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The Effects of Low Volume Fraction Palm Kernel Shell Nanoparticles on the Thermal Conductivity of Ethylene Glycol

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ABSTRACT

This research studies the level of enhancement in the thermal properties of ethylene glycol (EG) based nanofluids, using low volume fractions palm kernel shell (PKS) nanoparticles within the range of 0.001% to 0.05%. The method used for obtaining nanoparticles of 200 nm diameter from palm kernel shell was pulverization (crushing) and screening. From experimental results of this research, the thermal conductivity of PKS-ethylene glycol nanofluid increased from 0.2542 W/mK to 0.2590 W/mK, corresponding to 0.001% to 0.05% volume fractions of PKS nanoparticles respectively. The thermal conductivity enhancement ratio, also increased with increase in volume fraction, with values ranging from 1.00315 to 1.01969. The thermal conductivity of ethylene glycol and the PKS-ethylene glycol nanofluid samples increased with increase in temperature. The result of the research shows that, low volume fractions of palm kernel shell nanoparticle will result in low thermal conductivity enhancement level of ethylene glycol.

1. INTRODUCTION

In many fields of industry, such as, transportation, air conditioning, power generation, electronic, etc., the role of heat transfer cannot be over emphasized. Moreover, high-performance cooling is widely needed in industrial technologies. Due to this fact, various studies and research are aimed to increase cooling performance of working fluids (Behi and Mirmohammadi, 2012).

A cooling fluid (coolant) is a substance, typically liquid or gas that is used to reduce or regulate the temperature of a system. An ideal coolant has high thermal conductivity, low viscosity, is low-cost, non-toxic, chemically inert and neither causes nor promotes corrosion. Currently, most prevailing fluids utilized for cooling are water, ethylene glycol and engine oil which have much lower thermal conductivity compared to lots of solids. A uniform dispersion of solid nano-sized metallic, non-metallic, or polymeric particles with thermal conductivities, an order of magnitude higher than that of base liquid coolants, can result in enhanced thermal conductivity properties of these base liquid (Choi, 1995; Zussman, 2002; Eastman *et al.*, 2004; Das *et al.*, 2003; Xuan et al., 2003; Eastman *et al.*, 1997; Eastman *et al.*, 2001; Lee *et al.*, 1999). This fact was starting point of an idea, which was creating mixture of solid and fluid in order to improve thermal conductivity of fluid and to have better heat transfer performance

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consequently (Ozerinc *et al.*, 2010).

Dispersions of nanoparticles with the size of 1 to 100 nm inside base fluids also known as nanofluids 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 (Das *et al.*, 2008). In heat transfer, one of the major parameters is thermal conductivity of working fluid. 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 (Awua *et al.,* 2016).

The likely benefits of using nanofluids as coolants are determined by the increase in thermal conductivity of nanofluids over that of base fluid. 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. (Shibin and Krishnakumar, 2015).

Oil Palm (*Elaeis guineensis*) is dominantly grown as a plantation crop in the rainforest region of West Africa in tropical climates such as Nigeria etc. Its economically importance due to its high-yielding source of edible and technical oils (Ikpambese, 2010). The oil palm bears fruits in bunch ranging from 10 to 40kg. The palm fruit consist of an outer skin (the exocarp), 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 (Albert and Enno, 2013).

The need to explore the use of bio-based materials like oil palm shell (endocarp) nanoparticles for nanofluid research became necessary when reports on the elemental composition of oil palm shell materials indicated traces of metallic materials like Cu, Zn and Fe shown in Table 1, which are critical composition of base materials for nanofluid source when their oxides are used for thermal conductivity enhancement (Evbuomwan, 2013).

Table 1: Elemental Composition of Palm Kernel Shell (Evbuomwan *et al.*, 2013)

Heavy metals (mg/kg)	**Palm Kernel Shell**
Magnesium	50.96
Copper	4.54
Zinc	8.61
Potassium	118.7
Iron	34.51
Calcium	32.06
Nickel	Nil
Cadmium	Nil
Chromium	Nil
Lead	Nil

Vajjha and Das (2009), 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 reported by Awua *et al.,* (2016), who combined water and ethylene glycol with nanoparticles of palm kernel fibers suspended in 50:50% and 60:40% of water and ethylene glycol by volume percentage.

