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Numerical Study of Convective Heat Transfer in Plain Tubes with Tri-hybrid Nanofluids for Turbulent Flow Regime

Anwar Ilmar Ramadhan[1*], Wan Hamzah Azmi[2], Raslan A. Alenezi[3], Efrizon Umar[4]

[1]*Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta, Indonesia*
[2]*Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Malaysia*
[3] *Department of Chemical Engineering, College of Technological Studies, Kuwait*
[4]*National Research and Innovation Agency, Indonesia*

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ABSTRACT

The use of increased heat transfer techniques, can improve the thermal performance of the tubes. Computational fluid dynamics studies have been carried out to study the heat transfer characteristics and friction factor of the Al_2O_3-TiO_2-SiO_2 nanofluids-ethylene glycol (EG)/water (W) (40:60) flowing in the plain tube. The three-dimensional turbulent k-ε model that can be realized with enhanced use of heat treatment on the wall is used for turbulent flow regime. The overall evaluation of tubular performance-tested is based on thermo-hydrodynamic performance index. The results showed that behavioural differences depend on the selected parameters to compare *tri*-hybrid nanofluids with the base fluid. In addition, the heat transfer coefficient increases with the increase in volume concentration of nanoparticles at the same Reynolds number. The friction factor of Al_2O_3-TiO_2-SiO_2 nanofluids decreased exponentially with an increase of Reynolds number. The conventional correlations that have been used in turbulent flow regimes to predict heat transfer rates and friction factors are Dittus-Boelter and Blasius correlations, for tubes also apply to *tri*-hybrid nanofluids tested which assume that *tri*-hybrid nanofluids have a homogeneous fluid behaviour.

INTRODUCTION*

The use of heat transfer enhancement techniques can improve the thermal performance of the tubes. The heat transfer technique can be broadly classified into three techniques: Active techniques that require external power to enable the desired flow modifications to improve heat transfer such as electrostatic fields, mechanical assistants, jet cleaning impacts, suctions, injections, surface vibrations, and fluid vibrations: Passive techniques that do not require external power such as rough surfaces, swirl flow devices, treated surfaces, expanded surfaces, displacement enhancements, surface fixtures, surface fasteners, and additives such as nanoparticles: Combined technique that is a combination of two or more techniques mentioned above at a time. There are many applications of heat transfer augmentation by using nanofluids to meet the necessary cooling challenges such as photonics, transportation, electronics, and energy supply industries [1-11].

Many studies have documented that the application of tube ribs, one passive technique, increases heat transfer but at the same time increases the pressure drop [12-18]. For the case of laminar flow, some researchers concluded that heat transfer and pressure drop was not significantly affected by increased tubes [12, 13]. Meanwhile, there is an agreement in the conclusions of the researchers on the heat transfer coefficient and the increased pressure drop for the turbulent flow in the enhanced tube [19-21].

The double tube coaxial heat exchanger is heated by solar energy using a nanofluid Aluminum oxide and is experimentally and numerically presented by Luciu, et al. [22]. Forced convection of the nanofluid turbulent flow using Al_2O_3/water with variable wall temperature in an annular tube has been experimentally tested by Prajapati, et al. [23]. The results of improved heat transfer has been shown by the presence of nanoparticles in the fluid.

* Corresponding author.
E-mail address: anwar.ilmar@umj.ac.id

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In another study by Bozorgan, et al. [24] the authors examined numerically and experimentally horizontal double-tube heat exchangers with opposite turbulent flow. This study included experiments and simulations using FLUENT software. The results showed that nanofluids were significant in improving heat transfer and also, in good consent with other experimental data. Turbulent flow using nanofluids such as TiO2, Al_2O_3, and CuO with different volume concentrations flowing through the channels under constant heat flux conditions with two-dimensional models have been numerically analyzed by Rostamani, et al. [25]. The effect of nanoparticle Al_2O_3 with volume concentrations of 1-10% in EG/W mixture base fluid was studied numerically and experimentally, and the results showed that increasing the concentration of particles at constant Reynolds numbers, heat transfer rate increased rapidly [26].

Li, et al. [27], in their report described the mechanism of heat transfer by visualizing the flow in helical finned tubes. They show that the bubbles follow parabolic patterns in the laminar flow, and this pattern is broken due to random separation of vortices in the turbulent regime. Liu, et al. [28], expanded the research using two helical finned tubes in a fully developed single-phase turbulent. In another study, Al-Fahed, et al. [20] shows that heat transfer and pressure drop in the micro-fin tube are only slightly higher than the ordinary tubes and they recommend that micro-fine tubes are not used for laminar flow conditions. Dong, et al. [29], examined four spiral corrugated tubes in terms of pressure drops and heat transfer coefficients. They concluded that the heat transfer coefficient in the turbulent flow regime did not increase as a frictional factor. Abdolbaqi, et al. [30], computational fluid dynamics studies have been conducted to study the characteristics of heat transfer and friction factors of nanofluid Al_2O_3 EG/W flowing through the flat tube. They indicate that behavioral differences depend on the parameters selected to compare the nanofluid with the base fluid. The friction coefficient and heat transfer increase with the concentration of nanoparticles in the same amount of Reynolds.

Many researchers conducted experiments on convective heat transfer for laminar and turbulent flow from the nanofluid in the tube [31-33]. The correlation to the Nusselt number, using nanofluids comprising water and Cu, TiO_2, and Al_2O_3 nanoparticles are proposed. Improved heat transfer performance above the basic fluid for the specified Reynolds number is observed. Experimental results for nanofluid-based Al_2O_3 (27-56 nm)/water heat transfer flows through copper tubes in the laminar regime are reported by Wen, et al. [34]. It was observed that the increase in heat transfer coefficient was very large in the entrance area, and reduced with axial distance. The performance of heat transfer of CNT nanofluids in a tube is investigated by Ding, et al. [35]. The results show that the increase in heat transfer coefficient is significantly higher than the increase in effective thermal conductivity.

