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Thermal Conductivity Enhancement of Al_2O_3 Nanofluid in Ethylene Glycol and Water Mixture

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Abstract

The ability of nanofluids that exhibits enhanced thermal performance is acknowledged by researchers through studies since decades ago. However, the observation of thermal properties for nanofluids in water and ethylene glycol based is not fully explored yet. Hence, this paper presents the thermal conductivity of water and ethylene glycol (EG) based Al_2O_3 nanofluid. The 13 nm sized Al2O3 nanoparticles were dispersed into three different volume ratio of water: EG such as 40:60, 50:50 and 60:40 using a two-step method. The measurement of thermal conductivity was performed using KD2 Pro Thermal Properties Analyzer at working temperatures of 30 to 70 °C for volume concentration of 0.5 to 2.0 %. The results indicate that the thermal conductivity increases with the increase of nanofluid concentration and temperature. While the percentage of ethylene glycol increase, the range of thermal conductivity decreases due to ethylene glycol properties. The measurement data of the nanofluids give maximum enhancement of thermal conductivity at condition 2.0 % volume concentration, temperature of 70 °C and for all base fluid.

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Keywords: nanofluid; aluminium oxide; thermal conductivity enhancement; water:eg mixture

1. Introduction

Thermal fluids are vital to remove excess heat from a system or assist heating process in industrial field such as electronic engineering, medical, automotive and HVAC. Thus, thermal conductivity of fluids act as the main properties to be apprehensive in developing an energy efficient heat transfer equipment. Nevertheless, commercialized fluids have low properties i.e. thermal conductivity compare to solids materials. In the early years of 1990’s, Masuda et al. [1] introducing suspended nanometer sized particles

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to the research field and found out that nanometer size particles have higher stability when suspended in conventional fluid than micrometer and millimeter size particles. Research team at Argonne National Laboratory of USA, Choi [2] termed the suspended nanometer size particle as "Nanofluids" conducted investigation of nanofluid thermal ability. As the next generation of thermal fluids, researchers conducted a deeper study on the effective thermal conductivity of nanoparticles suspended in a liquid to understand the nature of nanofluids.

In the first study of combining water and ethylene glycol, Vajjha and Das [3] found out that suspending nanoparticles in the mixture increased thermal conductivity compare to base fluid. This increment is also found by Tadjarodi et al. [4] which 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 Al_2O_3 nanofluid using three different mixture ratio solutions of water and ethylene glycol as base solution. The experiment is conducted using 13 nm Aluminum Oxide (Al_2O_3) dispersed in 60:40, 50:50 and 40:60 (water: ethylene glycol) mixture base solution. The temperature is varied between 30 to 70 °C using KD2 Pro Thermal Analyzer and controlled water bath.

Nomenclature

Al_2O_3	Aluminium Oxide
BF	Base Fluid
EG	ethylene glycol
ϕ	volume concentration, %
φ	volume fraction, $\varphi = \phi/100$
k	thermal conductivity, W/m.K
m	mass, kg ($m = \rho / V$)
nf	nanofluid
p	particle
T	temperature, °C
V	volume, m^3
W	water

2. Experimental Setup

2.1. Preparation of Nanofluid

The Al_2O_3 nanofluid used in the present paper are prepared using two step method which is dispersing 13 nm Al_2O_3 nanopowder in the base fluids. The powder nanoparticles is purchased from Sigma-Aldrich with 99.8 % purity. The density value of Al_2O_3 nanoparticle provided by the manufacturer is 4000 kg/m^3. The base fluid is prepared using distilled water and ethylene glycol following designated ratio based by volume percentage which are 40:60, 50:50 and 60:40. Ethylene glycol (EG) has density of 1100 kg/m^3 with AR grade (99.5 % purity).

Following two step method, Eq. (1) is used to calculate mass of Al_2O_3 nanoparticles before dispersed in the 100 ml mixture base. The designated nanofluid is prepared at volume concentrations 0.5 %, 1.0 %, 1.5 % and 2.0 %. To prolong the stability of nanofluid, the solution is mixed using magnetic stirrer and immersed in ultrasonic homogenizer for 2 hours. After preparation, the stability is observed as in Fig. 1 (a) – (c).

$$\phi = \frac{\left(m_p / \rho_p\right)}{\left(\dfrac{m_p}{\rho_p} + V_{BF}\right)} \times 100 \qquad (1)$$

