International Communications in Heat and Mass Transfer 61 (2015) 61–68

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Experimental Investigation of Thermal Conductivity and Electrical Conductivity of Al_2O_3 Nanofluid in Water - Ethylene Glycol Mixture for Proton Exchange Membrane Fuel Cell Application ☆

Irnie Zakaria [c], W.H. Azmi [a,*], W.A.N.W. Mohamed [c], Rizalman Mamat [a], G. Najafi [b]

[a] Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[b] Tarbiat Modares University, Jalale-E-Aleahmad Highway, Tehran, Iran
[c] Faculty of Mechanical Engineering, Universiti Teknologi Mara (UiTM),40450 Shah Alam, Selangor, Malaysia

ARTICLE INFO

Available online 27 December 2014

Keywords:
Nanofluid
Aluminium oxide
Thermal conductivity
Eelectrical conductivity
Fuel cell
Thermo-electrical conductivity ratio

ABSTRACT

Nanofluid is an alternative promising cooling liquid with superior performance characteristic compared to conventional cooling liquid for Proton Exchange Membrane fuel cell (PEMFC). In this paper, new findings on ratio of thermal conductivities and electrical conductivities of nanofluids in water: ethylene glycol (EG) mixtures are established. Thermal conductivities and electrical conductivities of base fluids which are water: EG mixtures with concentration ranging from 0 % ethylene glycol up to 100 % ethylene glycol were measured. These base fluids are then dispersed with Al_2O_3 at 0.1, 0.3 and 0.5 % of volume concentration and thermal conductivities and electrical conductivities are then measured at temperature of 20 °C. The result demonstrates that thermal conductivities reduced as the EG content percentage increases in the water: EG mixture. Thermal conductivities for 0.5 % volume concentration of Al_2O_3 is 0.6478 W/m.K and 0.2816 W/m.K for 0 and 100 % EG content in water: EG mixture. However, at a specific EG percentage, thermal conductivities also increased as a function of volume concentration. Electrical conductivities measured in 0.1, 0.3 and 0.5 % volume concentration of Al_2O_3 in base fluid also observed to decrease as the EG concentration increased even though the base fluids' electrical conductivity behave differently. Thermo-electrical conductivity ratio (TEC) has also been established based on both thermal and electrical conductivity findings.

1. Introduction

Heat transfer advancement plays a vital role in the field of thermal engineering. The improvement of forced heat transfer coefficient for cooling mediums namely water, oils, propylene glycol and ethylene glycol have shown significant importance due to their vast application in the transfer of thermal energy. Apart from heat transfer coefficient, various efforts have been taken to improve heat transfer performance such as increasing heat transfer area and temperature difference that results in heat flow. However all these efforts have come to a saturated zone [1]. Miniaturization of heat transfer devices in today's globalization world has also driven the need for developing new thermal fluids with superior heat transfer performance without sacrificing the compactness of the design. Enhancement in heat transfer performance of new thermal fluids is made possible by dispersing nano-sized particles with diameter of 1 to 100 nm into the base liquids which results in higher heat transfer coefficient compared to conventional liquids and it is termed as nanofluids [2]. These uniformly dispersed nanoparticles in base fluids have attracted researchers due to their highly enhanced thermal conductivity property. This enhancement is due to the thermal conductivity of nanoparticles which can be either metal or metal oxides with many orders of magnitude higher than the liquid.

Nanoparticles in water - EG base fluid has received tremendous attention from researchers, perhaps due to its wide application in heat transfer especially in cold countries region. Different ratios of water: EG is generally formulated to lower the freezing point of this aqueous solutions [3]. Propylene glycol application also served the same purpose as ethylene glycol. However, under low temperatures, ethylene glycol mixtures have better heat transfer characteristics compared to Propylene glycol [4].There are various studies done on thermal conductivity properties. Lee et al. [2] observed a 40 % increase of thermal conductivity with 10 nm Cu added to ethylene glycol base fluid. Similar enhancement also reported by Eastman et al. [5] with Cu dispersed in ethylene glycol. However, Eastman et al. [5] also added a non-metallic nanoparticle which turned out to be 22 % enhancement from base fluid but at 4 % volume concentration. Murshed et al. [6] also experimented 5 % of both Al and TiO_2 in ethylene glycol and findings showed that the enhancement is 45 % and 18 % consecutively.

☆ Communicated by W.J. Minkowycz.

* Corresponding author.
E-mail addresses: irnieazlin@gmail.com (I. Zakaria), wanazmi2010@gmail.com (W.H. Azmi), wanajmi@salam.uitm.edu.my (W.A.N.W. Mohamed), rizalman@ump.edu.my (R. Mamat), najafi14@gmail.com (G. Najafi).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2014.12.015
0735-1933/

Nomenclature

ATC	Temperature compensation
C_k	Thermal conductivity enhancement
C_μ	Viscosity enhancement
EDL	Electrical double layer
FESEM	field emission scanning electron microscopy
HEG	Hydrogen exfoliated graphene
EG	Ethylene glycol
k	thermal conductivity, W/m K
k_r	thermal conductivity ratio of nanofluid to base fluid, (K_{nf}/K_{bf})
k_{EG}	thermal conductivity of pure ethylene glycol, W/m.K
m	mass, gram
n	empirical shape factor
PEMFC	Proton exchange membrane fuel cell
TEC	Thermo-electrical conductivity ratio
TEG	Thermal exfoliated graphene

