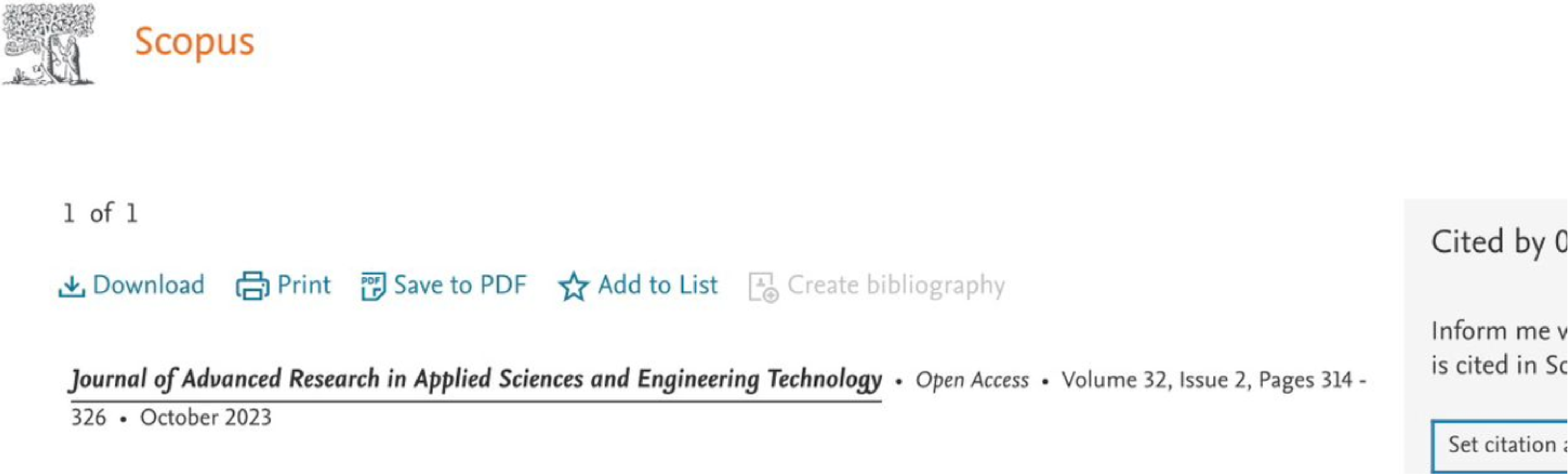

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Exploring the Potentials of Copper Oxide and CNC Nanocoolants

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ABSTRACT

The characteristics, stability, kinematic viscosity, viscosity index, thermal conductivity, and specific heat changes of Copper Oxide (CuO) and Cellulose Nanocrystal (CNC) hybrid nanocoolants at low concentrations are investigated in this work. The hybrid nanocoolants were created using different ratios of CNC and CuO nanoparticles and compared to single nanoparticle coolants. The existence of Cu-O and other similar formations was verified using Fourier Transform Infrared Spectroscopy (FTIR). Visual examination and UV Spectrophotometry stability study revealed that the nanocoolants were stable for up to 8 weeks, with little precipitation seen for single nanoparticle coolants after 12 weeks. When tested against temperature, kinematic viscosity decreased with increasing temperature, with very minor differences amongst coolants. The results of the Viscosity Index (VI) indicated that the hybrid nanocoolant performed similarly to the basic fluid, Ethylene Glycol (EG), even at high temperatures. Thermal conductivity rose as temperature increased, with a single CuO nanocoolant and a CNC:CuO (80:20) hybrid having the maximum conductivity. Specific heat capacity measurements revealed a declining trend as temperature rose. Overall, the CNC:CuO (80:20) hybrid nanocoolant and the CuO single nanocoolant displayed improved characteristics and stability, suggesting their potential for increased heat transfer applications.