In the present study, heat transfer performance in a plain tube is carried out. The computational fluid dynamics is performed using FLUENT software with finite volume method. The heat flux of 7,957 W/m^2, Reynolds numbers is 3,000–11,000 and the volume concentration are 1.0, 2.0 and 3.0% respectively. The nanoparticles of Al_2O_3, TiO_2, and SiO_2 in EG/water (40:60) mixture base fluid.

EXPERIMENTAL METHOD

Preparation of *tri*-hybrid nanofluids

The preparation of nanofluids can be classified into two different methods. The first technique is a one-step process, where nanoparticles are synthesized and are immediately dispersed in the base fluid. The second technique is a two-step process, where the metal particles are initially produced in the form of nano-powder, then the nanoparticles are dispersed in the base fluid. Detailed preparation method of nanofluid containing 11 nm, 50 nm, and 23 of Al_2O_3, TiO_2, SiO_2 nanoparticles has been reported by Azmi, et al. [36]. Al_2O_3, TiO_2, SiO_2 nanoparticles dispersed in 60:40% EG/W nanofluid was prepared using the two-step method.

Measurement of thermal properties

The nanofluid's thermal properties were measured experimentally in the Advance Automotive Liquids Laboratory at the University of Malaysia, Pahang. The nanofluid's thermal conductivity is measured by KD2 Pro thermal properties analyzer from Decagon Devices, Inc., USA. It should be noted that many researchers have used the KD2 Pro in their thermal conductivity measurements [16, 18, 37-41]. The thermal conductivity meter is hotwiring while KD2 Pro is used to determine the thermal conductivity of this sample. Sensors are calibrated by determining the thermal conductivity of distilled water and glycerin. The thermal conductivity measured at room temperature is 0.610 and 0.280 W/mK, respectively for distilled water and glycerin, corresponding to the values in the literature of 0.613 and 0.285 W/mK, respectively with ± 5% accuracy. Furthermore, water baths are used to maintain a constant temperature of 0.1 ^oC. To ensure that measurements are within 5%, at least five measurements are performed for each concentration at a given temperature as described by Yang, et al. [42] and Tso, et al. [43]. Furthermore, the commercial Brookfield DV-II viscometer has been used for the measurement of the nanofluid's viscosity at 25^oC. Firstly, distilled water has been used to calibrate the measurement of the viscosity. Then the nanofluid's viscosity was measured. The hot wire method was used for the measurement of thermal conductivity and a viscometer for viscosity measurement. **Table 1** shows the properties of *tri*-hybrid nanofluids in the channel of the study.

Table 1. Properties of *tri*-hybrid nanofluids [41]

ϕ (%)	ρ_{nf} (kg/m^3)	μ_{nf} (Ns/m^2)	C_{nf} (J/kg.K)	k_{nf} (W/m.K)
1	1149.3	0.003043	3250.35	0.447
2	1243.3	0.003841	3036.73	0.468
3	1337.2	0.004849	2853.13	0.484

Thermal properties

The density (ρ_{nf}), specific heat capacity (C_{nf}) of *tri*-hybrid nanofluids is obtained by the relation [18].

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi(R\rho)_{Al_2O_3} + \varphi(R\rho)_{TiO_2} + \varphi(R\rho)_{SiO_2} \quad (1)$$

$$C_{nf} = \frac{(1-\varphi)\rho_{bf}C_{bf} + \varphi(R\rho C)_{Al_2O_3} + \varphi(R\rho C)_{TiO_2} + \varphi(R\rho C)_{SiO_2}}{\rho_{nf}} \quad (2)$$

The problem assumption is that the *tri*-hybrid nanofluids behave as a Newtonian fluid at a concentration less than 4.0%.

Numerical model for plain tube

Numeric calculations have been performed using ANSYS FLUENT 15.0 for the studied geometry. The governing equation is solved at each cell for all flow, pressure, and temperature values. The first step involves the creation of a 3-dimensional geometric model of the problem using the model designer followed by the second step of creating a mesh model using the ANSYS software. The plain tube geometry considered is illustrated in **Figure 1**. Cartesian coordinate system (x, y, z) was used to represent flow in the numerical simulation for this present study model. Heat transfer and turbulent flow are simultaneously formed downstream in the tube. Additionally, the condition for the inlet boundary of the EG/W or *tri*-hybrid nanofluids is specified as the velocity inlet whereas the pressure outlet is selected for outlet boundary conditions. The boundary conditions given in the model are constant heat flux 7,957 (W/m^2) have been applied to exterior walls. The plain tube material is copper, where the physical properties of copper are taken as a constant density, ρ = 8,978 (kg/m^3), specific heat, C_p = 381 (J/kg.K), and thermal conductivity, k = 387.6 (W/mK). The boundary conditions of the plain tube are illustrated in **Figure 2**.

