An experimental study on the thermal conductivity and dynamic viscosity of TiO$_2$-SiO$_2$ nanofluids in water: Ethylene glycol mixture

M.F. Nabil$^a$, W.H. Azmi$^{a,b,*}$, K. Abdul Hamid$^a$, Rizalman Mamat$^{a,b}$, Ftwi Y. Hagos$^{a,b}$

$^a$ Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
$^b$ Automotive Engineering Centre, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

**A R T I C L E   I N F O**

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**A B S T R A C T**

The hybrid nanofluid has been thriving among researchers due to its potential to improve heat transfer performance. Therefore, various studies on heat transfer properties need to be carried out to provide a better understanding on hybrid nanofluid performance. In this paper, the experimental work is focused on the thermal conductivity and dynamic viscosity of TiO$_2$-SiO$_2$ nanofluids in a mixture of water and ethylene glycol (EG) with volume ratio of 60:40. The stable suspension of TiO$_2$-SiO$_2$ prepared at volume concentrations of 0.5 to 3.0%. The measurements of thermal conductivity and dynamic viscosity were performed at a temperature range of 30 to 80 °C by using KD2 Pro Thermal Properties Analyser and Brookfield LVDV III Ultra Rheometer, respectively. The thermal conductivity of TiO$_2$-SiO$_2$ nanofluids was improved by increasing the volume concentration and temperature with 22.8% maximum enhancement. Besides, the viscosity of TiO$_2$-SiO$_2$ nanofluids showed evidence of being influenced by nanofluid concentration and temperature. Additionally, the TiO$_2$-SiO$_2$ nanofluids behaved as a Newtonian fluid for volume concentration up to 3.0%. The properties enhancement ratio suggested that TiO$_2$-SiO$_2$ nanofluids will aid in heat transfer for concentrations of more than 1.5% and within the range of the temperature studied. A new correlation for thermal conductivity and dynamic viscosity of TiO$_2$-SiO$_2$ nanofluids were developed and found to be precise.

1. Introduction

For the past decades, various investigations proved that nanofluids have the ability to improve the heat transfer characteristics for industrial equipments in various applications such as heat exchangers, cooling devices, lubrication, vehicle cooling systems and solar collectors [1–9]. Only in recent years, hybrid nanofluid was introduced and the investigation focused more on the characteristics and the thermophysical properties such as thermal conductivity and viscosity [10–18].

According to Sarkar et al. [19], the hybrid nanofluid can be defined as a combination of two or more different types of nanoparticles in a base fluid, or suspension of hybrid (composite) nanoparticles in a base fluid. The advantages of using nanofluids in heat transfer applications are higher thermal conductivity and lower viscosity than microfluids [20]. Hence, the investigations on these two properties, namely thermal conductivity and viscosity are essential to understand the thermal performance and physical behaviour of nanofluids, respectively. Previously, several studies were conducted for thermal conductivity and viscosity of nanofluids for the base mixture of waterethylene glycol (EG). There were several factors that affected the enhancement in thermal conductivity such as concentration, working temperature, particle size, surface-volume ratio of nanoparticles and stability of nanofluids [21–24]. In most studies, thermal conductivity mostly increases with the addition of nanoparticles into the base fluid. However, the enhancement may vary for different nanofluids as proven by Turgut et al. [25]. In their studies, they found that no temperature dependence related to the enhancement of thermal conductivity. A study on viscosity was conducted by Sundar et al. [26] with Fe$_3$O$_4$ nanoparticles dispersed in three mixtures of EG:water for ratios of 60:40, 40:60 and 20:80. They observed that 1.0% volume concentration of nanofluid in a 60:40 mixture is enhanced by 2.94% compared to other mixture ratios of base fluids. Yu et al. [27] used 55:45 (W:EG) mixture base fluid in their investigation. They found that the temperature and volume concentration significantly affected the nanofluid viscosity. In addition, the nanofluid exhibited Newtonian behaviours for temperatures below 45 °C. The Al$_2$O$_3$ nanoparticles in 40:60 water-EG mixture base was studied by Said et al. [28]. A similar behaviour was observed by them where the nanofluid exhibited Newtonian behaviours for low concentrations of below 40 °C.

In recent years, several studies on the thermal conductivity and

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* Corresponding author at: Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

E-mail addresses: nabilffkr0112@gmail.com (M.F. Nabil), wanazmi2010@gmail.com (W.H. Azmi), khamisah0301@gmail.com (K. Abdul Hamid), rizalman@ump.edu.my (R. Mamat), ftwi@ump.edu.my (F.Y. Hagos).

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