Keywords:
Nano coolant; automobile radiator; compact engines

1. Introduction

Because of their improved thermal characteristics, nanofluids, which are suspensions of nanoscale particles in a base fluid, have emerged as a potential topic of study [1]. According to research, adding a tiny concentration of nanoparticles to these fluids may considerably boost their

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thermal conductivity [2]. Copper Oxide (CuO) nanoparticles in particular have received a great deal of attention due to their exceptional thermal characteristics. Anoop *et al.,* [3] discovered that the thermal conductivity of water based nanofluids enhanced dramatically at low particle densities. This, in turn, improves heat transmission efficiency dramatically. Meanwhile, the use of Cellulose Nanocrystals (CNC) in nanofluids has gotten a lot of interest because of its unique properties including high aspect ratio, high thermal stability, and renewable nature [4]. While research on CNC-based nanofluids is rather rare, first findings suggest encouraging outcomes in terms of improved heat transfer capacities [5]. CNC represent a class of nanomaterials that are synthesised from cellulose, a highly plentiful and renewable natural polymer. The utilisation of CNCs in various engineering applications is receiving significant attention due to their exceptional mechanical properties, biodegradability, and sustainability. Cellulosic nanocrystals have garnered substantial attention in the scientific community owing to their remarkable mechanical, optical, chemical, and rheological attributes. The notion of hybrid nanofluids has been presented as a technique to potentially produce synergistic effects by combining two or more kinds of nanoparticles in a base fluid. Lee *et al.,* [5] proved that hybrid nanofluids can outperform single-component equivalents, opening the path for additional research into other nanoparticle combinations. Despite these advances, a complete investigation on the thermal properties of hybrid nanocoolants consisting of CuO and CNC has yet to be published, to the best of our knowledge. Given their unique thermal qualities, their combination might result in a significant improvement in heat transfer efficiency. In addition to the current literature, a number of additional studies on nanoparticle-enhanced coolants have reported significant findings, indicating the potential of hybrid nanocoolants in heat transmission. Farhana *et al.,* [6] analysed CNC nanofluids in solar collector and it has been observed that the thermal conductivity of CNC nanofluids exhibits a significant enhancement. Hashim *et al.,* [7] applied hybrid CNC nano lubricant in engine oil and found significant improvement in viscosity index. Akilu *et al.,* [8] described the improved heat transfer properties of various metal oxide (including CuO) nanofluids, claiming that the heat transfer coefficient of the nanofluids was much higher than that of the base fluid owing to increased thermal conductivity. These findings give strong grounds to investigate the possible synergy of CuO with other nanoparticles. The concept of combining two kinds of nanoparticles has been investigated, although it is relatively new in the field of nanofluid research. According to Asadi *et al.,* [9], binary nanofluids or hybrid nanofluids have a considerably larger capacity to increase heat transmission than traditional nanofluids. This research revealed that the right mix of nanoparticles might provide a synergistic effect, resulting in better heat transfer enhancement than individual nanoparticles. Despite these encouraging results, significant research into the combination of CuO and CNC has yet to be conducted. Given the unique features of these nanoparticles, this work attempts to address a huge research need. Furthermore, as Sundari *et al.,* [10] point out, the use of nanocoolants in real-world systems necessitates a detailed evaluation of their stability. This work on CuO and CNC nanocoolants seeks to investigate not only their heat transfer capability, but also the long-term stability of these hybrid nanocoolants. As a result, this literature analysis offers convincing evidence for continued investigation of CuO and CNC as hybrid nanocoolants. Given the positive findings achieved from individual nanoparticle and hybrid nanofluid experiments, it is feasible to hypothesise that a CuO-CNC hybrid nanocoolant might have improved heat transfer capabilities.

2. Methodology

The Copper Oxide nanoparticles of average particle sizes 40 nm at purity of 99% (US Research Nanomaterials Inc.) and CNC nanoparticles with crystal length 0f 100-100 nm and crystal diameter of

9-14 nm (Blue Goose Bio Refinerie Inc) are used to prepare the studied nanocoolant samples. Table 1 and Table 2 listed the properties of CuO and CNC respectively as provided by the supplier. Nanocoolant at 0.01 vol% with two single nanocoolant and three different hybrid nanocoolant solution are added in EG as its base fluid using Two step method.

