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Heat transfer augmentation of mixture ratio TiO_2 to SiO_2 in hybrid nanofluid

K.A. Hamid [1], W.H. Azmi[1,2], M.F. Nabil[1],*
Rizalman Mamat[1],
[1] Advanced Automotive Liquid Laboratory, Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.
[2] Automotive Engineering Centre, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

**khamisah0301@gmail.com*

ABSTRACT

The efficiency in heat transfer fluid for cooling systems can be improved with the use of hybrid nanofluid. The combination of two or more single nanoparticles in the hybrid nanofluid improve their thermo-physical properties, hence contribute in heat transfer performance. The experimental investigation on forced convection heat transfer of hybrid nanofluid have been carried out on the evaluation of heat transfer coefficient and Nusselt number. The designated working temperature was 30°C, tested for various volume percentage of TiO_2 *to* SiO_2*. The experiment was conducted in a plain tube under constant heat flux at 7,955W/*m^2*. The hybrid nanofluid was prepared at 1.0% volume concentration at three mixture ratios of* TiO_2 *to* SiO_2*. The range of average enhancement in the heat transfer coefficient and Nusselt number observed were 13.6-29.7% and 9.0-17.8%, respectively. The ratio of* TiO_2 *to* SiO_2 *at 20:80 showed the optimum ratio that can be used to obtain maximum enhancement in heat transfer coefficient and Nusselt number. The pressure drop of the hybrid nanofluid increased about double the base fluid for ratio 50:50. Due to the small increment in friction factor which was 1.03 times, the hybrid nanofluid are appropriate for application of cooling systems. It is recommended to use* TiO_2*-* SiO_2 *nanofluid at ratio 20:80 due to its significant enhancement in heat transfer but least increment in friction factor.*

Keywords: *forced convection, heat transfer,* TiO_2*-*SiO_2 *hybrid nanofluids, mixture, water-ethylene glycol.*

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Introduction

Nanofluids as a heat transfer fluid plays an important role for cooling purpose. The nanofluids field have advances in exploring the hybrid nanofluid where two or more nanoparticles are combine to improve the thermal properties. Several factors were observed to have effect on the performance of hybrid nanofluid as reviewed by Sundar et al. [1], Ganvir et al. [2] and Nabil et al. [3]. The thermal conductivity is one of the important thermal properties of heat transfer fluid which can be improved by dispersion of nanoparticles into the base fluid [4-6]. Harandi et al. [7] reported the effect of temperature and concentration to the thermal conductivity of *f*-MWCNTs–Fe_3O_4/EG hybrid nanofluids where the interaction between the nanoparticles and Brownian motion depict the augmentation. The effect of concentration and temperature were also found by Soltani and Akbari [8] but to the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid. The hybrid nanofluid viscosity is increased with the increased in concentration but decreased with the increased in temperature. The similar trend was also observed by others researchers [9-11].

Previous studies have conducted investigations on the heat transfer performance of various nanofluids and hybrid nanofluids [12-16]. Suresh et al. [13] investigated the convective heat transfer using Al_2O_3-Cu/water hybrid nanofluid in laminar region. The maximum enhancement in Nusselt number reported is 13.6%; compared to water. Takabi et al. [14] conducted a study for turbulent flow where the Reynold number ranging from 10,000 to 100,000 and nanofluid concentration at range of $0\% \leq \phi \leq 2\%$. The enhancement in Nusselt number is estimated to be 32.1% compared to base fluid. A numerical study on laminar convective heat transfer using CFD modelling was conducted by Moghadassi et al. [17]. The finding shows that the enhancement in Nusselt number was about 13.5%, compared to water. The hybrid nanofluid used in their study was also Al_2O_3-Cu. The investigation was set at laminar region for Reynolds number less than 2,500 and constant heat flux at $9{,}549 W/m^2$.

Until recently, there were lack of investigations in convective heat transfer using hybrid nanofluids compared to studies using single nanofluids. In our previous investigation, TiO_2 and SiO_2 nanoparticles were used in the investigation of heat transfer for single nanofluids and gained positive enhancement. To extend the used of these single nanofluids, we utilize both nanoparticle to synthesis hybrid TiO_2-SiO_2 nanofluid. However, most studies in hybrid nanofluid used ratio of 50:50 when mixing the two nanoparticles to produce hybrid nanofluids. Therefore, the present study aims to investigate the effect of various mixture ratio between the two nanoparticles (in producing the hybrid nanofluids) and its influence to the heat transfer performance. The ratio of TiO_2 to SiO_2 selected are 20:80, 50:50 and 80:20.

