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FORCED CONVECTION HEAT TRANSFER USING WATER- ETHYLENE GLYCOL (60:40) BASED NANOFLUIDS IN AUTOMOTIVE COOLING SYSTEM

N.A. Usri, W.H. Azmi*, R. Mamat and K. Abdul Hamid

Faculty of Mechanical Engineering, Universiti Malaysia Pahang,
26600 Pekan, Pahang, Malaysia
*Email: wanazmi2010@gmail.com
Phone: +6094246338; Fax: +6094246222

ABSTRACT

Coolant has an important role in stabilizing the temperature of automotive components to prevent damage and failure. As a new class of thermal fluid, nanofluids as a coolant was introduced and its heat transfer coefficient performance is studied. This paper evaluates and analyzes the convective heat transfer coefficient of 60: 40 water-ethylene glycol based nanofluids. Nanofluids are prepared using dilution technique for Titanium Oxide (TiO_2) in 60:40 (water: ethylene glycol) mixture. The experiments were conducted at a constant heat flux boundary under turbulent region with the Reynolds number more than 10,000 and working temperature of 70 ^oC for application in automotive cooling system. It was found that the heat transfer coefficient of the nanofluids enhanced with increased concentration. As a conclusion, the optimum heat transfer enhancement of TiO_2 nanofluids is observed as 33.9 % higher than base liquid of water-ethylene glycol (60:40) mixture at 1.5 % volume concentration. This paper recommend to use Titanium Oxide with 1.0 % and 1.5 % volume concentration dispersed in 60:40 water-ethylene glycol mixture base for automotive cooling system.

Keywords: Titanium Oxide; nanofluids; heat transfer coefficient; ethylene glycol.

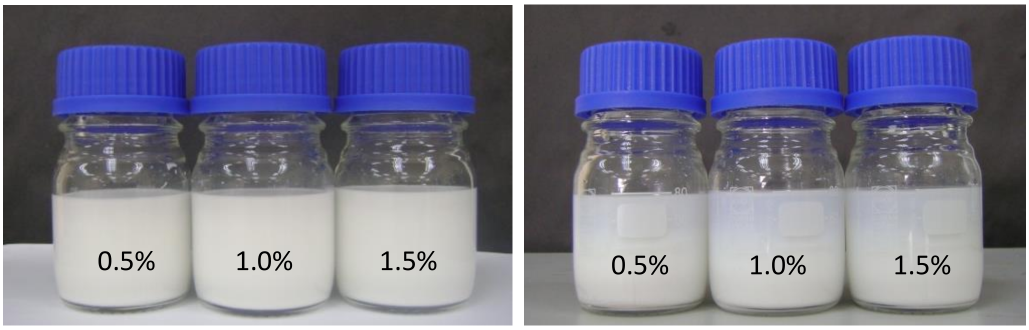
INTRODUCTION

Forced convection heat transfer plays an important role in automobile cooling systems [1]. Throughout the automotive component heat must be added, removed or moved from one process to another. However, the poor thermal ability inherent by conventional fluids puts a limitation on heat transfer to give the best performance. Therefore, it is important to develop a new heat transfer fluid which can give high thermal performance compare to common fluid. In order to overcome the problem, the nanofluids was introduced by Masuda and colleagues [2]. As reviewed by Godson, Raja [3], nanofluids provide enhancement in thermophysical properties such as thermal conductivity and viscosity compare to traditional base fluids such as water and ethylene glycol. Based on previous research conducted by Lee, Choi [4], CuO dispersed in water with weight concentration of 0.9 % in circular tube under turbulent region shows heat transfer coefficient of nanofluids higher than water. The research was further studied by Eastman, Choi [5] using ethylene glycol as based solution with enhancement of thermal conductivity by 40 % higher than based liquid. Hence, this paper aim to investigate heat transfer ability of Titanium Oxide nanofluids using mixture solution of water and ethylene glycol as base solution at temperature of 70 ^oC through experimental evaluation as a contribution to thermal fluid research area. The experiment is conducted at temperature of 70°C in order to meet the minimum requirement of automotive cooling system as provided by Leong, Saidur [6]. The experiment is conducted using Titanium Oxide (TiO_2) dispersed in 60:40 (water: ethylene glycol) mixture base solution.

