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Experimental and numerical study of heat transfer and friction factor of plain tube with hybrid nanofluids

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ABSTRACT

The use of heat transfer enhancement techniques, can improve the thermal performance of the tubes. In this study, the convective heat transfer from nanoparticles TiO_2–SiO_2 was dispersed to W/EG in the plain tube, under constant wall heat flux studied numerical and experimental. The type of nanofluid used is the TiO_2–SiO_2 base fluid EG/water mixture. The volume concentrations used were 1.0, 2.0 and 3.0%. The Reynolds number (*Re*) used ranges from 2900 to 11,200. The effect of nanofluids on heat transfer coefficients and friction factors is presented in this work. The results show that heat transfer increases with Reynolds number for numerical and experimental in plain tube. Hybrid nanofluids at volume concentration of 3.0% had the highest amount of Nusselt and the highest friction factor was followed by 2.0% and then 1.0%. Experimental and numerical results are compared in terms of Nusselt number average deviation found was 8.8, 8.9 and 7.9% for the volume concentration of 1.0, 2.0, and 3.0% in this study. The friction factor average deviation is 4.1, 3.8 and 3.5% for the volume concentration of 1.0, 2.0, and 3.0%, respectively.

1. Introduction

The use of heat transfer enhancement techniques, can improve the thermal performance of the tubes. The heat transfer technique can be classified into three broad techniques: Active techniques that require external power to enable desired flow modifications to improve heat transfer such as electrostatic field, mechanical assistant, jet cleaning, suction, injection, surface vibration, and fluid vibration: the combined technique is a mixture of two or more techniques mentioned at a time. 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. There are many applications of heat transfer augmentation by using nanofluids to obtain the necessary cooling challenges such as photonics, transport, electronics, and energy supply industries [1–8].

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 [9–13]. For the case of laminar flow, some researchers concluded that heat transfer and pressure drop were not significantly affected by increased tubes [9,10,14]. Meanwhile, there is 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 [15–17].

The double tube coaxial heat exchanger is heated by solar energy using an experimental and numerical presented nanofluid Aluminum oxide by Luciu et al. [18]. Forced convection of the nanofluid turbulent flow using Al_2O_3/Water with variable wall

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Nomenclature

C	specific heat
d	diameter
EG	ethylene glycol
f	friction factor
h	heat transfer coefficient
k	thermal conductivity
L	length
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
T	temperature
V	volume
v	velocity
W	water

Greek symbols

ø	volume concentration, %
μ	dynamic viscosity, mPa.s
ϕ	volume fraction
ρ	density, kg/m^3
ω	weight concentration, %

Subscript

bf	base fluid
Bl	Blasius
DB	Dittus-Boelter
nf	nanofluid
p	nanoparticle

temperature in an annular tube has been experimentally tested by Prajapati et al. [19]. The results shown by the presence of nanoparticles in heat transfer fluid have been improved.

Another study by Bozorgan et al. [20] the authors examined numerically and experimentally horizontal double tube heat exchanger with opposite turbulent flow. This study includes experiments and simulations used FLUENT. The results showed that nanofluid was significant in improving heat transfer and also, good consent with other experimental data. Turbulent flow using nanoparticles of TiO_2, Al_2O_3 and CuO with different volume concentrations flowing through the channels in constant heat flux conditions with two-dimensional models have been numerically analyzed Rostamani et al. [21]. The effect of nanoparticle Al_2O_3 with volume concentrations of 1–10% in ethylene glycol-water mixture base fluid was studied numerical and experimental, the results showed that increasing the concentration of particles in constant Reynolds numbers, increased heat transfer rate increased rapidly [22].

Li et al. [23], in their report describing 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. [24], expanding research with two helical finned tubes in a fully developed single phase turbulent. In another study, Al-Fahed et al. [16] 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. [25], examine 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 frictional factor.

Abdolbaqi et al. [26], computational fluid dynamics studies have been conducted to study the characteristics of heat transfer and friction factors of nanofluid Al_2O_3/Ethylene glycol-water flowing in 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 nanofluid in the tube by Ref. [27–29]. 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. [30]. 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. [31]. The results show that the increase in heat transfer coefficient is significantly higher than the increase in effective thermal conductivity.

