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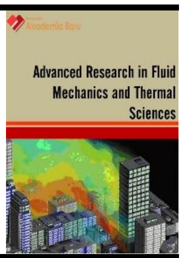

Enhancement of Tribological Behaviour and Thermal Properties of Hybrid Nanocellulose/Copper (II) Oxide Nanolubricant

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ABSTRACT

Many researchers tried to improve the tribological and thermal properties of the lubricating oil. The main advantages of using nanolubricants is they are relatively insensitive to temperature and that tribochemical reactions are limited, compared to the traditional additives. For this research, an attempt is made to enhance the tribological behaviour and thermal properties of lubricant (thermal conductivity and specific heat capacity) by adding hybrid cellulose nanocrystal/ copper (II) oxide (CNC-CuO) into the engine oil (SAE 40). CNC-CuO nanoparticle with an average size 80nm was dispersed into the SAE 40 at 0.1%, 0.5% and 0.9%wt concentration. Magnetic stirrer and ultrasonic bath were used to dispersed the nanoparticle in the SAE 40. Friction force and wear rate were measured using a tribometer based on ASTM G181. The results show that frictional force when using the CNC-CuO nanolubricant at 0.1%was reduced by 54% and 22% comparing with the base oil respectively. The wear rate is also reduced when using the nanolubricants. Thermal Conductivity and specific heat capacity are also measured for the nanolubricants. The results showed that the thermal conductivity was increased about 4.2% while specific heat capacity was increase 2.1% when using CNC-CuO nanolubricant respectively. The results indicate that the hybrid CNC-CuO nanoparticles improve the tribological and thermal properties of the lubricant oil.

1. Introduction

The major function of a lubricant is to protect two or more moving surfaces against friction and wear. Currently, developing nanolubricant as an alternative for current lubricant in the market has captured most of the researcher and academician's attention because it is proven that

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nanolubricants can reduce wear via "ball bearing" effect. Furthermore, using nanolubricant can improve engine efficiency in an internal combustion engine. All of these reasons can prove that using nanolubricant as an alternative lubricant can elongate the deterioration time for the engine component [1-3]. The performance of nanolubricants is directly associated with the formulations, preparation and the nanoparticle characterization. Over several decades, researchers have developed several additives to diminish all of the tribological aspects challenges such as friction and wear (abrasion, adhesion, corrosion, and oxidation) on lubricant base stock. Furthermore, many attempts conducted to investigate the thermal behavior of the lubricant oil, their chemical composition and physical properties.

CNCs have drawn industry and academic community attention because of their interesting characteristics such as low cost, extraction from renewable sources, low toxicity, high mechanical properties. The high thermal conductivity nanofluid have the ability of acting as a thermal transporter by carrying most of the heat produced and thus prolong the tool failure and helps to produce fine surface finish on the workpiece for heat transfer sector [4].

Thermal properties like thermal conductivity and specific heat capacity are the primary key parameters to study the nanolubricants properties. Material, size and the quantity of surfactant as a dispersant are all affected the thermal conductivity and specific heat capacity of nanolubricant. Despite the engine oil function serve as a lubricant to alleviate wear but it also acts as a cooling agent for the system [5]. The two properties, thermal conductivity and specific heat capacity are crucial properties for heat transfer analysis. Higher specific heat capacity leads to a lower temperature increment as per amount of heat energy absorption. For example, uncooled low heat rejection (LHR) for diesel engines are not contain radiator and coolant thus only engine oil can reduce the amount of heat energy absorption from the engine. For that reason, the heat transfer properties of the lubricant for LHR diesel engines important to measure the heat transfer capability of lubricants [6]. However, even though heat capacity is the crucial properties for thermal properties studies, research study for the specific heat capacity of lubricant are still inadequately. The aberration among the publishes values are up to 18% as the literature data uncertainty is very high [7-8]. This paper discussed about the effect tribological factor of nanolubricant (friction and wear) at different concentration together with the thermal properties of nanolubricant (thermal conductivity and specific heat capacity.

