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Investigation of Thermal Conductivity of Palm Kernel Fibre Nanofluid Using De-Ionized Water and Ethylene Glycol Mixed at Ratio of 50:50 and 60:40

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Abstract

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 fibres were collected and thoroughly washed with water and caustic soda (NaOH) to remove the residual palm oil and sundried for 10 days. Palm kernel fibre nanoparticles were synthesized by subjecting the dry fibre materials to extensive ball milling for 24hours. The resulting nanoparticles were dispersed into mixture of de-ionized water and ethylene glycol mixed at ratios of 50:50 and 60:40 and subjected to ultrasonic agitation for one hour in a constant temperature thermal bath. Volume fractions of 0.1, 0.2, 0.3, 0.4 and 0.5 % of nanofluids were formed for the different base fluid mixtures. Particle characterization was done using Scanning Electron Microscopy and Transmission Electron Miscroscopy and the result showed slight agglomeration and near spherical shaped particles with average size of about 100 nm. Temperatures was varied from 10 to 50^{o}C and thermal conductivity at the different volume fractions were determined for the different base fluids and their nanofluids. Result showed that thermal conductivity increased with increase in volume fraction and temperature and the thermal conductivity of the nanofluids were higher than that of the base fluids. An enhancement in thermal conductivity of 16.1 and 18.0 % were recorded for nanofluid with 50:50 and 60:40 (de-ionized water and ethylene glycol) base fluid respectively. Maxwell, Hamilton Crosser and Wasp models defied prediction of theoretical values of thermal conductivity.

Keywords: *Basefluid, Palm kernel fibre, Nanoparticles, Nanofluid; De-ionized water, Ethyleneglycol, Thermal conductivity, Ultrasonication.*

1. INTRODUCTION

The potential benefits of using nanofluids as coolants are determined by the increase in thermal conductivity of nanofluids over that of base fluid. Dispersions of nanoparticles in fluids, have attracted attention as potential high performance heat transfer fluids as their effective thermal conductivity is significantly greater than the thermal conductivity of the fluid in which the particles are dispersed [1]. The unique characteristics of nanofluids have made them excellent candidate for the development of energy efficient cooling systems that can be employed in heat exchangers, automobile coolants, electronics etc. [2]. Thermal management of reactors involves indirect contact between process and utility streams, through coils or jackets. Similarly, microchannel heat sinks use liquid coolants to dissipate the heat enabling maintenance of substrate temperatures. Commonly used liquid coolants are water and ethylene glycol-water mixture (in automobile radiators). These coolants have relatively low thermal conductivities. A uniform dispersion of solid materials with thermal conductivities, an order of magnitude higher than that of liquid coolants, can result in enhanced thermal conductivities.

Nanofluids are solid-liquid composite materials prepared by dispersing nanometer-sized (1-100nm) solid particles in fluids such as water, ethylene glycol, engine oil etc [3]-[10] for use in important fields such as electronics, transportations, medical and HVAC. 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 [11]. Thermal conductivities of nanofluids prepared using carbon nanotubes, metallic nanoparticles (Ag, Cu) and metal oxide nanoparticles (Al_2O_3, CuO, TiO_2, SiO_2, Fe_3O_4) dispersed in conventional coolants have been reported [12], [13], [14], [15], [16], [17].

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 [18], [19], [20], [21], [22]. 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 [23].

Studies have confirmed oxidation-induced DNA fragmentation following exposure to metal oxide nanoparticles [19], [22]. 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 [23].

The properties of ethylene glycol based nanofluids have been widely studied [24], [25], [26] 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.% [27]. 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° north of the equator [28]. 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 [29].

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 Table 1 indicated 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 [30].

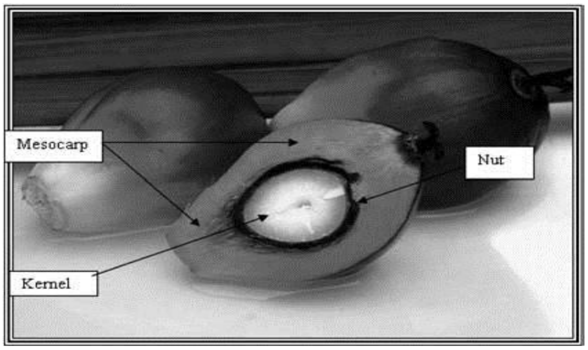

Fig 1: Cross-section of an oil palm fruit [29].

