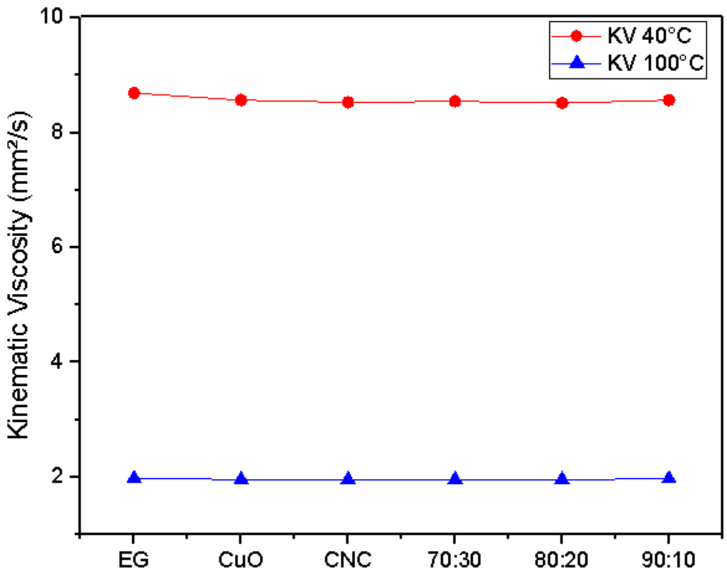


Fig. 6. Kinematic viscosity for EG, CuO and CNC mixture

This finding is crucial for the practical implementation of nano coolants in real-world applications, as it ensures minimal adverse effects on the fluid's circulation and heat transfer capabilities while retaining the benefits of enhanced thermal conductivity provided by the nanoparticles. It is also worth noting that the viscosity behaviour observed in this study is consistent with that of other nanofluids reported in the literature. The consistency of the viscosity reduction across various nano coolants may indicate that the type and concentration of nanoparticles have a negligible effect on the overall fluid viscosity. Further studies could explore the impact of varying particle size, concentration, and shape on the nano coolant's viscosity behaviour. Additionally, investigations into the influence of different base fluids and their interactions with nanoparticles could provide valuable insights into developing new nano coolants with improved thermophysical properties for specific applications.

3.5 Specific Heat Capacity

Figure 7 illustrates the impact of temperature on the specific heat capacity for single nano coolants and hybrid nano coolants in the studied nanofluid suspensions. A decrease in specific heat is observed as the temperature increases, consistent with findings from Wole-Osho *et al.,* [24]. This downward trend remains constant for each sample. It is determined that the specific heat capacity of the nano coolants decreases with increasing particle volume concentrations. This behaviour can be ascribed to the addition of nanoparticles possessing lower specific heats, resulting in a diminished proportion of the higher-specific heat fluid. The hybrid nano coolant with an 80:20 ratio (CNC:CuO) exhibits the most significant specific heat capacity value among the specimens. For single nano coolants, CuO demonstrates the highest specific heat capacity [24]. Integrating CNC nanoparticles into the hybrid nano coolant reduces specific heat capacity, which is most evident at the 90:10 ratio. As the volume concentration of CuO in the hybrid nano coolants increases, the specific heat capacity improves compared to the single CNC nano coolant and its 90:10 hybrid nano coolant counterpart. This outcome can be attributed to the high mass fraction of CuO, which exhibits the highest specific heat capacity.