Hence, this paper aims to measure the effect of low volume fraction oil palm kernel shell nanoparticles on the thermal conductivity of Ethylene glycol. This experiment has the potential of producing a nanofluid that has efficient thermal properties when used as a coolant.

2. Materials and Method

2.1 Materials

Palm kernel shells were obtained as biomass from a local market in Benin City, Edo State, Nigeria. Analytical grade reagents were used; Caustic alkali (NaOH), Ethylene glycol, Sulphuric Acid, and water.

2.2. Methods

2.2.1 Preparation of palm kernel shell nanoparticles

The collected palm kernel shells were separated from the palm fiber as much as possible and washed adequately, then for 72 hours and oven-dried at a temperature of 40°C for 30 minutes. The dried palm kernel shells (P.K.S.) were crushed to fine particles using a milling machine. The palm kernel shells were crushed thoroughly into very fine particles.

500g of the crushed palm kernel shell particles was measured and was mixed with 500ml of water. This mixture was passed through a 0.38mm thick cotton fabric with a pore size of about 200 nm, of which the nanoparticle mixture was separated from other particles of palm kernel shell larger than 200mm in the mixture. During the separation process, the nanoparticles flow with the water into a container while particles larger than the cotton fabric's pore size are trapped on the fabric. The separation process was carefully done to ensure that particles obtained after separation are within the size range (<200nm). The obtained nanoparticle mixture was dried for about 3hours using an oven to obtain dried palm kernel shell nanoparticles. The nanoparticle obtained was about 20wt% of the mass of crushed palm kernel shell particles measured, which was 500g.

Nanoparticles obtained after drying of the nanoparticle mixture, were washed using caustic alkali (NaOH) of 0.5M to remove impurities such as oil, which would affect the nanofluid mixture. After washing with NaOH, the nanoparticles became basic. Hence, it was neutralized using Sulphur acid of 0.2M, where pH indicator papers were used to test for the pH value of the nanoparticle during neutralization until the nanoparticles became neutral. It is important to note that red color for pH indicator paper signifies strong Acid, with pH range <3, orange or yellow color signifies weak acid with pH range of 3-6, green color signifies neutral with pH value of 7, blue color signifies weal alkali with pH range of 8-11 and indigo or violet color signifying strong alkali with pH range >11. The neutralized nanoparticle mixture was placed in the oven to dry for 4 hours, after which dried, neutralized nanoparticles were obtained.

2.2.2 Preparation of various volume fractions of Nanofluid

Dried palm kernel shell nanoparticles were divided into various volume fractions that were then mixed, each with an equal weight of ethylene glycol (50g) in other to achieve varying concentrations of the mixture (Nanofluid). Volume fractions of nanofluid obtained ranged from 0.001%- 0.05%, with eleven (11) samples of nanofluid formed. This was achieved using a mathematical model equation to calculate the weight of base fluid (ethylene glycol) and nanoparticles required to achieve various volume fractions. The equation is given below.

$$\text{Volumetric fraction } \varphi \times 100 = \frac{\frac{Wp}{\rho p}}{\frac{Wp}{\rho p} + \frac{Wf}{\rho f}} \qquad (1)$$

Where Wp the weight of the nanoparticle is, ρ is the density of the nanoparticle, Wf, is the weight of base fluid and ρf is the density of the base fluid.

The density of the nanoparticles (ρ) was determined by measuring the weight of the nanoparticle for a given volume 1.78 grams of the nanoparticle was determined using a weighing balance as the weight of the nanoparticle for 5 ml. of the nanoparticle, of which the density of the nanoparticle was calculated using the following equation,

$$\rho p = \frac{\text{mass}}{\text{volume}} \quad (2)$$

The values of the required weights to achieve the desired volume fractions were calculated and tabulated.

