INVESTIGATION INTO THERMAL CONDUCTIVITY OF PALM KERNEL FIBRE NANOFLUIDS WITH MIXTURE OF ETHYLENE GLYCOL/WATER AS BASE FLUID

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ABSTRACT

Nanofluids have been found to possess enhanced thermo-physical properties such as thermal conductivity, heat capacity, as well as convective heat transfer coefficients compared to conventional heat transfer fluids like water, ethylene glycol and oil. The high level of hazards involved in the use of metallic nanoparticle in nanofluid research is a source of worry since there are reported literatures showing damaging effects of metal oxides to human cells. In this paper, a readily available bio–based Palm kernel nano-fibres (nanoparticle) were produced by first washing the raw fibre material with caustic soda (NaOH) to remove the residue palm oil and sundried for 10 days. The dried palm kernel fibre was ball milled for 24 hours and the resulting nanoscale fibre particles were dispersed into mixtures of water and ethylene glycol (50:50) as base fluid to form palm kernel fibre nanofluid with volume concentrations of 0.1, 0.2, 0.3, 0.4 and 0.5 %. Images of Scanning and transmission electron microscopy revealed a nearly spherical particle shape and a particle size of 100 nm. Thermal conductivity experiments were conducted in temperature range of 10 to 60 °C. Results showed that thermal conductivity of the nanofluid increased with increase in volume concentrations and temperature. An enhancement in thermal conductivity of 16.1 % was recorded for volume concentration of 0.5 %. The Maxwell, Hamilton and Crosser and Wasp models over predicted the thermal conductivity of palm kernel fibre nanofluid.

Key words: *ethylene glycol, water, palm kernel fibre, volume fraction, thermal conductivity, nanofluids.*

INTRODUCTION

Single phase heat transfer fluids such as water, engine oil, transformer oil, and ethylene glycol are commonly used in many industrial sectors including power generation, heating and cooling processes, transportation, chemical processes, etc. However, these fluids cannot meet the performance requirements of mechanical devices such as heat exchangers and condensers because of their low thermal conductivity. The properties of these fluids may be enhanced by suspending small or nano-sized metallic, non-metallic or polymeric particles to form colloidal solutions. Choi, [1] dispersed solid nano-sized particles in fluids and then identified as nanofluids. The unique characteristics of nanofluids have made them an excellent candidate for the development of energy efficient cooling systems that can be employed in heat exchangers, automobile coolants, electronics etc. [2].

Thermal conductivity of liquids lie between that of insulators and non-metallic solids [3]. It is possible to tailor the thermos-physical properties like thermal conductivity and viscosity through use of nanoparticle dispersions. Nanofluid, colloidal dispersion of solid nanoparticles in a liquid belongs to a new class of coolants on which extensive research has been carried out over the past two decades [1].

So, it can be understood that nanofluid consists of nanoparticles and a base fluid. Stabilization of the dilution is a relevant aspect to get trustable results, sometimes additives such as dispersants are added to avoid sedimentation of particles. Moreover, different facets of samples can be analyzed in order to discover the reasons which lead to having great unexpected results for common thermo-physical properties. The main parameters that affect nanofluid behaviors are: particle size, concentration and shape, nanoparticle material, base fluid nature, sonication time of sample, method manufacturer employed or pH-value of dilution [4].

The properties of ethylene glycol based nanofluids have been widely studied [5, 6, 7] due to their use as coolants in automobiles. Sand–ethylene glycol–water dispersions prepared using stirred bead milling and ultrasonication showed thermal conductivity enhancement of above 20% at a particle concentration of 1.8 vol.% [8].

Oil Palm (*Elaeis Guineensis*) is dominantly found in the rainforest region of West Africa. The main belt runs through the Southern Latitude of Cameroon, Cote'voire, Ghana, Liberia, Nigeria etc. Because of its economic importance a high-yielding source of edible and technical oils, the oil palm is grown as a plantation crop in most countries with high rainfall in tropical climates within 10^{o} north of the equator [9]. The palm bears its fruits in bunch ranging from 10 to 40kg. The palm fruit shown in Figure 1 consist of an outer skin (the exorcarp), a pulp (mesocarp) containing the palm oil in a fibrous matrix, central nut consisting of a shell endocarp, and the kernel, which also contains oil [10].

