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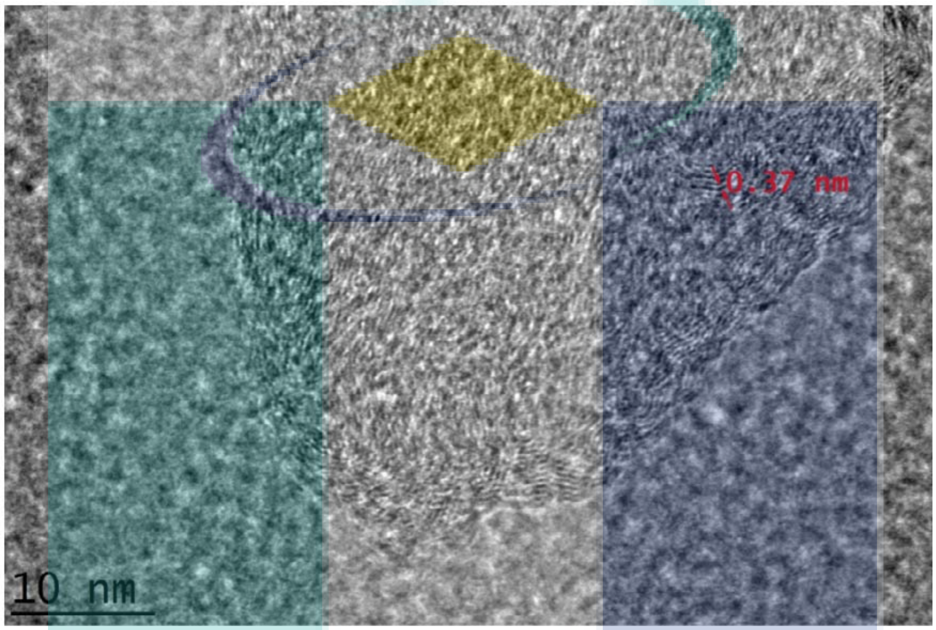

NANO-STRUCTURED DIAMOND & SILICA COATINGS ON CO-CR-MO SUBSTRATE FOR BIOMEDICAL APPLICATION

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ABSTRACT (120 words)

Nanofluids are the suspensions of solid nanoparticles in the liquids as base fluids. They have been the latest engineering material among the investigators as they exhibit promising enhanced thermal properties and many other possible developments. In this project, experimental studies are conducted in the effort to measure the thermal conductivity and viscosity of nanocellulose particles dispersed in ethylene glycol and water (EG-water) mixture with the weight concentration of 40/60% volume ratio. The experimental measurements are performed at various volume concentrations up to 1.3% and temperature ranging from 30 C to 70 C. The result demonstrates that as the measured temperature increases, thermal conductivities increases as well. The nanofluid has maximum thermal conductivity enhancement of 9.05% were found at 1.3% volume concentration when it is compared to the base fluid at 30 C. As expected, viscosity values increase when the volume fraction increases. However, viscosities of the nanofluids are found to be decreasing when the temperature increases. At 1.3% volume concentration and 30 C, nanofluid viscosity recorded the highest value, about 4.16 times of the base fluid. Finally, a new correlation with acceptable accuracy was proposed to predict the thermal conductivity and viscosity of nanofluids by using the obtained experimental data.