Greek symbols

ϕ	volume concentration, %
φ	volume fraction, $\varphi = (\phi/100)$
ρ	density, kg/m^3
ψ	Ratio of surface area of pshere
σ	electrical conductivity
α	conductivity ratio, $\alpha = (\sigma_p/\sigma_{bf})$

Subscripts

bf	base fluid
eff	effective
nf	nanofluid
p	particle
r	ratio

Sundar et al. [7] experimentally studied the mixture of ethylene glycol and Al_2O_3 nanoparticles at the 1.5 % volume concentration in water: ethylene glycol for mixture of 80:20, 60:40 and 40:60 over a temperature range and found out that the highest increment of thermal conductivity of 32.26 % in 80:20 ratio at 60 °C. He also mentioned that ethylene glycol has a poorer thermal conductivity compared to water and addition of ethylene glycol will only suppress the thermal conductivity of the base fluid.

Same base fluid ratio of 40:60 (water: ethylene glycol) has also been studied by Vajjha and Das [8] by dispersing CuO, ZnO and Al_2O_3 at higher volume concentration up to 10 % in temperature range of 298 K to 363 K. He also observed that the thermal conductivity increases with the increase of particle size. Apart from particle size, other factors such as temperature, nano particle shape, base fluid materials, additives and aggregation effect on thermal conductivity of nanofluid also been reviewed by Philips and Shima [9].

Another frequently studied thermo-physical property of nanofluid is viscosity [7,10–14]. TiO_2 and Al_2O_3 at volume concentration range of 0 to 4 % in water: ethylene glycol mixture of 80:20 has been investigated

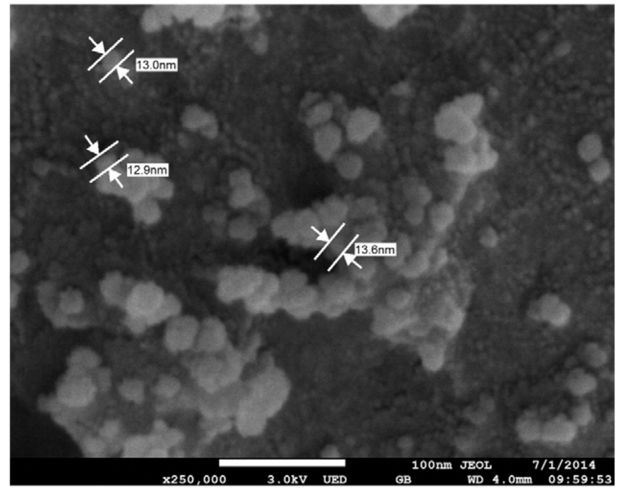

Fig. 1. FESEM image of dry Al_2O_3 nanoparticle at X 250,000 magnification. **(a)** Nanofluid samples after preparation. **(b)** Nanofluid samples after a month. **(c)** Nanofluid samples after 10 months.

by Yiamsawas et al. [14] and deduced that the theoretical model is not really applicable for predicting viscosity of a nanofluid. Viscosity does has a significant role in determining whether a specific nanofluid gives a better thermal performance than its base fluid thru a ratio of enhancement in viscosity over thermal conductivity, (C_μ/C_k). Prasher [15] studied that the enhancement of viscosity has to be lower than 4 compared to thermal conductivity in laminar range, while Garg [16] specified the feasible limit to 5 in turbulent flow. If the ratio goes beyond this limit, then the nanofluid application in any specific case affectivity is doubtful.

Electrical conductivity is less investigated of all thermo-physical properties of nanofluids. Sources of literatures on this property are very scarce, perhaps due to the lack of nanofluid applications in the electrically active thermal devices such as PEMFC. Electrical conductivity of a nanofluid is correlated to the ability of charged ions in the nanofluid mixture to carry electrons also termed as charges whenever an electric potential is applied [17]. This is possible due to the formation of electrical double layer (EDL) around the surface of the dispersed nanoparticles. The whole structure movement towards oppositely charged electrode is measured as electrical conductivity of a nanofluid.

Application in PEMFC cooling system would require electrical conductivity properties as a judgment whether it is feasible or not for the system. The electrical conductivity requirement which is as low as 1.5 to 2 μS/cm [18] and 5 μS/cm at 20 °C [19] which need to be maintained over time. This is a big challenge as the coolant keeps receiving ions from contamination of bipolar plate [20] and oxidation of glycol [21] as it degrades. Elhamid et al. [22] and Gershun et al. [23] mentioned in their patents that high electrical conductivity in the coolant will cause shunt current and coolant electrolysis on the electrical appliance. Shunt current will decrease the efficiency of the electrical appliance. In addition to that, it is harmful to the user.

Efforts has been made to encounter this by adding anti oxidant to coolant [24] while these researchers have tackled this through kerosene hydrocarbon coolant and addition of carboxylic acid to coolant consecutively [25,26]. Nanofluid also been discovered by Mohapatra [27,28] as a potential coolant which is capable of maintaining low electrical

Table 1
Properties of nanoparticles and base fluid used in the experiment.

Nano particle/Base fluid	Thermal conductivity κ, W/m.K	Electrical conductivity σ, μS/cm	Dielectic constant ε	Density ρ, kg/m^3	Reference
Al_2O_3	36	10^{-8}	9.1-9.3	4000	[38,39,52,53]
Distilled water	0.615	6	80	999	[4,38,39,51,54]
Ethylene glycol	0.252	1.07	38	1110	