The literature on toxicity of nanoparticles reveals a trend of toxicity among transition metal oxides like TiO_2, CuO and ZnO in human cell lines [11–15]. An investigation on the toxicity of oxides of Cr, Mn, Fe, Co, Ni, Cu, and Zn, each of which is widely used in industry showed that toxicity increased with atomic number with Fe_2O_3 having the lowest toxicity than expected and CoO higher toxicity than expected. Fahmy and Cormier also identified a similar relationship of CuO and Fe_2O_3 toxicity in airway epithelial cells (HEp-2) [16]

Studies have confirmed oxidation-induced DNA fragmentation following exposure to metal oxide nanoparticles [12,15,16]. In response to DNA insult, cells attempt to repair the damaged DNA. Repair failure may lead to cell death. CuO nanoparticles exert a strong effect regarding cytotoxicity, DNA damage and Reactive Oxygen Specie (ROS) generation which can lead to significant damage to human cell structures. [17].

The need to explore the use of bio based materials like palm kernel fibre nanoparticles for nanofluid research became necessary when reports on the elemental composition of palm kernel fibre materials shown in table1 indicating traces of metallic materials like Cu, Zn and Fe which are critical composition of base materials for nanofluid source when their oxides are used for thermal conductivity enhancement [18].

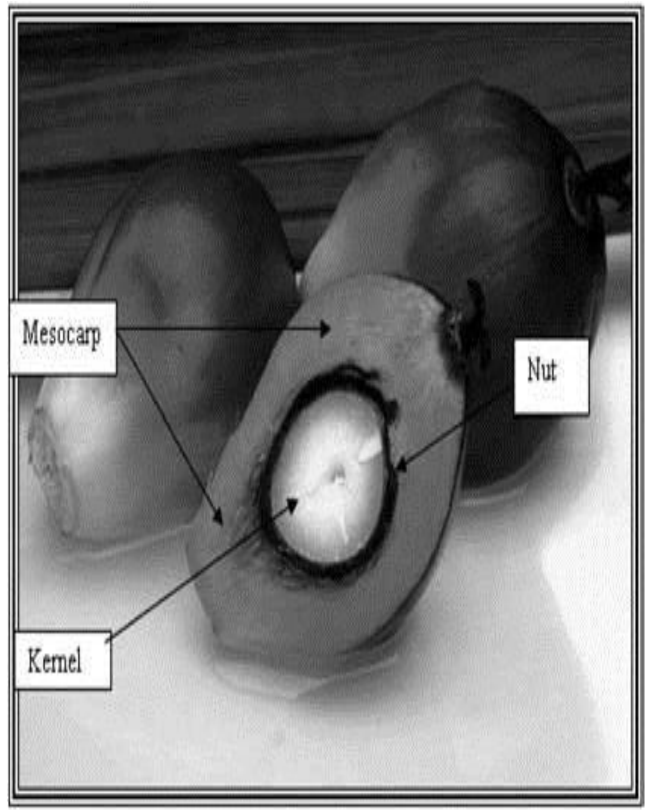

Figure 1. Cross-section of an Oil Palm Fruit [10]

Table 1. Elemental Composition of Palm Kernel and Oil Palm Fibre [18]

Heavy metals (mg/kg)	Palm kernel Shell	Oil Palm Fibre
Magnesium	50.96	57.69
Copper	4.54	3.34
Zinc	8.61	16.84
Potassium	118.7	579.1
Iron	34.51	45.89
Calcium	32.06	83.37
Nickel	NIL	NIL
Cadmium	NIL	NIL
Chromium	NIL	NIL
Lead	NIL	NIL

Vajjha and Das [19], first studied combination of water and ethylene glycol to produce nanofluid, they observed that suspending nanoparticles in the mixture of water and ethylene glycol increased thermal conductivity compared to base fluid. This increment is also found by Tadjarodi *et al,* [20] who conducted measurement for nanoparticles suspended in 60 % of ethylene glycol and 40 % of water by volume percentage.