Physical model

Stream is assumed to be stable, incompressible, Newtonian fluid, and turbulent with a constant thermophysical nature of nanofluid, no gravitational effects, and heat conduction in the axial direction. The k-ε turbulence model that can be realized by heat treatment on the wall is used for turbulent flow simulation. Simulation results for plain tube with tri-hybrid nanofluid compared to Equation Blasius **Eq. (3)** for friction factor and Dittus-Boelter for Nusselt number. The problem assumption is that nanofluids behave as Newtonian fluid for volume concentrations of 1.0, 2.0, and 3.0%. For dynamic equality conditions for two media streams, nanoparticles and basic fluid in the tubes, the friction factor can be written as follows [44].

$$f_{Bl} = \frac{0.3164}{Re^{0.25}} \quad (3)$$

for 2300 <Re<10^5

The forced convection coefficient for the turbulent regime can be estimated by Dittus-Boelter **Eq. (4)** for Reynolds number Re > 10^4.

$$Nu_{DB} = 0.023Re^{0.8}Pr^{0.4} \quad (4)$$

for Re > 10^4; 0.6 <Pr<200

Reynolds number on the diameter of the tube can be calculated using **Eq. (5)**

$$\mathrm{Re} = \frac{\rho v d}{\mu} \quad (5)$$

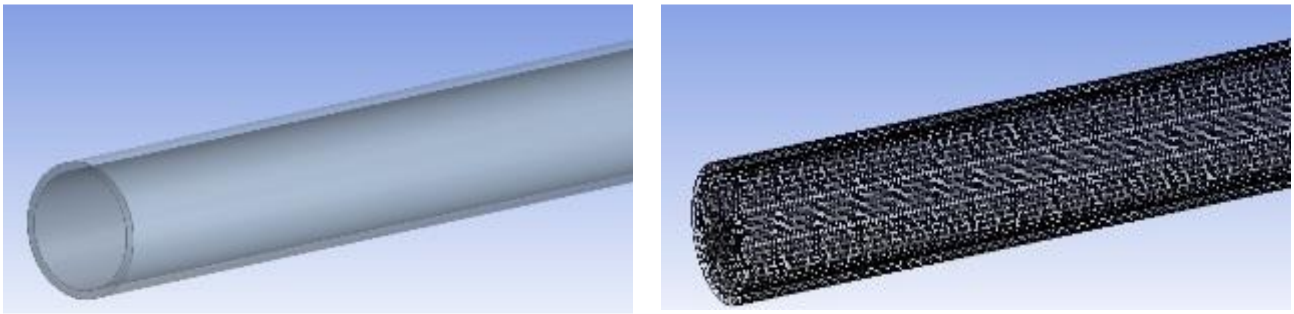
Governing equations

The *k-ε* turbulence model that can be realized with enhanced wall care is used for turbulent flow simulation. Turbulent kinetic energy, *k*, and turbulent dissipation rate, *ε*, are combined to the governing equations using the relation of the turbulent viscosity μ_t = ρCμk2/ε where C_μ = 0.09 and the following values have been assigned as empirical constants: C2 = 1.9, στ = 0.85, σ_κ =1.0 and σε = 1.2. Moreover, the inlet turbulent kinetic energy, *k*, and its dissipation rate *ε*, are obtained by using **Eq. (6)**.

$$k = \frac{3}{2}(u.l)^2, \varepsilon = C_u{}^{3/4}\frac{k^{3/2}}{L} \quad (6)$$

The turbulent characteristic length scale, *L* in the above equation was set at 0.07(d/2) in the current study. In addition, the factor of 0.07 was adopted based on the maximum value of the mixing length in a fully developed turbulent pipe flow. For an initial guess of turbulent quantities (k and ε), the turbulent intensity has to be calculated using **Eq. (7)** [45].

$$I = 0.16 \times Re^{-1/8} \quad (7)$$



(a) (b)

