INVESTIGATION OF THE THERMAL CONDUCTIVITY OF NANOFLUID PREPARED FROM PALM KERNEL FIBRE NANOPARTICLES USING DE-IONIZED WATER AND ETHYLENE GLYCOL (60:40) AS BASE FLUID

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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 fibre materials (which constitute environmental waste) was collected and thoroughly washed with water and caustic soda (NaOH) to remove the residue 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 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. Particle characterization was done using Scanning Electron Microscopy and Transmission Electron Miscroscopy and the result showed that the particles were slightly agglomerated and nearly spherical in shape and the average particle size was estimated to be about 100 nm. Thermal conductivity of the different volume fractions were determined by varying volume fraction and temperatures from 0.1 – 0.5 % and 10 to 50^{o}C respectively. Result showed that thermal conductivity increased with increase in volume fraction and temperature. Thermal conductivity enhancement of 18.0 % was recorded for nanofluid with 60:40 (mixture of de-ionized water and ethylene glycol) base fluid respectively. Maxwell and Hamilton Crosser models defied prediction of theoretical values of thermal conductivity. An enhancement of the thermal conductivity of ethylene glycol/water based fluid by adding palm kernel fibre nanoparticle improved 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.

Key words: *Investigation, palm kernel fibre, nanoparticles, nanofluid, de-ionized water, ethylene glycol*

Introduction

Heat transfer fluids such as water, engine oil, transformer oil, and ethylene glycol are single phase fluids which are commonly used in many industrial sectors including power generation, heating and cooling processes, transportation, chemical processes, etc. However these fluids often 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 micro or nanoparticles, of metallic and non-metallic or polymeric particles to form colloidal solutions. Choi [1] created dispersions of solid nanosized particles in fluids and identified them 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 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 such stable dispersions of nanoparticles (typically < 100 nm in diameter) in a base fluid like conventional heat transfer fluids [1].

An investigated into the thermal conductivity of various nanofluids and heat transfer coefficient along with nanofluids pressure drop was executed by Devdatta et.al [3]. They employed a base fluid of 60%:40% of ethylene glycol and water, which was the first attempt apart from the use of ethylene glycol or water alone. Nanofluid viscosity decreased exponentially with increase in temperature. Also CuO nanofluid showed higher viscosity than other nanofluids.

Toxicity of nanoparticles as revealed in literature showed a trend among transition metal oxides like TiO_2, CuO and ZnO in human cell lines [4, 5, 6, 7, 8]. An investigation on the toxicity of oxides of Cr, Mn, Fe, Co, Ni, Cu, and Zn, each of which is widely used in industry indicated 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 [9] also identified a similar relationship of CuO and Fe_2O_3 toxicity in airway epithelial cells (HEp-2).

Studies have confirmed oxidation-induced DNA fragmentation following exposure to metal oxide nanoparticles [5, 8, 10]. In response to DNA insult, cells attempt to repair the damaged DNA. Repair failure may lead to cell death.

Biobased materials like the Oil Palm (*Elaeis Guineensis*) is mostly 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 [11]. 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 [12].

Exploring 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 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 [13].

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 [14]. Four similar measurements of thermal conductivity of nanoparticles in 60% ethylene glycol and 40% water by volume percentage, showed a tremendous increment [15].

