Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 79 (2015) 252 – 258

Energy Procedia

2015 International Conference on Alternative Energy in Developing Countries and Emerging Economies

Experimental Investigation of Al_2O_3 - Water Ethylene Glycol Mixture Nanofluid Thermal Behaviour in a Single Cooling Plate for PEM Fuel Cell Application

Irnie Zakaria[a*], W.A.N.W Mohamed[a], A.M.I Bin Mamat[a], R.Saidur[b] , W.H. Azmi[c], Rizalman Mamat[c], S.F.A Talib[a]

[a]*Faculty of Mechanical Engineering, Universiti Teknologi Mara (UiTM), 40450 Shah Alam, Selangor, Malaysia*
[b]*Center of Research Excellence in Renewable Energy, King Fahd University of Petroleum and Minerals, 31261 Dahran Saudi Arabia*
[c]*Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia*

Abstract

Thermal enhancement through application of nanofluid coolant in a single cooling plate of Proton Exchange Membrane (PEM) fuel cell was experimentally investigated in this paper. The study focuses on low concentration of Al_2O_3 dispersed in Water - Ethylene Glycol mixtures as coolant in a carbon graphite PEM fuel cell cooling plate. The study was conducted in a cooling plate size of 220mm x 300mm with 22 parallel mini channels and large fluid distributors. The mini channel dimensions are 100mm x 1mm x 5 mm. A constant heat load of 100W was applied by a heater pad that represents the artificial heat load of a single cell. Al_2O_3 nanoparticle used was 0.1 and 0.5 vol % concentration which was then dispersed in 50:50 (water: Ethylene Glycol) mixture. The effect of different flow rates to heat transfer enhancement and fluid flow represented in Re number range of 20 to 120 was observed. Heat transfer was improved up to 13.87% for 0.5 vol % Al_2O_3 as compared to the base fluid. However the pressure drop also increase which result in pumping power increment up to 0.02W. The positive thermal results implied that Al_2O_3 nanofluid is a potential candidate for future applications in PEM fuel cell thermal management.

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE

Keywords: mini channel; nanofluid; heat transfer; PEMFC; fluid flow

---

* Corresponding author. Tel.: +0-603-355435261 ; fax: +0-603-5543-5160 .
E-mail address: irnieazlin@gmail.com

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE
doi:10.1016/j.egypro.2015.11.474

1. Introduction

Effective cooling is crucial for a safer and more efficient operation of proton exchange membrane fuel cell (PEM) fuel cell especially when dealing with higher power of fuel cell stack. An effective thermal management of a fuel cell gives a better performance of a (PEM) fuel cell as high temperatures can result in membrane degradation while low temperatures will lower the kinetic reaction and sometimes causing flooding issue [1-3]. Mini channels have been adopted in PEM fuel cell cooling plate designs as it allows a more compact stack size and allows improved heat transfer rates that leads to lower maximum cell temperature [4-6].

In addition to miniaturization of channel dimension, nanofluid is also seen as one of the alternative coolant for PEMFC due to its higher value of heat transfer coefficient as compared to base fluid [7]. Nanofluid in mini channels has been experimentally investigated mostly for electronic heat sink and automotive heat exchangers [4, 8-10]. Nanofluid cooling effects at different nanoparticle fractions to variations in heat sink channel designs, operation and materials are normally reported. Naphon and Nakharintr [9] studied TiO_2 in de-ionized water nanofluid heat transfer characteristic by varying three different channel heights. Sohel et al [11] studied the effect of different flow rates to thermal performance of Al_2O_3 in water at volume fractions range of 0.1 to 0.25 %. Both studies reported an enhancement of 42.3% and 11% of max convective heat transfer respectively as compared to base fluids. Apart from adoption in mini channel heat sink, nanofluid in an electrically active heat transfer environment such as fuel cell mini channel is a potential area to be explored. However, information on electrical conductivity of nanofluid is still insufficient as compared to other thermo physical properties of nanofluids. Zakaria et al. [12] has established a thermo-electrical conductivity ratio for Al_2O_3 nanofluid in water:EG mixture for (PEM) fuel cell. According to the findings, Al_2O_3 in 50:50 (water: EG) is one of the potential base fluid as it meets both thermal and electrical characteristic required for PEMFC. Sarojini et al. [13] experimented nanoparticles of Al_2O_3, CuO and Cu in distilled water and EG and report that electrical conductivity increases as the volume concentration increase.

In this study, a customized test bench was developed to represent the working conditions of a PEM fuel cell cooling plate. The thermal effects in applying nanofluid on heat transfer and fluid flow on graphite mini channel was investigated for base fluid, 0.1 and 0.5 vol % Al_2O_3 in 50:50 (water: EG) mixture. The experimental was conducted under constant heat flux and inlet Reynolds number range between 20 to 120. The 50:50 (water:EG) ratio was selected due to its compliance to previous TEC ratio [12].