Figure 1. (a) Model of plain tube (b) Grid of plain tube

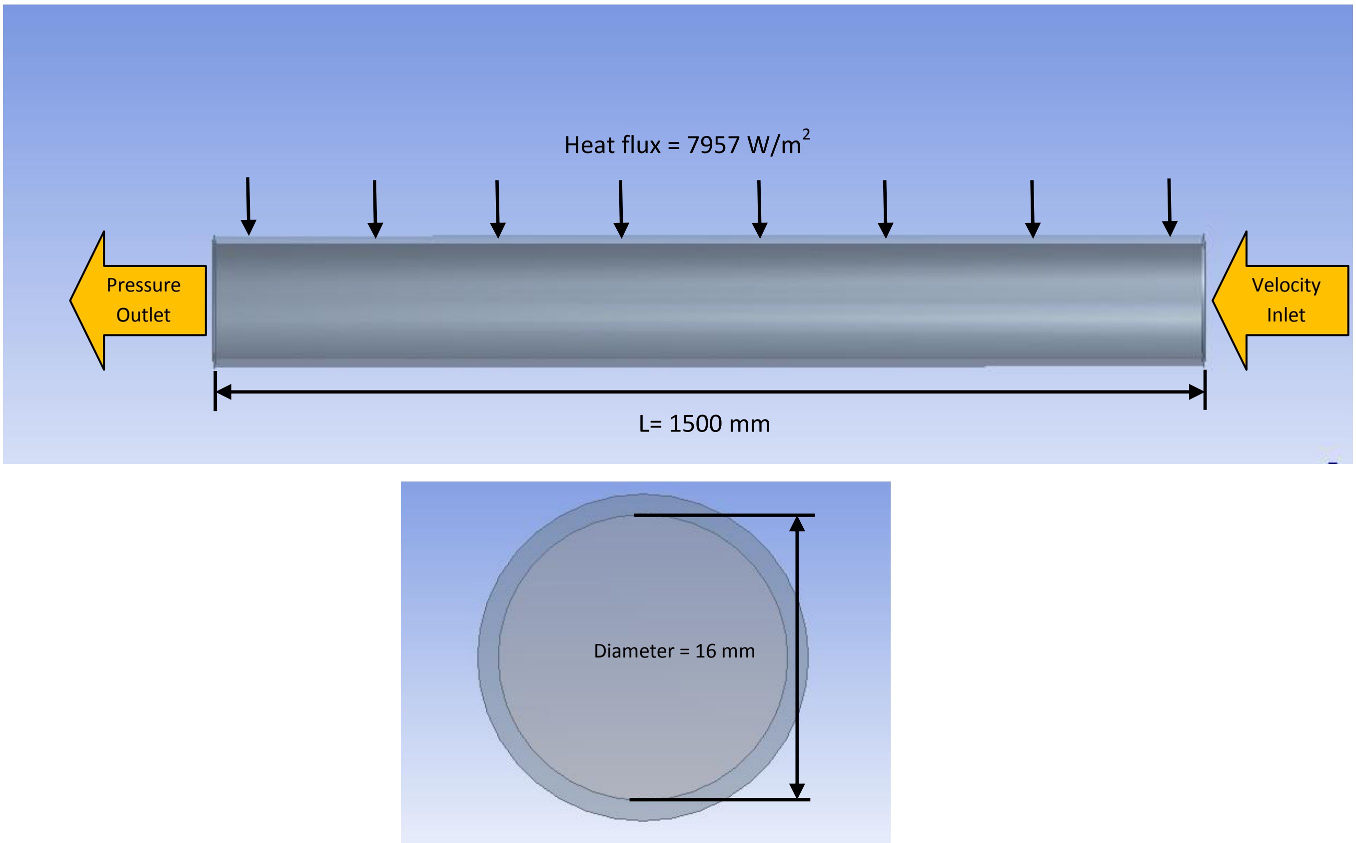


Figure 2. Boundary condition of plain tube model

RESULTS AND DISCUSSION

Grid independent test

Grid Independent has been tested in ANSYS FLUENT 15.0 for mesh sizes with 0.7, 1.0, 1.1, 1.2, 1.3 mm, according to **Table 2**. To find the most suitable mesh size, grid independent tests are performed for physical models. In this study, grid independence is examined using different grid systems, and 5 mesh sizes for pure water. Nusselt numbers and friction factors are estimated for all 5 types of mesh sizes and the results are approaching. Throughout the process of recurrence, the proper monitoring of the remnants has been done. When all the governing equations are lower than 10^{-6}, all solutions are considered united. Finally, the results are available when the ANSYS FLUENT 15.0 iteration leads to a unified decision set by a set of criteria. The Nusselt number and friction factor in mesh size can be found throughout the computing domain at the post-stage stage. This can be seen in **Figure 3.**

Table 2. Grid independent test with the mesh size

Mesh size (mm)	Grid Node	Nu
0.7	583180	174.4351
1.0	261868	172.8473
1.1	195237	171.4666
1.2	158309	170.5730
1.3	108643	165.9348

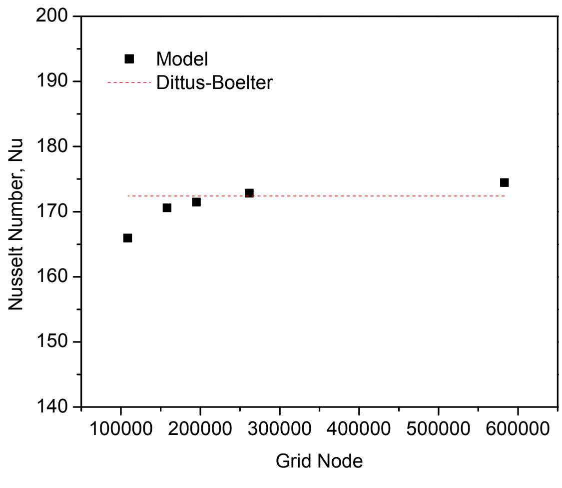


Figure 3. Grid independent test for Nusselt number

The grid independent test of Nusselt number against Reynolds has been done in relation to all grid mesh sizes. All the sizes of the mesh are suitable, but in this study, the mesh size of 1.0 mm is considered optimum. Although the size of mesh for these five cases can be applied, the mesh size of 1.0 mm is the best in terms of accuracy, as shown in **Figure 4**.

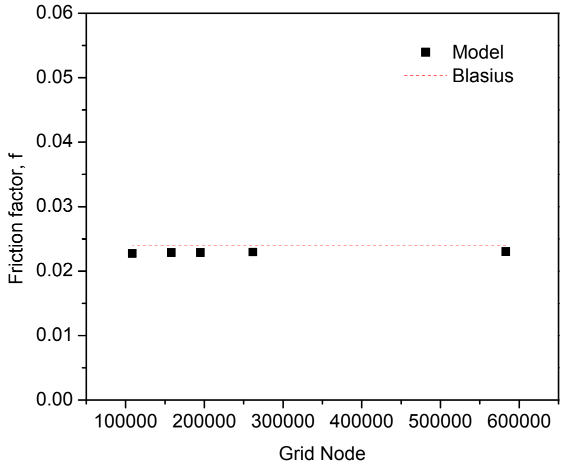
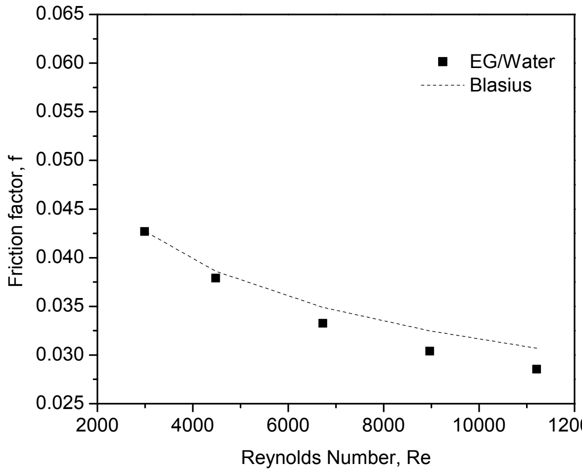