Hence, this paper intended to measure thermal conductivity of palm kernel fibre nanofluid using mixture ratio solutions of water and ethylene glycol as base solution. The experiment was conducted using 100nm palm kernel fibre dispersed in 50:50 (water: ethylene glycol) mixture base solution. The temperature is varied between 10 to 60 ^{o}C using KD2 Pro Thermal Analyzer and controlled water bath.

MATERIALS/ EXPERIMENTATION

MATERIALS

Raw Palm Kernel fibre, Powdered Sodium Hydroxide (NaOH), Ethylene Glycol and Dionized water, KD2 PRO Thermal property analyser, RADWAG AS 220-R2 Sensitive weighing scale (10mg – 220g), ball mill, GAUTRACK POTCH Oven, GAUSTING GT225 Impact Grinder (ball miller)

PREPARATION AND CHARACTERISATION OF PALM KERNEL FIBRE NANOFLUID

Raw palm kernel fibre (about 100 g) was collected from areas where palm oil extraction takes place on an industrial scale. It was washed with about 10g powdered caustic soda (NaOH) to remove the residue palm oil from the fibre materials and the resulting product was rinsed thoroughly with water and sundried for ten days. This was then oven dried at temperatures of 50-60 ^{o}C to ensure that the residual moisture has been reasonably eliminated. The dried palm kernel fibre was fed into a ball mill and the ball mill was allowed to run continuously for 48hours. This reduced the fibre to nanoscale powder.

Using the two-step method, A pre-calculated weight of nanoparticles corresponding to a known volumetric fraction of the desired nanofluid samples was measured using highly Sensitive RADWAG AS 220-R2 digital weighing machine with maximum capacity of 220g, minimum capacity of 10mg and accuracy of 0.001g and the synthesized palm kernel fibre nanoparticles with measured density of 1.565 g/cm^3 were dispersed into mixture of di-ionized water and ethylene glycol (50:50) base fluid. The mixture was ultra-sonicated with a 24-kHz UP200S Hielscher ultrasonic processor for laboratory with S14 sonotrodes for one hour to obtain a homogenized dispersion of nanoparticles and the base fluid. Volume concentrations of 0.1, 0.2, 0.3, 0.4 and 0.5 % shown in Figure 2 were prepared.

Scanning Electron Microscopy (SEM) ZEISS GEMINI ULTRA PLUS 6360 image in Figure 3 shows shape and structural distribution of the nanoparticles.

Transmission electron microscopy (TEM) images in Figure 4 were obtained on a JEOL JEM–2100F microscope operated at 200 KV, to determine the particle size and morphology of the nanoparticles. The result shows that the palm kernel nanoparticle was nearly spherical with an average particle size of 100nm.

Figure 2. Image of Prepared Palm Kernel Fibre Nanofluid with Di-ionized water and Ethylene Glycol (50:50) as Base Fluid.

