EFFECT OF TITANIUM OXIDE NANOFLUID CONCENTRATION ON PRESSURE DROP

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ABSTRACT

The new technology of nanoparticle has introduced the advance heat transfer fluid called nanofluid. In an automobile engine cooling system, the pumping power has to be considered in order to optimize the overall system. Reflecting to the statement, this paper concentrate on the study of pressure drop for Ethylene Glycol (EG) based nanofluid. The nanofluid is prepared by dilution technique of Titanium Oxide (TiO_2) in based fluid of mixture water and ethylene glycol (EG) in volume ratio of 60:40, at three volume concentrations of 0.5 %, 1.0 % and 1.5 %. The experiment was conducted under a flow loop with a horizontal tube test section at various values of flow rate for the range of Reynolds number less than 30,000. The experimental result of TiO_2 nanofluid pressure drop is compared with the Blasius equation for based fluid. It was observed that pressure drop increase with increasing of nanofluid volume concentration and decrease with increasing of nanofluid temperature insignificantly.

Keywords: TiO_2 nanofluid, ethylene glycol, pressure drop, friction factor.

INTRODUCTION

Nanofluid is a composite fluid that consists of nanoparticles with a dimension measured in nanometers, less than 100 nm dispersed in a based fluid. Over the past decade, many researchers reported that the nanofluids possess substantially higher thermal conductivity [1-4]. This advantage makes them very useful as heat transfer fluids in many applications such as coolants in the automotive field and electronic industries [3, 5-7]. One of the importance why the need to study on nanofluids is because the enhancement in thermal conductivity will increase the heat transfer rate. Due to nanoparticles size suspended in the based fluids, there were drastic changes of properties that benefit in heat transfer. Moreover, the nanofluids are most suitable for rapid heating and cooling systems [2, 8]. The study of nanofluid was started in 1990s by Choi [9] and Eastman [10]. Later on, many researchers have studied on nanofluids properties using various types of nanoparticles such as Al_2O_3, TiO_2 and CuO. With the interesting findings in nanofluid performance especially in heat transfer, the research has expanding the application on the devices such as car radiator coolant [7,11-15], heat exchanger [2,12,16-19], coolant in electronic heat sink [20] and coolant in nuclear reactor [21]. The study on pressure drop is essential because the nanofluid may cause negative impact on the pressure drop. Due to nanofluid owns characteristics and thermo-physical properties, they may have high pressure drop penalty to the fluid flow in the system. This reason also becomes the main factor whether nanofluids are applicable in industrial or not. Arani and Amani [22] studied on TiO_2 nanofluid at very low concentration in convective heat transfer where the pressure drop affected by the Reynolds number. At high Reynolds number greater than 30000, more power needed to compensate the pressure drop of the nanofluid compare to low Reynolds number. Sahin, Gultekin, Manay, and Karagoz [23] used alumina in water nanofluid at concentration from 0.5 to 4.0 %. They found that the friction factor decreases with increasing of Reynolds number. However, due to nanofluid viscosity (nanofluid at high concentration), the friction factor increases when the volume concentration increases. Duangthongsuk and Wongwises [24] studied on TiO_2-water nanofluid at concentration of 0.2 % used in heat exchanger with the findings that the nanofluid has little penalty in pressure drop. The increases in nanofluid temperature affect to nanofluid viscosity which resulted in a reduction of the pressure drop in the fluid flow. From the study conducted by Azmi et al. [25], the pressure drop of the SiO_2 water-based nanofluid increase with the particle concentration up to 3.0% and decreases thereafter. With the increasing in Reynolds number, the friction factor of the nanofluid decreases for all nanofluid concentration in the study.