As reviewed, pressure drop and convective heat transfer behaviour in various plain tube at constant heat fluxes were not investigated by previous works both experimentally and numerically. In addition, a number of studies have focused on the evaluation of heat transfer characteristics in the area of plain tube development for experimental purposes only. In this study, the convective heat transfer from nanoparticles TiO_2–SiO_2 was dispersed to W/EG in the plain tube, under constant wall heat flux studied numerical and experimental. Homogeneous models with constant effective properties are used to predict the behaviour of nanofluids heat transfer.

2. Methodology

2.1. Preparation of hybrid nanofluids

In the present study, the TiO_2 and SiO_2 nanoparticles in suspended form were procured from US Research Nanomaterials, Inc. (USA) with 40% and 25% weight concentrations, respectively. The study used a mixture of water (W) and Ethylene Glycol (EG) at a constant volume ratio of 60:40 (W:EG) as the base fluid. Eq. (1) was used to calculate the initial volume concentration of TiO_2 and SiO_2 single nanofluids. Furthermore, Eq. (2) was used to dilute both single nanofluids from initial volume concentration to 1.0% volume concentration. Finally, the TiO_2–SiO_2 nanofluid is prepared at 1.0% volume concentration with variations of nanoparticle mixture ratios (TiO_2:SiO_2) of 20:80 by volume percent. According to previous studies [32–36], the optimum heat transfer performance of TiO_2 nanofluids was observed at 1.0% volume concentration. Therefore, the present study was considered to use 1.0% concentration for performance investigation of TiO_2–SiO_2 nanofluids. During the preparation, the samples are subjected to the mixing process using a mechanical stirrer for 1 h. The solutions further underwent the sonication process by using ultrasonic bath for different sonication times and up to 2 h to formulate a stable final solution.

$$\varphi \frac{\omega \rho_{pf}}{\left(1 - \frac{\omega}{100}\right)\rho_p + \frac{\omega}{100}\rho_{pf}} \tag{1}$$

$$\Delta V = (V_2 - V_1) = V_1\left(\frac{\varphi_1}{\varphi_2} - 1\right) \tag{2}$$

2.2. Numerical model

Numeric calculations have been performed using ANSYS FLUENT 15.0 for the studied geometry. The governing equation is solved in each cell for all flow, pressure and temperature values. The first step involves the creation of a 3-dimensional geometric model of the problem with the model designer followed by the second step of creating a mesh model in the ANSYS. 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 at the downstream of the tube. Additionally, the condition of the EG/Water or hybrid nanofluids for inlet is specified as the velocity inlet as well as the pressure outlet is selected for outlet boundary conditions. The boundary conditions given in the model are constant heat flux 7957 (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, $\rho = 8978$ (kg/m^3), specific heat, $C_p = 381$ (J/kg.K), and thermal conductivity, $k = 387.6$ (W/mK). The boundary condition of the plain tube is considered illustrated in Fig. 1.

