International Journal of Engineering & Technology, 7 (4.14) (2018) 365-368

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Augmentation of Nanofluids Heat Transfer in a Circular Pipe with Coiled Tube Insert as Heat Source and Swirl Generator

S.D. Salman*

Biochemical Engineering Department, Al-khwarizmi College of Engineering, University of Baghdad, Baghdad 47024, Iraq
**Corresponding author E-mail: sami.albayati@gmail.com*

Abstract

This research present steady state heat transfer and fluid flow characteristics in concentric pipe with coiled tube insert for turbulent flow regime with metal oxide nanofluid using ANSYS-FLUENT 18.0 where the governing equations of mass, momentum and heat transfer were solved simultaneously, using the k-e two equations turbulence model. Copper was chosen as the as metal for the construction of pipe and the helical tube insert. Coiled tube with curvature to pitch ratio as 1 and 2.5 mm in diameter with 1% volume fractions of TiO_2 and CuO Nanofluid with Reynolds number ranged from 4000-16000 were considered in this research. The heat generated from constant water temperature (80 °C) with constant flow rates in helical coil (Re=4000). The Result shows that the heat and friction coefficients conducted by vortex generator raised with Reynolds number and accretion of nanoparticle presence. Furthermore, the maximum rate of heat transfer with significant intension in friction coefficient has been produced TiO2 nanofluid by as compared with CuO and water.

Keywords: *Heat transfer enhancement, Coiled tube insert, computational fluid dynamics (CFD).*

1. Introduction

Heat transfer enhancement technique plays substantial role for laminar flow regime, due to the deficiency of heat transfer coefficient in plain tubes. The enhancement technique can be labeled as active and passive techniques [1, 2]. Active techniques require external power source, such as electric field, surface vibration, or Jet impingement. Whereas, passive techniques require fluid additives, surface modifications, or swirl/vortex flow devices to enhance heat transfer. The swirl flow apparatus includes helical coiled wire, and twist tape inserts. So, many published articles related to experimental and numerical investigation on convective heat transfer using helical coil and water as test fluid have been reported in the literature [3–13]. The limitation of thermos-physical properties and low thermal conductivity of water lead up to innovative new fluid to enhance the heat transfers. Small amount of nanoparticles was dispersed into base fluid to improve its thermal conductivity. The resultant fluid of suspended nanoparticles into base fluid was called nanofluid. Nanofluids were first used by Choi and Eastman [14] in 1995 at Argonne National Laboratory, USA. Subsequently, different types of metal and metal oxides nanoparticles were utilized for nanofluid preparation; gold (Au), copper (Cu), and silver (Ag) and TiO_2, Fe_3O_4, Al_2O_3, and CuO [15–21]. Metal oxides are prioritized for heat transfer application based on their significantly lower cost as with metal nanoparticles.

In the present work a numerical investigation on heat transfer enhancement in concentric pipe with coiled tube insert as vortex generator with 1% v/v of CuO and TiO_2 and nanofluids is simulated using Computational Fluid Dynamic (CFD). The results demonstrate around 10% augmentation in heat characteristics for CuO nanofluid with a significant increase in friction characteristics compared to TiO_2 nanofluid and water.

2. Materials and Method

2.1. Physical model

Geometry and Grid of 1000 mm of copper concentric pipe fitted with coiled tube insert with curvature to pitch ratio as 1 and 2.5 mm in diameter was created using ANSYS-FLUENT 18.0 as shown in Figures 1, 2.Water, TiO_2 and CuO Nanofluid are selected as working fluids.