EXPERIMENTAL SETUP

Preparation of Nanofluids

TiO_2 nanofluids solution is procured from US Research Nanomaterials, Inc. The nanofluids is used in the experiments after dilution process. The method of dilution technique is detailed by Azmi, Sharma [7] and Azmi et al. [8]. Approximately 15 L of the nanofluids is prepared for the conduct of heat transfer experiments. The test solutions are homogenized using ultrasonic homogenizer for 2 hours. It was observed stable during the experiment. Figure 1 shows the test solution in different volume concentration. It was found that the solution is stable for more than 2 months.



(a) First day of preparation (b) After 2 months

Figure 1. Nanofluids prepared by dilution at different volume concentrations.

Thermo-physical Properties

The thermo-physical properties of nanofluids namely thermal conductivity and viscosity for each concentration are measured using KD2 Pro thermal properties analyzer and Brookfield LVDV-III Ultra Rheometer. Whereas, the density and specific heat of nanofluids are obtained using solid-liquid mixture relation given by,

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_{bf} \tag{1}$$

$$C_{nf} = \frac{(1-\varphi)(\rho C)_{bf} + \varphi(\rho C)_p}{(1-\varphi)\rho_{bf} + \varphi\rho_p} \tag{2}$$

where $\varphi = \phi/100$

ρ_{nf} is the density of nanofluids in kg/m³,

φ is the volume fraction,

ϕ is the volume concentration in %,

ρ_p is the density of nanoparticle in kg/m³,

ρ_{bf} is the density of based fluid in kg/m^3,
C_{nf} is the specific heat of nanofluids in J/kg.K,
C_p is the specific heat of nanoparticle in J/kg.K,
C_{bf} is the specific heat of based fluid in J/kg.K.

The summary of thermophysical properties for mixture 60:40 (water: ethylene glycol) based solution as well as TiO_2 nanofluids at different concentration are presented in Table 1.

Table 1. Thermo-physical properties of TiO_2 nanofluids at temperature of 70 ^oC.

Volume Concentration, ϕ (%)	Density, ρ (kg/m^3)	Specific Heat, C (J/kg.K)	Thermal Conductivity, k (W/m.K)	Viscosity, μ (kg/m.s)
0.0	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

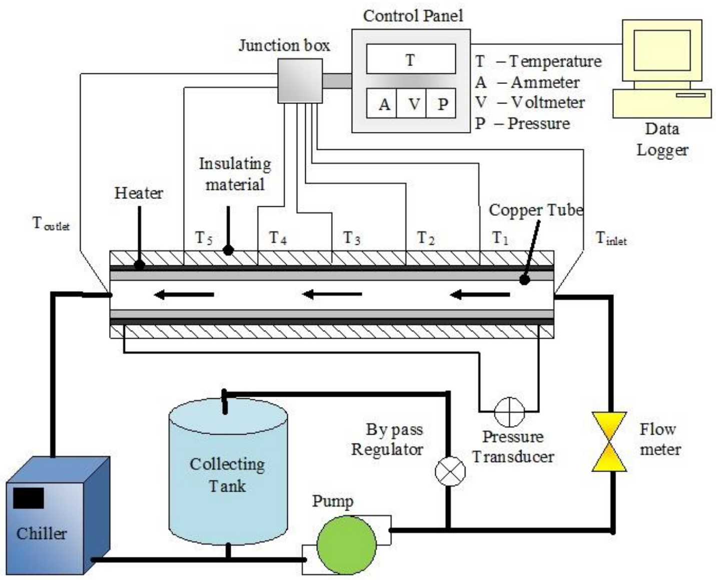


Figure 2. Schematic diagram.