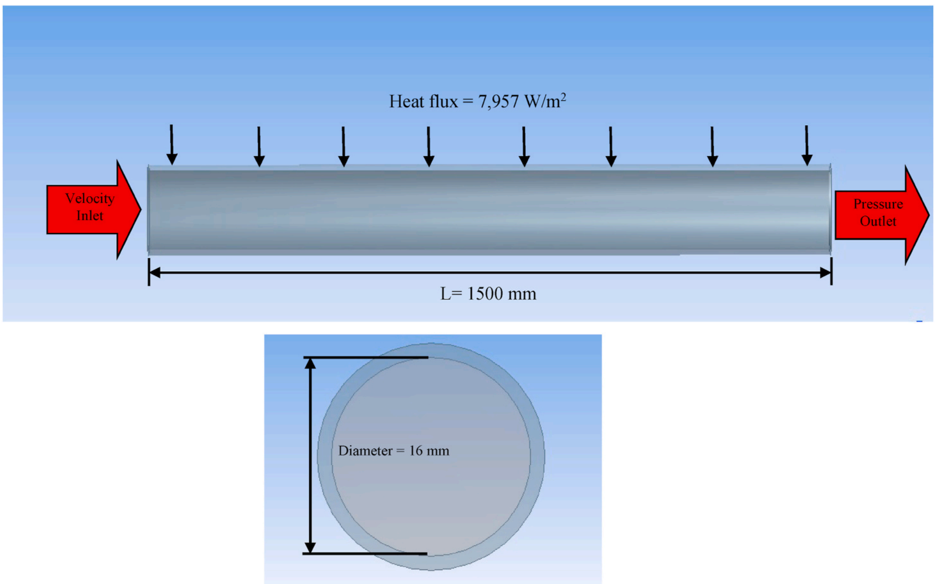


Fig. 1. Boundary condition of plain tube model.

2.3. Thermal properties

The density (ρ_{nf}), specific heat capacity (C_{nf}), thermal conductivity (k_{nf}) and viscosity (μ_{nf}) of hybrid nanofluids is obtained by the relation [37,38].

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi(R\rho)_{TiO_2} + \varphi(R\rho)_{SiO_2} \tag{3}$$

$$C_{nf} = \frac{(1-\varphi)\rho_{bf}C_{bf} + \varphi(R\rho C)_{TiO_2} + \varphi(R\rho C)_{SiO_2}}{\rho_{nf}} \tag{4}$$

$$K_r = \frac{K_{nf}}{K_{bf}} = \left(1 + \frac{\phi}{100}\right)^{5.58}\left(1 + \frac{T}{70}\right)^{0.077} \tag{5}$$

$$\mu_r = \frac{\mu_{nf}}{\mu_{bf}} = 0.081\ \exp\left(0.111\phi + 0.355\frac{T}{70}\right) \tag{6}$$

The problem assumption is that the hybrid nanofluids behaves as a Newtonian fluid because of its concentration of less than 4.0%. Table 1 shows the properties of nanofluids in the research tube. The estimation using equations (3)–(6) was used to obtain the thermal properties hybrid nanofluid used in the numerical simulation process.

2.4. Physical model

Stream is assumed to be stable, incompressible, Newtonian fluid, and turbulent with a constant thermo physical 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 hybrid nanofluid compared to Equation Blasius Eq. (7) 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 base fluid in the tubes, the friction factor can be written as follows [32].

$$f_{Bl} = \frac{0.3164}{\mathrm{Re}^{0.25}} \quad for\ 2300 < \mathrm{Re} < 10^5 \tag{7}$$

The forced convection coefficient for the turbulent regime can be estimated by Dittus-Boelter Eq. (8) for Reynolds number $\mathrm{Re} > 10^4$.

$$\varphi \frac{\omega\rho_{bf}}{\left(1-\frac{\omega}{100}\right)\rho_p + \frac{\omega}{100}\rho_{bf}} \quad Nu_{DB} = 0.023\mathrm{Re}^{0.8}pr^{0.4}\ for\ \mathrm{Re} > 10^4;\ 0.6 < pr < 200 \tag{8}$$

Reynolds number on the diameter of the tube can be calculated use Eq. (9).

$$\mathrm{Re} = \frac{\rho v d}{\mu} \tag{9}$$

2.5. Governing equations

The *k-ε* turbulence model that can be realized with enhanced wall care are 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 $C_\mu = 0.09$ and the following values have been assigned as an empirical constants: C2 = 1.9, στ = 0.85, $\sigma_\kappa = 1.0$ and $_{\sigma\varepsilon}$ = 1.2. Moreover the inlet turbulent kinetic energy, *k*, and its dissipation rate *ε*, are obtained by.

$$k = \frac{3}{2}(u.l)^2,\ \varepsilon = C_u^{3/4}\frac{k^{3/2}}{L} \tag{10}$$

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 fully developed turbulent pipe flow. For an initial guess of turbulent quantities (k and ε), the turbulent intensity has to be calculated using [39].

Table 1
Properties of hybrid nanofluids.

φ (%)	ρ_{nf} (kg/m^3)	μ_{nf} (Ns/m^2)	C_{nf} (J/kg.K)	k_{nf} (W/m.K)
1.0	1109.336	0.002974	3339.68	0.436
2.0	1163.282	0.003064	3192.41	0.450
3.0	1217.228	0.003126	3058.20	0.467

$$I = 0.16 \times Re^{-1/8} \tag{11}$$

3. Results and discussion

3.1. 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 in mesh size can be found throughout the computing domain at the post-stage stage.