Table 1
Properties of CuO

Parameter	Value
Morphology	Nearly spherical
Size	40 nm
Purity	99%
Melting point	1326 °C
Density	6.4 g/m3
Hardness	3.5 Mohs

Source: https://www.us-nano.com/inc/sdetail/222

Table 2
Properties of CNC

Parameter	Value
Crystallinity index	80%
Crystal length	100-150 nm
Crystal diameter	9-14 nm
Hydrodynamic diameter	150 nm
Zeta potential	-35 mv
Carboxyl content	0.15 mmol/g
Sulfate Half Ester Moiety	Not detected

Source: https://bluegoosebiorefineries.com/product/

2.1 Characterization of Nanoparticles

The size distribution, morphology, and structure of CNC and CuO nanoparticles were characterized using Field Emission Scanning Electron Microscope (FESEM), Energy Dispersive X-ray (EDX) and X-ray diffractions (XRD). FESEM used highly focused and low energy electron beams provides topographical and morphological study of nanoparticles. The elemental compositions and characterization of CNC and CuO information will be provide by JEOL JSM-7800F FESEM facilitated with Energy Dispersive Xray (EDX). FTIR spectroscopic investigate the morphology of the nanocoolant particles as obtained by SEM and TEM analysis. The Nicolet iS50 Spectrometer operates effectively to acquire spectra from far-infrared to visible light range for applied-research FTIR spectrometer. Complied with the ASTM E1421, Standard Practice for Describing and Measuring Performance of Fourier Transform Mid-Infrared (FT-MIR) Spectrometers it is equipped with three detectors for the main sample compartment result in high-resolution standard.

2.2 Nanocoolant Preparation

The preparation on nanocoolant is carefully performed beginning from weighing the nanoparticles then adding the weighted nanoparticles into the base fluid. The single and hybrid nanocoolant are prepared by adding predetermined CNC and/or CuO in Ethylene Glycol by using a magnetic stirrer and ultrasonic bath. The nanocoolant samples are prepared in glass beaker of 1000 ml in volume. The preparation of the nanocoolant was fixed under the variation of one volume concentration (0.01%) of two single nanocoolant of CNC and CuO with three other hybrid nanocoolant of CNC:CuO ratio at 90:10, 80:20 and 70:30.

2.3 Dispersion Stability of Nanocoolant

Stability test of the dispersion stability for nanocoolant is priority for exploring the application of nanofluids in thermal applications. Visual inspection, UV-Vis Spectrophotometer and Zeta potential analysis is the most effective method used by many researchers to quantify the nanocoolant dispersion stability [11,12]. Sedimentation apparatus is used to observe the settling characteristics of nanoparticles using visualization technique at room temperature. Ultraviolet-Visible Spectrophotometer (UV-vis) device is an effective tool to analyse the stability of nanocoolant by the amount of light absorbed by the nanoparticles dispersed in the base fluid. The absorbance peak value identifies the most populated nanoparticles suspension within the nanocoolants. In this study, the Thermo Scientific™ GENESYS™ 50 UV-Visible Spectrophotometer with a wavelength range of 190 nm to 1100 nm with accuracy of ±0.5 nm was utilized in this investigation. The stability assessment by the zeta potential index is correspondent to the electrostatic repulsion forces among the nanoparticles. A stable nanocoolant exhibit higher value of repulsion forces as it indicates lower collisions of the nanoparticles. The higher value of zeta potential showed escalation of electrostatic repulsion and resultant in the nanocoolant stability.

2.4 Measurement of Kinematic Viscosity

Valuation of kinematic viscosity is imperative at the perspective of the ability for a coolant to efficiently protects engines from overheating and lubricates the moving parts. The Anton Paar's SVM 3001 Viscometer measures the kinematic viscosity of any transparent Newtonian liquids and the specification according to ASTM D445 and ISO 3104. Kinematic viscosity testing was performed according to American Society for Testing (ASTM) D445 at 40 °C and 100 °C. Analysing of kinematic viscosity provide the knowledge on the ability of fluid's lubricant resistance [6] to flow under gravity and effect of elevated temperature on the flow characteristic. In this study, the volume concentration of nanocoolant and temperature are predetermined as the two controllable parameters, which were effective for the viscosity of engine coolant, was evaluated.