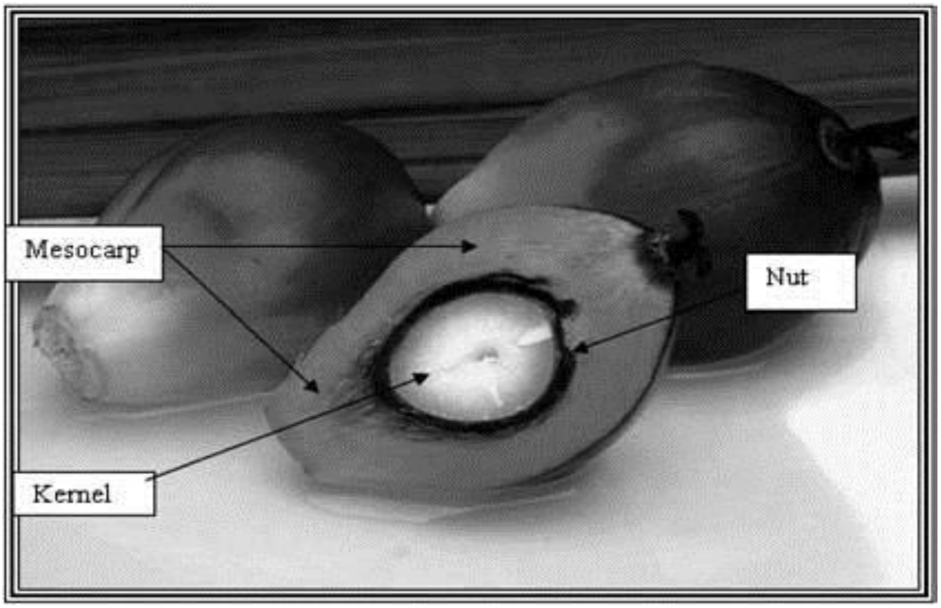

Figure. 1. Cross-section of an Oil Palm Fruit [12].

Table 1. Elemental Composition of Palm Kernel and Oil Palm Fibre

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

Source: Evbuomwan et al [13]

In this present work, nanofluid will be prepared using palm kernel fibre nanoparticle with mixture ratio of 60:40 water/ethylene glycol (WT/EG) base fluid. Thermal conductivity of palm kernel fibre nanofluid will be measured and the average enhancement in thermal conductivity will be measured and theoretical values will be predicted using Maxwell and Hamilton/ Crosser models.

2.0 MATERIALS/ EXPERIMENTATION

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

2.1 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. 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 de-ionized water and ethylene glycol (60:40) 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.

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 shows shape, size and structural distribution of the nanoparticles.