After mixing the various weighed samples of nanoparticles with a measured volume of base fluid to achieve different volume fractions from 0.001-0.05, magnetic stirrer containing a magnetic stirring bar is used to stabilize the nanofluid mixtures for about 90 minutes for each volume fraction at a stirring speed of 315 RPM of the magnetic stirring bar. This I s to ensure proper mixing of the two-phase phases of the mixture. All samples of the nanofluid were stored in 100ml bottles.

2.2.3 Sonication of volume fractions of Nanofluid

The various volume fractions of the Nanofluid went through the sonication process in the lab after stirring with a magnetic stirrer. This is to prevent the nanoparticles from settling in the base fluid (ethylene glycol), creating a continual suspension of the particles in the fluid. The sonication process carried for hours at 40°C each of the eleven samples. Because of the size the sonicator, all samples could not undergo the sonication process the same time. Hence, the process conducted The first session of was samples volume fraction (6 samples). Sonication started the end of the first session and for the remaining samples with fraction 0.03-0.05 the end the sonication samples ready for further measurement processes.

2.2.4 Thermal Conductivity measurement (calculation) for Nanofluid samples

Using a water bath-thermometer setup, the thermal conductivity of various volume fractions of the Nanofluid measured. 15 litres of water was placed in the water bath, which was set at a constant temperature of 85° C, and 500ml of water was placed in a 500ml beaker, which was also placed in the water bath. The setup was allowed to attain temperature stability for about 30 minutes, after which 25ml of a sample of the nanofluid with a volume fraction of 0.001 was placed in a test tube, and a thermometer was placed at the center of the test tube containing the nanofluid, the Temperature of the sample was initially recorded to be 30°C, and it was placed in the beaker containing 500ml water in the water bath, the time taken for the Temperature of the nanofluid to 40°C Also, the time is taken for the nanofluid to attain a temperature of 50°C, 60°C and 70°C, respectively, was recorded. This procedure was repeated for all remaining samples of the nanofluid with a volume fraction of 0.005-0.05. The time value was recorded and tabulated.

3 Results and Discussion

3.1 Results of the thermal conductivity of Nanofluid

The thermal conductivity of PKS-Ethylene glycol-based nanofluid is a very crucial parameter in the determination of the functionality and application of such Nanofluid in thermal systems. From the experimental procedure of this research, the thermal conductivity for varying temperature conditions was calculated using standard heat equations.

3.2 Effect of low volume fraction on thermal conductivity of nanofluid

The volume fraction of the nanoparticles presents in the base fluid, either low or high, can affect the thermal conductivity of the Nanofluid formed. From Fig 1 below, it is observed that as the volume fraction of the nanoparticles in the base fluid increased, the thermal conductivity also increased. This suggests a nonlinear relationship between the thermal conductivity of the nanofluid and the volume fraction of the palm kernel shell nanoparticles. Though, in some cases researchers have observed a linear relationship between thermal conductivity and nanoparticle volume (Esfe *et al.*, 2015; Barbe´s *et al.*, 2014; Yu *et al.*, 2011; Das *et al.*, 2017; Iqbal *et al.*, 2017; Alawi *et al.*, 2014; Jeong *et al.*, 2013; Huminic *et al.*, 2015), whereas in other cases a non-linear relationship has been observed (Zhu *et al.*, 2006; Chopkar *et al.*, 2008; Park and Kim, 2014; Li *et al.*, 2006; Wang *et al.*, 1999; Sundar *et al.*, 2013; Murshed *et al.*, 2005; Seyhan *et al.*, 2017; Pang *et al.*, 2012; Lee *et al.*, 2011; Paul *et al.*, 2010; Yoo *et al.*, 2007).