2.5 Measurement of Viscosity Index

Viscosity Index quantifies the viscosity of fluid change relative to the changes of temperature. Ideally, the lower viscosity of nanocoolant is desirable as to reduce the pumping power [7]. The higher the value of Viscosity Index the lesser is the change in the nanocoolant's viscosity as temperature change. The Automatic kinematic viscometer SVM 3001 by Anton Paar's was used to measure the Viscosity Index of studied nanocoolant.

2.6 Measurement of Thermal Property

Thermal conductivity of applied nanocoolant in temperature range from 30°C to 90°C has been measured by KD2 Pro thermal property analyser. The KD2 Pro equipped with handheld controller and sensor and the operating principle is based on transient hot-wire method. The attached sensor 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 calibrate by measuring the thermal conductivity glycerine provided by the supplier at 20°C.

2.7 Measurement of Specific Heat Capacity

Specific heat capacity (C_p) of nanocoolant is decisive for heat storage and transfer applications [8]. 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 nanocoolant at fixed volume concentrations and the base fluid. The Specific heat capacity was measured from 30°C to 90°C.

3. Results and Discussion

In this research, the attention was focused on measuring and evaluating characteristic, stability, kinematic viscosity, viscosity index, thermal conductivity, and specific heat variations in single CNC and CuO nanocoolant and its hybrid nanocoolant at low concentration.

3.1 Characterization of Nanoparticles by FESEM

In this study, the nanoparticles composed of CuO and CNC were subjected to comprehensive characterization utilising various state-of-the-art characterization equipment. One such instrument employed was the Field-emission scanning electron spectroscopy (FESEM) system, specifically the model JSM-7800F manufactured in Japan. The CNC nanoparticles is rod-like nanocrystal configuration similar as observed by Razali *et al.,* [13] as shown in Figure 1.

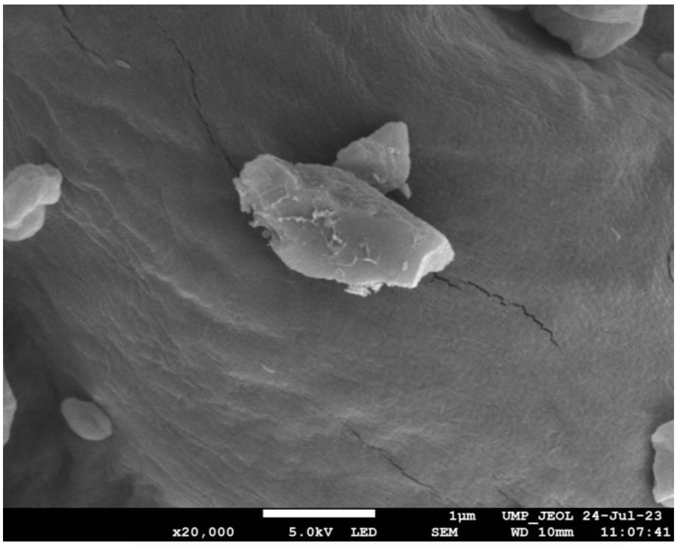

Fig. 1. FESEM morphology of CNC nanoparticles

The CuO morphology were spherical in shape as shows in Figure 2 and the average diameter obtained is 57.84nm.

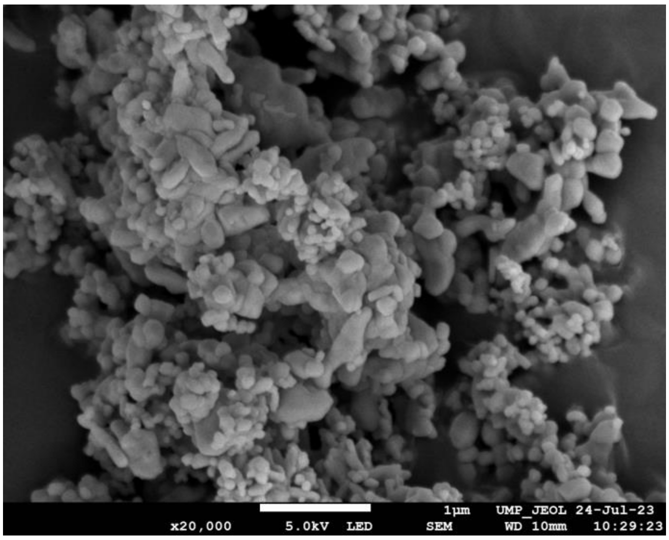

Fig. 2. FESEM morphology of CuO nanoparticles

3.2 FTIR

The Fourier Transform Infrared Spectroscopy (FTIR) technique is characterized by distinguishing and quantify different particle matter vibrate either through bending or stretching as it diffuses at specific light wavelengths. It is noticeably from Figure 3 the characteristic of the broad absorbance peaks in the regions of 3300 cm^{-1} are attributed of the stretching vibrations of the hydroxyl (OH) functional group from the base fluid (EG) [14].