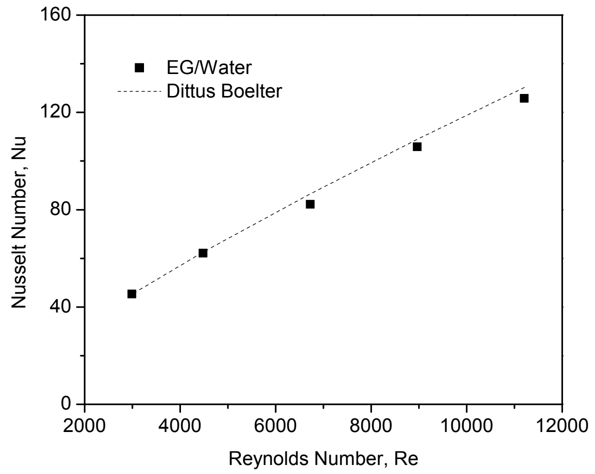
Figure 4. Grid independent test for friction factor

Validation of Results

The validation process is very important to check the results using the optimal size mesh model. It can be felt in **Figure 5(a)** with an increase in Reynolds number, there was a decrease in the friction factor under turbulent flow conditions. Blasius **Eq. (3)** results are indicated as dotted black lines. It seems to be a good deal between CFD results and its equality with the equation. **Figure 5(b)** shows the comparison between equations provided by Dittus-Boelter **Eq. (4)** and data collected from Azmi et al., [44] with the calculated value of the Nusselt number for *tri*-hybrid nanofluids of EG/W mixture base fluid. As observed, a very good deal has been obtained with calculated values of the theoretical equations in various Reynolds numbers.



(a)



(b)

Figure 5. The verification process for (a) friction factor and (b) Nusselt number

The effect of nanofluid volume concentration

The heat transfer coefficient for *tri*-hybrid nanofluids and volume concentrations of 1.0, 2.0, and 3.0% with Reynolds number is shown in **Figure 6**. It appears that the effect of nanofluid volume concentration is significant. Where increased volume fraction increases the rate of heat transfer. When there is an increase in volume concentrations, it is profitable but the increase should take into account the power of pumping. As well as the Nusselt number for EG/W (40:60) mixture is also shown in **Figure 7**.

While **Figure 8** illustrated the friction factor versus Reynolds number at different *tri*-hybrid nanofluids with a volume concentration of 1.0, 2.0, 3.0% in plain tube. The friction factor is evident, where the volume concentration of 3.0% has the highest increase followed by 2.0 and 1.0%. The friction factor value decreases as temperature increases. In addition, the percentage of basic fluid mixing plays an important role in increasing the rate of heat transfer through the transformation of basic thermal fluidization properties such as viscosity, density, specific heat capacity, and thermal conductivity.

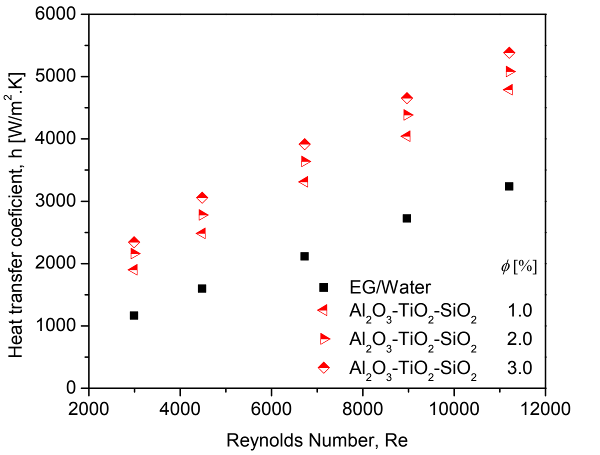


Figure 6. Effect of nanofluid concentration on the heat transfer coefficient at Reynolds number