Teng, Hung, Jwo, Chen, and Jeng [26] studied the pressure drop in circular pipes using TiO_2-water nanofluid in laminar and turbulent flow. They found that the pressure drop reduce when the temperature increase. However, the laminar flow showed that the enhancement ratio for pressure drop is higher than turbulent flow. Sajadi and Kazemi [27] studied on turbulent convective heat transfer and pressure drop of TiO_2/water nanofluid in circular tube at concentration less than 0.25 %. The findings showed that the pressure drop of nanofluid was slightly higher than that of the base fluid and increased with increasing the volume concentration. Fotukian and Nasr Esfahany [28] studied on CuO in water nanofluid at volume concentration less than 0.24 % in a circular tube, found that the pressure drop increased about 20 % for nanofluid with 0.031 % volume concentration. Kayhani, Soltanzadeh, Heyhat, Nazari and Kowsary [29] used TiO_2-water nanofluid through a uniformly heated horizontal circular tube at concentration range from 0.1 to 2.0 %. The result point out that there was no significant increase in pressure drop for the nanofluid as compared to the distilled water. Aly [30] investigated the numerical study on Al_2O_3 water-based nanofluid flowing inside coiled tube-in-tube heat exchangers for volume concentration of 0.5 to 2.0 %. The result indicates that the friction factor increases with the increase in curvature ratio and pressure drop penalty is negligible with increasing the nanoparticles volume concentration. Until recently, many studies concentrate on nanoparticle dispersed in based fluid of water. However, lack of investigation performed on nanofluid in based of mixture water and ethylene glycol; hence this study is carried out with the intention to provide findings of nanofluids behavior in such mixture based. The effect of titanium oxide nanofluid concentration on pressure drop is analyzed based on comparison with the Blasius equation.

EXPERIMENTAL SETUP

Nanofluid Preparation

The TiO_2 nanofluid used in this study is prepared by dilution technique with average size of 50 nm [25]. Volume concentration at 1.5 % is prepared by calculation from Eqn. (1), then dilute to new concentration of 1.0 % and 0.5 % using Eqn. (2). The nanofluid are immersed in ultrasonic bath for two hours before undergo experiment. The thermo-physical properties of the nanofluids are measured at 50 ºC and 70 ºC. The properties of the nanofluids used in the analysis are presented in Table-1 and Table-2 for temperature of 50 ºC and 70 ºC, respectively.

$$\phi = \frac{\omega \rho_{bf}}{\left(1 - \frac{\omega}{100}\right)\rho_p + \frac{\omega}{100}\rho_{bf}} \tag{1}$$

$$\Delta V = \left(V_2 - V_1\right) = V_1\left(\frac{\phi_1}{\phi_2} - 1\right) \tag{2}$$

where ϕ is volume concentration
ω is weight concentration
ρ is density
$_{bf}$ is based fluid
V is volume

Table-1. Thermo-physical properties of TiO_2 nanofluids at 50 ºC.

Volume concentration, ϕ	Density, ρ	Specific heat, C_P	Thermal conductivity, k	Viscosity, μ
[%]	[kg/m³]	[J/kg.K]	[W/m.K]	[kg/m.s]
mixture water/EG	1045.35	3569.0	0.428	0.00157
0.5	1061.27	3511.7	0.432	0.00164
1.0	1077.20	3456.0	0.448	0.00177
1.5	1093.12	3402.0	0.488	0.00182

Table-2. Thermo-physical properties of TiO_2 nanofluids at 70 ºC.

Volume concentration, ϕ	Density, ρ	Specific heat, C_p	Thermal conductivity, k	Viscosity, μ
[%]	[kg/m³]	[J/kg.K]	[W/m.K]	[kg/m.s]
mixture water/EG	1033.37	3636.0	0.438	0.00111
0.5	1049.35	3576.7	0.443	0.00125
1.0	1065.34	3519.1	0.462	0.00143
1.5	1081.32	3463.3	0.501	0.00148

Forced Convection Apparatus

The schematic diagram of the experimental setup is shown in Figure-1. The setup consists of a flow meter, pressure transducer, water pump, collecting tank, control panel, chiller and test section. A copper tube of 1.5 m length having inner diameter of 16 mm and outer diameter of 19 mm. The working liquid is circulated with a pump of 1.0 horse power rating to force the fluid through the copper tube. The liquid is stored in a collecting tank made of stainless steel of 30 L capacity. Uniform heating of the 1.5 m copper tube is achieved by wrapping it with two nichrome heaters each of 1.5 kW maximum electric rating. The tube is enclosed in ceramic fiber insulation to minimize heat loss to the atmosphere. K-type thermocouples are attached to the test section at the inlet, outlet and on the surface at 0.25, 0.5, 0.75, 1.0 and 1.25 m from the inlet of the tube to record temperatures at various locations. A flow meter in the range of 0 to 30 LPM is connected to the test section. A chiller of 1.4 kW maximum capacity is connected to the collecting tank to regulate the inlet temperature of the liquid to a desired value. A pressure transducer connected across the test section to record the pressure drop. The total length of the fluid flow considering the flexible piping is approximately 4.0 m which ensures fully turbulent flow condition at the entry to the test section.