2. Methodology

2.1 Nanolubricants Preparation

Combination of Cellulose Nanocrystal (CNC) and Copper Oxide (CuO) has been considered in this research since they both exhibit better thermal conductivities, large surface area and chemically stable [9]. CNC used in this research is extracted from the acetate grade dissolving pulp that is the Western Hemlock plant is to be in the slightly off-white gel form that contain water. CNC was procured from Blue Goose Biorefineries Inc with 7.4% weight/water weight suspension in water. Two-step method suggested by Yu and Xie [10] is used in the preparation of three diverse nano lubricant samples with volume concentrations from 0.1% to 0.9%. There are two processes in this method, which are (i) synthesis of the nanoparticles in the powder form (ii) dispersion of the nanoparticles into the base fluids to form a stable and homogeneous solution. Nanocellulose neither melts at high temperature nor dissolves in a universal aqueous solvent because of their hydrophilic nature is a significant challenge to properly dry CNC from an aqueous suspension [11]. Amongst several methods of drying process for nanocellulose suspensions, spray drying was proposed as a technically appropriate process manufacturing. For the preparation of CNC in a powder form, the suspensions were spray dried with a mini blower [12]. The moisture in these suspensions is quickly evaporated upon direct contact with the hot air flow through the orifice of the nozzle on the spray dryer resulting in drying–out and stable CNCs flake form. After that, the flakes were pulverized into powder form. The CNC then was dry mixing together with CuO. Nanolubricant samples with the solid volume fraction of 0.1%, 0.5% and 0.9% were prepared by adding CNC and CuO in SAE40 by using a magnetic stirrer and ultrasonic bath. Nanoparticles in suspension tend to agglomerate due to their high surface area and surface activity.

2.2 Tribological Testing

The test was conducted using custom-made friction and wear tester which also replicates regarding contact geometry relevant to the tribological phenomena occurring during the piston ring-cylinder liner contact in an engine. The schematic diagram of the friction pairs is shown in Figure 1.