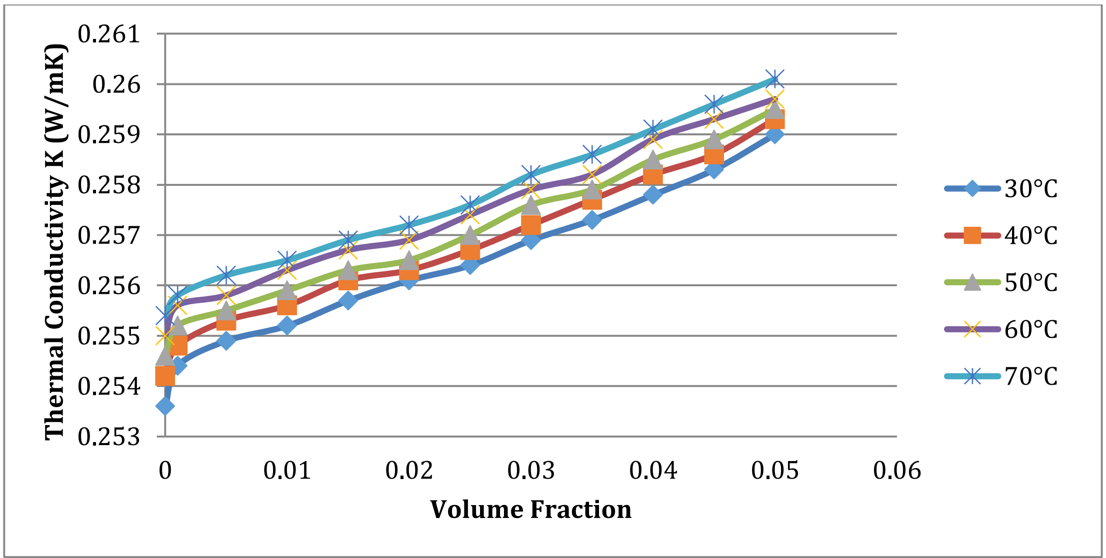

Figure 1: A graph of thermal conductivity against volume fraction at varying temperatures

The enhancement of the thermal conductivity of various volume fractions ethylene glycol based nanofluid was seen to be increase with increase in the volume fiction of nanoparticles present in the nanofluid mixture, from experimental results, the thermal conductivity enhancement increased from 0.24% to 1.89% for volume fractions ranging from 0.001 to 0.05 at 40°C. These values of thermal conductivity steadily increased but at a low rate as the volume fractions of the PKS nanoparticles mixed with a fixed volume of base fluid (ethylene glycol) increased from 0.001 to 0.05. The thermal conductivity of solids is generally higher than that of liquids. Hence when there is a mixture of solid particles and a liquid, the thermal conductivity of the liquid tends to increase. This is a function of the concentration of the solid particle present in the nanofluid mixture. In general, experimental data has shown that nanofluid thermal conductivity increases with nanoparticle volume fraction (Zhu *et al.*, 2006; Esfe *et al.*, 2015; Chopkar *et al.*, 2008; Park an Kim, 2014; Li *et al.*, 2006; Barbe´s *et al.*, 2014; Agarwal *et al.*, 2016; Wang *et al.*, 1999; Sundar *et al.*, 2013; Yu *et al.*, 2011; Murshed *et al.*, 2005; Lee *et al.*, 2011; Paul *et al.*, 2010; Yoo *et al.*, 2007; Iqbal *et al.*, 2017, Alawi *et al.*, 2014; Jeong *et al.*, 2013; Huminic *et al.*, 2015).

3.3 Effect of Temperature on the thermal conductivity of nanofluid

The thermal conductivity of the base fluid (ethylene glycol) of the increasing temperatures, 30°C, 40°C, 50°C, 60°C and

70°C was calculated to be 0.2542 W/mK, 0.2546W/mK, 0,2550W/mK and 0.2554W/mK respectively. A plot of the thermal conductivity of the base fluid and various volume fractions against varying temperature conditions Fig 2, revealed that the relationship between temperature of nanofluids and the thermal conductivity of nanofluids gave a linear relationship. As the temperature of nanofluids increases the thermal conductivity also increases. This implies that the hotter the nanofluid, the higher the rate at which it can conduct heat, this corresponds with research by (Janki *et al.*, 2017).