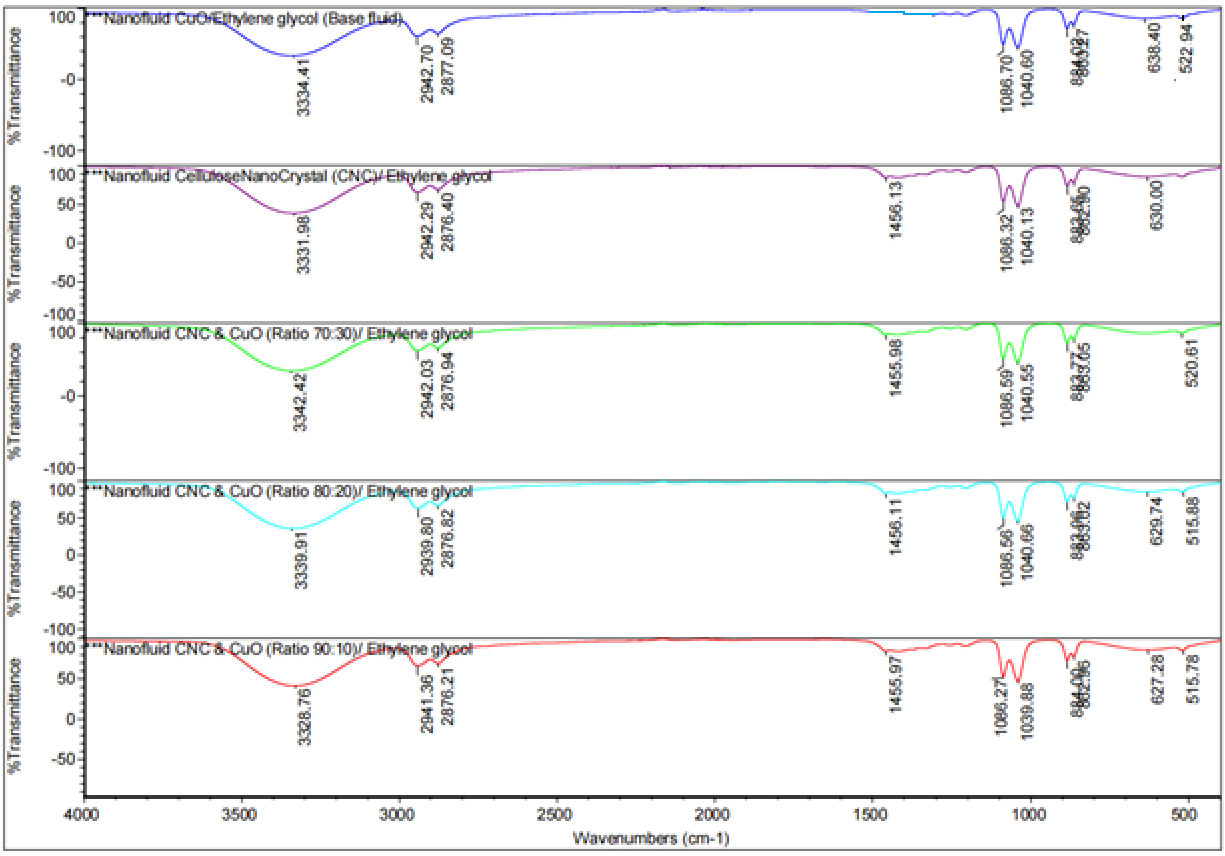

Fig. 3. FTIR Spectra of Single and Hybrid Nanocoolant

The peaks range from 2800 to 2900 cm^{-1} coincide to CH stretching [11]. The peaks observed in the range of 1450–1460 cm^{-1} corresponded to the symmetric bending of CH_2 which is related to cellulose. The FTIR spectrum band peaked at 522.94 (single CuO nanocoolant), 520.61 (70:30 hybrid nanocoolant), 515.88 (80:20 hybrid nanocoolant), and 515.78 (90:10 hybrid nanocoolant) respectively indicates modes of bending vibration of the CuO formation [12]**.**