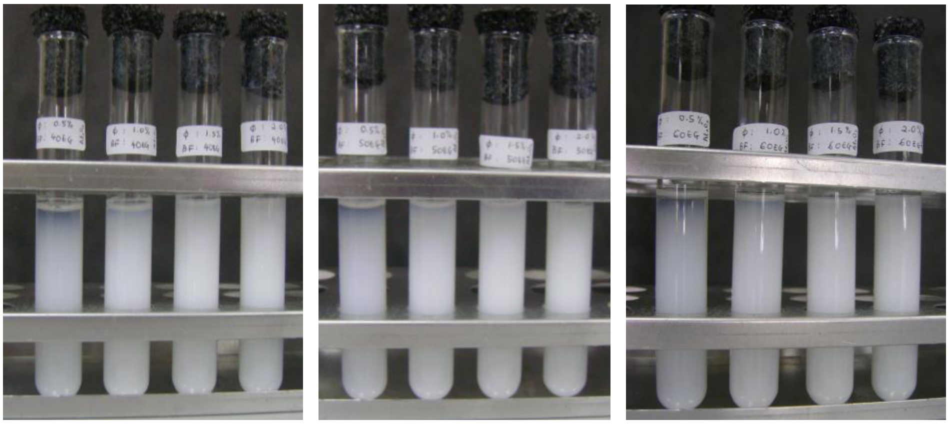

Fig. 1. (a) Al_2O_3 dispersed in 60W:40EG; (b) Al_2O_3 dispersed in 50W: 50EG; (c) Al_2O_3 dispersed in 40W:60EG

2.2. Thermal Conductivity Measurement

There are several technique have been adopted to measure thermal conductivity of nanofluid such as transient hot-wire method (THW), steady-state parallel-plate method and cylindrical cell method [5]. The method used is similar to [5-8]. This paper utilized thermal constant analyzer technique to measure thermal conductivity of Al_2O_3 nanoparticles dispersed in different base ratio water to ethylene glycol (60:40, 50:50 and 40:60) as in Fig 2. A KD2 Pro Thermal Property Analyzer manufactured by Decagon Devices, Inc., USA is used to measure the thermal conductivity based on THW theory. The KD2 Pro consists of a handheld controller and 60 mm sensors that is inserted into the test medium. The measurement is conducted under controlled temperature ranging from 30 to 70 ^{o}C using a Memmert water bath. The measurements are taken after 5 minutes immersed in the water bath to ensure the temperature is stable. Each readings are taken with 15 minutes interval time until 20 readings to avoid experimental error. The average value is collected after completed one set of data.

Fig. 2. Thermal Conductivity measurement setup using thermal constant analyzer technique

3. Results and Discussion

Before conducting the nanofluids measurement, the experiment setup and method is establish by performing measurement for base fluid at different ratio of W:EG (60:40, 50:50, 40:60) in temperature range of 30 to 70 ^{o}C. Fig. 3 shows the measured thermal conductivities compare to available literature [9]. Thus, the present measurement is in good agreement with both literature with deviation less than 1 %.

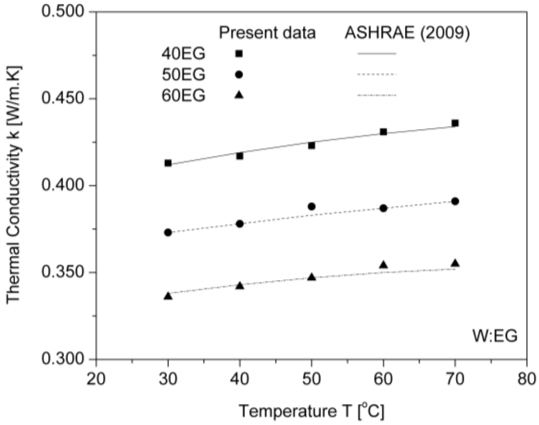

Fig. 3. Validation of thermal conductivity measurement for water to ethylene glycol mixture compare to ASHRAE [9].

The data of thermal conductivity for Al_2O_3 nanofluid with different base ratio at volume concentration of 0.5 %, 1.0 %, 1.5 % and 2.0 % is shown in Fig. 4(a). As observed from the figure, by increasing nanoparticles in each base ratio, the thermal conductivity increases. The highest value of thermal conductivity is observed for cluster in base ratio (BR) of 60:40 (W:EG), followed by 50:50 (W:EG) based and the lowest is in cluster 40:60 (EG:W). Since pure ethylene glycol have lower thermal conductivity compare to pure water, this pattern shows that increment of volume percentage for ethylene glycol in the BR leads decreasing thermal conductivity cluster. The similar pattern was found by Sundar et al. [10] 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). On the other hands, Fig. 4(b) shows percentage enhancement of Al_2O_3 in the three base ratios. It indicates that by using higher percentage of ethylene glycol in the base fluid, the percentage enhancement increment is increase. This due to Brownian motion by nanoparticles in all direction pushing molecules in front of it along each temperature gradient which increase thermal conductivity in each base fluid [11]. The enhancement is also assisted by temperature gradient that allowing velocity in the base fluid increase rapidly consequently increase thermal conductivity.