The grid independent test of Nusselt number against Reynolds has been done with respect to all grid mesh sizes. All the sizes of the mesh are approach, but in this study the mesh size of 1.0 mm is considered as 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 Fig. 2.

3.2. Validation of results

The validation process is very important to check the results using the optimal size mesh model. This can be felt on Fig. 3(a) with increasing Reynolds number, the friction factor decreases under turbulent flow conditions. Blasius eqs. (14), results are indicated as dotted black lines. It seems to be a good deal between CFD results and its equality with the equation. Fig. 3(b) shows the comparison between equations provided by Dittus-Boelter Eqs. (15) and data collected from Refs. [32] with the calculated value of the Nusselt number for hybrid nanofluids of Ethylene Glycol-Water mixture base fluid. As observed, a very good deal has been obtained with calculated values of the theoretical equations in various Reynolds number.

3.3. Comparison of heat transfer coefficient

Fig. 4 shows a numerical and experimental comparison of heat transfer coefficient for hybrid nanofluids with concentration volumes of 1.0, 2.0 and 3.0% at Reynold number 2900–11200. In general, the increase of the heat transfer coefficient between numerically and experimentally has the same pattern influenced by Reynolds Number. It seems that the influence of nanofluid volume concentration is significant. Where increasing volume fraction increases heat transfer rate. Since increasing the volume concentration is advantageous but the increase should take into account the pumping strength.

3.4. Comparison of Nusselt number

Experimental and numerical results of Nusselt (*Nu*) on Reynolds number in plain tube at various concentration volumes of 1.0, 2.0 and 3.0%, are presented in Fig. 5. As expected, the Nusselt number increased as the Reynolds number increased, in volume concentration. In other words, the *Nu* for the plain tube considered increases with Re due to an increase in wall temperature gradient. Flow issues are related to increasing speed, which increases heat transfer.

Moreover, it can be observed that Nusselt increases with increasing volume of nanoparticles, in particular Reynolds number, as it increases the thermal conductivity of the base fluid as well as the Brown motion of the nanoparticles. The results are consistent with the experiment the results of Hamid et al. [40]. The Nusselt number is highly dependent on the thermal conductivity of the heat transfer medium.

For this reason, nanoparticles are dispersed in the base fluid to increase the final thermal conductivity due to the higher thermal conductivity of solid particles. The average deviation between the numerical and experimental results showed good agreement of approximately 8.8, 8.9 and 7.9% for the volume concentration of 1.0, 2.0, and 3.0%, respectively.

3.5. Comparison of friction factor

Fig. 6 illustrated the friction factor versus Reynolds number (Re) of different hybrid nanofluids with a volume concentration of 1.0,

Table 2
Grid independent test with mesh size.

Mesh size (mm)	Grid Node	Average *Nu*
0.7	583,180	174.4351
1.0	261,868	172.8473
1.1	195,237	171.4666
1.2	158,309	170.5730
1.3	108,643	165.9348