Experimental Apparatus

The schematic diagram of experimental setup is shown in Figure 2. The setup is consists of control panel, chiller, collecting tank, pressure transducer, flow meter, circulating pump, by pass regulator, thermocouples, heater and a test section. In the test section, a tube of copper contains heater installed inside along its length of 1.5 m with inner diameter of 16 mm whereas outer diameter is 19 mm. Besides that, the total length of the entry pipe line is approximately 4.0 m which ensures turbulent flow condition at the entry of the section test. At the test section, 1.0 HP pump is connected to collecting tank of 0.03 m^3 capacity. The function of this pump is to circulate the working fluid through test section. Test section is wrapped with ceramic fiber insulation and two nichrome heaters; each with 1500 W rating. On the other hands, the digital flow meter is connected between the pump and the inlet of the test section for measuring the flow rates. The digital flow meter can measure the flow rate in liter per minute (LPM) up to 30 LPM. A chiller with capacity of 1.4 kW and a collecting tank each mounted on both ends of the test section. At surface of the test section, seven K-type thermocouples were installed. Five of them were installed with position at 0.25 m, 0.5 m, 0.75 m, 1.0 m and 1.25 m from the inlet. The other two of the thermocouples was installed at the inlet and outlet of the test section to measure the temperature of working fluid. Power supply of 600 W will be set constantly to supply heat during the experiment. In the meanwhile, the chiller will be adjusted to obtain fluid bulk temperature of 70 ^{O}C with a deviation of 1 ^{O}C at a predetermined flow rate. Figure 3 shows the test rig setup of the experiment.

Figure 3. Test rig setup.

Experimental Procedure

Experiments are undertaken at different flow rate to determine the heat transfer coefficients of nanofluids for concentration of 0.5 %, 1.0 % and 1.5 %. The flow rate, the temperature of the fluid at the inlet and outlet, and the surface temperatures are recorded under steady condition. The heat transfer coefficient is estimated using the electrical energy supplied represent in Eq. [9] considering heat losses are insignificant and rearranged Newton's law of cooling represent in Eq. (4).

$$Q = V \times I \quad [9]$$

$$h = \frac{Q}{A_s\left(T_s - T_b\right)} \quad (4)$$

where $T_b = \left(T_{inlet} + T_{outlet}\right)/2$; Q is the heat input in W; V is the input voltage in V; I is the input current in A; h is the heat transfer coefficient in W/m^{2}K; A_s is the surface area in m^2; T_s is the surface temperature in ^{o}C; T_b is the bulk temperature in ^{o}C; T_{inlet} is the inlet temperature in ^{o}C; T_{outlet} is the outlet temperature in ^{o}C.

The heat transfer coefficient from the experiment will be used in the dimensionless parameter of Nusselt number as shown in Eq. (5):

$$Nu_{\exp} = \frac{h_{\exp} D}{k_{nf}} \tag{5}$$

where, $Nu_{\exp}$ is experimental Nusselt number, $h_{\exp}$ is the experiment heat transfer coefficient, D is copper tube diameter, and k_{nf} is thermal conductivity of nanofluids. This experimental analysis is similar to previous researcher [7, 8, 10, 11] which consider constant heat flux.

RESULTS AND DISCUSSION

Thermal Conductivity and Viscosity

The measured value of thermal conductivity and viscosity are presented in Figure 4 and 5. Figure 4 illustrates that the thermal conductivity of nanofluids increased with volume concentration. In addition, thermal conductivities of nanofluids are higher compare to based solution. Meanwhile, Figure 5 presented increment pattern of viscosity for nanofluids with volume concentration. For both figures, the measured value of thermal conductivity and viscosity are plotted with the based solution data given by ASHRAE [12] showing the effect of adding nanoparticles in the base fluid for both properties. The similar pattern was found by previous researcher Abdul Hamid, Azmi [13] as in the paper, they investigate heat transfer performance for Titanium Oxide nanofluids dispersed in 60:40 water-ethylene glycol mixture based at working temperature of 30 ^{o}C.