Methodology

Nanofluid preparation

Two types of nanoparticles used in preparing the hybrid nanofluid are TiO_2 and SiO_2. The details of nanoparticles, water and ethylene glycol (EG) are presented in Table 1. The base fluid W/EG is mixed at 60:40 (vol.%) ratio. Three mixture ratios of TiO_2 to SiO_2 were prepared at 20:80, 50:50 and 80:20, in vol.%. Each ratio is in bulk volume of 22L for the experimental testing of forced convection heat transfer. The single nanofluids TiO_2 and SiO_2 were prepared beforehand by diluting the suspended respective nanoparticles into the W/EG at volume concentration ϕ=1.0%. Then, both TiO_2 and SiO_2 were subjected to mixing process with mechanical stirrer for 1 hour and sonication process using ultrasonic bath for 2 hours to enhance their stability.

Table 1: Details of nanoparticles TiO_2, SiO_2, water and EG [18-20]

Description	TiO_2	SiO_2	Water	EG
Phase	Solid	Solid	Liquid	Liquid
Size [nm]	50	22	-	-
Thermal conductivity k [W/m.K]	8.4	1.4	0.619	0.253
Dynamic viscosity, μ x10^{-3} [kg/m.s]	-	-	1.41	0.777
Density, ρ [kg/m^3]	4,230	2,220	995	1,110
Specific heat, C_p [J/kg.K]	692	745	4,070	2,430

Thermo-physical properties measurement and estimation

Thermal conductivity and dynamic viscosity of hybrid nanofluid were measured with KD2 Pro Thermal Analyzer and Brookfield LVDV III Rheometer. A water bath was used during the measurement to maintain the sample temperature at 30°C. The density and specific heat are estimated using mixture relation as in Equation (1) and Equation (2), respectively;

$$\rho_{hnf} = (1-\varphi)\rho_{bf} + (R\varphi\rho)_{TiO_2} + (R\varphi\rho)_{SiO_2} \tag{1}$$

$$C_{hnf} = \frac{(1-\varphi)\rho_{bf}C_{bf} + (R\varphi\rho C)_{TiO_2} + (R\varphi\rho C)_{SiO_2}}{\rho_{hnf}} \tag{2}$$

where φ ($\varphi=\phi/100$), ρ (kg/m^3), R and C (J/kg.K) are volume fraction, density, ratio fraction and specific heat; respectively. The subscripts $_{hnf}$ and $_{bf}$ represent the hybrid nanofluid and base fluid.

Forced convection heat transfer

The forced convection heat transfer experimental investigation was conducted at constant heat flux 7,955W/m^2 and bulk temperature at 30°C. The main test section is built from a plain tube with 16mm (inner) and 19mm (outer) diameters and a nichrome heater of 12kW ratings. Ceramic fiber insulator used to insulate the section. Seven K-type thermocouples were installed in the location of inlet, outlet and at the tube wall surfaces. Sample of hybrid nanofluid with 22L was placed in the tank, circulated through the system by 1.0hp pump. The nanofluid was heated in the main test section with constant power input at 600W and maintain at the bulk temperature of 30°C by the addition of chiller at the outlet. The variation of fluid flow rate was adjusted within 4 to 20LPM using the bypass regulator and measured with the digital flow meter. The pressure drop between the inlet and outlet was measured with 1.0psi differential pressure transducer. The thermocouples and pressure transducer are connected to ADAMView Advantech data acquisition system to record the data of temperature and pressure. The schematic diagram of the test rig is illustrated in Figure 1. The experimental testing was started with W/EG initially, to validate the Nusselt number with Dittus-Bolter [21] and to ensure the test rig is eligible for testing with nanofluid. The test rig was previously used by Azmi et al. [22], Hamid et al. [23], and Usri et al. [15] with various nanofluid such as TiO_2, SiO_2 and Al_2O_3 in their experimental investigation on forced convection heat transfer.