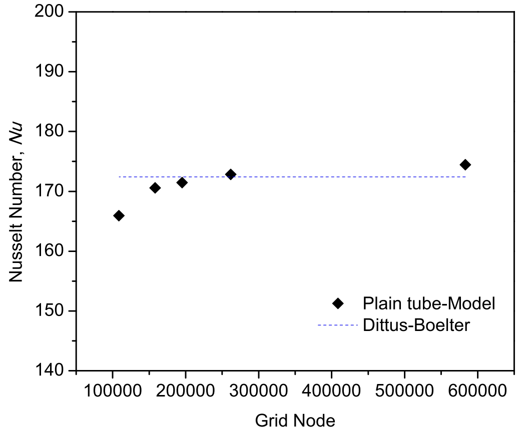
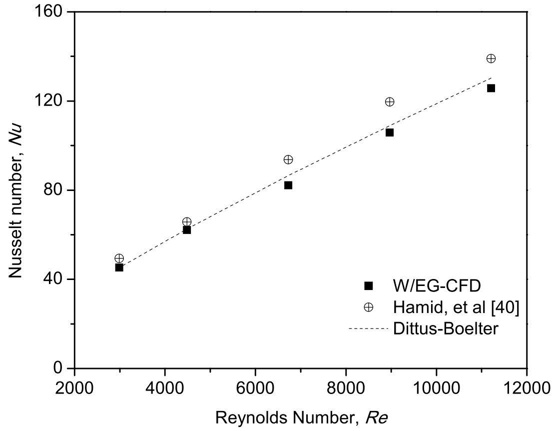
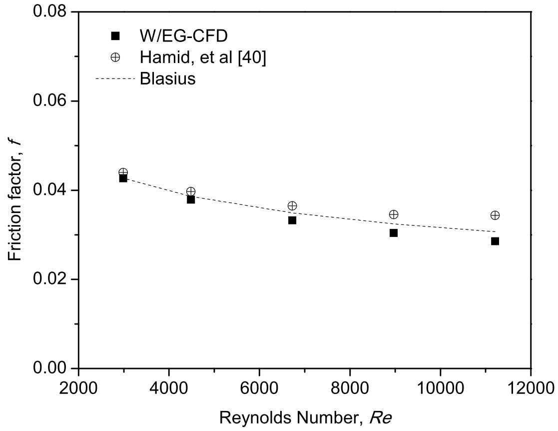


Fig. 2. Grid independent test for Nusselt number.



(a)



(b)

Fig. 3. Validation results for (a) Nusselt number and (b) friction factor.

2.0, and 3.0% in numerical and experimental plain tube. The friction factor is obvious, with the volume concentration of 3.0% having the highest increase followed by 2.0 and 1.0%. Hamid et al. [40], previously reported the similar results. The average deviation value of the numerical results indicates reasonable agreement with the experimental results. The average deviation is 4.1, 3.8 and 3.5% for the volume concentration of 1.0, 2.0, and 3.0%, respectively.

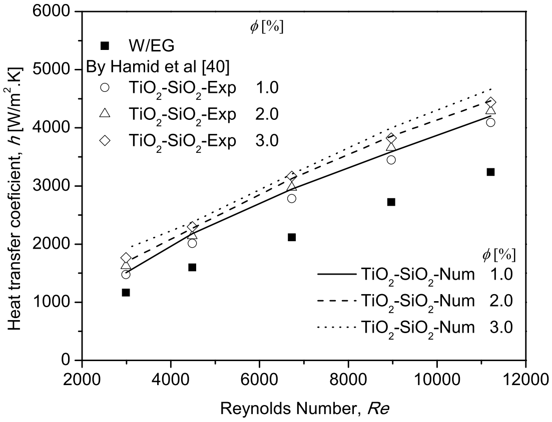


Fig. 4. Comparison of heat transfer coefficient from numerical data and experimental data by Hamid et al. [40].

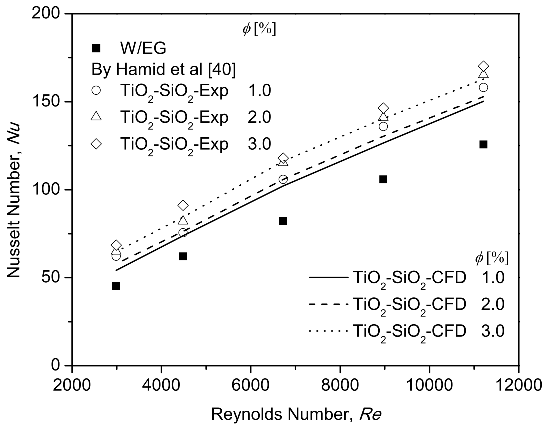


Fig. 5. Comparison of Nusselt number from numerical data and experimental data by Hamid et al. [40].