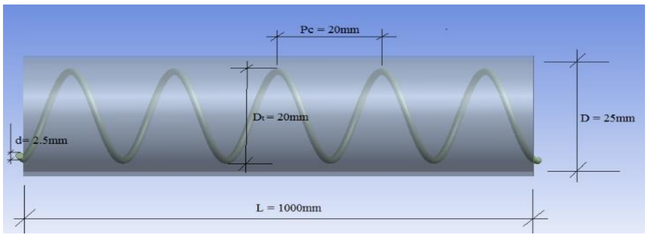

Figure1: Coiled tube Model

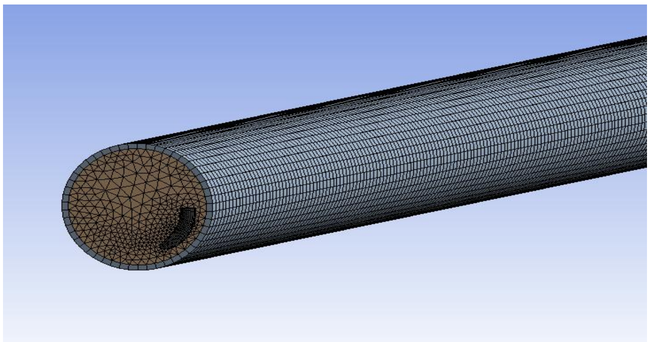

Figure 2: Grid for concentric pipe with coiled tube model

3.1. Text font of entire document

Nanofluids thermos-physical specification of this research was calculated using equations [22] as follow:

$$\rho_{nf} = (1-\emptyset)\rho_f + \emptyset_{np} \tag{1}$$

$$(\rho Cp)_{nf} = (1-\emptyset)(\rho Cp)_f + \emptyset_{np} \tag{2}$$

Where

ρ_f, ρ_{np} and φ are water, nanoparticles and nanoparticle volume fraction.

$(\rho Cp)_f$ and $(\rho Cp)_{np}$ are heat capacities of specific heat of water and nanoparticles.

Likewise, the effective thermal-conductivity calculated using equations [22] below:

$$K_{eff} = K_{Static} + K_{Brownian} \tag{3}$$

$$K_{Static} = K_f \left[\frac{(K_{np}+2K_f)-2\emptyset(K_f-2K_{np})}{(K_{np}+2K_f)+\emptyset(K_f+K_{np})}\right] \tag{4}$$

$$K_{Brownian} = 5\times 10^4 \beta\emptyset\rho_f Cp_f \sqrt{\frac{kT}{\rho_{np}R_{np}}} f(T,\emptyset) \tag{5}$$

where

$\beta = 9.881(100\emptyset)^{-0.9446}$ for CuO nanoparticle

k = Boltzman costant

Rnp = Nanoparticle radius

$f(T,\emptyset) = (2.8217\times 10^{[illegible]}\emptyset + 3.917\times 10^{[illegible]})\left(\frac{T}{T_0}\right) + (-3.669\times 10^{[illegible]}\emptyset - 3.91123\times 10^{[illegible]}$

Whereas, an effective viscosity of naofluids obtained using the following equations [23]:

$$\mu_{eff} = \frac{\mu_f}{1-34.87\left(\frac{d_p}{d_f}\right)^{-0.3}\times\emptyset^{1.03}} \tag{6}$$

$$d_f = \left[\frac{6M}{N\pi\rho_{fo}}\right] \tag{7}$$

where:

M is the molecular mass water, N is Avogadro number (N = 6.022x1023 mol^{-1}), and ρ_{fo} is the mass density of water at reference temperature (T_o=20 ˚C).

3.3. Parameters and Numerical method

Commercial CFD software, ANSYS-FLUENT 18.0 was selected to solve the following three-dimensional model equations of mass converstion, momentum conversation and energy converstion for turbulant steady state flow (Re= 4000-16000) of water and Nanofluid at 25 °C through pipe whereas hot water at 80 °C in turbulant flow Re=4000 through the coiled tube insert. .

$$\frac{\partial \rho}{\partial t} + (\rho\vec{v}) + S_m \tag{8}$$

$$\frac{\partial v}{\partial t} + \rho(\vec{v}.\nabla)\vec{v} = -\nabla p + \rho g + \nabla.\tau_{ij} + \vec{F} \tag{9}$$

$$\rho\frac{\partial(\rho E)}{\partial t} + \nabla.\{\vec{v}(\rho E+\rho)\} = \nabla.\{K_{eff}\nabla T - \sum h_i(\overrightarrow{\tau_{eff.}}\vec{v})\} + S_h \tag{10}$$

4. Result and Discussion

4.1. Mesh independence test

Three mesh volumes were observed the independence effect of mesh sizes (789270, 776533 and 823866) on the simulated Nusselt number values at Re = 2000. Their results similar values for Nusselt number with approximated error less than 0.3%. Therefore, mish size of 775533 was selected to minimize the computation time.