The dimensionless parameter; Reynolds number (*Re*), Prandtl number (*Pr*) and Nusselt number (*Nu*) are determined form Equations (3)-(6) [24]. The experimental values of Nusselt number are compared with Dittus-Boelter equation [21]. Heat transfer coefficient are determined from Equation (7). The friction factor of experimental is estimated from Equation (8) while pressure drop is calculated from the input voltage of differential pressure transducer; compared to Blasius [25], as in Equations (9)-(11).

$$Re = \frac{\rho v D}{\mu} \tag{3}$$

$$Pr = \frac{\mu C_P}{k} \tag{4}$$

$$Nu_{\mathrm{exp}} = \frac{hD}{k} \tag{5}$$

Dittus-Boelter [21]:

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

$$h_{\mathrm{exp}} = \frac{Q}{A \Delta T} \tag{7}$$

$$f_{\exp} = \frac{\Delta P_{\exp}}{\left(\frac{L}{D}\right)\left(\frac{\rho v^2}{2}\right)} \tag{8}$$

$$\Delta P_{\exp} = \text{input from pressure transducer} \tag{9}$$

Blasius [25]:
$$\Delta P_{Blasius} = f_{Blasius}\left(\frac{L}{D}\right)\left(\frac{\rho v^2}{2}\right) \tag{10}$$

where
$$f_{Blasius} = \frac{0.3164}{Re^{0.25}} \tag{11}$$

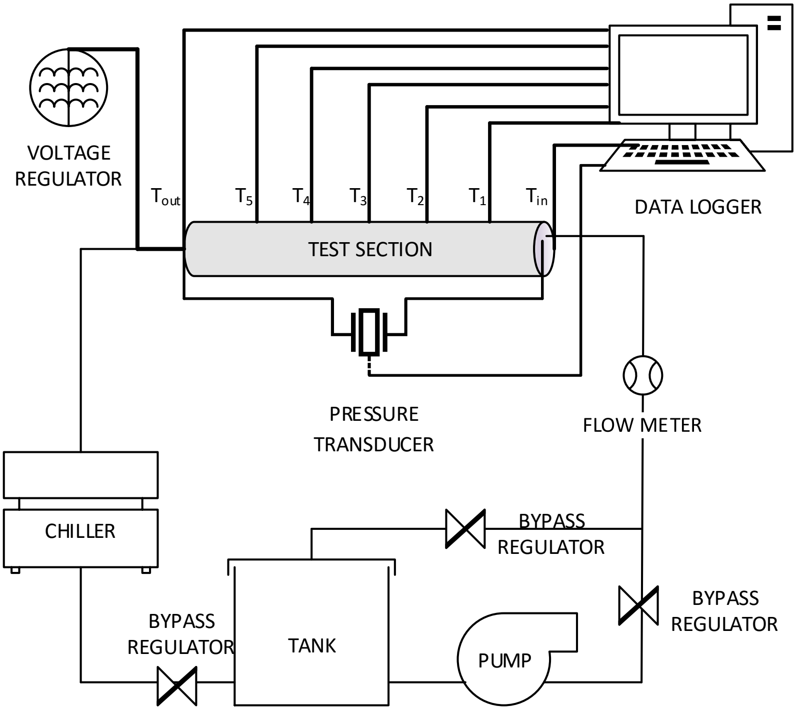

Figure 1: Forced convection heat transfer test rig

Results and Discussion

Thermo-physical properties

The thermo-physical properties of hybrid nanofluid are presented in Figure 2 and Figure 3. All measurement and estimation were conducted at 30ºC. The validation of base fluid W/EG is based on ASHRAE data [26]. The thermal conductivity of hybrid nanofluids shows enhancement compare to W/EG at range of 5.3 to 10.2%. Hybrid nanofluid at ratio 20:80 record the maximum enhancement with 10.2%. The dynamic viscosity of the hybrid nanofluid also varies with the variation of mixture ratio. The 50:50 ratio has greater increment in viscosity value compare to other ratio with increment about 1.24 times the base fluid. The density of hybrid nanofluid increased slightly with value less than 3%; compared to W/EG. The specific heat however decreased up to 2.8%.