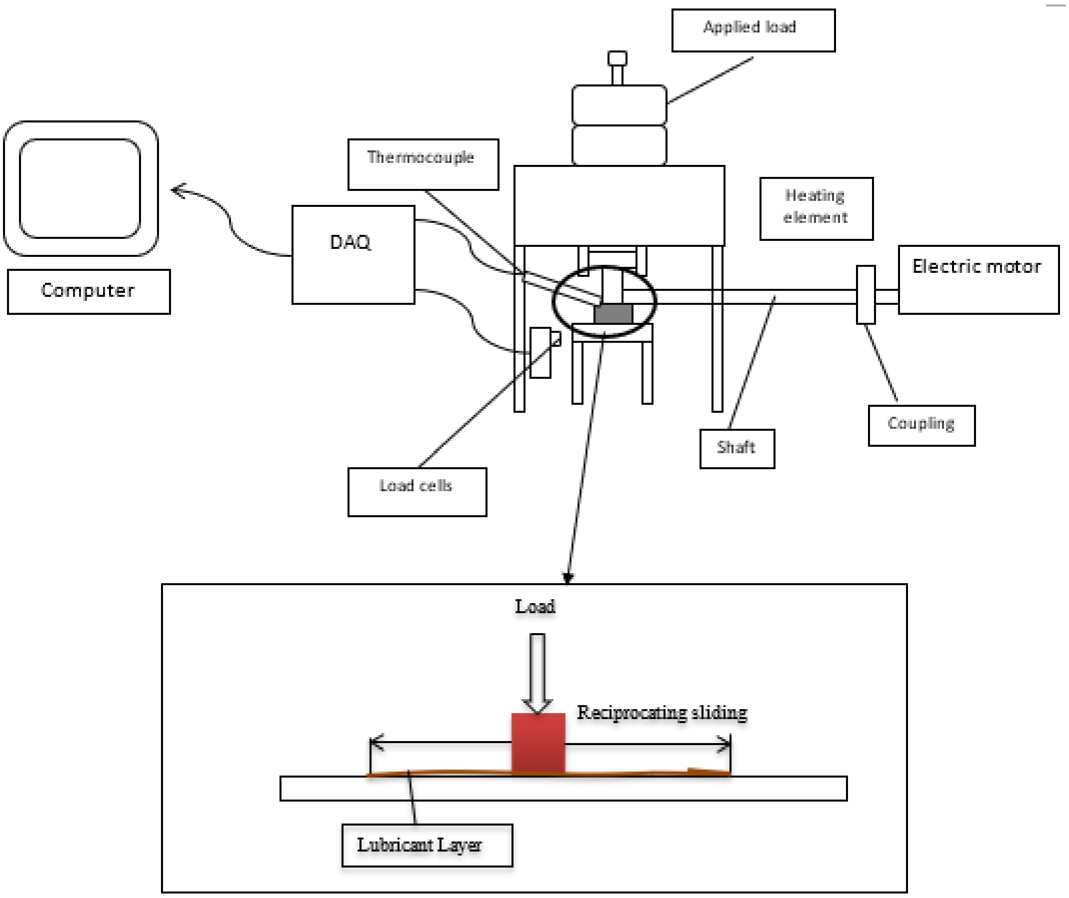

Fig. 1. Tribology testing setup

The wear test conducted under lubricated sliding condition. Wear test involve making linear reciprocates movements similar to a cylinder-piston ring pair operating under real conditions. Wear morphology that caused at the surface of specimen and during the linear reciprocating sliding motion against the outer surface of aluminium 6061 for 30 minutes at boundary lubrication regime (low speed and high load) in the presence of SAE 40 and different concentration of nanoparticle (0.1, 0.3 and 0.5) added in SAE 40 was also reported. The temperature was at 85˚C which is the regime temperature of the internal combustion engine and the operating time was 30 minutes per specimen. The coefficient of friction was recorded automatically using NI-DAQ via the ratio of friction force to normal load. The wear loss of the friction pairs was calculated by the weight of the samples before and after sliding, to an accuracy of 0.1 mg. Each sliding test was repeated three times to obtain a standard deviation.

2.3 Thermal Conductivity and Specific Heat Capacity Measurement

A KD2 Pro thermal property analyzer from Decagon Devices Inc., USA was used to measure thermal conductivity for nanofluid. Most researchers used KD2 Pro to measure thermal conductivity [13-16]. The device works based on the transient hot-wire method and it has been calibrated by glycerin. The measured thermal conductivity value is supplied by the manufacturer which was 0.286 W/m K with an accuracy of ±0.35%. To keep a constant temperature of the samples uniformly, hot water bath temperature was used. The measurement of thermal conductivity was repeated five times and the average value of thermal conductivity from five sets of reading was considered. To minimize the error during the measurement of free convection, a minimum of 15-minute interval time was considered before the next reading for different concentrations and temperatures. The error can happen due to the variation along the sensor that had direct contact with the nanolubricant sample. Furthermore, the probe of the KD2 Pro device had to be kept vertically straight into the nanolubricant sample during the thermal conductivity measurement to minimize the errors resulted from the free convection,

In order to determine the specific heat capacity of nanolubricant, a differential scanning calorimeter (DSC), model DSC1000-/C from Linseis Messgeräte GmbH, Selb, Germany was employed. DSC is a thermal analysis technique that looks at how a material's heat capacity (Cp) is changed over temperature. Nanolubricant is heated or cooled and the changes in its heat capacity are tracked during changes in the heat flow. The samples were placed in aluminum crucibles and heated from 30°C up to 90°C at a heating rate of 5°C min^{-1} under a dynamic atmosphere of nitrogen. The nanolubricant samples were heated from the room temperature at the heating rate of 5°C- 1 up to 30°C.

3. Results
3.1 Coefficient of Friction

Figure 2 present the coefficient of friction (COF) of samples lubricated by base oil (SAE 40) and nano lubricant at 0.1, 0.5 and 0.9 concentration at low speed and high load. At low speed and high load, usually COF is the highest and according to Wang *et al.,* [17] at this state the index lubrication value is known as lambda value (λ) less than 1 which indicate the boundary lubrication regime at the Stribeck Curve. As shown in Figure 2, SAE 40 clearly shows the highest friction compared to a lubricant that contents CNC-CuO nanoparticle. At the initial stage, 0.1, 0.5 and 0.9 show almost the same COF while SAE 40 shows the highest friction. At minutes 4 for 0.1 concentration, COF show a sudden increase of COF that almost the same as in SAE 40. This might be due to the slight vibration from the test rig base. From the figure curve as well, the graph indicates the same pattern, at minutes 2 until minutes 8, COF starts to increase and slowly become constant at from minutes 8 to 12 and start to drop at minutes 15 upwards. When the tribological tests are conducted at low speed and high load, the high friction makes temperature rise and the temperature of the friction region was taken during the experiment and it is approximately 40 °C, which results in a decrease in the viscosities of the SAE 40 and CNC-CuO nanolubricants. The average COF result as shown in Figure 2 also shows that SAE 40 is the highest, while at different concentration of CNC-CuO did not shows many differences.

Figure 3 shows the weight loss of after the tribology testing. SAE 40 shows the highest COF while there is a drastic change when added with 0.1 CNC-CuO nanoparticle. In contrast, by adding different concentration, the weight loss value did show much different. This can be concluded that the concentration parameter did not affect the coefficient of friction and weight loss result.