4.1. Effect of configuration

Nusselt number and friction characteristics with different Reynolds number in plain pipe with coiled tube insert using water-water system are depicted shown in Figs. 3 and 4. It's obvious that with Reynolds number increase, the heat transfer coefficient increases whereas, friction factor decreases. Mainly, this phenomenon is conducted due to the mutual effects of normal swirling flow generated by the coil insert and turbulence flow due to Reynolds number along the pipe. These effects lead to thermal boundary layer annihilation with superior fluid mixing between at the core of the pipe and inner pipe surface.

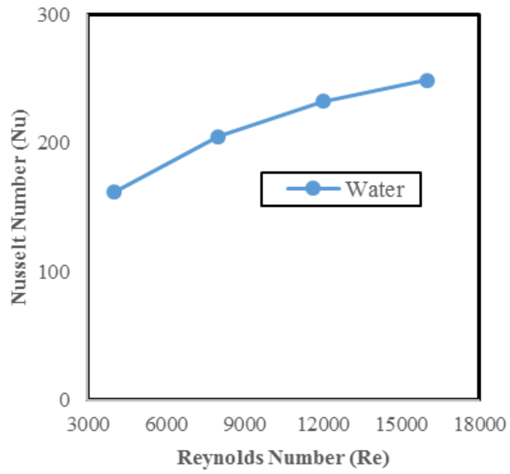

Figure 3: Nusselt Number with at different Reynolds Numbers for water-water system

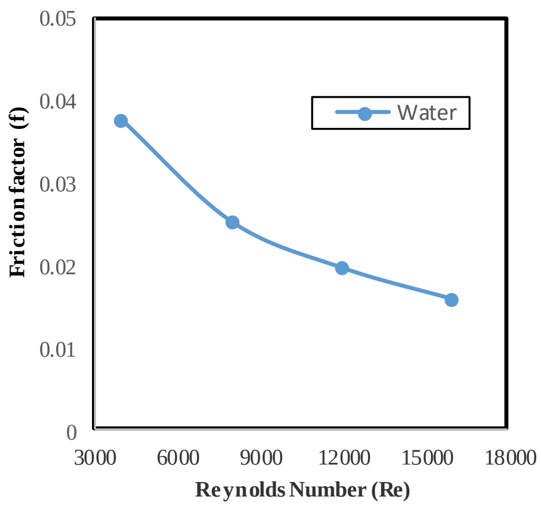

Figure 4: Friction factor with different Reynolds Numbers for water-water system

3.3 Effect of nanofluid with model configuration

The simulated results of Nusselt number and friction factor versus Reynolds number variation in a plain pipe with the coiled tube insert using water- water, CuO-water and TiO_2-water nanofluid with 1% volume fraction system are presented in Figs. 5 and 6. It's can be observed from Fig. 5 that significant increases in Nusselt number with type of fluid and of nanoparticles volume fraction. This result is possibly occurred due to the thermal flow dispersion due to the random movements [24]. Fig. 6 shows the variation of friction factor with the Reynolds number of water and nanoparticles. It is obviously seen that the presence of nanoparticles suspension increases of the shear stress nearby the pipe surface which consequently causes a slight effect on friction coefficient [25].

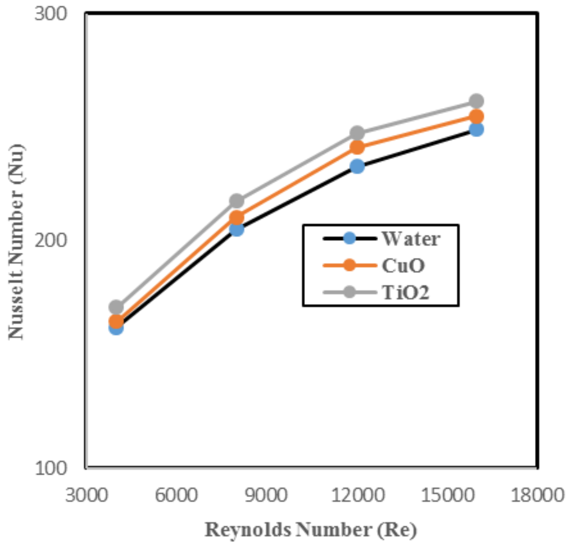

Figure 5: Nusselt number with different Reynolds Numbers for water-nanofluid system