A constant value of 600 W is supplied by the heaters to the test section. The chiller adjusted to attain a liquid average temperature of 50 ºC and 70 ºC in the test section with a maximum variation of ±1 ºC. A data logger is connected to record the surface temperature of the copper tube (test section) and the inlet and outlet temperatures of liquid every second to determine the state of the experiment. At steady state, the temperatures, the flow rate and the power input to the heater as well the pressure drop are recorded. Experiments are undertaken at different flow rates to determine the pressure drop of nanofluid for 0.5 %, 1.0 % and 1.5 % volume concentration. The friction factors are calculated using Darcy pressure drop equation. The friction factors are determined for mixture water/EG and TiO_2/mixture water/EG nanofluid at various mass flow rate in tube. The values recorded by the pressure transducer for flow in a tube are analyzed with Darcy equation given by Eqn. (3) and compared with Blasius equation [31] as in Eqn. (4).

$$\Delta P = \frac{f \rho v^2 L}{2D} \tag{3}$$

$$f = \frac{0.3164}{Re^{0.25}} \tag{4}$$

where ΔP is pressure drop
f is friction factor
ρ is density
v is velocity
L is length
D is diameter
Re is Reynolds number

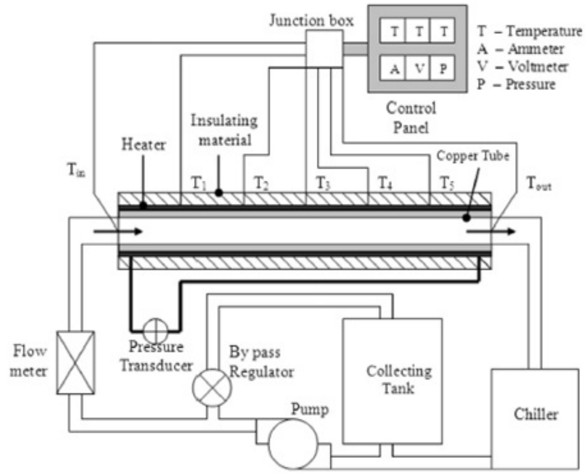

Figure-1. Schematic diagram for convective heat transfer and pressure drop.

RESULTS AND DISCUSSIONS

Pressure Drop

The pressure drops from experimental results are presented in Figure-2 and Figure-3 for temperature of 50 ºC and 70 ºC, respectively. From Figure-2, it shows that the pressure drop increases with increasing in Reynolds number and concentration. Also, the same trend is shown in Figure-3 where the pressure drop also influences by concentration and Reynolds number. However, the pressure drop for nanofluid with concentration of 0.5 % at 70 ºC is much lower than nanofluid at 50 ºC, as shown in Figure-4. This is due to the reason where the temperature rise will reduce the nanofluid viscosity hence will cause deduction in pressure drop as found by Duangthongsuk and Wongwises [24] and Teng et al. [26].

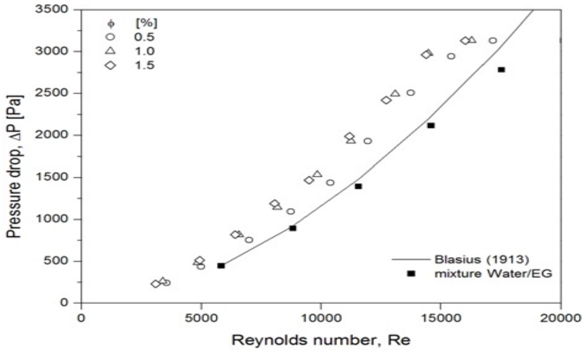

Figure-2. Pressure drop for TiO_2 nanofluid at 50 ºC.