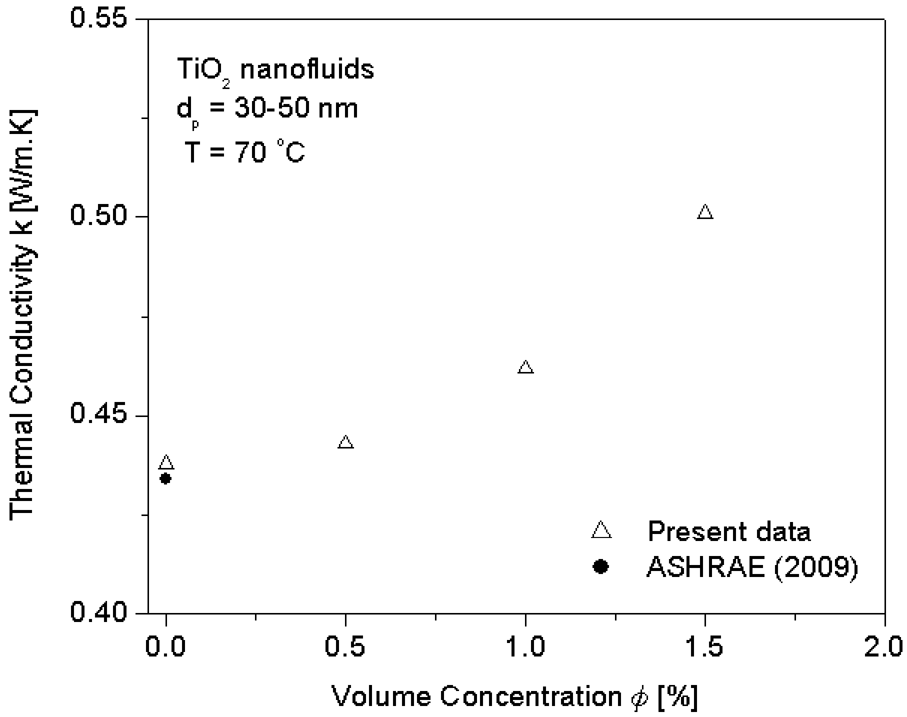


Figure 4. Thermal conductivity of TiO_2 nanofluids.

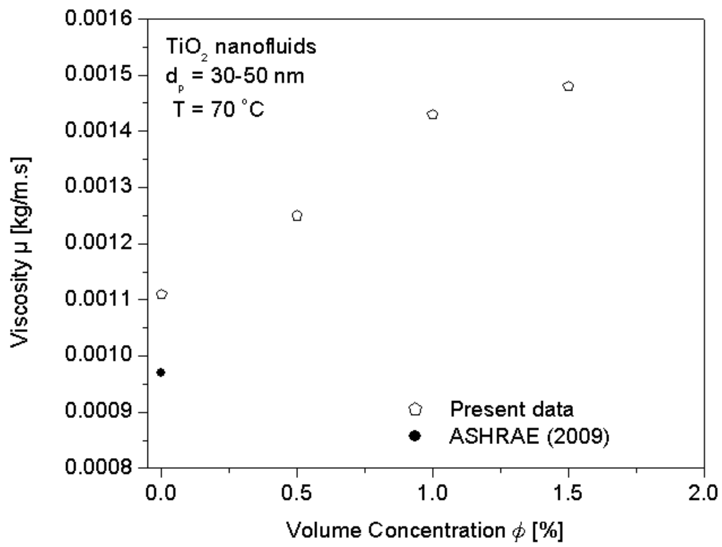


Figure 5. Viscosity of TiO_2 nanofluids.

Forced Convection Heat Transfer

The reliability of the experimental setup is established by comparing Nusselt number of 60:40 ratio (water: ethylene glycol) mixture with single-phase liquid relation by Dittus and Boelter [14] in Eq. (6). This equation is valid for Re > 10^4 and 0.6 < Pr < 200.

$$Nu = 0.023\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \tag{6}$$

where, *Nu* is Nusselt number, Re is the Reynolds number, and Pr is Prandtl number.