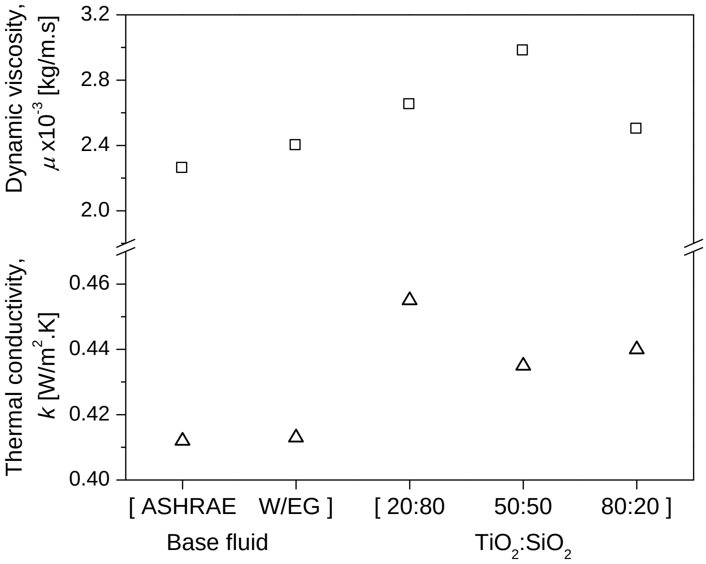

Figure 2: Thermal conductivity and dynamic viscosity of base fluid W/EG and TiO_2-SiO_2 nanofluid

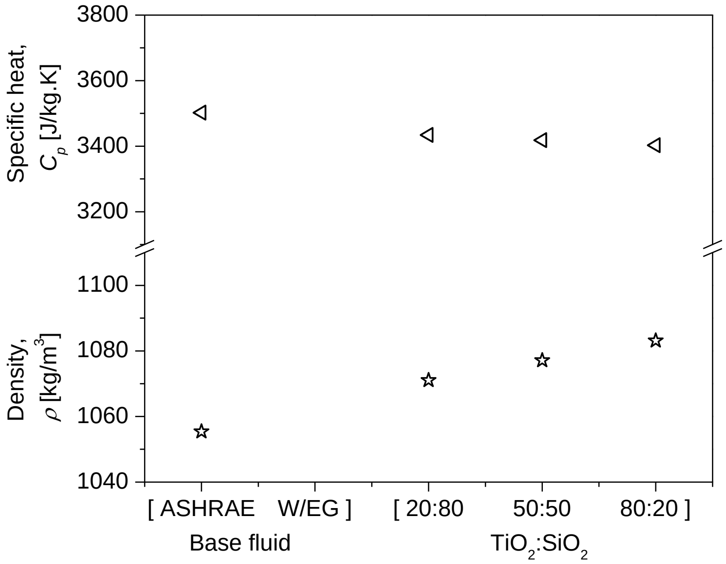

Figure 3: Density and specific heat of base fluid W/EG and TiO_2-SiO_2 nanofluid

Heat transfer performance

The heat transfer coefficient determined from Equation (7) is presented in Figure 4 for Reynolds number range from 3,000 to 11,000. All values of heat transfer coefficient for ratios 20:80, 50:50 and 80:20 show positive enhancement compare to W/EG and follow the trend of the base fluid. With the increasing of Reynolds number, the heat transfer coefficient of hybrid nanofluids are increased. Between the three ratios, 20:80 demonstrate the greater enhancement with 29.7%, followed by 80:20 with 20.8% and 50:50 with 13.6%. The improvement in thermal conductivity of the mixture hybrid nanofluid affect the thermal performance of the hybrid nanofluid, as observed in previous studies [10, 12, 23].

The tabulation of Nusselt number for hybrid nanofluid under Reynolds number ranging from 3,000 to 11,000 is shown in Figure 5. The Nusselt number of hybrid nanofluid increased with the increasing in Reynolds number. The rise in Nusselt number are more prominent when the Reynold number is higher. The increment in Nusselt number varies from the three ratios. This is due to the variation of increment in heat transfer coefficient and thermal conductivity, based on Equation (5). Similar with the trend of the heat transfer coefficient, ratio 20:80 seems to have the largest enhancement compare to ratios 50:50 and 80:20. Ratio 20:80 indicates the maximum enhancement up to

17.8%; whereas ratios 50:50 and 80:20 enhanced at about 9.0% and 13.5% compare to W/EG.