Researchers have conducted experiments to determine the effects of temperature on the thermal conductivity of nanofluids, concluding that the thermal conductivity of nanofluids increases with temperature [Raja *et al.*, 2010; Agarwal *et al.*, 2017; Maheshwary *et al.*, 2017; Patel *et al.*, 2010; Sundar *et al.*, 2013; Yeganeha *et al.*, 2010; Alawi *et al.*, 2014; Jeong *et al.*, 2013; Huminic *et al.*, 2015; Das *et al.*, 2003).

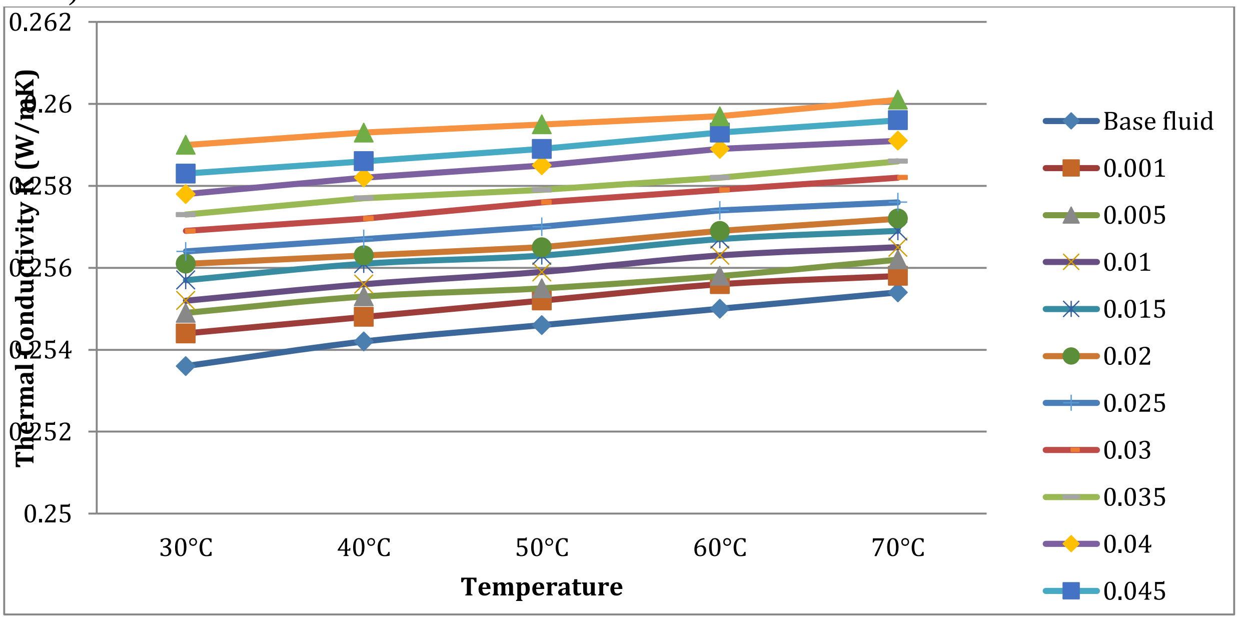

Figure 2: A graph of thermal conductivity of nanofluid against temperature

3.4 Thermal conductivity ratio of the nanofluid to the base fluid

The thermal conductivity ratio of the nanofluid was calculated by taking the ratio of the thermal conductivity of various volume fractions of the nanofluid at varying temperatures the thermal conductivity of ethylene glycol at 30°C. The thermal conductivity ratio can be used to understand the enhancement level of the thermal conductivity of the base fluid, for enhancement of the thermal conductivity of ethylene glycol to occur, the thermal conductivity ratio of the nanofluid must be above 1. The increase in the thermal conductivity ratio of the nanofluid will lead to the increase to the degree of enhancement of the thermal conductivity of ethylene glycol (base fluid). The thermal conductivity ratio of nanofluid to ethylene glycol gotten from experimental results are all above 1, which implies that every volume fraction of palm kernel shell nanoparticle used in the production of nanofluid in the course of this research, enhanced the thermal conductivity of the base fluid (ethylene glycol).