Figure 2. Image of Prepared Palm Kernel Fibre Nanofluid

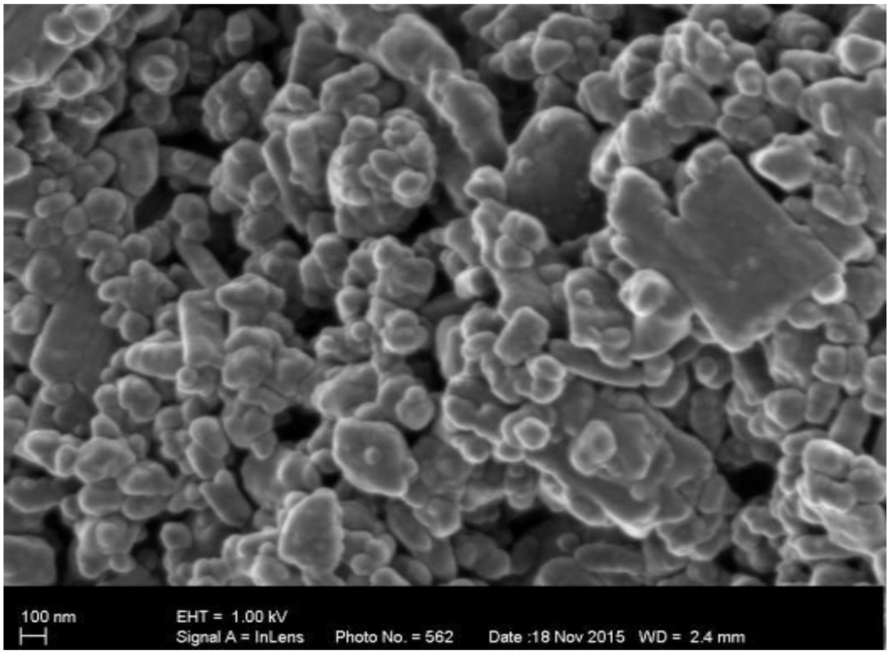

Figure 3. SEM Image of Palm kernel Fibre Nanoparticles

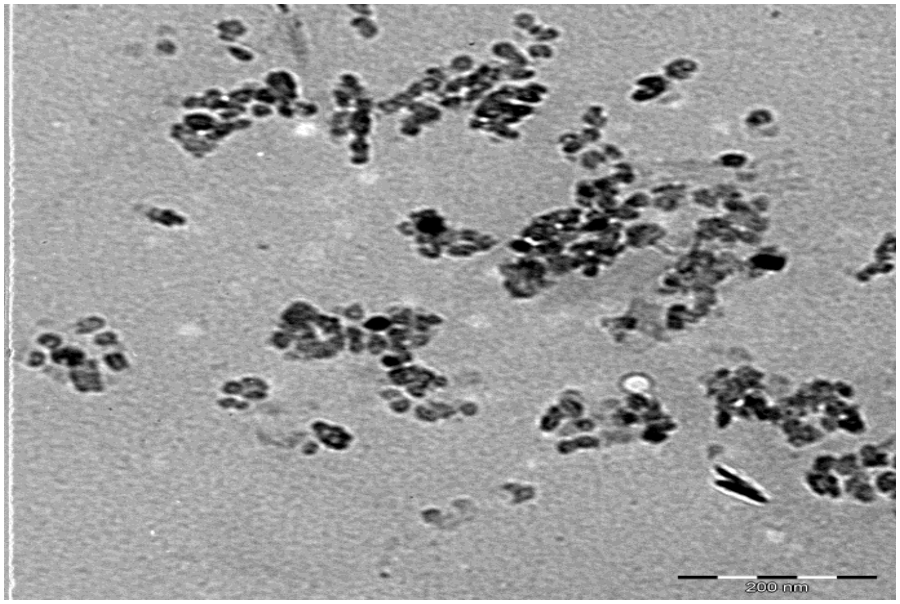

Figure 4. TEM Image of Palm Kernel Nanoparticles

2.2 Thermal Conductivity Measurement

KD2 Pro thermal property meter, was used to collect 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 consecutively 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 collecting readings.

Figure. 5 Setup for Thermal Conductivity

3.0 RESULTS AND DISCUSSION

TEM and SEM results of the Palm kernel fibre nanoparticles used in this study showed that the nanoparticles were nearly spherical in shape with average particle size distribution of 100nm.

The thermal conductivity values of palm kernel fibre nanofluid with de-ionized water and ethylene glycol at 60:40 mixture ratio of base fluid is shown in Figures 6. It can be seen that thermal conductivity of palm kernel fibre nanofluid increased with increase in temperature and volume fraction. 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 was increased, thermal conductivity also increased. Highest thermal conductivity values of 0.696W/mK was recorded for volume concentration of 0.5 % at 50 ^{O}C. A lowest enhancement in thermal conductivity of 5.1% at 0.1 % volume concentration and maximum average enhancement of 18.0% at 0.5 % for temperatures of 10 to 50 ^{O}C was recorded and indicated 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 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. Same trend was reported by María Jones for ethylene glycol-based Al_2O_3 nanofluids [16].

Chandrasekar et al, [17] measured the thermal conductivity of Al_2O_3 with water and ethylene glycol (WT75/EG25) and 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 % volume fraction which agrees with present work.

13 nm Al_2O_3 nanoparticles was prepared using two step methods by considering three different mixture base ratio as base fluid WT: EG (60:40, 50:50 and 40:60). Result obtained indicates that as percentage of ethylene glycol in the base ratio increases, the thermal conductivity decreases

with the ratio 60:40(WT:EG) having the highest value Usri et al [18]. Similar trend was observed by Sundar et al. [19] which investigate characteristics of Fe_3O_4 suspended in mixture of ethylene glycol and water for three different weight ratio (20:80, 40:60 and 60:40) which strongly agrees with present work. Syam *et al* [20] 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 thermal conductivity of the base fluid.