Based on agreement of present experimental data with Eq. (6) shown in Figure 6, experiments are further undertaken with TiO_2 nanofluids in the volume concentration of 0.5 %, 1.0 % and 1.5 % at various flow rates.

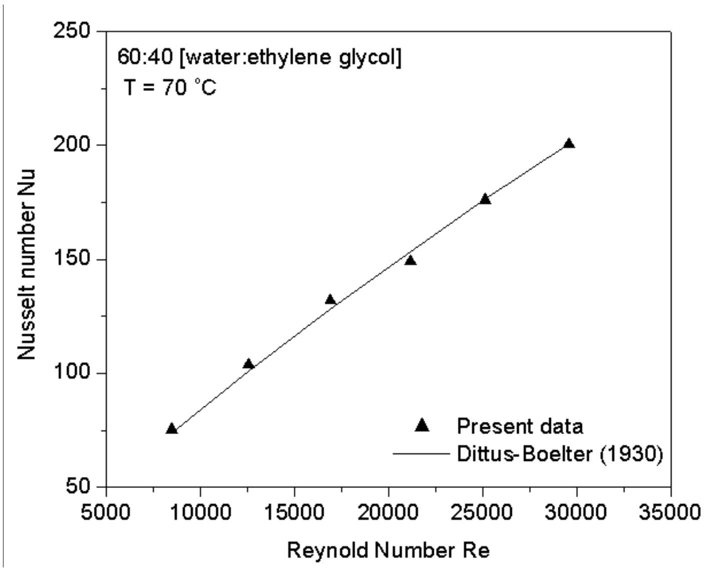


Figure 6. Nusselt number comparison of based fluid with Dittus-Boelter equation.

The convective heat transfer coefficient of TiO_2 nanofluids for volume concentration of 0.5 %, 1.0 % and 1.5 % were investigated experimentally in fully develop turbulent region ranging for Re > 10 000 flowing through a plain tube at temperature of 70 ^oC. Figure 7 shows the heat transfer coefficient of nanofluids for different volume concentrations. Experimental results convey that the heat transfer coefficients of nanofluids are significantly higher than the based fluid. Vajjha, Das [15] mention in their research paper, at higher concentrations, more particles are taking part in heat transport. There is higher surface area of the particles interacting with the base fluid, thereby enhancing the heat transfer process.

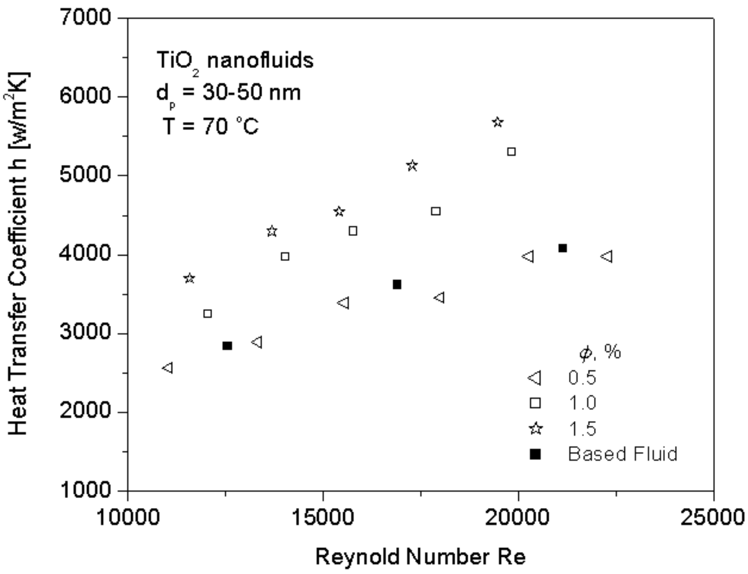


Figure 7. Experimental heat transfer coefficient of nanofluids at different volume concentrations.