3.3 Stability Inspection of Nanocoolant

3.3.1 Stability investigation using photo capturing and visual inspection

The stability studies of low volume percentage of nanocoolant were prepared with two single nanocoolant and three hybrid nanocoolant of different ratio of CNC and CuO were made using two methods including a magnetic stirrer and bath ultrasonic. Then, all the studied samples were maintained inside the test tube in a fully stable condition. The nanocoolant stability investigation were visually inspected and recorded periodically. Photograph of the nano lubricants was captured at various week intervals as shown in Figure 4. From the images of Figure 4(a) and 4(b), it can be seen that up to 8 weeks all the nanocoolants are stable and then the sedimentation of nanoparticles starts to take places 12 weeks onwards. From observation as in Figure 4(c), samples with the single CuO and CNC nanocoolant showed noticeable precipitation after 12 weeks. In the consideration of the lower volume percentage of the nanoparticles in hybrid nanocoolants sample there is very little precipitation was seen even after 12 weeks. The results also show that the stability of hybrid nanocoolant of CNC and CuO was good with the increase of the storage time. The aggregation occurs for single nanocoolant due to the Brownian motion and the Van der Wall forces of the nanoparticles were greater than the repulsive forces [13].

Fig. 4. (a) 0 week, (b) 8 weeks, (c) 12 weeks

3.4 Kinematic Viscosity

In order to study the nanocoolant viscosity changes with temperature, the variations of kinematic viscosity with the temperature at different ratio of hybrid nanocoolant and two single nanocoolant are presented in Figure 5. It is clear that the kinematic viscosity of nanocoolant decrease with an increase in temperature. This is due to the weakening of intermolecular attractive forces which allows more suspended nanoparticles to move rapidly in the nanocoolant that contribute less resistance to motion resulting the kinematic viscosity to decrease. Upon the obtained results from this experiment, the value of kinematic viscosity at 100 °C and 40°C, all the nanocoolant have the same amount of effect on the base fluid viscosity. Additionally, it could be observed that the kinematic viscosity for all nanocoolant had a very little amount of reduction with respect to the base fluid, Ethylene Glycol. Low volume percentage of nanoparticles when added to the base fluid, these nanoparticles are located between the EG layers which lead to the ease of movement for the layer of fluid on top of each other. Therefore, the kinematic viscosity value will slightly decrease.

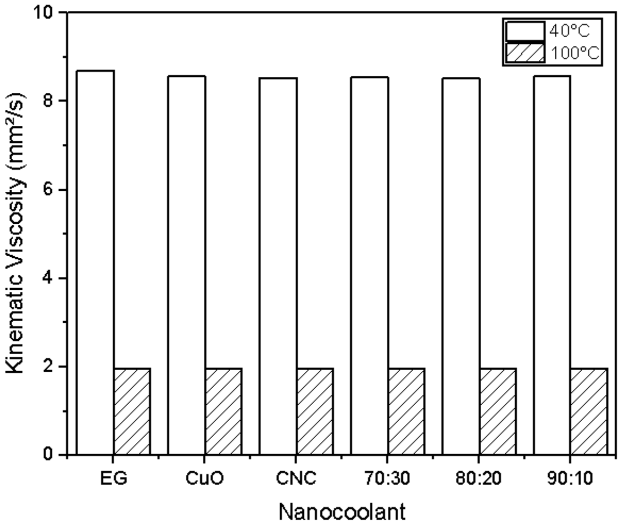

Fig. 5. Kinematic viscosity

3.5 Viscosity Index

The viscosity index (VI) serves as a quantifiable metric for assessing the variation in a fluid's viscosity in reaction to changes in temperature. VI is a dimensionless parameter that serves as an indicator of the rate at which a lubricant's viscosity changes with respect to temperature variations. A higher VI value signifies a reduced rate of viscosity alteration in response to temperature fluctuations. The enhancement in VI with the use of nanoparticles in the lubricants which could lead to an improved fuel economy in engineering systems. Through implementing nanoparticles with high viscosity index into the base fluid, the viscosity of the resulting nanofluid can be significantly increased, thereby offering enhanced heat transfer performance.