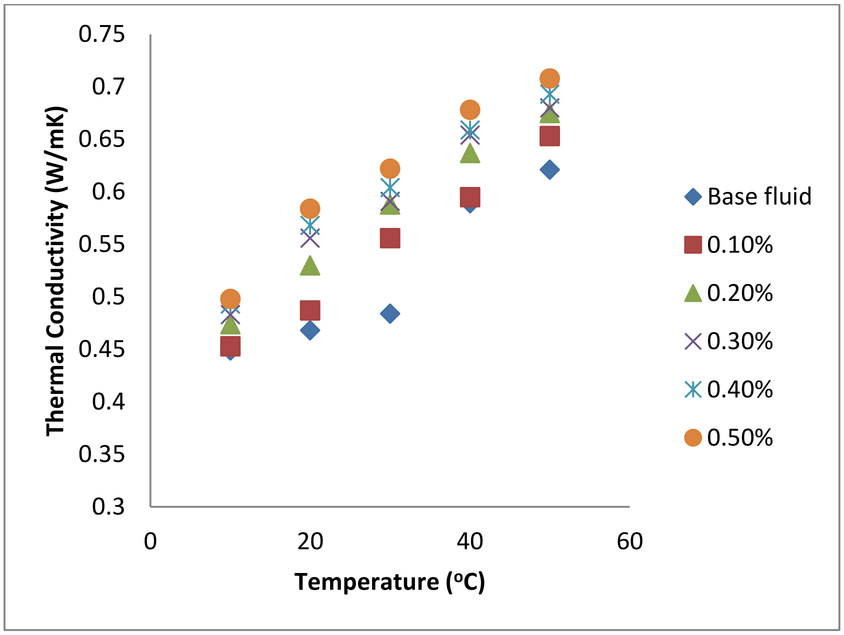

Figure 6. . Effect of Temperature and volume fraction on Thermal Conductivity of 0.1 - 0.5 % volume concentrations of Palm Kernel fibre nanofluid with WT/EG(60:40) Base Fluid.

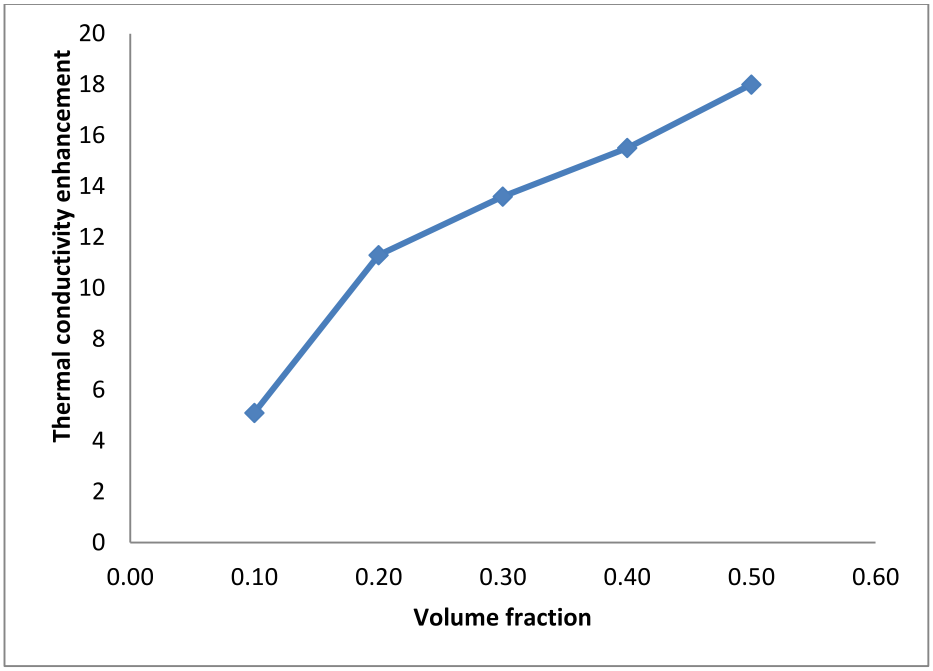

Fig 7. Thermal conductivity enhancement For Palm Kernel Fibre nanofluid with water and Ethylene Glycol (60:40) Base Fluid.