1. INTRODUCTION

Heat transfer enhancement has become a vital challenge in the field of thermal engineering. Due to their vast application in the thermal energy transfer, the researchers have found a latest method of enhancing the heat transfer performance. This can be done by the dispersion of the nano-sized particles into the base liquids which would produce a higher heat transfer coefficient when it is compared to the conventional liquids [1]. It is termed as nanofluid, which is basically prepared by suspending the nanometer sized particles in a base fluid [2]. The development of the new thermal fluids with superior heat transfer performance is driven by miniaturization of heat transfer devices in today's globalization world [3,4]. The determination of the thermophysical properties such as thermal conductivity and viscosity of nanofluids experimentally has been initiated by Masuda et al. [5]. The most common nanoparticles used in the literature are Al_2O_3, TiO_2 and CuO, and the studies resulting with the increment of the volume fraction, the effective thermal conductivity increases as well [6]. Many researchers have determined the thermal conductivity enhancement with different particles and base fluids in the similar way. Thermal conductivity of four oxide nanofluids (Al_2O_3 in water, Al_2O_3 in ethylene glycol, CuO in water, and CuO in ethylene glycol) that are measured by Lee et al. [7] reported that glycol–CuO nanofluid has enhancement of more than 20%. A new breakthrough has been reported by Eastman et al. [8] with the enhancement of thermal conductivity in ethylene glycol–Cu nanofluids up to 40%. In other research of different base fluids, Xie et al. [9] has found that the thermal conductivity of the base fluid increases with the decrease of thermal conductivity ratio. Al_2O_3 and SiO_2 nanoparticles at 0.5% volume concentration were dispersed in methanol and Pang et al. [10] observed 10.74% and 14.29% effective enhancement of thermal conductivity respectively. Other than that, combination of volume concentration and size of nanoparticle also contributed in the enhancement of the thermal conductivity. The thermal conductivity of Al_2O_3/EG for volume concentrations of 0.3–1.5% have been studied by Sundar et al. [11] and have come to a conclusion that there is significant increase in the thermal conductivity of the nanofluid with the increment of the volume fraction. In other research, Choi [12] has obtained a significant enhancement of effective thermal conductivity by suspending nanoparticles with the size particles of the diameter from 1 to 100 nm in a base fluid

2. RESEARCH METHODOLOGY

Nanofiber of Cellulose Nanocrystal (CNC), used in this research is extracted from Western Hemlock plant. CNC is supplied by BlueGoose Biorefineries Inc with 8.0% weight/weight suspension. Since the supplied CNC in weight fraction, it need to be converted to volume fraction. Varying nanofluid volume concentration is prepared by diluting it with base fluid. Two-step method is carried out to prepare nanofluid by dispersing bought CNC in ethylene glycol-distilled water mixture. Then, the nanofluid is stirred by using magnetic stirrer for 30 minutes for well mixing. Later, the prepared solution is left in ultrasonic bath. Thermal conductivity is measured by using KD2 Pro thermal analyzer device (Decagon Devices). It uses transient hot wire method which meets the ASTM D5334 and IEEE 442-1981 standards. As shown in Fig. 1, water bath (model name - Memmert) is used to provide uniform heating during thermal conductivity measurement. Before measurements were taken, the thermal analyser is validated with glycerine provided by the manufacturer. Minimum of 20 consistent results is collected for each parameter to ensure data accuracy and micro convection effect at high temperatures can be avoided. As for equipment validation, thermal conductivity is measured for ethylene glycol-deionized water mix-ture at 50:50 volume ratio and compared with ASHRAE standard data. The maximum deviation among the basefluid and ASH-RAE data is 1.4% which shows the reliability of the equipment in providing data.