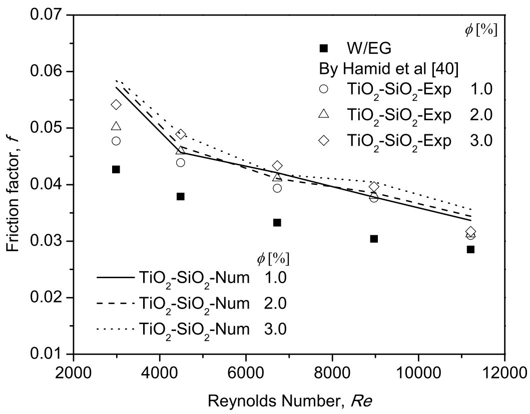


Fig. 6. Comparison of friction factor from numerical data and experimental data by Hamid et al. [40].

4. Conclusion

In the present study, forced laminar flow of hybrid nanofluids in a plain tube has been studied numerically and experimentally. The type of nanofluid used is the TiO_2–SiO_2 base fluid EG/water mixture. The volume concentrations used were 1.0, 2.0 and 3.0%. The Reynolds number (*Re*) used ranges from 2900 to 11,200. The effect of nanofluids on heat transfer coefficients and friction factors is presented in this work. The results show that heat transfer increases with Reynolds number for numerical and experimental in plain tube. Hybrid nanofluids at volume concentration of 3.0% had the highest amount of Nusselt and the highest friction factor was followed by 2.0% and then 1.0%. Experimental and numerical results are compared in terms of Nusselt number average deviation found was 8.8, 8.9 and 7.9% for the volume concentration of 1.0, 2.0, and 3.0% in this study. The friction factor average deviation is 4.1, 3.8 and 3.5% for the volume concentration of 1.0, 2.0, and 3.0%, respectively.

CRediT authorship contribution statement

A.I. Ramadhan: Data curation, Investigation, Writing - original draft. **W.H. Azmi:** Project administration, Supervision, Methodology. **R. Mamat:** Conceptualization. **K.A. Hamid:** Resources, Writing - review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The authors are grateful to the Universiti Malaysia Pahang for financial supports given under PGRS1903147. The authors also thank the research team from Automotive Engineering Centre (AEC) and Advanced Automotive Liquids Laboratory (AALL), who provided insight and expertise that greatly assisted in the research.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.csite.2020.100782.

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 Al_2O_3 nanofluid, Int. Commun. Heat Mass Tran. 69 (2015) 34–40.
[7] B. Mosavati, M. Mosavati, F. Kowsary, Solution of radiative inverse boundary design problem in a combined radiating-free convecting furnace, Int. Commun. Heat Mass Tran. 45 (2013) 130–136.
[8] 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, p. 12054.
[9] S. Pal, S.K. Saha, Laminar fluid flow and heat transfer through a circular tube having spiral ribs and twisted tapes, Exp. Therm. Fluid Sci. 60 (2015) 173–181.
[10] Y. Wang, B. Zhou, Z. Liu, Z. Tu, W. Liu, Numerical study and performance analyses of the mini-channel with discrete double-inclined ribs, Int. J. Heat Mass Tran. 78 (2014) 498–505.
[11] S.K. Saha, Thermal and friction characteristics of laminar flow through rectangular and square ducts with transverse ribs and wire coil inserts, Exp. Therm. Fluid Sci. 34 (1) (2010) 63–72.
[12] 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, Appl. Therm. Eng. 31 (14–15) (2011) 2702–2708.
[13] 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, Int. J. Heat Mass Tran. 50 (1–2) (2007) 381–390.
[14] 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, 012078.
[15] 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, J. Enhanc. Heat Transf. 1 (2) (1994).
[16] S. Al-Fahed, L. Chamra, W. Chakroun, Pressure drop and heat transfer comparison for both microfin tube and twisted-tape inserts in laminar flow, Exp. Therm. Fluid Sci. 18 (4) (1998) 323–333.
[17] A.I. Ramadhan, E. Diniardi, E. Dermawan, Numerical study of effect parameter fluid flow nanofluid Al_2O_3-water on heat transfer in corrugated tube, in: AIP Conference Proceedings, AIP Publishing LLC, 2016, 050003.
[18] R.S. Luciu, T. Mateescu, V. Cotorobai, T. Mare, Nusselt number and convection heat transfer coefficient for a coaxial heat exchanger using Al_2O_3–water pH= 5 nanofluid, Bul. Inst. Polit. Iasi 55 (2009) 71–80.
[19] O.S. Prajapati, A. Rajvanshi, Effect of Al 2 O 3-water nanofluids in convective heat transfer, Int. J. Nanosci. 11 (3) (2012) 1240005.
[20] N. Bozorgan, N. Bozorgan, Evaluation of the using Al_2O_3/EG and TiO_2/EG nanofluids as coolants in the double-tube heat exchanger, Int. J. Adv. Des. Manuf. Technol. 5 (2) (2012).
[21] 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, Int. Commun. Heat Mass Tran. 37 (10) (2010) 1426–1431.
[22] J. Bayat, A.H. Nikseresht, Thermal performance and pressure drop analysis of nanofluids in turbulent forced convective flows, Int. J. Therm. Sci. 60 (2012) 236–243.