TABLE I. ELEMENTAL COMPOSITION of PALM KERNEL and OIL PALM FIBRE [30].

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

The first attempt to study the combination of water and ethylene glycol to produce nanofluid, showed that suspending nanoparticles in the mixture of water and ethylene glycol increased thermal conductivity compared to base fluid [31]. Four similar measurements of thermal conductivity of nanoparticles in 60% ethylene glycol and 40% water by volume percentage [32], showed a tremendous increment.

This present work intends to measure thermal conductivity of palm kernel fibre nanofluid using mixture ratio solutions of 50:50 and 60:40 water and ethylene glycol(WT/EG) as base fluid.The average thermal conductivity enhancement will be measured and theoretical values will be determined using existing models.

II. MATERIALS/ EXPERIMENTATION

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), GAUTRACK POTCH Oven, GAUSTING GT225 Impact Grinder (ball miller).

a. *Preparation and Characterisation of Palm Kernel Fibre Nanofluid*

Raw palm kernel fibre (about 100 g) was collected from areas where palm oil extraction take place on an industrial scale. It was washed with about 10g powdered caustic soda (NaOH) to remove any residual 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 to reduce 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 de-ionized water and ethylene glycol prepared at ratios of 50:50 and 60:40. 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.

ZEISS GEMINI ULTRA PLUS 6360 Scanning Electron Microscopy (SEM) image in Figure 3 and JEOL JEM–2100F Transmission Electron Microscopy (TEM) images in Figure 4 show shape, size and structural distribution of the nanoparticles.

Fig 2: Image of prepared palm kernel fibre nanofluid

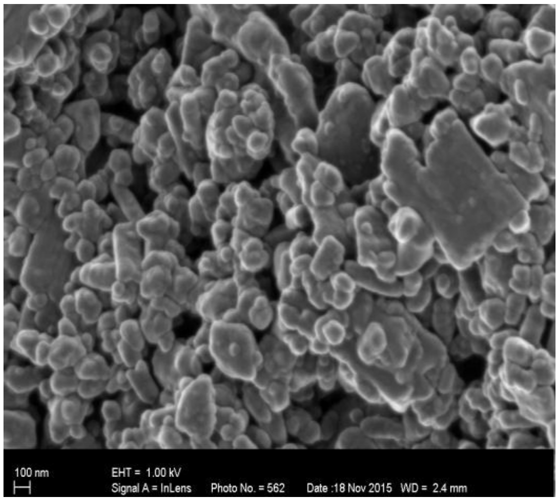

Fig 3: SEM image of palm kernel fibre nanoparticles

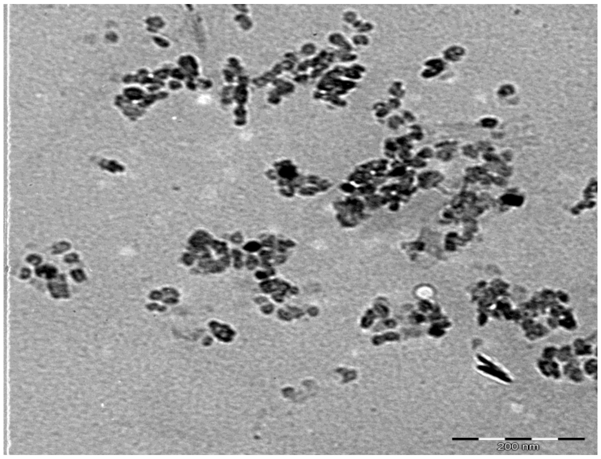

Fig 4: TEM image of palm kernel nanoparticles

b. *Thermal Conductivity Measurement*

KD2 Pro thermal property meter, was used to obtain the thermal conductivity readings with 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.

Thermal conductivities were measured for base fluid and 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 obtaining readings.

Fig: 5 Setup for thermal conductivity

III. RESULTS AND DISCUSSION

Palm kernel fibre nanoparticles used in this study had nearly spherical shape and average particle size distribution of 100nm.