2. Methodology

2.1. Nanofluid thermo physical properties measurement

Thermo physical properties such as thermal conductivity and viscosity of nanofluids were measured at temperature of 27°C. Thermal conductivity of nanofluid was measured using KD2 Pro thermal property analyzer of Decagon Devices, Inc., USA while viscosity was measured using Brookfield LVDV-III Ultra rheometer

The density of nanofluid is calculated using Pak and Cho [14] using Equation *(1)* :

$$\rho_{nf} = (1-\emptyset)\rho_f + \emptyset\rho_p \qquad (1)$$

Specific heat is calculated using model from Xuan and Roetzel [15] using Equation *(2)* :

$$C_{nf} = \frac{(1-\emptyset)(\rho C)_f + \emptyset(\rho C)_p}{(1-\emptyset)\rho_f + \emptyset\rho_p} \tag{2}$$

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

Nano particle / Base fluid	Thermal conductivity (κ, W/m.K)	Specific Heat Cp, (J/kg.K)	Viscosity μ, (mPa.s)	Density ρ, (kg/m^3)	Reference
Al_2O_3	36	765	-	4000	[14, 16-18]
Distilled water	0.615	4180	0.854	999	[16, 17, 19-21]
Water : EG (50:50)	0.3712	3354	3.21	1110	

where $\emptyset$ is referred as particle volume fraction and subscripts f, p and nf referred to fluid, particle and nanofluid. Properties measured and calculated were tabulated in Table 1.

2.2. PEMFC Single cooling plate experimental set up

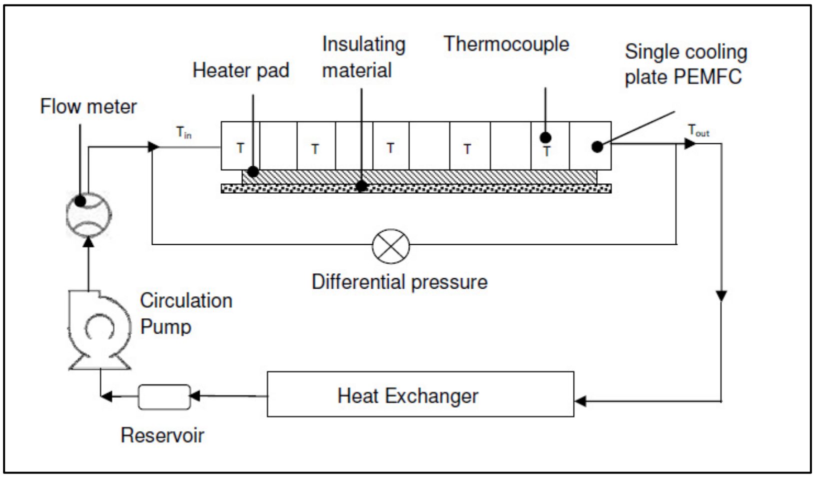

Fig. 1. Experimental set up of single cooling plate PEMFC

Carbon graphite plate of was used to mimic a single cooling plate of a PEMFC. The plate consists of 22 parallel mini channels with dimensions of 5mm x 1mm x 100 mm . The plate was then subjected to a constant heat load of 100 W and insulated with fibre glass insulator material to minimize the heat loss to the surrounding. Temperature of both fluid and plate were measured using K-type thermocouples. Differential pressure used to measure the pressure difference between inlet and outlet of fluid. A volumetric flow meter was also installed to measure the volumetric flow rate of nanofluids. All experimental data were taken using a dedicated data logger as the data acquisition system.

2.3. Mathematical model

Plate temperature of the cooling plate is calculated using Equation *(3)* where base height effect is considered [9].

$$T_b = T_{ave} + \frac{q_{in} H_b}{k_{cooling\ plate} A_b} \tag{3}$$

Where cooling plate base area is defined as in Equation (4)

$$A_b = L_{ch} N (W_{ch} + W_{fin}) \tag{4}$$

The convective heat transfer performance based on constant surface heat flux condition can be determined from Equation *(5)*

$$\bar{h} = \frac{\dot{q}_s}{T_b - T_m} \tag{5}$$

A dimensionless Nusselt number which evaluate the proportionality of convective heat transfer to the conductive heat transfer is calculated from Equation *(6)*.