[23] 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.
[24] X. Liu, M.K. Jensen, Numerical investigation of turbulent flow and heat transfer in internally finned tubes, J. Enhanc. Heat Transf. 6 (2–4) (1999).
[25] Y. Dong, L. Huixiong, C. Tingkuan, Pressure drop, heat transfer and performance of single-phase turbulent flow in spirally corrugated tubes, Exp. Therm. Fluid Sci. 24 (3–4) (2001) 131–138.
[26] 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 Al_2O_3-ethylene glycol nanofluids under turbulent flows in a flat tube, Jurnal Teknologi 78 (9–2) (2016).
[27] Y. Xuan, Q. Li, Heat transfer enhancement of nanofluids, Int. J. Heat Fluid Flow 21 (1) (2000) 58–64.
[28] 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.
[29] Y. Xuan, Q. Li, Investigation on convective heat transfer and flow features of nanofluids, J. Heat Tran. 125 (1) (2003) 151–155.
[30] D. Wen, Y. Ding, Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions, Int. J. Heat Mass Tran. 47 (24) (2004) 5181–5188.
[31] Y. Ding, H. Alias, D. Wen, R.A. Williams, Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids), Int. J. Heat Mass Tran. 49 (1–2) (2006) 240–250.
[32] W.H. Azmi, K.V. Sharma, P.K. Sarma, R. Mamat, G. Najafi, Heat transfer and friction factor of water based TiO_2 and SiO_2 nanofluids under turbulent flow in a tube, Int. Commun. Heat Mass Tran. 59 (2014) 30–38.
[33] W.H. Azmi, K. Abdul Hamid, N.A. Usri, R. Mamat, M.S. Mohamad, Heat transfer and friction factor of water and ethylene glycol mixture based TiO_2 and Al_2O_3 nanofluids under turbulent flow, Int. Commun. Heat Mass Tran. 76 (2016) 24–32.
[34] W.H. Azmi, K. Abdul Hamid, R. Mamat, K.V. Sharma, M.S. Mohamad, Effects of working temperature on thermo-physical properties and forced convection heat transfer of TiO_2 nanofluids in water – ethylene glycol mixture, Appl. Therm. Eng. 106 (2016) 1190–1199.
[35] W. Duangthongsuk, S. Wongwises, Heat transfer enhancement and pressure drop characteristics of TiO_2–water nanofluid in a double-tube counter flow heat exchanger, Int. J. Heat Mass Tran. 52 (7–8) (2009) 2059–2067.
[36] A.I. Ramadhan, W.H. Azmi, R. Mamat, M. Mazlan, A new correlation of thermal-properties of tri-hybrid nanoparticles in water-ethylene glycol mixture, Technology Reports of Kansai University 62 (2) (2020) 1151–1160.
[37] 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 TiO_2-SiO_2 nanofluids, Int. J. Heat Mass Tran. 116 (2018) 1143–1152.
[38] 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, 012068.
[39] A. Fluent, Ansys Fluent Theory Guide, 15317, ANSYS Inc., USA, 2011, pp. 724–746.
[40] K.A. Hamid, W.H. Azmi, M.F. Nabil, R. Mamat, Experimental investigation of nanoparticle mixture ratios on TiO_2–SiO_2 nanofluids heat transfer performance under turbulent flow, Int. J. Heat Mass Tran. 118 (2018) 617–627.