The thermal conductivity values of palm kernel fibre nanofluid with de-ionized water and ethylene glycol at 50:50 and 60:40 mixture ratio as base fluid are shown in Fig. 6 and 7. It can be seen that thermal conductivity of palm kernel fibre nanofluid increased with increase in temperature and volume concentration. This was observed at 50:50 and 60:40 mixture ratio of de-ionized water and ethylene glycol. 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 thermal conductivity values of 0.676W/mK and 0.696W/mK were recorded for nanofluids with 50:50 and 60:40(WT/EG) base fluid with volume concentration of 0.5 % at 50 ^{O}C. A lowest enhancement in thermal conductivity of 2.7 and 5.1 at 0.1 % volume concentration and maximum average enhancement of 16.1 and 18.0 at 0.5 % volume concentration for temperatures of 10 to 50 ^{O}C were recorded for nanofluid with 50:50 and 60:40(WT/EG) base fluid respectively as shown in Figure 8. Almost a linear relationship 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 Fig. 9. 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. Same trend was reported by María Jones for ethylene glycol-based Al_2O_3 nanofluids [33].

A linear increase in thermal conductivity of EG/water (base fluid) Al_2O_3 nanofluid at temperature range of 25 to 45 ºC for particle sizes of 20 and 40 nm was observed [34]. 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 measured the thermal conductivity of Al_2O_3 with water and ethylene glycol (WT75/EG25) and as a function of volume fraction and temperature [35]. 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 % volume fraction which agrees with present work. An estimation of thermal conductivity of Al_2O_3 nanofluid with influence of particle concentrations, temperatures and base fluid [36], which are key factors considered in present work. Here, three base fluids of ratios 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. This 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 thermal conductivity of base fluid.

An experimental estimation of the thermal conductivity of 50:50 ethylene glycol/water mixture based Al_2O_3 and CuO nanofluids at different volume concentrations and temperatures with particle concentrations up to 0.8 % and a temperature range of 15 - 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 (Syam et al., 2012).

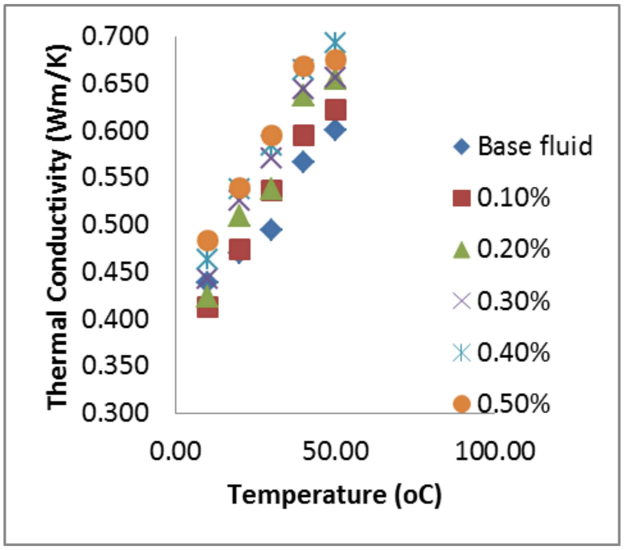

Fig 6: Effect of temperature and volume fraction on thermal conductivity of 0.1 - 0.5 % volume concentrations of palm kernel fibre nanofluid with WT/EG(50:50) base fluid.