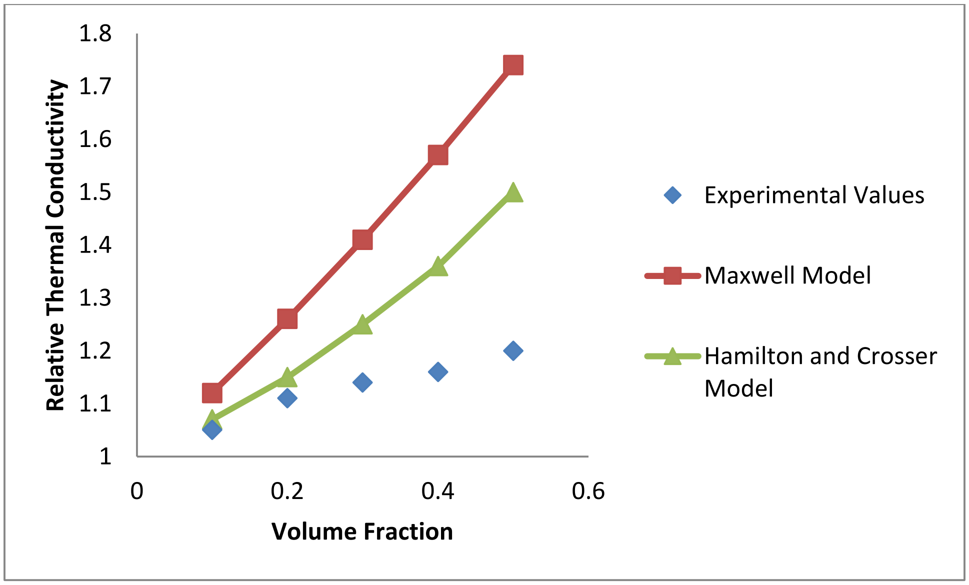

Fig 8. Comparism of experimental value and predicted values of relative thermal conductivities of palm kernel fibre nanofluid with mixture of water and ethylene(60:40) as base fluid.

4.0 CONCLUSION

An increase in thermal conductivity with increase in temperature and volume fraction was recorded for palm kernel fibre nanofluid with mixture of water and ethylene glycol(60:40) . Highest value of 0.696W/mK was recorded for volume concentration of 0.5 % at 50 ^{O}C. The nanofluid showed lowest enhancement in thermal conductivity of 5.1% at 0.1% volume fraction and maximum average enhancement of 18.0% at 0.5% volume fraction for temperatures of 10 to 50 ^{O}C. Maxwell, Hamilton and Crosser 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.

Reference

[1] S.U.S. Choi, Enhancing Thermal Conductivity of Fluids with Nanoparticles, 66, American Society of Mechanical Engineers—Fluids Engineering Division (Publication) FED, New York, 1995, pp. 99–105.

[2] Shibin H.A., and Krishnakumar T. S., (2015). Experimental Study on Thermal Conductivity of Ethylene Glycol/Water Mixture Based Nanofluids. *International Journal of Advanced Research Trends in Engineering and Technology* (IJARTET) Vol. II, Special Issue X.

[3] Devdatta P. Kulkarni, Debendra K. Das , Ravikanth S. Vajjha, *Application of nanofluids in heating buildings and reducing pollution.* Applied Energy 86 (2009) 2566–2573.

[4] Lai, J.C., Lai, M.B., Jandhyam, S., Dukhande, V.V., Bhushan, A., Daniels, C.K., and Leung, S.W. , (2008).
Exposure to titanium dioxide and other metallic oxide nanoparticles induces cytotoxicity on human neural cells and fibroblasts. *Int. J. Nanomed., 3*, 533-545.