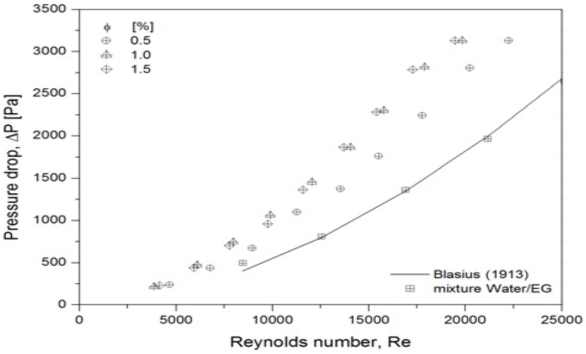

Figure-3. Pressure drop for TiO_2 nanofluid at 70 ºC

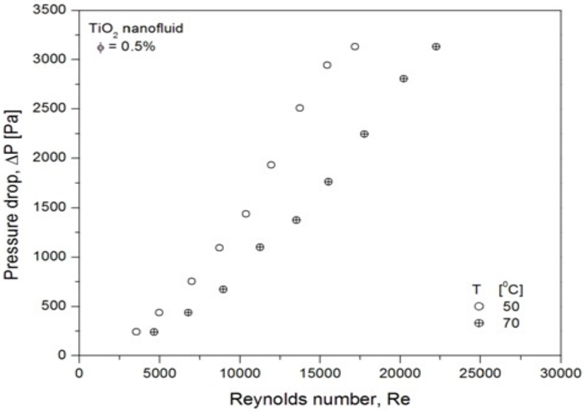

Figure-4. Pressure drop distribution with Reynolds number for 50 ºC and 70 ºC.

Friction Factor

The experimental result of friction factor at 50 °C and 70 °C are shown in Figure-5 and Figure-6, respectively. From the graphs, the friction factor decreases when the Reynolds number increases. However, the nanofluid concentration did not give significant effect to friction factor as compared to mixture of water and EG where the data are scatter near each other within the based fluid (mixture water/EG) points. As a result, the use of nanofluid as heat transfer coolant is applicable and will not cause extra pumping power to the system.

Regression Equation for Friction Factor

Figure-7 displays the comparison of experimental friction factor of the nanofluid with the values from Eqn. (5). The equation developed with an average deviation of 7.1 % and applicable for TiO_2 nanofluid volume concentration up to 1.5 %, temperature of 50 °C and 70 °C, and Reynolds number from 5000 to 30000.

$$f = 0.8243(1+\phi)^{-0.01768} T^{0.04262} Re^{-0.3726} \quad (5)$$

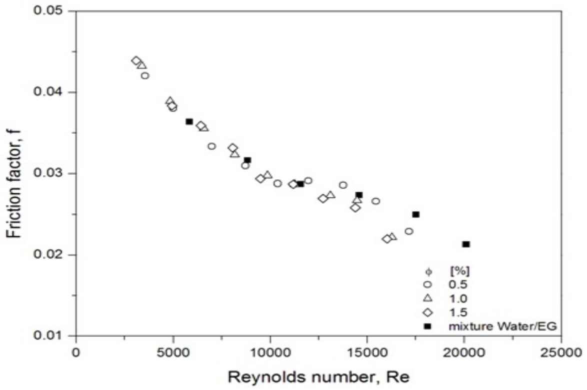

Figure-5. Friction factor at 50 °C.

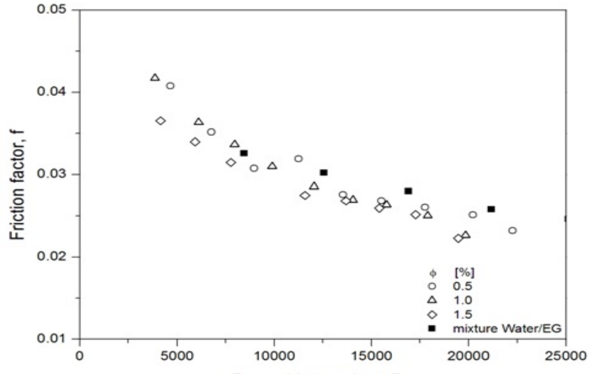

Figure-6. Friction factor at 70 °C.

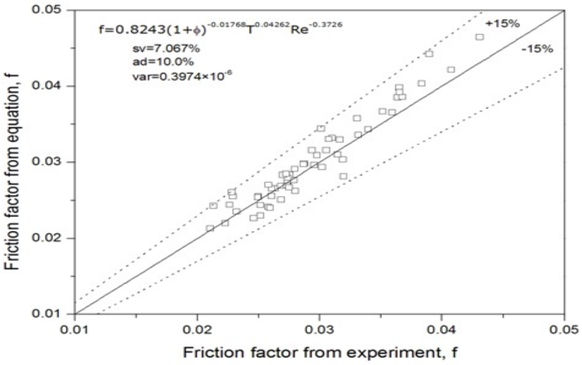

Figure-7. Comparison of friction factor from experiment and equation.

CONCLUSIONS

Pressure drop for TiO_2 nanofluid is not significantly increased compare to based solution. The working temperature of nanofluid will reduce the pressure drop due to the decreasing in nanofluid viscosity. The friction factor of TiO_2 nanofluid can be estimated using Eqn. (5). The TiO_2 nanofluid dispersed in mixture of water and EG can be used in application and will not have significant effect to the pumping power consumption.

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