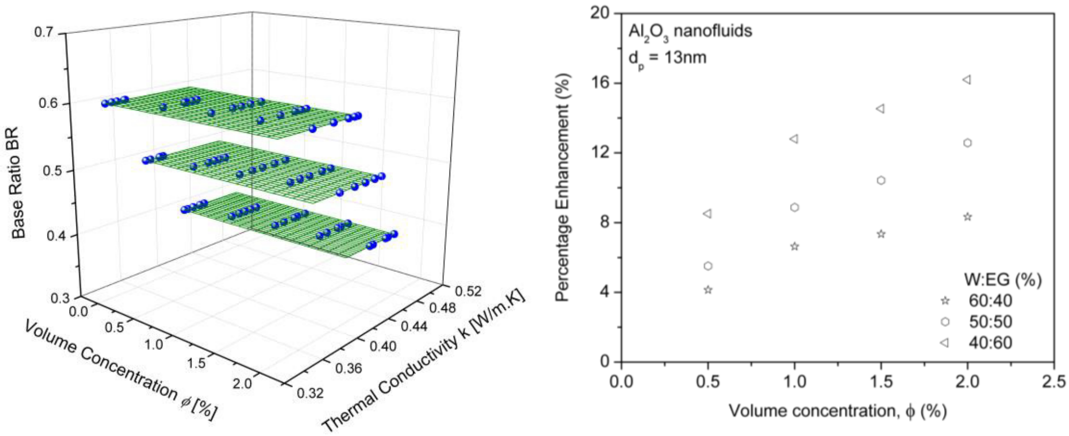

Fig. 4. (a) The distribution of thermal conductivity of Al_2O_3 nanofluid at 0.5% to 2.0% in three base fluids; (b) The percentage enhancement of thermal conductivity for three base fluids clustered in volume concentrations.

There is no theoretical correlation available in literature for Al_2O_3 dispersed in these three different base ratio for designated volume concentration. The proposed Eq. (2) is to estimate thermal conductivity for different base ratio (BR). The correlation have an average deviation of 1.43 % and in good agreement within ± 5 % compare to present data as shown in Fig. 5 For $0.5 < \phi < 2.0$, $30 < T < 70^oC$, and $0.4 < BR < 0.6$.

$$k_{nf} = 0.634(1+\phi)^{0.1045}\left(\frac{T}{70}\right)^{0.1094}(1+BR)^{-1.1590} \quad (2)$$

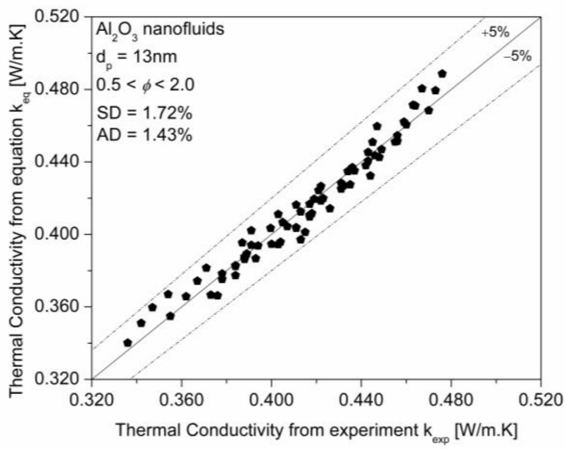

Fig. 5. Comparison of nanofluid thermal conductivity between present data and proposed equation.

4. Conclusions

The 13 nm Al_2O_3 nanoparticles is prepared using two step methods by considering three different mixture base ratio as base fluid W: EG (60:40, 50:50 and 40:60). The investigation is conducted using KD2 Pro Thermal Analyzer with transient hot wire method. Through result obtained, it indicates that as percentage of ethylene glycol in the base ratio increase, the thermal conductivity decrease. As particle concentration increases, the thermal conductivity increase for all base ratio. Enhancement of thermal conductivity could be found in each base fluid. The paper proposed a correlation for Al_2O_3 nanofluid from 0.5 to 2.0 % of volume concentration.

Acknowledgements

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