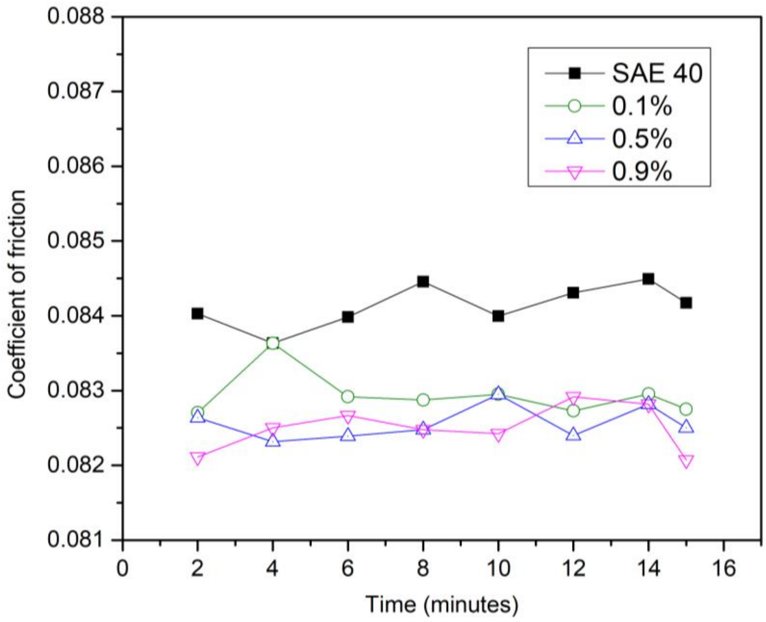

Fig. 2. Coefficient of friction versus time for CNC-CuO

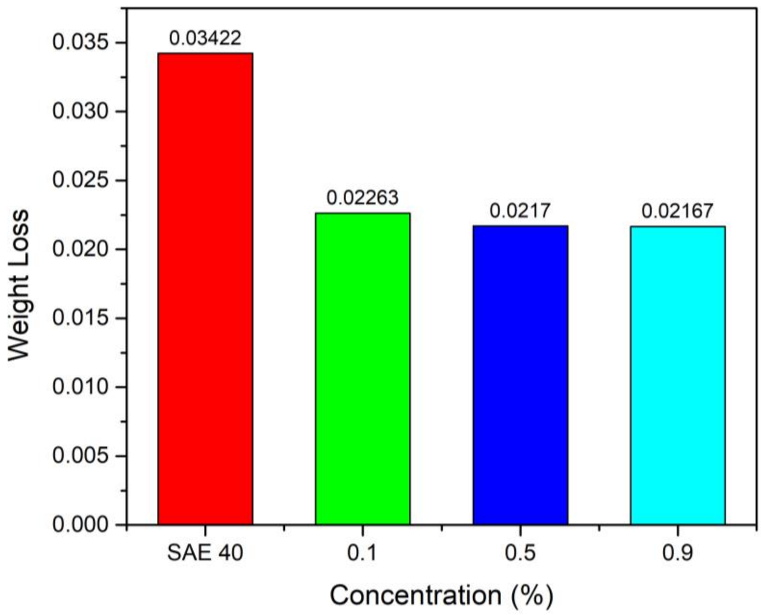

Fig. 3. Wear loss after tribology testing

3.2 Thermal Conductivity and Specific Heat Capacity Evaluation

As shown in Figure 4, the thermal conductivity value shows the inconsistent result as the temperature increases. At 0.5, the value of thermal conductivity at 50°C is increased first then it started to decrease gradually until 90°C. As for 0.9wt% the thermal conductivity value increases slightly until 90°C. This result might be due to the hybrid between organic nanoparticle (CNC) and inorganic nanoparticle (CuO) as the thermal conductivity value shows the consistent increasing pattern for CNC nanolubricant as shown in Figure 5 while Mansor *et al.,* [18] shows the consistent decreasing pattern for CuO nanolubricant. Figure 6 shows the variation of experimental result for average specific heat capacity versus temperature of base fluid (SAE 40) with CNC-CuO nanolubricant at different concentration. Oil with a higher specific heat capacity value indicates lower temperature increment for an amount the absorption of heat energy thus the higher value of Cp exhibit the better lubricant in terms of heat transfer performance [5]. In this circumstance, the specific heat capacity of the hydrodynamic lubricants is an important characteristic to improve the load carrying limit [19]. The temperatures in the bearing gaps are smaller when the point where the specific heat capacity of engine oil is high, thus the heat capacity is high at the same operating condition [20].