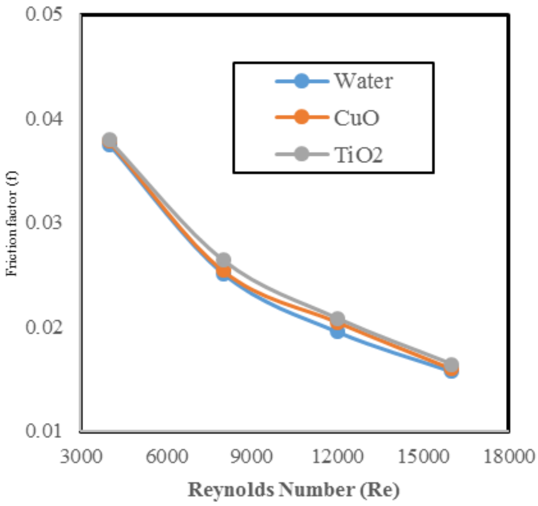

Figure 6: Friction factor with different Reynolds Numbers for water-nanofluid system

5. Conclusion

CFD simulation on heat transfer augmentation in a plain pipe with coiled tube insert for turbulent flow regime of water and metal oxide nanofluids using ANSYS-FLUENT 18.0 has been reported. The results of simulation show that the Nusselt number enhanced with accretion of nanoparticle volume fraction and Reynolds number. The results also revealed that the combined nanoparticle with presence of helical coil has superior dominant effect compared with water-water system. Furthermore, water-CuO nanofluid system offered highest enhancement in heat transfer coefficient with significant intension in friction factor compared with water-CuO and water-water system.

It can be concluded that best heat transfer enhancement over helical coil insert was obtained by using TiO_2 as the working fluid with 1% volume fraction at Reynolds number of 16000.

Nomenclature

CuO Copper oxide
Cp Fluid specific heat, J/kg K
dp Diameter of Nanoparticle, nm
Dc Coil turn diameter, mm
E Component of Energy, J
F Component of Force, N
f Friction factor
g Gravity acceleration, m/s2
keff Thermal conductivity, W/m K
m Fluid mass flow rate, kg/s
Nu Nusselt number, dimensionless
Re Reynolds number, dimensionless
p Pressure component in momentum equation, N/m2
Pc Coil pitch, mm
Sm Mass accumulation, Kg
Sh Energy accumulation, J
TiO2 Titanium oxide
T Temperature. °C.
v Fluid velocity, m/s

Greek symbols
ρ Fluid density
$\overrightarrow{\tau_{eff}}$ Fluid stress, N/m2

Acknowledgement

The author gratefully acknowledges the technical support from University of Baghdad, Al-Khwarizmi College of Engineering, Department of Biochemical Engineering