$$\overline{Nu} = \frac{\bar{h} D_h}{k_{nf}} \tag{6}$$

Pumping power is estimated using Equation *(7)* :

$$W_p = \dot{Q} \times \Delta P \tag{7}$$

3. Result and discussion

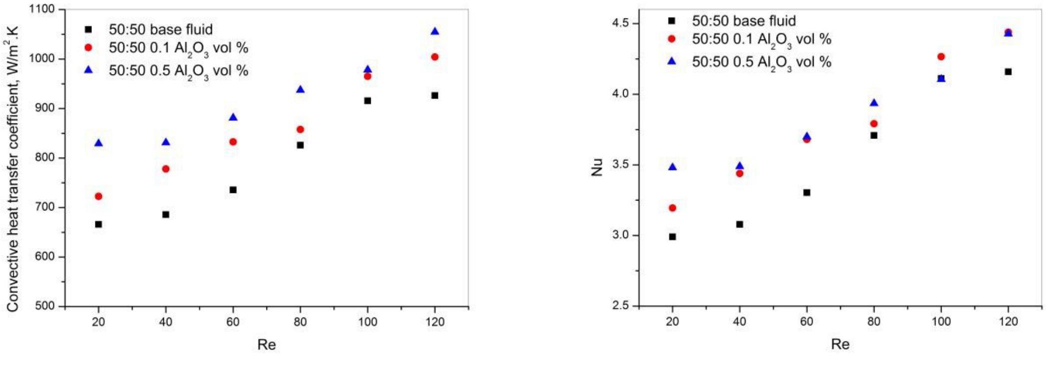

Fig. 2. (a) Variation of convective heat transfer coefficient against Reynold number; (b) Effect of nanofluid to Nusselt number against Reynold number

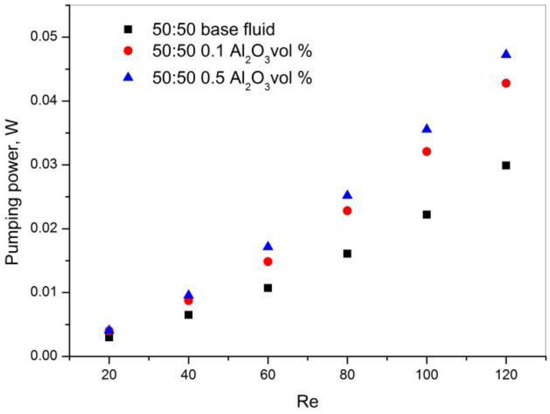

Fig. 3. Effect of pumping power with nanofluid application

Thermal performance of nanofluids is evaluated based on the convective heat transfer coefficient and Nusselt number. The convective heat transfer increased as both vol % concentration and Re number increased. The highest increment is at 0.5 vol% concentration with 15.2% of enhancement compared to the base fluid at Re 120. The higher thermal conductivity of nanofluid as compared to base fluid is the main reason for the enhancement. The increase of vol % concentration has eventually increased the thermal conductivity and the Brownian motion which has improved the heat transfer coefficient. The heat transfer coefficient is then converted to a non dimensionalized Nu number. The Nu number is 7.7% higher for 0.5 vol% concentration at Re 120 as compared to base fluid. Convective heat transfer coefficient and Nu number are illustrated in **Figure 2 (a)** and **(b)** consecutively.

Fluid flow of nanofluid in mini channel was evaluated with the pressure drop measurement between inlet and outlet fluid. High pressure drop was expected as the coolant has been forced to pass through a narrow channel of cooling plate PEMFC. The increase in pressure drop eventually has increased the additional pumping power required in order to move a more viscous and a higher density of nanofluid. Highest pumping power is measured at 0.5 vol% concentration at Re 120 which is an additional of 0.02W as compared to the base fluid which is equivalent to 58% increment as shown in Figure 3.

4. Conclusion

In this experimental work, heat transfer and fluid flow performance of Al_2O_3 in base fluid of 50:50 (water:EG) in a single cooling plate of PEMFC cooling plate are presented. The findings show that there is an enhancement in heat transfer performance with Al_2O_3 in 50:50 (water:EG) as compared to the base fluid of 50:50 (water:EG). This enhancement is represented by improvement in both convective heat transfer coefficient and Nu number. However, the pumping power increase for a single plate is relatively small compared to the heat transfer enhancement and can be neglected. The effect of high electrical conductivity to an actual fuel cell operation is the main concern and a correlation on cooling rate improvement to electrical power loss is currently being investigated.

Acknowledgment

The author would like to thank Universiti Teknologi MARA (UiTM) for financial supports given under 600-RMI/ERGS 5/3 (32/2013).

References

[1] G. Zhang and S. G. Kandlikar, "A critical review of cooling techniques in proton exchange membrane fuel cell stacks," *international journal of hydrogen energy,* vol. 37, pp. 2412-2429, 2012.