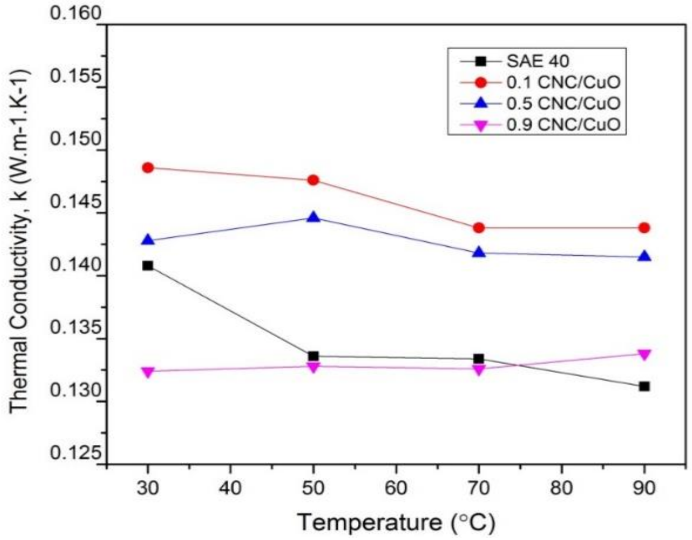

Fig. 4. Thermal conductivity at increasing temperature

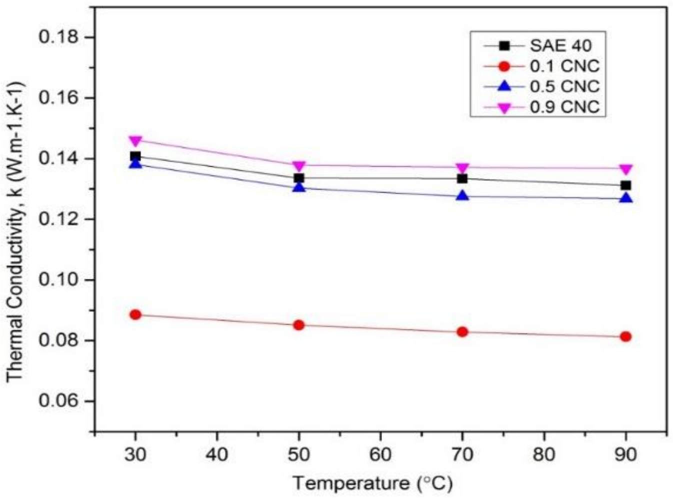

Fig. 5. Thermal conductivity of CNC at different concentration

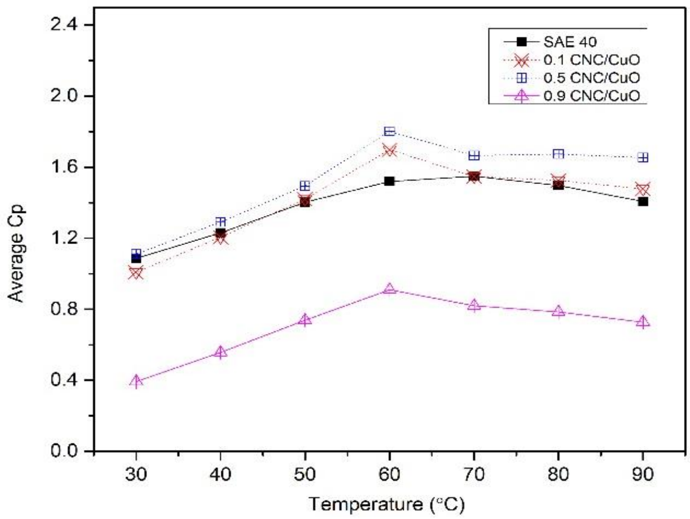

Fig. 6. Specific heat capacity

4. Conclusions

The results show that frictional force when using the CNC-CuO nanolubricant at 0.1%was reduced by 54% and 22% comparing with the base oil respectively. The wear rate is also reduced when using the nanolubricants. Thermal properties results showed that the thermal conductivity was increased about 4.2% while specific heat capacity was increase 2.1% when using CNC-CuO nanolubricant respectively. The results indicate that the hybrid CNC-CuO nanoparticles improve the tribological and thermal properties of the lubricant oil.

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