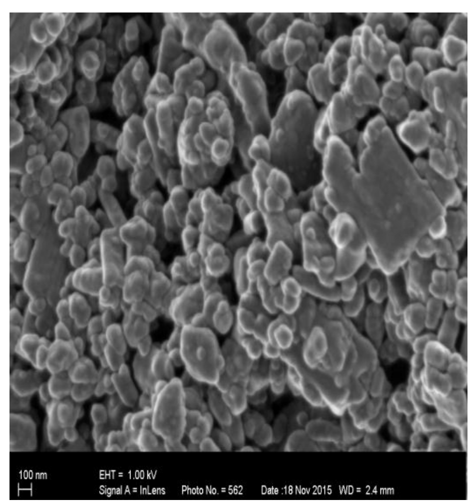

Figure 3. SEM Image of Palm kernel Fibre Nanoparticles

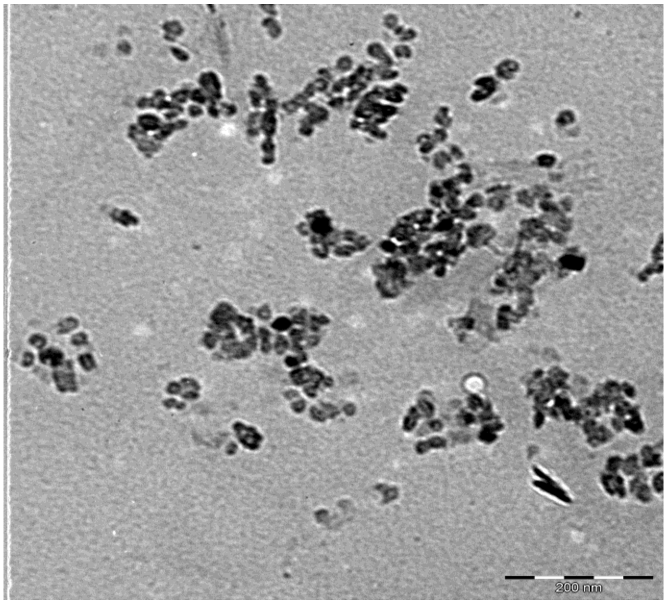

Figure 4. TEM Image of Palm Kernel Nanoparticles

THERMAL CONDUCTIVITY MEASUREMENT

KD2 Pro thermal property meter, was used to collect the thermal conductivity readings with $\pm$ 5% accuracy of measurement. This method is based

on applying a constant current to a platinum wire and measuring the time evolution of its electrical resistance due to temperature increase. It consists of a handheld microcontroller and sensor needle. The KD2's sensor needle contains both a heating element and a thermistor. The controller module contains a battery, a 16-bit microcontroller/AD converter, and power control circuitry. The sensor needle used was KS-1 which is made of stainless steel having a length of 60 mm and a diameter of 1.3 mm, and closely approximates the infinite line heat source which gives least disturbance to the sample during measurements.

15cm^3 of the sample was sealed in a thick cylindrical glass sample vial. The probe was then inserted vertically into the sample via a port in the lid of the vial. The sealed vial was then fully immersed in a temperature controlled water bath, model GRAND GD200 as seen in Figure 5, and allowed for one hour for thermal equilibrium to take place between the immersed sample and the surrounding water in the bath. Once the temperature of the set-up stabilizes at 10 ^{o}C (lowest limit for measurement of thermal conductivity), the thermal bath is switched off and the KD2 device is switched on and the reading at that temperature is taken. After the first reading, the thermal bath is switched on and temperature is increased for the next reading. Four readings were taken at each temperature and with a delay of at least 15 minutes between each other to ensure reproducibility.

The change in temperature and thermal conductivity were measured for base fluid and the volume concentrations of 0.1 % to 0.5 % at temperature range of 10 to 50 ^{o}C. The entire setup was well sealed and the thermal bath temperature was set at 10^{o}C and allowed for an hour for thermal equilibrium to take place before collecting readings.

Figure. 5 Setup for Thermal Conductivity

RESULTS AND DISCUSSION

The thermal conductivity of palm kernel fibre nanofluid with deionized water and ethylene glycol (50:50) as base fluid is shown in Figure 6. It can be seen that thermal conductivity of palm kernel fibre nanofluid increased with increase in temperature and volume concentration. Thermal conductivity values were recorded for volume concentrations of 0.1, 0.2, 0.3, 0.4 and 0.5 %, respectively. As the volume concentration increases, thermal conductivity also increases. Highest value was recorded for volume concentration of 0.5 % at 50 ^{o}C. A lowest enhancement in thermal conductivity of 2.7 % at 0.1 % volume concentration and maximum average enhancement of 16.1 % at 0.5 % for temperatures of 10 to 50 ^{o}C was recorded as shown in Figure 7. Almost a linear variation is observed for the effective thermal conductivity against the volume fraction. This also shows that variation of base fluid combination also increases or decreases the thermal conductivity.

