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Thermal Analysis of Heat Transfer Enhancement and Fluid Flow for Low Concentration of Al_2O_3 Water - Ethylene Glycol Mixture Nanofluid in a Single PEMFC Cooling Plate

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Abstract

Numerical analysis of thermal enhancement for a single Proton Exchange Membrane Fuel Cell (PEMFC) cooling plate is presented in this paper. A low concentration of Al_2O_3 in Water - Ethylene Glycol mixtures was used as coolant in 220mm x 300mm cooling plate with 22 parallel mini channels of 1 x 5 x 100mm. This cooling plate mimicked conventional PEMFC cooling plate as it was made of carbon graphite. Large header was added to have an even velocity distribution across all Re number studied. The cooling plate was subjected to a constant heat flux of 100W that represented the artificial heat load of a single cell. Al_2O_3 nano particle volume % concentration of 0.1 and 0.5 vol was dispersed in 50:50 (water: Ethylene Glycol) mixtures. The effect of different flow rates to heat transfer enhancement and fluid flow in Re range of 30 to 150 were observed. The result showed that thermal performance has improved by 7.3 and 4.6% for 0.5 and 0.1 vol % Al_2O_3 consecutively in 50:50 (water:EG) as compared to base fluid of 50:50 (water:EG). It is shown that the higher vol % concentration of Al_2O_3 the better the heat transfer enhancement but at the expense of higher pumping power required as much as 0.04W due to increase in pressure drop. The positive thermal results implied that Al_2O_3 nanofluid is a potential candidate for future applications in PEM fuel cell thermal management

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Keywords: mini channel; nanofluid; heat transfer; PEMFC; fluent

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1. Introduction

Fluid flow and convective heat transfer study in mini channel has received significant attention from researchers due to miniaturization of components design nowadays. Adoptions of mini channel cover from high power densities of electronic devices , fuel cell power sources such as proton exchange membrane fuel cell (PEMFC) and also concentrated solar panels [1].

Nanofluid in mini channel has been experimentally investigated by researchers mostly for electronic heat sink application [2, 3]. TiO_2 in de-ionized water nanofluid has been studied by Naphon and Nakharintr [3] in term of heat transfer characteristic by varying three different channel heights. Sohel et al [2] on the other hand studied 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

Mini channel in an electrically active heat transfer environment such as cooling plate of PEMFC is desirable due to compactness of the stack size required. Mini channel also help to improve heat transfer rates that leads to lower maximum cell temperature [1, 4-6]. Nanofluid in fuel cell mini channel is relatively new due to the limited availability of open literature on the electrical conductivity of nanofluid. Sarojini et al. [7] have measured electrical conductivity of Al_2O_3, CuO and Cu in distilled water and EG while Wong and Kurma [8] studied the effect of volume concentration on electrical conductivity of Al_2O_3 nanofluid

Electrical conductivity of nanofluid in PEMFC was investigated by Zakaria et al [9] which has eventually established a thermo-electrical conductivity (TEC) ratio for Al_2O_3 nanofluid in water:EG mixture for PEMFC . According to the study, Ethylene glycol (EG) concentration of more than 40% in a water:EG mixture is feasible for PEMFC application considering both thermal and electrical conductivity requirement. This study numerically investigates few potentials alternative coolants for PEMFC which are 0.1 and 0.5 % vol concentration of Al_2O_3 in 50:50 (water:EG) in term of heat transfer and fluid flow characteristic. A constant heat flux is subjected to the carbon graphite plate and performance in Re number 30 to 150 was observed.

2. Methodology

2.1. Nanofluid thermo physical properties measurement

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	[10-13]
Distilled water	0.615	4180	0.854	999	[11, 12, 14-16]
Water : EG (50:50)	0.3712	3354	3.21	1110	

Thermo physical properties such as thermal conductivity and viscosity of nanofluids used in this study were measured at temperature of 27°C. Thermal conductivity of nanofluid is 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 [10] using Equation (1) :

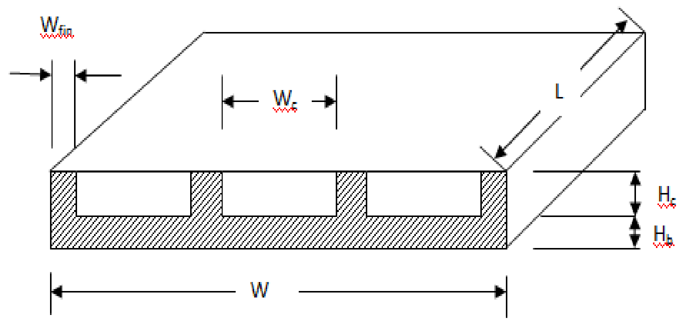
$$\rho_{nf} = (1 - \emptyset)\rho_f + \emptyset\rho_p \quad (1)$$