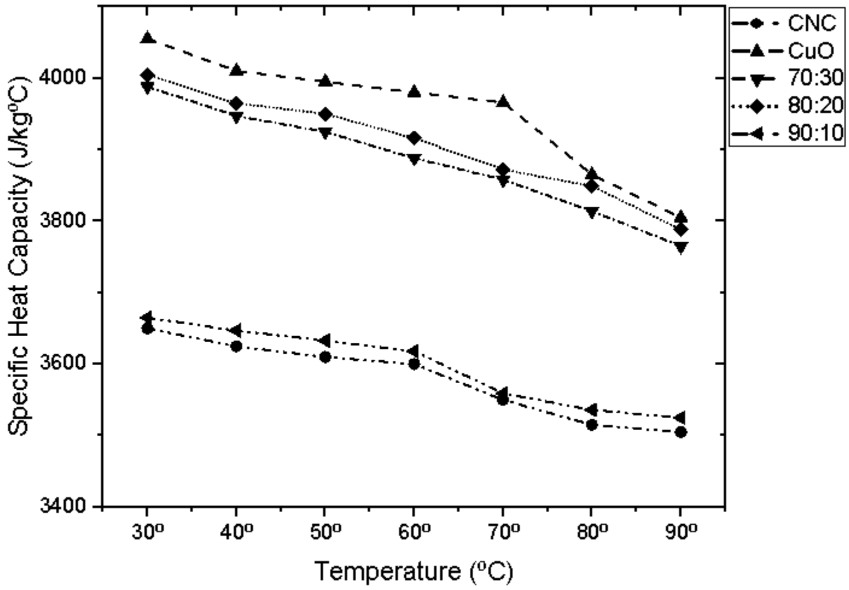


Fig. 7. Specific heat capacity for 30 °C to 90 °C

3.6 Heat Transfer

Figure 8 shows the outcomes of heat transmission for the investigated nano coolants. According to the graph, the 80:20 hybrid nano coolant obtained the most convective heat transfer at a flow rate of 1.25 l/min, or 21.64W. With a flow rate of 0.75 l/min, the heat transfer values for the single nano coolant CuO and CNC were 17.36W and 12.63W, respectively. Heat transmission increased gradually for all ratios and flow rates in studying hybrid nano coolants. The enhanced heat transmission efficiency of mixtures of nanoparticles over their components may account for this phenomenon. The higher thermal conductivity and more excellent dispersion of nanoparticles in the nano coolant liquid are responsible for the increase in heat transfer efficiency. The results of this research can be used to improve the performance of nano coolants in a wide range of heat transfer systems, from those used in electronics to those used in automobiles. Nano coolants' enhanced heat transfer efficiency can reduce power use, saving money in the long run. The study's findings may be used to increase heat transfer efficiency in various industrial settings since they thoroughly understand the heat transfer performance of various nano coolants and their hybrid combinations.