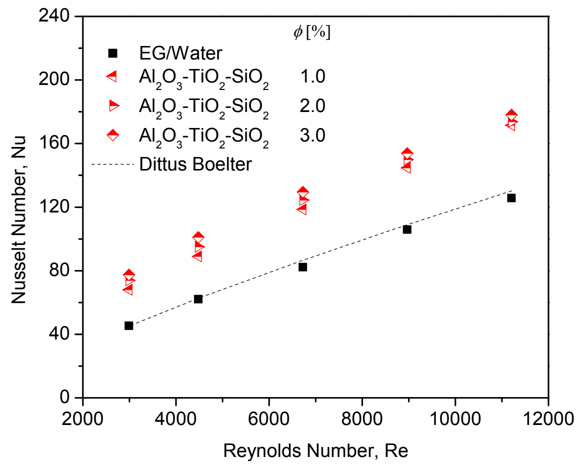


Figure 7. Effect of nanofluid concentration on Nusselt number at Reynolds number

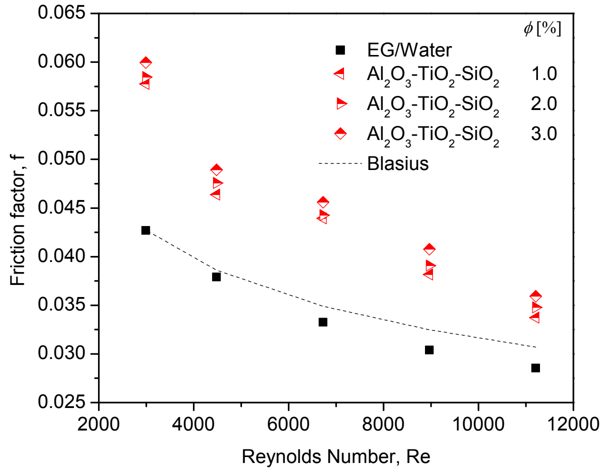


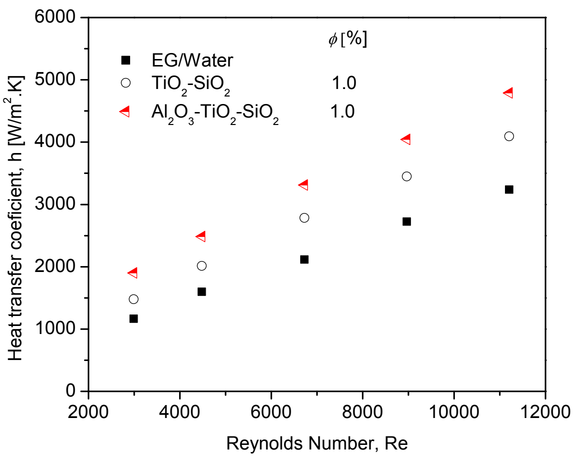
Figure 8. Effect of nanofluid concentration on friction factor at Reynolds number

Comparison results

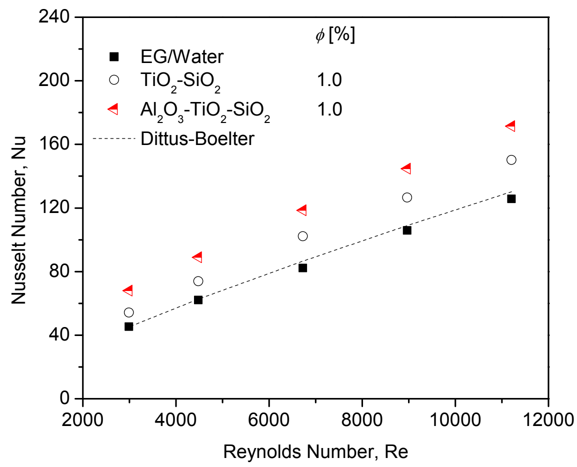
Figure 9(a) demonstrated the comparison of the current simulation of Nusselt Number for Al_2O_3-TiO_2-SiO_2 nanofluids or *tri*-hybrid nanofluids with TiO_2-SiO_2 nanofluid. The data comparisons were taken for a specific working condition i.e. 1.0% volume concentration, working temperature of 30 °C, and similar W/EG (60:40) mixture base fluid. The current heat transfer for volume concentration 1.0% of *tri*-hybrid nanofluids implies the highest heat transfer rate compared to TiO_2-SiO_2 nanofluids [40]. For increased heat transfer in *tri*-hybrid nanofluids is about 2.36 times higher than TiO_2-SiO_2 nanofluids.

This evaluation also affirms that the use of Al_2O_3-TiO_2-SiO_2 nanofluids or *tri*-hybrid nanofluids further improves the performance of nanofluid heat transfer. The Nusselt number for Al_2O_3-TiO_2-SiO_2 nanofluids and TiO_2-SiO_2 nanofluids of a volume concentration of 1.0% respectively by results simulation with CFD is presented in **Figure 9(b)**. The Nusselt number for Al_2O_3-TiO_2-SiO_2 nanofluids increases with Reynolds number and follows base fluid trends and Dittus Boelter [46]. *Tri*-hybrid nanofluids showed a increased Nusselt number of 1.17 times higher than hybrid nanofluids. Hybrid nanofluids are higher than 1.20 times than EG/W mixture base fluid.

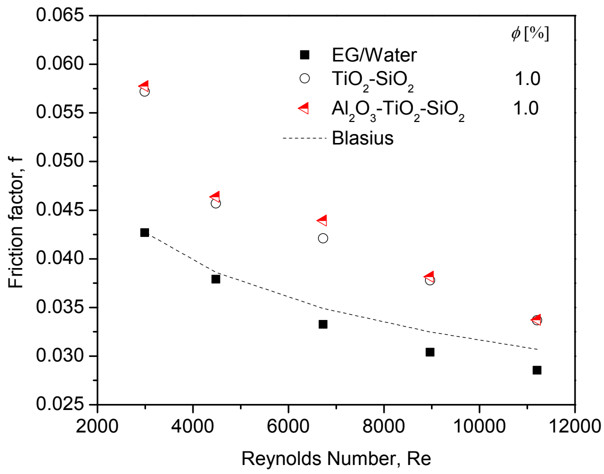
Figure 9 (c) shows the distribution of friction factor for *tri*-hybrid nanofluid with hybrid nanofluid for volume concentration 1.0% respectively by Reynolds number. The friction factor for Al_2O_3-TiO_2-SiO_2 nanofluids and TiO_2-SiO_2 nanofluids decreased exponentially with an increase in the Reynolds number. The increase in the average friction factor for the *tri*-hybrid nanofluid was 1.28 times higher than the W/EG mixed base fluid and 1.02 times higher than TiO_2-SiO_2 nanofluids.