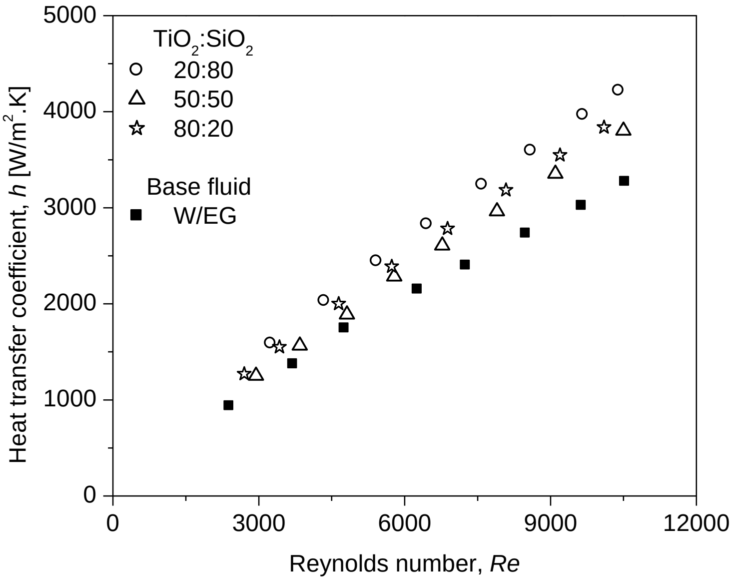

Figure 4: Effect of various mixture ratio TiO_2 to SiO_2 in hybrid nanofluid to heat transfer coefficient

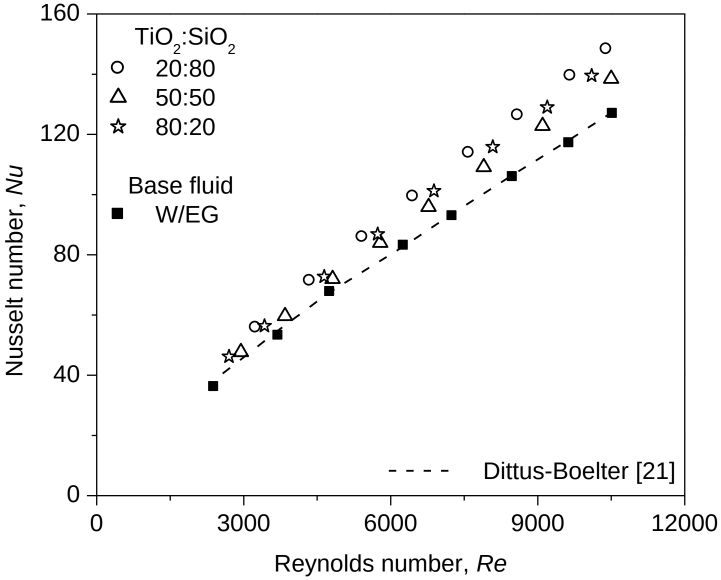

Figure 5: Effect of various mixture ratio TiO_2 to SiO_2 in hybrid nanofluid to Nusselt number

Pressure drop and friction factor

Figure 6 and Figure 7 illustrate the pressure drop and friction factor of hybrid nanofluid at three ratios for Reynolds number less than 11,000. The pressure drop of ratio 50:50 distributed at the highest. However, the rise in pressure drop at this ratio is at about 2 times the base fluid and consider to be small and reflected in the distribution of friction factor as in Figure 5. The friction factor of the hybrid nanofluid decreased exponentially with the increasing of Reynolds number. All ratios shows a very small increment in friction factor and spread closely with the Blasius [25] line and W/EG. The range of increment in the friction factor is 2.8-3.9% for all ratios.