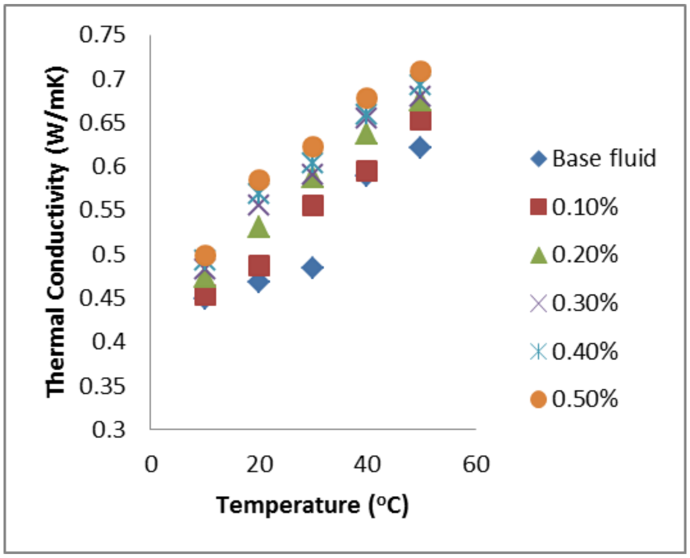

Fig 7: Effect of Temperature and volume fraction onThermal Conductivity of 0.1 - 0.5 % volume concentrations of Palm Kernel fibre nanofluid with WT/EG(60:40) Base Fluid.

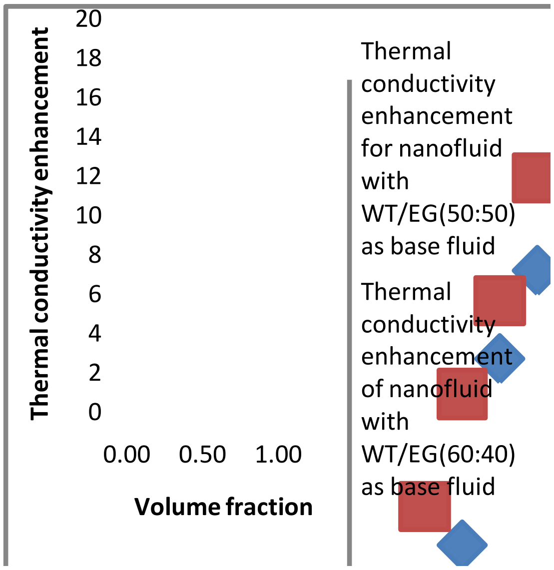

Fig 8: Thermal conductivity enhancement of palm kernel fibre nanofluid with mixture of de-ionized water and ethylene glycol(60:40 and 50:50) as Base Fluid.

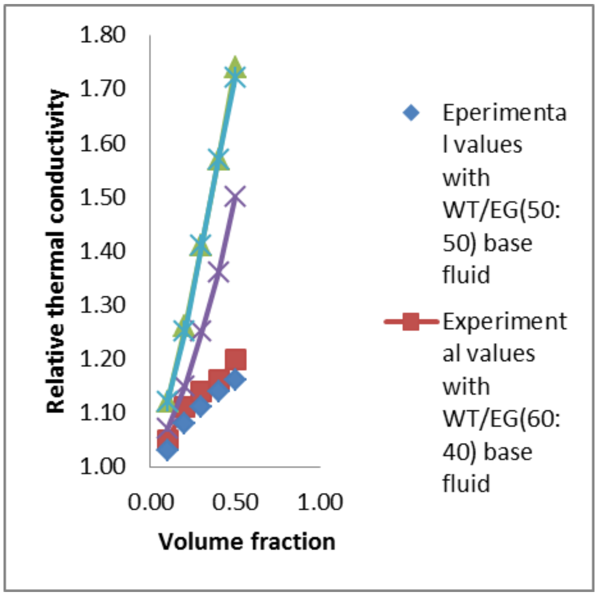

Fig 9: Comparism of experimental value and predicted values of relative thermal conductivities of palm kernel fibre nanofluid with 50:50 and 60:40(water and ethylene) base fluid.

4. Conclusion

The thermal conductivity of palm kernel fibre nanofluid with water and ethylene glycol (50:50 and 60:40) as base fluid were investigated. An increase in thermal conductivity was recorded as temperature and volume fraction increased. Highest values of 0.676W/mK and 0.696W/mK were recorded at volume concentration of 0.5 % at 50 ^{O}C for both nanofluids prepared with water and ethylene glycol at ratios of 50:50 and 60:40 respectively. Lowest enhancement in thermal conductivity of 2.7 and 5.1% at 0.1% volume was obtained and maximum average enhancement of 16.1 and 18.0% at 0.5% volume concentration for temperature range of 10 to 50 ^{O}C was obtained for nanofluid with 50:50 and 60:40 ratio of . 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 its heat transfer efficiency.

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