(a)



(b)



(c)

Figure 9. Comparison results for (a) heat transfer coefficient, (b) Nusselt number, and (c) friction factor at Reynolds number

CONCLUSION

In this study, the transfer of forced convection heat under the turbulent flow used *tri*-hybrid nanofluids in EG/water (40:60) mixture base fluid with numerical simulation with a uniform heat flux boundary condition of a plain tube is studied. Increased heat transfer due to various parameters such as Reynolds number and nanoparticles volume concentrations are reported. The governing equation has been solved by using ascending volume method with specific assumptions and precise boundary conditions. Nusselt number and friction factor are obtained through numerical simulation. The volume concentration of 3.0% for *tri*-hybrid nanofluids has the highest value of Nusselt number and an increase in heat transfer, followed by volume concentrations of 2.0 and 1.0%.

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REFERENCES

[1] M.K. Abdolbaqi, C.S.N. Azwadi, R. Mamat, Heat transfer augmentation in the straight channel by using nanofluids, Case Studies in Thermal Engineering, 3 (2014) 59-67.

[2] M. Khattak, A. Mukhtar, S.K. Afaq, Application of nano-fluids as coolant in heat exchangers: a review, J. Adv. Rev. Sci. Res, 22(1) (2016) 1-11.

[3] N.C. Sidik, O.A. Alawi, Computational investigations on heat transfer enhancement using nanorefrigerants, J. Adv. Res. Des., 1(1) (2014) 35-41.

[4] Y. Lee, The use of nanofluids in domestic water heat exchanger, J. Adv. Res. Appl. Mech, 3(1) (2014) 9-24.

[5] M.R. Abdulwahab, A numerical investigation of turbulent magnetic nanofluid flow inside square straight channel, J. Adv. Res. Fluid Mech. Therm. Sci, 1(1) (2014) 44-52.

[6] A.M. Khdher, N.A.C. Sidik, R. Mamat, W.A.W. Hamzah, Experimental and numerical study of thermo-hydraulic performance of circumferentially ribbed tube with Al2O3 nanofluid, International Communications in Heat and Mass Transfer, 69 (2015) 34-40.

[7] A.I. Ramadhan, W.H. Azmi, R. Mamat, Heat transfer characteristics of car radiator using tri-hybrid nanocoolant, in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2020, pp. 012054.

[8] M.A. Fikri, F.F. Asri, W.M. Faizal, H.K. Adli, R. Mamat, W.H. Azmi, A.I. Ramadhan, T. Yusaf, Effects of heat transfer based water for three square multilayer absorber solar collector, in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2020, pp. 012078.

[9] A.I. Ramadhan, E. Diniardi, E. Dermawan, Numerical study of effect parameter fluid flow nanofluid Al2O3-water on heat transfer in corrugated tube, in: AIP Conference Proceedings, AIP Publishing LLC, 2016, pp. 050003.

[10] M.A. Fikri, W.M. Faizal, H.K. Adli, R. Mamat, W.H. Azmi, Z.A.A. Majid, A.I. Ramadhan, Characteristic of TiO2-SiO2 Nanofluid With Water/Ethylene Glycol Mixture for Solar Application, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 81(2) (2021) 1-13.

[11] M.A. Fikri, W.M. Faizal, H.K. Adli, Z. Bo, X.X. Jiang, A.I. Ramadhan, Investigation on stability of TiO2-SiO2 nanofluids with ratio (70: 30) in W/EG mixture (60: 40), in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2021, pp. 012020.

[12] S. Pal, S.K. Saha, Laminar fluid flow and heat transfer through a circular tube having spiral ribs and twisted tapes, Experimental Thermal and Fluid Science, 60 (2015) 173-181.

[13] Y. Wang, B. Zhou, Z. Liu, Z. Tu, W. Liu, Numerical study and performance analyses of the mini-channel with discrete double-inclined ribs, International journal of heat and mass transfer, 78 (2014) 498-505.

[14] S.K. Saha, Thermal and friction characteristics of laminar flow through rectangular and square ducts with transverse ribs and wire coil inserts, Experimental Thermal and Fluid Science, 34(1) (2010) 63-72.

[15] W. Peng, P.-X. Jiang, Y.-P. Wang, B.-Y. Wei, Experimental and numerical investigation of convection heat transfer in channels with different types of ribs, Applied Thermal Engineering, 31(14-15) (2011) 2702-2708.

[16] T.-M. Jeng, S.-C. Tzeng, C.-H. Lin, Heat transfer enhancement of Taylor–Couette–Poiseuille flow in an annulus by mounting longitudinal ribs on the rotating inner

cylinder, International Journal of Heat and Mass Transfer, 50(1-2) (2007) 381-390.

[17] A.I. Ramadhan, W.H. Azmi, R. Mamat, K.A. Hamid, Experimental and numerical study of heat transfer and friction factor of plain tube with hybrid nanofluids, Case Studies in Thermal Engineering, (2020) 100782.

[18] A.I. Ramadhan, W.H. Azmi, R. Mamat, K.A. Hamid, S. Norsakinah, Investigation on stability of tri-hybrid nanofluids in water-ethylene glycol mixture, in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2019, pp. 012068.

[19] E. Esen, N. Obot, T.J. Rabas, Enhancement: Part I. Heat transfer and pressure drop results for air flow through passages with spirally-shaped roughness, Journal of Enhanced Heat Transfer, 1(2) (1994).

[20] S. Al-Fahed, L. Chamra, W. Chakroun, Pressure drop and heat transfer comparison for both microfin tube and twisted-tape inserts in laminar flow, Experimental Thermal and Fluid Science, 18(4) (1998) 323-333.

[21] W.H. Azmi, K.A. Hamid, A.I. Ramadhan, A.I.M. Shaiful, Thermal hydraulic performance for hybrid composition ratio of TiO2–SiO2 nanofluids in a tube with wire coil inserts, Case Studies in Thermal Engineering, 25 (2021) 100899.