[2] J. T. Cieśliński, B. Dawidowicz, and S. Smoleń, "Influence of stack temperature on PEM fuel cell performance," presented at the 3rd International Conference, Low Temperature and Waste Heat Use in Energy Supply Systems, Bremen, , 2012.

[3] Y. Wang, K. S. Chen, J. Mishler, S. C. Cho, and X. C. Adroher, "A review of polymer electrolyte membrane fuel cells: Technology, applications, and needs on fundamental research," *Applied Energy,* vol. 88, pp. 981-1007, 2011.

[4] B. Ramos-Alvarado, P. Li, H. Liu, and A. Hernandez-Guerrero, "CFD study of liquid-cooled heat sinks with microchannel flow field configurations for electronics, fuel cells, and concentrated solar cells," *Applied Thermal Engineering,* vol. 31, pp. 2494-2507, 2011.

[5] S. Pandiyan, K. Jayakumar, N. Rajalakshmi, and K. S. Dhathathreyan, "Thermal and electrical energy management in a PEMFC stack – An analytical approach," *International Journal of Heat and Mass Transfer,* vol. 51, pp. 469-473, 2008.

[6] S. G. Kandlikar and Z. Lu, "Thermal management issues in a PEMFC stack – A brief review of current status," *Applied Thermal Engineering,* vol. 29, pp. 1276-1280, 2009.

[7] R. Saidur, K. Y. Leong, and H. A. Mohammad, "A review on applications and challenges of nanofluids," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 1646-1668, 2011.

[8] S. S. Khaleduzzaman, R. Saidur, J. Selvaraj, I. M. Mahbubul, M. R. Sohel, and I. M. Shahrul, "Nanofluids for Thermal Performance Improvement in Cooling of Electronic Device " *ADVANCED MATERIALS RESEARCH,* vol. 832, 2014.

[9] P. Naphon and L. Nakharintr, "Heat transfer of nanofluids in the mini-rectangular fin heat sinks," *International Communications in Heat and Mass Transfer,* vol. 40, pp. 25-31, 2013.

[10] M. Keshavarz Moraveji, R. Mohammadi Ardehali, and A. Ijam, "CFD investigation of nanofluid effects (cooling performance and pressure drop) in mini-channel heat sink," *International Communications in Heat and Mass Transfer,* vol. 40, pp. 58-66, 2013.

[11] M. R. Sohel, S. S. Khaleduzzaman, R. Saidur, A. Hepbasli, M. F. M. Sabri, and I. M. Mahbubul, "An experimental investigation of heat transfer enhancement of a minichannel heat sink using Al2O3–H2O nanofluid," *International Journal of Heat and Mass Transfer,* vol. 74, pp. 164-172, 2014.

[12] I. Zakaria, W. H. Azmi, W. A. N. W. Mohamed, R. Mamat, and G. Najafi, "Experimental Investigation of Thermal Conductivity and Electrical Conductivity of Al2O3 Nanofluid in Water - Ethylene Glycol Mixture for Proton Exchange Membrane Fuel Cell Application," *International Communications in Heat and Mass Transfer,* vol. 61, pp. 61-68, 2015.

[13] K. G. K. Sarojini, S. V. Manoj, P. K. Singh, T. Pradeep, and S. K. Das, "Electrical conductivity of ceramic and metallic nanofluids," *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* vol. 417, pp. 39-46, 2013.

[14] B. C. Pak and Y. I. Cho, "Hydrodynamic and Heat transfer study of dispersed fluids with submicron metallic oxide particles," *Experimental Heat Transfer,* vol. 11, pp. 151-170, 1998/04/01 1998.

[15] Y. Xuan and W. Roetzel, "Conceptions for heat transfer correlation of nanofluids," *International Journal of Heat and Mass Transfer,* vol. 43, pp. 3701-3707, 2000.

[16] R. S. L. Alina Adriana Minea, "Investigations on electrical conductivity of stabilized water based Al2O3 nanofluids," *Microfluid Nanofluid,* vol. 13, 2012.

[17] K. G. K. Sarojini, S. V. Manoj, P. K. Singh, T. Pradeep, and S. K. Das, "Electrical conductivity of ceramic and metallic nanofluids," *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* vol. 417, pp. 39-46, 2013.

[18] S. Aldrich, "Safety Data Sheet," in *Aluminium Oxide*, ed, 2013.

[19] ASHRAE, "2009 ASHRAE® Handbook Fundamentals," in *Physical Properties of Secondary Coolants (Brines)*, ed, 2009.

[20] Y. A.Cengel and M. A.Boles, *Thermodynamics - An engineering approach* vol. 6th Edition: Mc Graw Hill, 2007.

[21] T. M. G. o. Companies, "Ethylene Glycol Product Guide," T. M. G. o. Companies, Ed., ed: The MEGlobal Group of Companies, 2008.