[5] Lin W., Xu Y., Huang, C.C., Ma Y., Shannon, K.B., Chen, D.R. and Huang, Y.W., (2009). Toxicity of nano- and micro-sized ZnO particles in human lung epithelial cells. *J. Nanopart. Res.*, *11*, 25-39.

[6] Huang, C.C.; Aronstam, R.S.; Chen, D.R. and Huang, Y.W., (2010). Oxidative stress, calcium

homeostasis, and altered gene expression in human lung epithelial cells exposed to ZnO nanoparticles. *Toxicol. in vitro, 24*, 45-55.

[7] Jin C.Y., Zhu B.S., Wang, X.F., and Lu, Q.H., (2008). Cytotoxicity of titanium dioxide nanoparticles in mouse fibroblast cells. *Chem. Res. Toxicol., 21*, 1871-1877.

[8] Karlsson H.L., Cronholm P., Gustafsson J., and Moller L., (2008). Copper oxide nanoparticles are highly toxic: A comparison between metal oxide nanoparticles and carbon nanotubes. *Chem. Res. Toxicol., 21*, 1726-1732.

[9] Fahmy, B., Cormier, S.A., (2009). Copper oxide nanoparticles induce oxidative stress and cytotoxicity in airway epithelial cells. *Toxicol. in vitro, 23*, 1365-1371.

[10] Bhattacharya, K., Davoren, M., Boertz, J., Schins, R.P., Hoffmann, E. and Dopp, E., (2009) Titanium dioxide nanoparticles induce oxidative stress and DNA-adduct formation but not DNA-breakage in human lung cells. *Part. Fibre. Toxicol., 6*, 17.

[11] Ikpambese. K.K., (2010). Production of gasket seals from bambara shell and palm kernel Master's of Engineering Thesis, Dept. of Mechanical Engineering, University of Agriculture, Makurdi.

[12] Albert K. M and Enno H. (2013). Palm Kernel Oil Production Process Characterization, *An Energy, Poverty and Gender (EnPoGen) Initiative of SNV Ghana*,.

[13] Evbuomwan B. O., Agbede A. M., and Atuka M. M., (2013). A Comparative Study of the Physico- Chemical Properties of Activated Carbon from Oil Palm Waste (Kernel Shell and Fibre). *Science and Engineering Investigations,* , vol. 2, issue 19, 2251-8843.

[14] Vajjha R. S., and Das D. K., (2009). Experimental determination of thermal conductivity of three nanofluids and development of new correlations, *International Journal of Heat and Mass Transfer*. 52, , pp. 4675-4682.

[15] Tadjarodi, A. Zabihi F., and. Afshar S, (2013). Experimental investigation of thermo-physical properties of platelet mesoporous SBA-15 silica particles dispersed in ethylene glycol and water mixture, *Ceramics International*. 39, pp. 7649-7655.

[16] María J., Pastoriza-G. , Luis L., José L., Legido M., and Piñeiro M., (2011). Thermal conductivity and viscosity measurements of ethylene glycol-based Al_2O_3 nanofluids *Nanoscale research letters* 6:221.

[17] Chandrasekar M., Suresh S., Bose A.C., (2010). Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al_2O_3/water nanofluid, *Experimental Thermal and Fluid Science 34* . 210–216.

[18] Usri N.A. Azmia W. H., Rizalman M, Abdul Hamid K., Najafi G. Thermal Conductivity Enhancement of Al_2O_3 Nanofluid in Ethylene Glycol and Water Mixture *Energy Procedia 79 (2015) 397 – 402.*

[19] L. S. Sundar, M. K. Singh, and A. C. M. Sousa, (2013). Thermal conductivity of ethylene glycol and water mixture based Fe_3O_4 nanofluid, *International Communications in Heat and Mass Transfer*. **49**, pp. 17-24.

[20] Syam S. L., Venkata R. E., Manoj K. S., Antonio C.M. S., (2014). Thermal conductivity and viscosity of stabilized ethylene glycol and water mixture Al_2O_3 nanofluids for heat transfer applications. *International Communications in Heat and Mass Transfer* 56, 86–95.