[22] R.S. Luciu, T. Mateescu, V. Cotorobai, T. Mare, Nusselt number and convection heat transfer coefficient for a coaxial heat exchanger using Al2O3–water pH= 5 nanofluid, Bul. Inst. Polit. Iasi, 55 (2009) 71-80.

[23] O.S. Prajapati, A. Rajvanshi, Effect of Al2O3-water nanofluids in convective heat transfer, International Journal of NanoScience, 11(03) (2012) 1240005.

[24] N. Bozorgan, N. Bozorgan, Evaluation of the using Al2O3/EG and TiO2/EG nanofluids as coolants in the double-tube heat exchanger, International Journal of Advanced Design and Manufacturing Technology, 5(2) (2012).

[25] M. Rostamani, S. Hosseinizadeh, M. Gorji, J. Khodadadi, Numerical study of turbulent forced convection flow of nanofluids in a long horizontal duct considering variable properties, International Communications in Heat and Mass Transfer, 37(10) (2010) 1426-1431.

[26] J. Bayat, A.H. Nikseresht, Thermal performance and pressure drop analysis of nanofluids in turbulent forced convective flows, International journal of thermal sciences, 60 (2012) 236-243.

[27] H. Li, K. Ye, Y. Tan, S. Deng, Investigation on tube-side flow visualization, friction factors and heat transfer characteristics of helical-ridging tubes, in: International Heat Transfer Conference Digital Library, Begel House Inc., 1982.

[28] X. Liu, M.K. Jensen, Numerical investigation of turbulent flow and heat transfer in internally finned tubes, Journal of Enhanced Heat Transfer, 6(2-4) (1999).

[29] Y. Dong, L. Huixiong, C. Tingkuan, Pressure drop, heat transfer and performance of single-phase turbulent flow in spirally corrugated tubes, Experimental Thermal and Fluid Science, 24(3-4) (2001) 131-138.

[30] M.K. Abdolbaqi, N.A.C. Sidik, M.N.A.W.M. Yazid, R. Mamat, W. Azmi, H.M. Kh, Experimental and Numerical Investigation of Heat Transfer Augmentation Using Al2O3-Ethylene Glycol Nanofluids under Turbulent Flows in a Flat Tube, Jurnal Teknologi, 78(9-2) (2016).

[31] Y. Xuan, Q. Li, Heat transfer enhancement of nanofluids, International Journal of heat and fluid flow, 21(1) (2000) 58-64.

[32] B.C. Pak, Y.I. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Experimental Heat Transfer an International Journal, 11(2) (1998) 151-170.

[33] Y. Xuan, Q. Li, Investigation on convective heat transfer and flow features of nanofluids, Journal of Heat transfer, 125(1) (2003) 151-155.

[34] D. Wen, Y. Ding, Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions, International journal of heat and mass transfer, 47(24) (2004) 5181-5188.

[35] Y. Ding, H. Alias, D. Wen, R.A. Williams, Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids), International Journal of Heat and Mass Transfer, 49(1-2) (2006) 240-250.

[36] W.H. Azmi, K.V. Sharma, P.K. Sarma, R. Mamat, S. Anuar, V.D. Rao, Experimental determination of turbulent forced convection heat transfer and friction factor with SiO2 nanofluid, Experimental Thermal and Fluid Science, 51 (2013) 103-111.

[37] A. Bergles, The implications and challenges of enhanced heat transfer for the chemical process industries, Chemical Engineering Research and Design, 79(4) (2001) 437-444.

[38] M.K. Jensen, A. Vlakancic, Technical Note Experimental investigation of turbulent heat transfer and fluid flow in internally finned tubes, International Journal of Heat and Mass Transfer, 42(7) (1999) 1343-1351.

[39] W.H. Azmi, K.A. Hamid, N.A. Usri, R. Mamat, M.S. Mohamad, Heat transfer and friction factor of water and ethylene glycol mixture based TiO2 and Al2O3 nanofluids under turbulent flow, International Communications in Heat and Mass Transfer, 76 (2016) 24-32.

[40] K.A. Hamid, W.H. Azmi, M.F. Nabil, R. Mamat, K.V. Sharma, Experimental investigation of thermal conductivity and dynamic viscosity on nanoparticle mixture ratios of TiO2-SiO2 nanofluids, International Journal of Heat and Mass Transfer, 116 (2018) 1143-1152.

[41] A.I. Ramadhan, W.H. Azmi, R. Mamat, Experimental investigation of thermo-physical properties of tri-hybrid nanoparticles in water-ethylene glycol mixture, Walailak Journal of Science and Technology (WJST), (2020).

[42] Y.-T. Yang, H.-W. Tang, B.-Y. Zeng, C.-H. Wu, Numerical simulation and optimization of turbulent nanofluids in a three-dimensional rectangular rib-grooved channel, International Communications in Heat and Mass Transfer, 66 (2015) 71-79.

[43] C. Tso, S. Fu, C.Y. Chao, A semi-analytical model for the thermal conductivity of nanofluids and determination of the nanolayer thickness, International Journal of Heat and Mass Transfer, 70 (2014) 202-214.

[44] W.H. Azmi, K.V. Sharma, P.K. Sarma, R. Mamat, G. Najafi, Heat transfer and friction factor of water based TiO2 and SiO2 nanofluids under turbulent flow in a tube, International Communications in Heat and Mass Transfer, 59 (2014) 30-38.

[45] A. Fluent, Ansys fluent theory guide, ANSYS Inc., USA, 15317 (2011) 724-746.

[46] F.W. Dittus, Heat transfer in automobile radiators of the tubler type, Univ. Calif. Pubs. Eng., 2 (1930) 443.