Table 3 illustrates the comparison for VI at varying concentrations of CNCs with the base oil, SAE 40. It can be observed that sample for CNC:CuO at 70:30 of viscosity index (VI) was almost similar with the base fluid Ethylene Glycol.

Table 3
Viscosity Index for CuO/CNC single nanocoolant and its hybrid nanocoolant

Nanocoolant	Viscosity Index
EG	-56.52
CuO	-55.88
CNC	-55.28
CNC:CuO (70:30)	-56.28
CNC:CuO (80:20)	-54.27
CNC:CuO (90:10)	-51.09

In addition, from Figure 6 the Viscosity Index for CNC and CuO single nanocoolant with two other two hybrid nanocoolant exhibit the similar range as base fluid, EG which ensures that nanocoolant remained effective even at high temperature by maintaining the thickness of the ethylene glycol film.

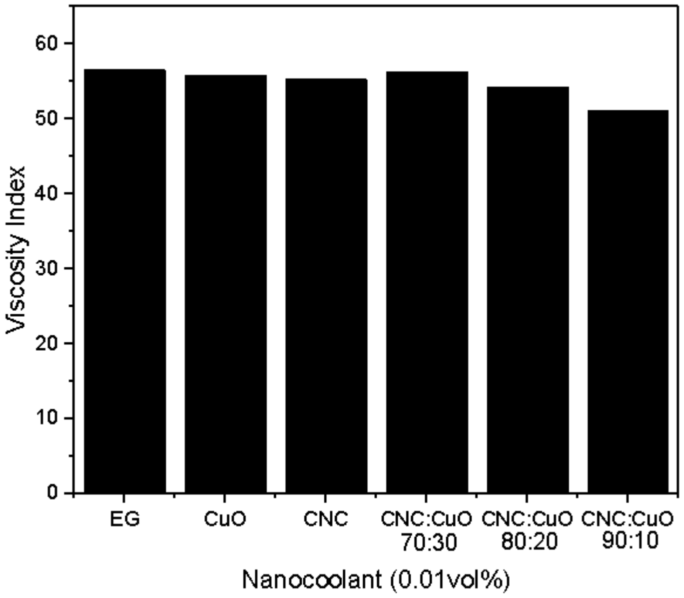

Fig. 6. Viscosity Index for single and hybrid nanocoolant

3.6 Thermal Conductivity

The thermal conductivity increased linearly with increasing temperature for all studied nanocoolant as showed in Figure 7 Single CuO nanocoolant inherent the highest thermal conductivity compared to all studied nanocoolant and hybrid nanocoolant of ratio 80:30 showed the highest value of thermal conductivity followed by ratio mixture of 70:30 and 90:10. Nanoparticles were moving at random in the liquid. The continuous clashes between nanoparticles and random moving behaviour which is known as Brownian motion [14] of CNC nanoparticles with smaller size compare to CuO results in thermal conductivity enhancement for hybrid nanocoolant CNC:CuO (80:20).