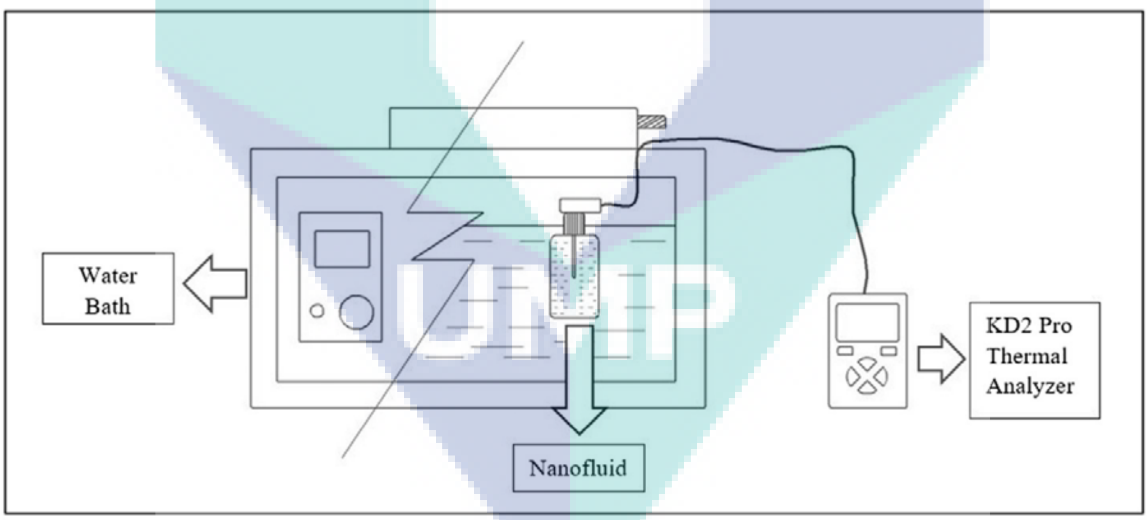


Figure 1: Water bath

3. LITERATURE REVIEW

Hence, researches on nanofluid using various nanomaterial has done globally. According to investigation, most literature study reported on TiO2 and Al2O3 nanoparticle dispersion in ethylene glycol-deionized water mixture [6]. In recent years, dispersion of Multi Walled Carbon Nanotube (MWCNT) is getting researchers attention and the results is promising compared to nanoparticle based nanofluid [7]. Conversely, there is no literature reporting on using Cellulose Nanocrystal (CNC) as a dispersant nanomaterial with any basefluid. Naturally, CNC is non-toxic, biodegradable, has large surface area and high strength [8]. These criteria provoke author to study thermophysical property; especially thermal conductivity and dynamic viscosity enhancement by using CNC as dispersed material in ethylene glycol-deionized water mixture at two different base ratios. Ironically, dispersion of small percentage of nanomaterial ranged from 1 to 100 nm into any base fluid able to enhance thermal conductivity drastically [9]. At certain stage, researcher felt that effective thermal conductivity and relative viscosity is suitable to be benchmarked for comparison among each other. This is because not all experiments are carried out by using same type of equipment and procedures. By calculating ratio among nanofluid with base fluid, it provides much accurate and reliable data for analyzing purposes in future [10]. For instance, Chen et al. [11] dispersed SiC nanoparticle into saline water and obtained 1.12 effective thermal conductivity ratio at 1.0% volume concentration. Meanwhile, Agarwal et al. [12] dispersed Al2O3 in ethylene glycol at volume concentration of 1.0% and temperature of 50 C acquire 1.13 of effective thermal conductivity. In another experiment, Agarwal et al. [13] used CuO nanoparticle in ethylene glycol and obtained effective thermal conductivity of 1.125 at 1.0% volume concentration and 50 C. On the other side, Nguyen et al. [14] experiment results produces 1.12 of relative viscosity when dispersed Al2O3 with 1.0% of volume concentration into water. Khedkar et al. [15] reported relative viscosity of 2.75 at volume concentration of 0.05% using TiO2 nanoparticle with ethylene glycol as base fluid. Lately, theoretical study on effective thermal conductivity and relative viscosity by empirical mathematical model development by using various soft computing method such as fractional factorial design approach [16], artificial neural network [17,18], semiempirical model development [19] and Response Surface Methodology (RSM) [20] is getting researchers attention.

4. FINDINGS

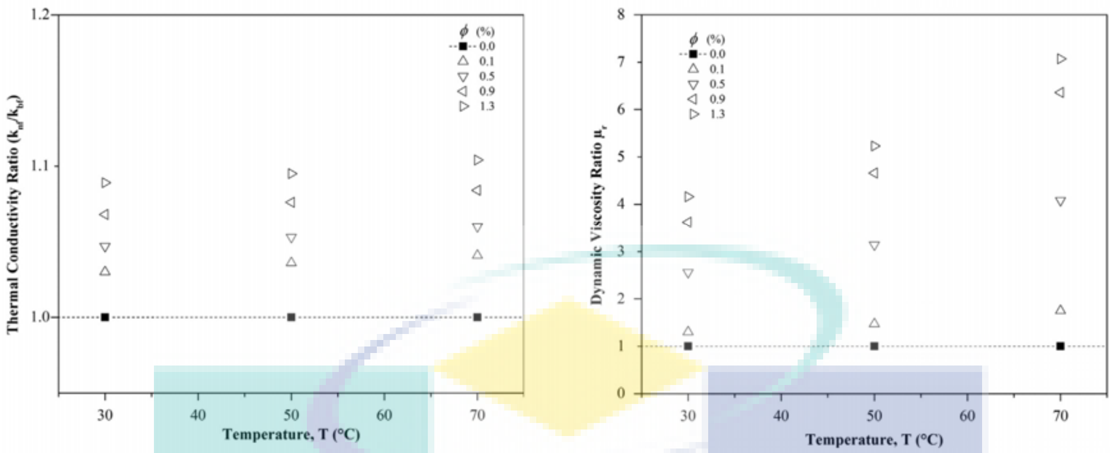
Experimental studies were conducted in the effort to measure the thermal conductivity and viscosity of nanocellulose particles dispersed in ethylene glycol and water (EG-water) mixture with the weight concentration of 40:60% ratio. Comparison of the measured thermal conductivity and viscosity for the EG-water mixture are done with the reference data, ASHRAE Handbook [20]. Overall, the average difference does not exceed 3.92% for the thermal conductivity and 9.28% for the viscosity and were in good agreement.