Specific heat is calculated using model from Xuan and Roetzel [17] using Equation (2) :

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

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

2.2. Mathematical model of mini channel in single cooling plate PEMFC



Parameter	*Dim (mm)*
W_{fin}	1
W_c	5
W	140
L	180
H_c	1
H_b	1.5

Fig. 1. Schematic of mini channel in cooling plate PEMFC

A 3D computational fluid dynamic (CFD) was developed based on a single cooling plate dimensions as in **Figure 1.** The material used for the mini channel is carbon graphite to mimic the conventional material used in cooling plate of PEMFC. The plate consists of 22 parallel mini channels with dimensions of 5mm x 1mm x 100 mm. The plate was subjected to a constant heat load of 100 W.
In order to simplify the analysis, few assumptions have been made:

1. The flow is incompressible, laminar and in steady state.
2. The effect of body force is neglected
3. The fluid properties are constant and viscous dissipation is neglected.
4. The fluid phase and nanoparticles are in thermal equilibrium with zero relative velocity and the resultant mixture can be considered as a conventional single phase.
5. All mini channels are identical in heat transfer and fluid flow characteristic thus only one channel is simulated for computation.

The governing equations on the above assumptions are as follows.

Continuity equation :

$$\nabla.\left(\rho_{nf}\,.V_m\right) = 0 \tag{3}$$

Momentum equation :

$$\nabla.\left(\rho_{nf}\,.V_m.V_M\right) = -\nabla P + \nabla.\left(\mu_{nf}\,.\nabla V_m\right) \tag{4}$$

Energy equation for coolant :

$$\nabla.\left(\rho_{nf}\,.C.V_m.T\right) = \nabla.\left(k_{nf}\,.\nabla T\right) \tag{5}$$

The heat conduction through the solid wall :

$$0 = \nabla.\left(k_s\,.\nabla T_s\right) \tag{6}$$

No slip boundary at the wall :

$$\vec{V} = 0\ (@Walls) \tag{7}$$

Boundary conditions at channel inlet were assumed as :

$$\vec{V} = V_m\ (@inlet) \tag{8}$$

$$P = atmospheric\ pressure\ (@outlet) \tag{9}$$

Heat is conducted through the solid and dissipated away via forced convection of cooling liquid that passes through the mini channel. Bottom surface is uniformly heated with constant heat flux.

$$-k_{nf}.\nabla T = q^{"}(@Bottom\ of\ mini\ channel) \tag{10}$$

$$-k_{nf}.\nabla T = 0(@Top\ of\ mini\ channel) \tag{11}$$

2.3 Heat transfer and fluid flow analysis

Heat transfer coefficient is then calculated using general Equation (12):

$$h = \frac{Nuk_{nf}}{D_h} \tag{12}$$

Pressure drop is determined through Darcy Friction factor [18] for fully developed laminar flow and expressed as :

$$\Delta p = f\,\frac{\rho u_m^2 L}{2D_h} \tag{13}$$

Pumping power is estimated using Equation (14) :

$$W_p = Q \times^{\cdot} \Delta P \tag{14}$$

3. Result and discussion

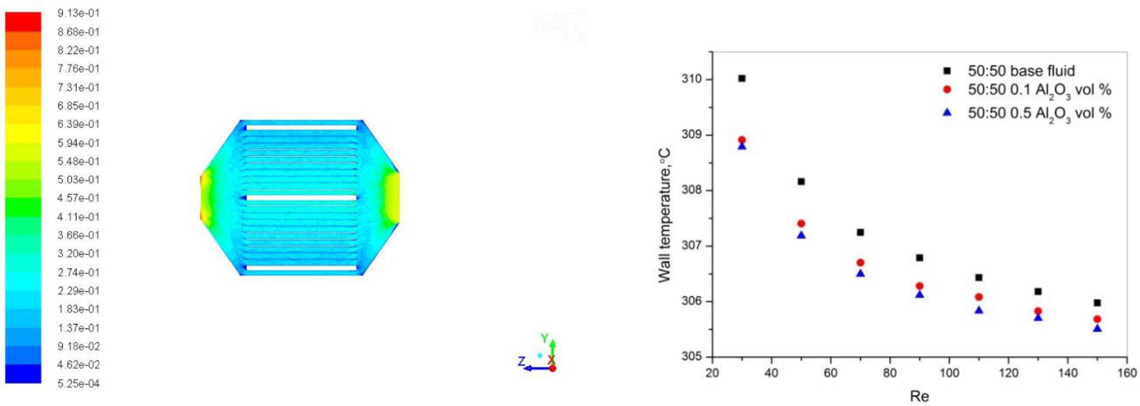


Fig 2. (a) Velocity vector of 0.5 vol % Al_2O_3 in 50:50 (water:EG) at Re 150 ; (b) Wall temperature effect