References

[1] Bejan and A. D. Kraus, Heat Transfer Handbook, John Wiley & Sons, 2003.
[2] Singh and N. Diwakar (2013), International Journal of Applied Research in Mechanical Engineering, 3,16–29.
[3] Tarbell JM, Samuels MR. (1973), Momentum and heat transfer in helical coils. Chem Eng J, 5, 117-127.
[4] Rindt CCM, Sillekens JJM, Van Steenhoven AA. (1999), The influence of the wall temperature on the development of heat transfer and secondary flow in a Coiled heat exchanger. Int Commun Heat Mass Transfer, 26, 187-98.
[5] Ujhidy A, Nemeth J, Szepvolgyi J. (2003), Fluid flow in tubes with helical elements. Chem Eng Process, 42, 1-7.
[6] Wang CY. (2001), On the low-Reynolds number flow in a helical pipe. Journal of Fluid Mech, 108,185-94.
[7] Huttl TJ, Friedrich R. (2001), Direct numerical simulation of turbulent flows in curved and helically coiled pipes. Comput Fluids, 30, 591-605.
[8] Yamamoto K, Akita T, Ikeuchi H, Kita Y. (1995), Experimental study of the flow in a helical circular tube. Fluid Dyn Res,16, 237-49.
[9] Yamamoto K, Alam MdM, Yasuhara J, Aribowo A. (2000), Flow through a rotating helical pipe with circular cross-section. Int J Heat Fluid Flow, 21, 213-20.
[10] Yamamoto K, Aribowo A, Hayamizu Y, Hirose T, Kawahara K. (2002), Visualization of the flow in a helical pipe. Fluid Dyn Res, 30, 251-67.
[11] S.S. Pawar, Pritam Shetty,Ancila John, Sairaj Pawar, Pravin Jagtap. (2015), Experimental study for comparison of overall heat transfer co-efficient in helical coils of fixed length using water.
[12] International Journal of Latest Research in Science & Technology, 4; 2, 161-166.
[13] Pramod S. Purandare, Mandar M. Lele, Rajkumar Gupta (2012), Parametric Analysis of Helical Coil Heat Exchanger. International Journal of Engineering Research & Technology, (IJERT) 1; 8, 01-05.
[14] Sreejith K., T.R. Sreesastha Ram, Jaivin A. Varghese, Manoj Francis, Mossas V.J., Nidhin M.J., Nithil E.S., Sushmitha S. (2015),

Experimental Investigation of a Helical Coil Heat Exchanger, 5; 8, 01-05

[15] S. U. S. Choi and J. A. Eastman. (1995), Enhancing thermal conductivity of fluids with nanoparticles. Developments and Applications of Non-Newtonian Flows, 1, 99–105.

[16] Y. Tsai, H. T. Chien, P. P. Ding, B. Chan, T. Y. Luh, and P. H. Chen. (2004), Effect of structural character of gold nanoparticles in nanofluid on heat pipe thermal performance. Materials Letters, 58; 9,1461–1465.

[17] M.-S. Liu, M. C.-C. Lin, C. Y. Tsai, and C.-C.Wang. (2006), Enhancement of thermal conductivity with Cu for nanofluids using chemical reduction method. International Journal of Heat and Mass Transfer, 49, 17-18, 3028–3033.

[18] E.Tamjid and B.H.Guenther. (2010), Rheology and colloidal structure of silver nanoparticles dispersed in diethylene glycol. Powder Technology, 97; 1-2, 49–53.

[19] S. M. S.Murshed, K. C. Leong, and C. Yang. (2005), Enhanced thermal conductivity of TiO2 water based nanofluids. International Journal of Thermal Sciences, 44, 4, 367–373.

[20] H. Zhu, C. Zhang, S. Liu, Y. Tang, and Y. Yin. (2006), Effects of nanoparticle clustering and alignment on thermal conductivities of Fe3O4 aqueous nanofluids. Applied Physics Letters, 89, Article ID 023123.

[21] J. A. Eastman, U. S. Choi, S. Li, L. J. Thompson, and S. Lee. (1996), Enhanced thermal conductivity through the development of nanofluids. MRS Proceedings, vol. 457.

[22] M. E.Meibodi, M. Vafaie-Sefti, A. M. Rashidi, A. Amrollahi,M. Tabasi, and H. S. Kalal. (2010), "Simplemodel for thermal conductivity of nanofluids using resistance model approach. International Communications in Heat and Mass Transfer, 37; 5, 555–559.

[23] R.S. Vajjha, D.K. Das. (2009), Experimental determination of thermal conductivity of three nanofluids and development of new correlations. International Journal of Heat and Mass Transfer, 52;, 21–22, 4675–4682.

[24] M. Corcione. (2010), Heat transfer features of buoyancy-driven nanofluids inside rectangular enclosures differentially heated at the side walls. International Journal of Thermal Sciences, 49; 9, 1536–1546.

[25] Shailesh Kumar, Santosh Kumar Prasad, Jyotirmay. (2010). Analysis of flow and thermal field in nanofluid using a single phase thermal dispersion model. Applied Mathematical Modelling, 34; 3, 573-592.

[26] Maiga, S. E. B., S. J. Palm, C. T. Nguyen, G. Roy and N. Galanis. (2005), Heat transfer enhancement by using nanofluids in forced convection flows. International Journal of Heat and Fluid Flow, 26; 4, 530-5546.