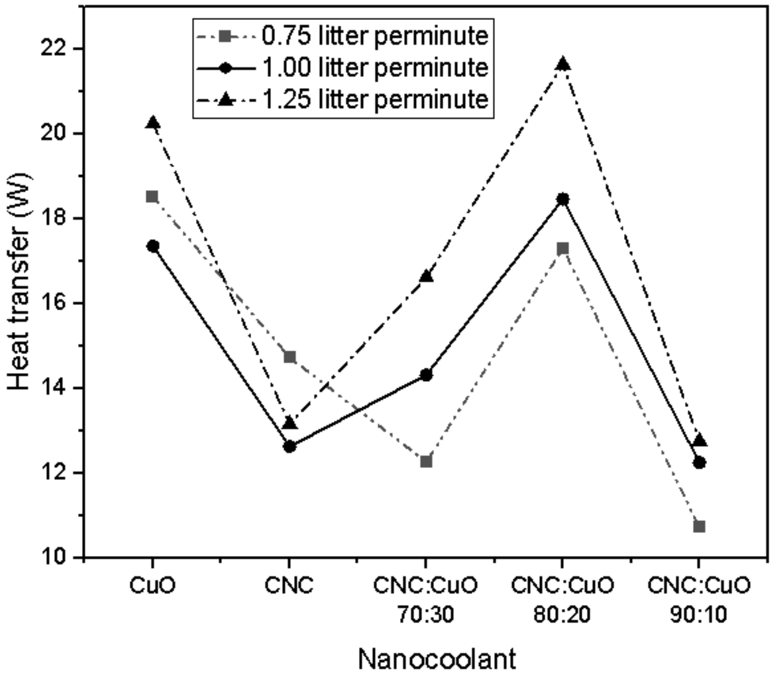


Fig. 8. Heat transfer for nano coolant at different flow rate

Figure 9 displays the experimentally determined heat transfer coefficient vs flow rate (LPM). At a flow rate of 0.75 litres per minute, the heat transfer coefficient was most significant for the 80:20 hybrid nano coolant, followed by CuO alone. The convective heat transfer coefficient was greatly improved by incorporating CNC and CuO nanoparticles into the base fluid. The experimental findings indicated an attractive nonlinearity between a miniature radiator's flow rate and the heat transfer coefficient. The findings are because the complicated flow patterns in a smaller radiator can significantly impact the radiator's ability to transmit heat. Improved heat transfer efficiency results from CuO's and CNC:CuO (80:20) because of its high heat transfer coefficient, which is in turn connected with their high specific heat capacity and thermal conductivity.

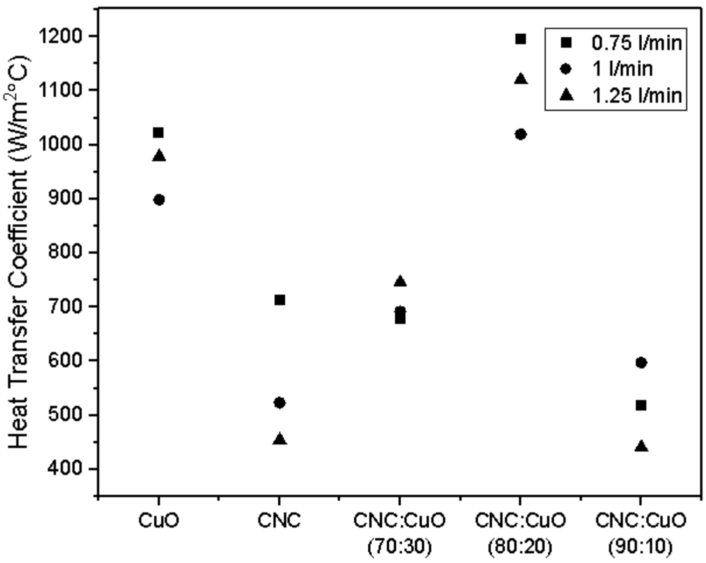


Fig. 9. Heat transfer coefficient for single and hybrid nano coolant

The research findings shed light on the heat transfer efficiency of various nano coolants and their hybrid combinations. Nanoparticles added to a base fluid can increase cooling performance in different uses by increasing heat transfer efficiency. The results of this research can be used to improve the performance of nano coolants in a wide range of heat transfer systems, from those used in electronics to those used in automobiles.

4. Conclusions

In this research, single and hybrid nano coolants composed of CNC and CuO nanoparticles were tested to see how well they improved heat transmission in a scaled-down car engine. Nanofluid stability was analysed, and all samples held up well during the 30-day research period. The experimental findings revealed that the particle volume % significantly impacted the heat transfer behaviour of the hybrid nano coolant. The maximum heat transfer enhancement is obtained for the hybrid nanocoolant of 80:20 ratio. The research showed that a little increase in the concentration of nano coolants used in a radiator might significantly boost its heat transfer rate, which could reduce the cooling system's weight and the vehicle's fuel consumption. According to the findings of the experiments, the size of an automobile radiator can be reduced by up to 71%. This research shed light on the feasibility of using nano coolants to enhance heat transfer efficiency in vehicle cooling systems. Nano coolants' superior stability throughout the trial period demonstrates their promise as a practical substitute for conventional cooling media. The overall significance of this study's findings lies in their relevance to designing more effective cooling systems for use in a wide range of industrial settings.

Acknowledgement
The authors would like to be obliged to Universiti Malaysia Pahang Al Sultan Abdullah to provide financial and laboratory through the research project of RDU213308 and PGRS220391.

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