Conclusions

The heat transfer performance of hybrid nanofluid evaluate the heat transfer coefficient and Nusselt number. The influence of thermo-physical properties shows a positive augmentation in the heat transfer coefficient and Nusselt number. Most of the published previous study used the 50:50 ratio when mixing the two single nanoparticles or nanofluids. The findings in the present study show that unequal ratio of two nanoparticles may lead to the improvement in the enhancement, which confirmed by ratio of 20:80 and 80:20. The enhancement in Nusselt number and heat transfer coefficient of these ratios are greater than 50:50 ratio. However, different combination of different types of nanoparticles other than TiO_2 and SiO_2 may have contribute to various performance. This is due to the other properties subjected to the nanoparticles (or single nanofluid) such as particles size, concentration, base fluid and working temperature. The summary of the findings can be concluded as follow:

i. Thermal conductivity of ratios 20:80, 50:50 and 80:20 enhanced up to 10% compared to W/EG. The greater enhancement in ratio 20:80 lead to enhancement in heat transfer coefficient.

ii. Nusselt number and heat transfer coefficient of ratios 20:80, 50:50 and 80:20 increased with the increasing of Reynolds number with maximum enhancement observed are 17.8% and 29.7%, respectively.

iii. Pressure drop and friction factor of hybrid nanofluid are slightly increased at maximum increment 3.9%. The use of hybrid nanofluid at concentration ϕ=1.0% is applicable and tolerable in the real application such as coolant in industrial heat exchanger due to the least increment in friction factor.

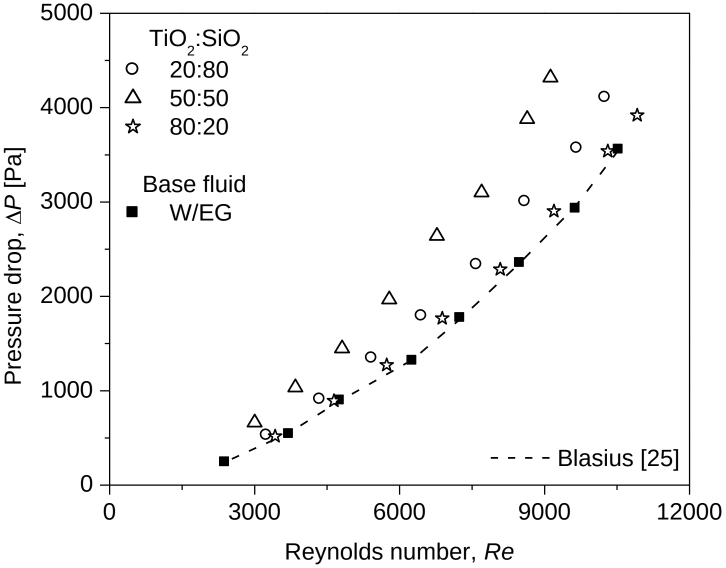

Figure 6: Effect of various mixture ratio TiO_2 to SiO_2 in hybrid nanofluid to pressure drop

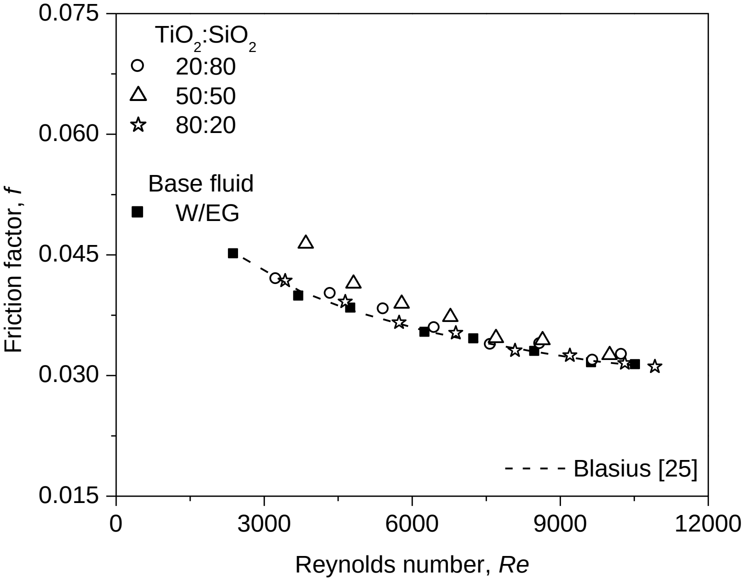

Figure 7: Effect of various mixture ratio TiO_2 to SiO_2 in hybrid nanofluid to friction factor

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