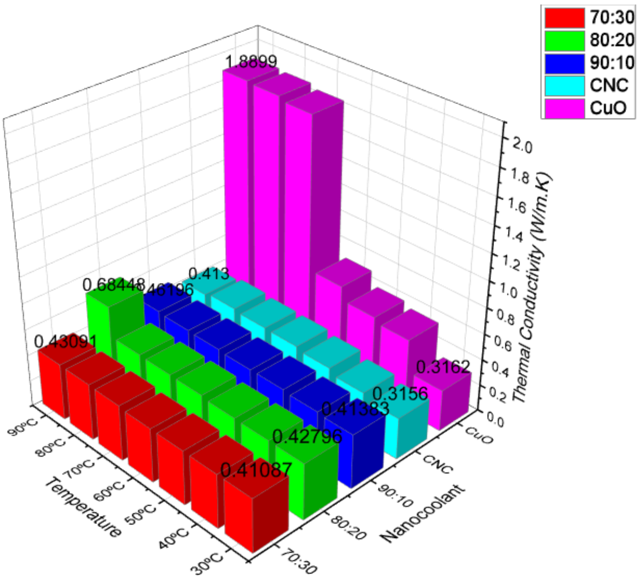

Fig. 7. Thermal conductivity

3.7 Specific Heat Capacity

The effect of temperatures on specific heat capacity for single nanocoolant and hybrid nanocoolant of studied nanofluid suspension is showed as in Figure 8. It is observed that specific heat decreased with increased of temperature. As temperature increased the specific heat capacity decrease [15]. The decreased trend are constant for each sample. It is found out that nanocoolant specific heat capacity decreases with the increase of particle volume concentrations. This can be attributed to the addition of the nanoparticles with lower specific heats, which is equivalent to the decrease in the proportion of the fluid of a higher specific heat. The hybrid nanocoolant of ratio 80:20 (CNC:CuO) showed the highest value of specific heat of capacity compared to another specimen. For single nanocoolant CuO exhibit the highest value of specific heat capacity. Adding CNC nanoparticles into the hybrid nanocoolant causes the specific heat capacity to reduce and at the ratio of 90:10

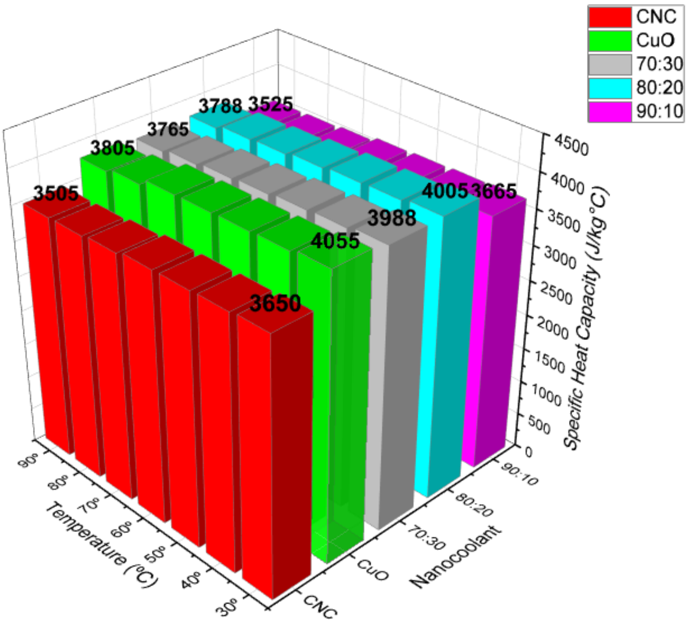

Fig. 8. Specific heat capacity

As the volume concentration of CuO in the hybrid nanocoolants increased results in better specific heat capacity than single CNC nanocoolant and its hybrid nanocoolant of 90:10. This is due to the increased of mass fraction of CuO which exhibit highest specific heat capacity.

4. Conclusions

In this paper, an experimental study on characterization, stability and viscosity analysis of CuO CNC dispersed in base fluid of EG have been successfully carried out. Morphology of the CNC and CuO nanoparticles was investigated with FESEM image, and the particle size has an average diameter of 57.84 nm. Stability validation by sedimentation observation after 8 weeks of preparation showed that all samples dispersed in EG are stable. In this research, the UV–vis method was used to identify the stability of nano lubricant via absorbance of light. Throughout the duration of four weeks, all single and hybrid nanocoolant are found to be stable with the peak wavelength range from 282 to 278 nm. It is interesting to observe that for all nanocoolants tested had lower kinematic viscosity and viscosity index compared to base fluid. Thermal conductivity and specific heat capacity of single nanocoolant are highest for CuO (1.899 W/m.K) and for hybrid nanocoolant solution of CNC:CuO at 80:20 ratio (0.68448 W/m.K) respectively. Finally, upon the obtained results, it can be concluded that single CuO nanocoolant and hybrid nanocoolant of CNC:CuO at 80:20 ratio are the most suitable concentration for improving properties of nanocoolant.

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