3.1. Thermal conductivity of nanofluids

The thermal conductivity properties of the nanofluid is determined by using the KD2 Pro thermal property analyser at 30 C, 50 C and 70 C. The data points correspond to the average of 5 readings. The trend observed is that the thermal conductivity values increases with increasing mixture temperature and it also increases with the increasing volume of the nanofluid. Fig. 2 shows the experimental thermal conductivity ratio values when it is compared with the 40:60 volume concentration of EG-water base fluid. The highest thermal conductivity value measured was 0.479 W/m K at the highest volume fraction of the nanofluid that is 1.3% and at the highest mixture temperature, 70 C. The thermal conductivity enhancement ratio is 1.104 times when the nanofluid is compared with the base fluid. The lowest thermal conductivity measured was 0.431 W/m K at the lowest volume fraction that is 0.1% and at the lowest mixture temperature, 30 C. The thermal conductivity enhancement ratio recorded is just 1.03 times when the nanofluid is compared with the base fluid. As the volume concentrations of the nanofluid increases, the thermal conductivity measured is also increases and the pattern agrees well in certain other studies. This phenomenon has been well explained by Fani et al. [21] where the thermal enhancement is being assisted by Brownian diffusivity due to the collision between the particles upon the increment of the volume concentration. The similar influence has been discussed and found by Vajjha et al. [30]. Beck et al. [22] has found the similar trend when they investigated the thermal conductivity for Al2O3 dispersed in water and ethylene glycol. According to Dawood, et al. [23], thermal conductivity enhancement is highly influenced by temperature and volume concentration. Besides that, physical of nanomaterial such as size and shape affect the thermal conductivity enhancement [24].

3.2. Viscosity of nanofluids

The viscosity properties of the nanofluid is determined by using the Brookfield LVDV-III Ultra Rheometer analyser at 30 C, 50 C and 70 C. As expected, the viscosity value of the nanofluid increases as the volume fraction increases. However, when the temperature increases, the nanofluid viscosity decreases exponentially. This reflects that the particle loading is more reasonable in the practical applications, as at the higher temperatures, the viscosities of the nanofluids is decreased. Fig. 3 shows the variations of the nanofluids viscosity ratio with temperature at different concentrations when it is compared with the 40:60 volume concentration of EG-water base fluid. The highest viscosity value measured was 0.00986 kg/m s at 1.3% volume concentration and 30 C with the viscosity enhancement ratio which is 4.16 times when the nanofluid is compared with the base fluid. For the lowest viscosity value, 0.00185 kg/m s was measured at 0.1% volume fraction and 70 C with the viscosity enhancement ratio which is 1.75 times when the nanofluid is compared with the base fluid. Based on Fig. 3, it is observed that the volume concentrations and temperatures are manipulating the trend of the data. It is also noted that the viscosity of nanofluids are higher than the base fluid. The increment of concentration has caused the viscosity to increase as well. The trend is seems to be parallel to the fact by Kole et al. [25], the viscosity increases when the volume concentration of nanoparticles which is suspended in the base fluid increases as well. Fedele et al. [26] and Nguyen et al. [27] have found the similar effect of the volume concentrations to the viscosity and agree nanofluid behaviour is always Newtonian, based on their find outs. On the other hand, the viscosity ratio of the nanofluid increases with increasing temperature. The same trend has been obtained by Sundar et al. [28,29] which is due to molecular viewpoint, subsequently forms the viscosity pattern.



ACHIEVEMENT

i) Name of articles/ manuscripts/ books published

- Comprehensive review of principle factors for thermal conductivity and dynamic viscosity enhancement in thermal transport applications: An analytical tool approach, International Communications in Heat and Mass Transfer 98 (2018) 13–21

- Thermophysical properties measurement of nano cellulose in ethylene glycol/water, Applied Thermal Engineering 123 (2017) 1158–1165

- Investigation on effective thermal conductivity and relative viscosity of cellulose nanocrystal as a nanofluidic thermal transport through a combined experimental – Statistical approach by using Response Surface Methodology, Applied Thermal Engineering 122 (2017) 473–483

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ii) Human Capital Development

- Kallirasan Ramachandran – Graduated 2016

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