Table 2. Percentage enhancement of heat transfer coefficient for different volume concentrations.

Volume Concentration, ϕ [%]	Percentage Enhancement [%]
0.5	-3.7
1.0	20.9
1.5	33.9

The percentage enhancement of heat transfer coefficient at 70 ^oC with respect to volume concentration, ϕ is tabulate in Table 2 and shown in Figure 8. At 1.5 % volume concentration, the heat transfer coefficient shows highest percentage enhancement compare to based fluid by 33.9 %. However, the diminish pattern of heat transfer coefficient is observed at volume concentration of 0.5 % by 3.7 %. Prasher, Bhattacharya [16] conducted convective heat transfer model of analysis in laminar flow. The model is extended by Garg, Poudel [17] in turbulent flow with constant pressure drop. They observed the condition of decrease enhancement in nanofluids convective heat transfer coefficient by considering the amount of heat removed from nanofluids and it's based fluid. Referring to their model analysis, when the enhancement ratio of viscosity to thermal conductivity is greater than 5.0, the nanofluids does not aid heat transfer. This explain the diminish pattern at low concentration of 0.5 % and sum up that TiO_2 nanofluids shows enhancement of convective heat transfer coefficient for volume concentration higher than 1.0 %.

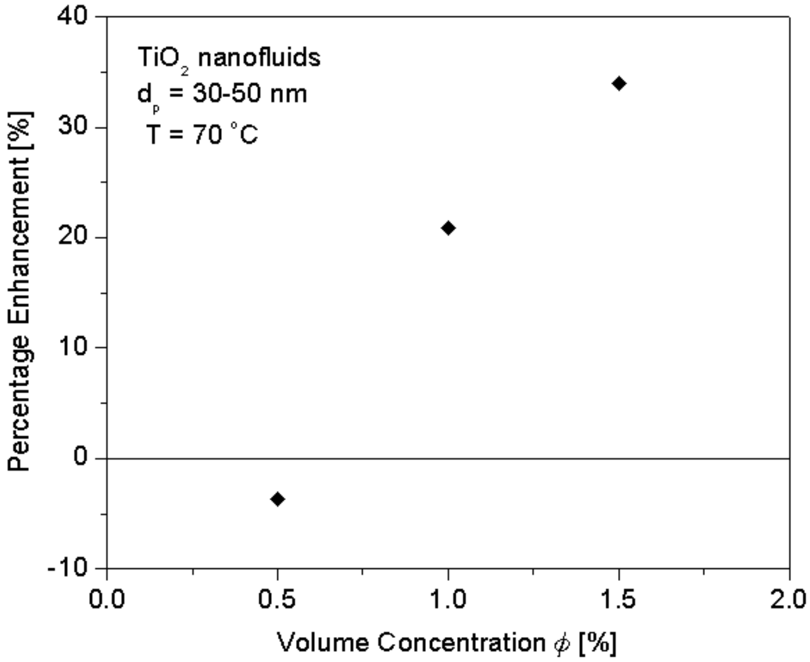


Figure 8. Enhancement of heat transfer coefficient for TiO_2 nanofluids.

CONCLUSION

In this paper, the heat transfer coefficient has been obtained through experiment using TiO_2 nanoparticle dispersed in 60:40 (water: ethylene glycol). The experiment was conducted at a constant heat flux boundary condition under turbulent region with Reynolds number higher than 10 000 for high temperature of 70 ^{o}C through a horizontal circular tube. The enhancement of heat transfer shows positive increment at volume concentration of 1.0 % and 1.5 % by 20.9 % and 33.9%, respectively. Nevertheless, TiO_2 nanofluids has no heat transfer enhancement at volume concentration of 0.5 %. Therefore, TiO_2 nanofluids with 1.0 % and 1.5 % volume concentration are recommended for implementation in an automotive cooling system at temperature of 70 ^{o}C.

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