Maxwell, Hamilton and Crosser and Wasp models were used to predict the relative thermal conductivity of palm kernel fibre nanofluid as shown in Figure 8. Result shows that all the predicted values were greater than the experimental values, which means that the models over predicted the thermal conductivity of palm kernel fibre nanofluid, this also reported by Pastoriza-Gallego for [ethylene glycol-based Al_2O_3 nanofluids [21].

Lalit and Ghuge, [22] reported almost a linear increase in thermal conductivity of EG/water (base fluid) Al_2O_3 nanofluid at temperature range 25 to 45 ºC for particle sizes of 20 nm and 40 nm. At constant volume concentration (0.1%, 0.3 % and 0.5 %) of nanoparticles (Al_2O_3) the thermal conductivity enhancement was almost linear with respect to temperature. Chandrasekar et al, [23] measured the thermal conductivity of Al_2O_3/DW, Al_2O_3/EG and Al_2O_3/DW (75 %)/EG(25 %) as a function of volume fraction and temperature. The thermal conductivity of the nanofluid was observed to increase with an increase in temperature and particle volume fraction with a minimum enhancement of approximately 1 % for 0.1 % volume fraction and a maximum enhancement of 5 – 6 % for 1.0 % which agrees with present work.

Syam *et al* [24] reported an estimation of thermal conductivity of Al_2O_3 nanofluid with influence of particle concentrations, temperatures and base fluid, which are key factors considered in present work. Here, three base fluids such as 20:80 %, 40:60 % and 60:40 % EG/W were considered. At maximum particle concentration of 1.5 %, the enhancement in thermal conductivity for 20:80 % EG/W nanofluid was 32.26 %, for 40:60 % EG/W nanofluid was 30.51 % and for 60:40 % EG/W nanofluid was 27.42 % at a temperature of 60 °C respectively compared to base fluid. The trend here is in agreement with present work. Thermal conductivity enhancement of nanofluid not only depends on the particle concentration and temperature but it also depends on the base fluid thermal conductivity.

An estimation of the thermal conductivity of 50:50 ethylene glycol/water mixture based Al_2O_3 and CuO nanofluids experimentally at different volume concentrations and temperatures. The particle concentrations up to 0.8 % and a temperature range of 15 ^{o}C-50 ^{o}C were considered. Both nanofluids exhibit higher thermal conductivity compared to the base fluid. Under same volume concentration and temperature, thermal conductivity of CuO nanofluid was higher compared to Al_2O_3 nanofluid [25].

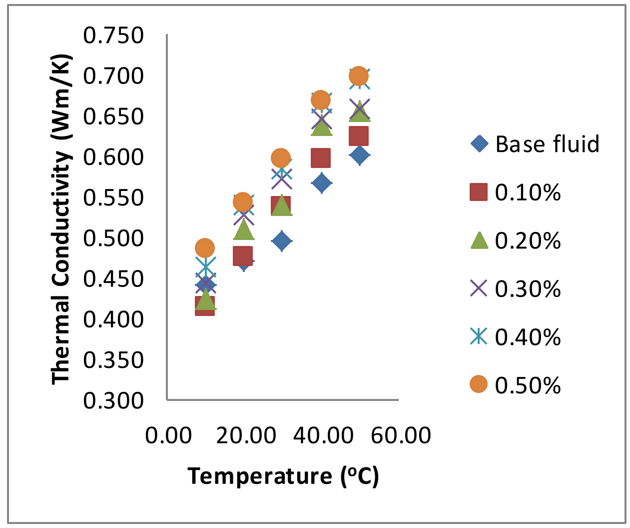

Figure 6. Effect of Temperature and volume fraction on Thermal Conductivity of 0.1 - 0.5 % volume concentrations of Palm Kernel fibre nanofluid with WT/EG(50:50) Base Fluid.