Even fluid flow of nanofluids as an effect of large distributor used in this analysis is shown in **Figure 2 (a).** Plate temperature effect from this nanofluids flow is then monitored as shown in **Figure 2 (b).** In general, 0.5 vol % of Al_2O_3 in 50:50 (water:EG) at Re 20 was capable of reducing the plate temperature by 1.2°C as compared to base fluid of 50:50 (water:EG). It was also observed that plate temperature reduces as both vol % concentration and Re number is increased.

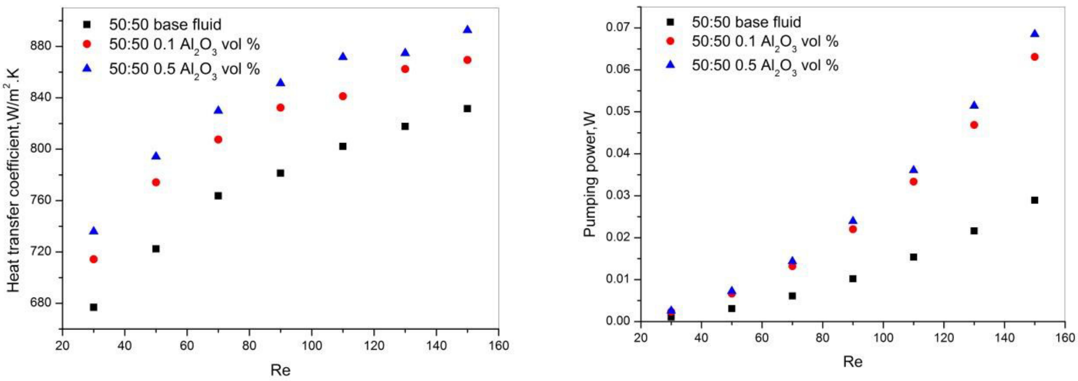


Fig 3. (a) Convective heat transfer effect at different vol concentration; (b) Effect of nanofluid to pumping power

The lower plate temperature resulted in higher convective heat transfer enhancement as shown in **Figure 3(a).** Highest heat transfer coefficient is at Re 150 for 0.5% vol % with 7.3% higher as compared to base fluid. The heat transfer coefficient increases as both the volume concentration and Re number are increased for all Al_2O_3 nanofluids. The addition of nano particles have enhanced the thermo physical properties of nanofluids over base fluids in term of thermal conductivity and Brownian motion which eventually improved the thermal performance of the nanofluids.

As the fluid was forced thru a narrow passage in mini channel, a higher pressure drop was expected. This has resulted an additional pumping power requirement in order to overcome such losses. Higher density and viscosity of nanofluids have also contributed to the higher pumping power required as compared to the base fluid. Highest additional pumping power is observed at 0.5 vol % of Al_2O_3 at Re 150 with additional of 0.04W. This increment is at 1.37 times higher as compared to base fluid. **Figure 3b** describes the result of the pumping power effect with the adoption of nanofluids in mini channel.

4. Conclusion

In this study, heat transfer enhancement and fluid flow of 0.1 and 0.5 vol % of Al_2O_3 in 50:50 (water :EG) are numerically investigated. The results show that the heat transfer coefficient increases as both the volume % concentration and Re are increased. However, the heat transfer enhancement comes with a demerit of higher pumping power required as compared to base fluid. The balance between both heat transfer enhancement and the penalty of higher pumping power need to be further investigate to ensure that the adoption of nanofluid in PEMFC mini channel is beneficial.

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References

[1] 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.

[2] 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.

[3] 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.

[4] 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.

[5] 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.

[6] 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.

[7] 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.

[8] K. F. V. Wong and T. Kurma, "Transport properties of alumina nanofluids," *Nanotechnology,* vol. 19, 2008.

[9] 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.

[10] 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.

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

[12] 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.

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

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

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

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

[17] 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.

[18] F. Incropera, D. P.Dewitt, T. L.Bergman, and A. S.Lavine, *Fundamental of Heat and Mass Transfer*: John Wiley & Sons, 2005.