From Fig. 3, it is seen that the thermal conductivity ratio of the nanofluid to that of the base fluid increases with increase in temperature and volume fraction. The low values of thermal conductivity ratio imply the low level of enhancement of the thermal conductivity of ethylene glycol. The low level of the enhancement of the thermal conductivity of ethylene glycol from this research may be due to the low volume fractions of palm kernel shell nanoparticles used to prepare the nanofluid. Higher volume fraction like 0.1, 0.2 0.3 0.6, 0.9 etc. will lead to higher level of enhancement than the level gotten from the volume fractions used.

It can be concluded from the experimental findings, discussed above that the thermal conductivity of nanofluids increases with nanoparticle volume concentration. However, the rate of increase is different for various nanofluids due to the degree of agglomeration (Simpson *et al.*, 2018).

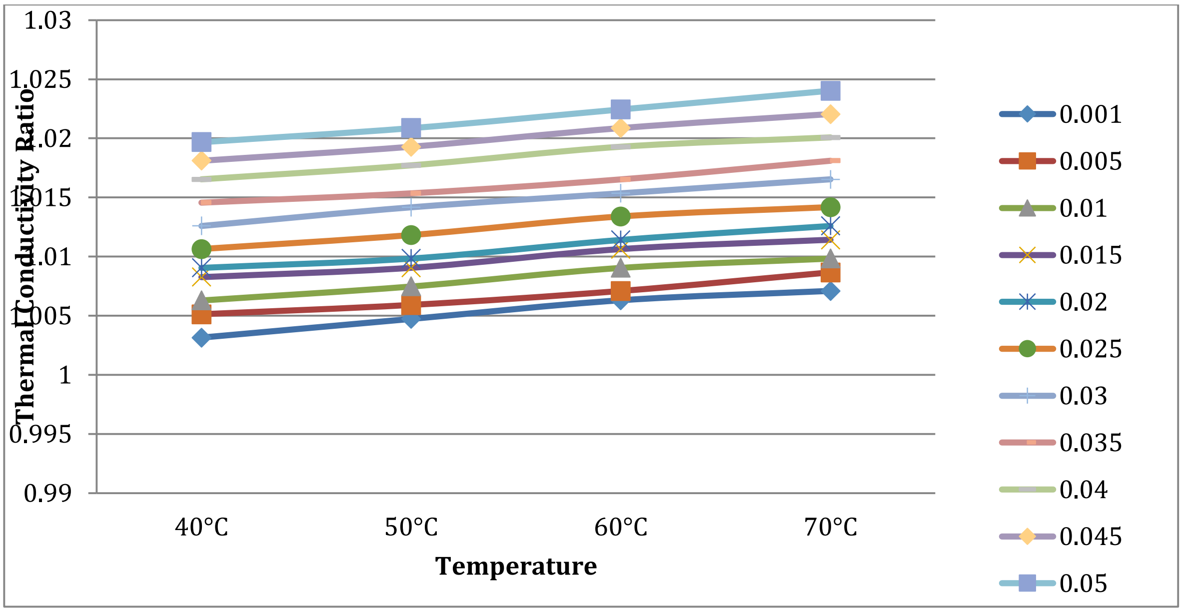

Figure 2: A graph of thermal conductivity ratio of nanofluid against temperature

4. Conclusion

The thermal conductivity of low volume palm kernel shell nanofluid with ethylene glycol as base fluid was studied. 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℃ for both nanofluids prepared with water and ethylene glycol at ratios of 50:50 and 60:40 respectively.

This study was on the effect of low volume fractions of palmi kernel shell nanoparticles on the thermal conductivity and viscosity of ethylene glycol. The method of obtaining palm kernel shell nanoparticles for this research was crushing and screening method to obtain nanosize particle in the order of 200nm. The data shows that the thermal conductivity enhancement is low; since the volume fractions used for this research are low volume fractions. For a higher level of improvement in the thermal conductivity of ethylene glycol, higher volume fractions can be used.

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