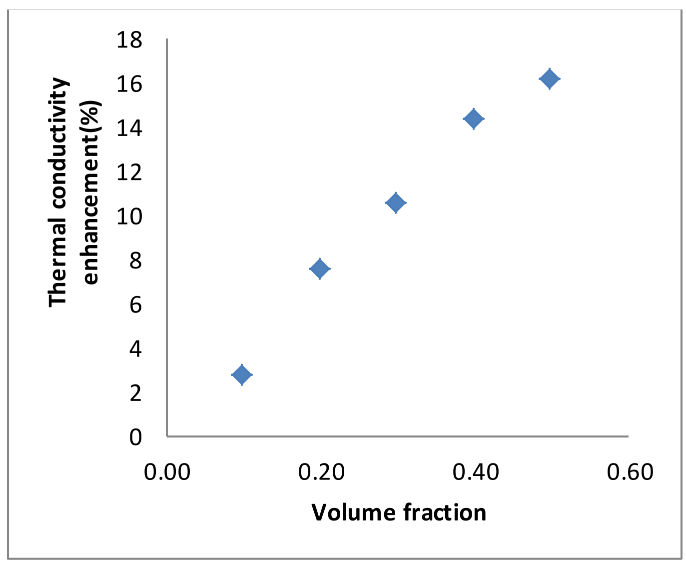

Figure 7. Thermal conductivity enhancement For Palm Kernel Fibre nanofluid with water and Ethylene Glycol(50:50) Base Fluid.

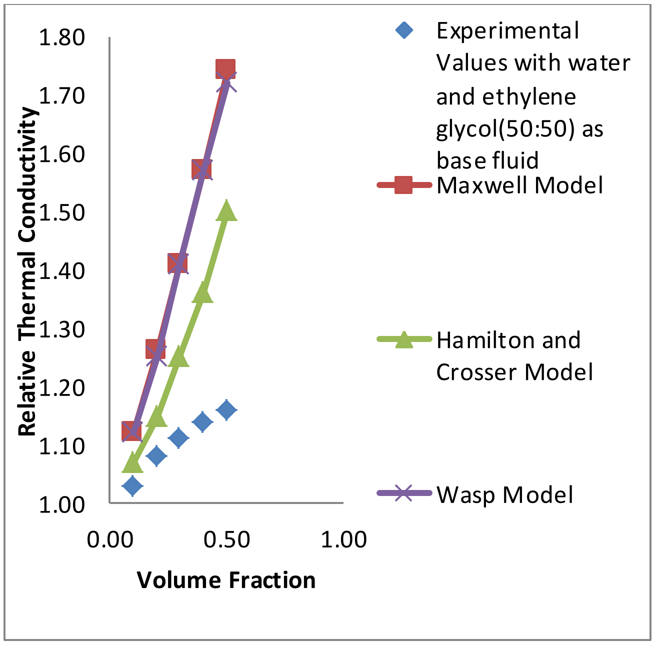

Figure 8. Comparism of experimental value and predicted values of relative thermal conductivities of palm kernel fibre nanofluid.

CONCLUSION

The thermal conductivity of palm kernel fibre nanofluid with water and ethylene glycol(50:50) was investigated. An increase in thermal conductivity was recorded as temperature and volume fraction increases. Highest values of 0.623 W/mK, 0.655 W/mK, 0.657 W/mK, 0.693 W/mK and 0.696 W/mK were recorded for volume concentrations of 0.1%, 0.2 %, 0.3 %, 0.4 % and 0.5 % at 50 ^{o}C. The nanofluid showed lowest enhancement in thermal conductivity of 2.7% at 0.1% volume concentration and maximum average enhancement of 16.1 % at 0.5% for temperatures of 10 ^{o}C to 60 ^{o}C.

Maxwell, Hamilton and Crosser and Wasp models were used to predict the relative thermal conductivity of palm kernel fibre nanofluid. Results showed that all the predicted values were greater than the experimental values, which means that the models over predicted the thermal conductivity of palm kernel fibre nanofluid. An enhancement of the thermal conductivity of ethylene glycol/water based fluid by adding palm kernel fibre nanoparticle will improve on its heat transfer efficiency and with more detailed research it can be used as heat transfer fluid in automobile heat exchanger, cooling in electronics and metal cutting with higher ratio of water. This investigation is a part of an ongoing research on using bio based materials as nanoparticles to produce nanofluids.

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