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Computational Analysis of Different Nanofluids effect on Convective Heat Transfer Enhancement of Double Tube Helical Heat Exchanger

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Abstract

The heat transfer enhancement and flow characteristics in double pipe helical coil heat exchanger using nanofluids are numerically studied and researched by many researchers. Studies are carried out for SiO_2, CuO, and Al_2O_3 nanofluid with different volume fractions (1-5%). The graphs are plotted for Nusselt number and Heat transfer coefficient for MIXTURE MODEL using ANSYS FLUENT 15. The finite volume method with k–ε standard turbulent model was used to discritize the main governing equations. Result showed that the value of Nusselt number for nanofluid is higher than that of the base fluid as water where the SiO_2 nanofluid yields the best heat transfer enhancement followed by CuO and Al_2O_3. Enhancement in heat transfer is achieved by increasing the Dean Number and volumetric concentration.

Keywords: *Nanofluid, FLUENT, Dean Number, Nusselt number, Heat transfer coefficient*

1. Introduction

Cooling is one of the most considerable scientific challenges in the industrial area, which applies to many varied productions, counting microelectronics, transportation and manufacturing and technological developments. There is an urgent need for new and spanking new coolants with superior performance. The new concept of 'nanofluids' – heat transfer fluids consisting of suspended of nanoparticles – has been expected as a vision for these challenges [1].some review papers have discussed on the preparation methods for nanofluids [2-4]. A nanofluid is a fluid produced by the distribution of nanoparticles with a typical size of less than 100 nm in a liquid. Nanofluids have enhanced thermal properties.

In an industry heat exchangers are broadly used and performance of heat exchangers can be improved by different methods. Due to the compressed structure and high heat transfer coefficient, helical coil heat exchangers find open use in industrial applications [5] such as power generation, nuclear industry, process plants, heat recovery systems, food industry, refrigeration,

Seban and McLaughlin [6] experimentally investigated the heat transfer in coiled tubes for both laminar and turbulent flows. . Prabhanjan et al. [7] investigated the heat transfer rates of a straight tube heat exchanger to that of a helically coiled heat exchanger. Wongwises et al. [8] studied the condensation heat transfer in a tube-in-tube helical heat exchanger.

Thermal performance in helically coiled heat exchangers was experimentally and numerically investigated by Jayakumar et al. [9]. It was studied that the constant wall flux boundary condition was a better hypothesis to investigate the heat transfer inside the helical coil than either constant wall temperature or constant wall heat transfer coefficient boundary conditions.

ABBREVIATIONS

Ac= flow area, m^2
Al_2O_3 =aluminium oxide
As =surface area, m^2
Cu =copper
CuO =copper oxide
Cp =specific heat, J/kg-K
CFD =computational fluid dynamics
dii=inner diameter of inner pipe, inch
dio=outer diameter of inner pipe inch
doi =inner diameter of outer pipe, inch
doo =outer diameter of outer pipe, inch
Dh = hydraulic diameter, mm
Dn =diameter of nanofluid particles
D = coil diameter, mm
De =Dean Number
HTF =Heat transfer fluid
h =heat transfer coefficient, W/m^2k
H =pitch of coil, mm
k =thermal conductivity, W/m-K
K =turbulent kinetic energy
L =length of pipe, m
m =mass flow rate, kg/s
n= number of turns
Nux =Local Nusselt Number
Nu=Average Nusselt number
P= Pressure, N/m2
Δp= Pressure drop
Pr= Prandtl Number
q= heat flux, W/m^2
q′ =total surface heat flux
Q =heat transfer rate (kW)
Re =Reynolds Number
Recr=Critical Reynolds number
St= Stanton Number
Thi=temperature of hot fluid at inlet, K
Tho=temperature of hot fluid at outlet, K
Tci= temperature of cold fluid at inlet, K
Tco= temperature of cold fluid at outlet, K
Tw= wall temperature, K
Tf= fluid mean temperature, K

ux, *uy* and *uz*=velocity in x ,y, z directions
x, *y*, *z* coordinates
X, *Y*, *Z* body force in x, y, z directions
V= Average velocity of flow
Vs = wetted volume, m^3

Greek symbol

β=surface area density, m^2/m^3
ρ =density, Kg/m^3
μ=dynamic viscosity, Kg/ms
Φ=Rayleigh dissipation factor
ε =dissipation kinetic energy (m^2/s^3)
φ =volume fraction (%)
δ= Curvature Ratio

Rennie and Raghavan [10] studied numerically on the heat transfer characteristics of a double tube heat exchanger. They showed that flow in the inner tube is the limiting factor of overall heat transfer coefficient of heat exchanger and while stabilizing other parameters. The overall heat transfer coefficient will increase, Also there is a widespread research had been done on the performance of other types of heat exchangers [11-13].

In present work, the heat transfer performance of a double helical coiled heat exchanger was investigated numerically. The end of the tubes act as the entry and exit of hot as well as cold fluid where the cold fluid flows in the outer pipe and the hot fluid flows in the inner pipe of the double pipe helical coil heat exchanger.

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In double tube helical heat exchangers, due to the curvature of tubes and application of centrifugal force on fluid flow, the secondary flow motion is generated which improves heat transfer coefficient considerably [14]. Dravid et al.[15] projected the correlation for inner Nu at the Dean number (De) range of 50 to 2000. He investigated the secondary flow motion produced by the curvature effects. He concluded that resultant centrifugal force makes heat transfer coefficient greater than that of straight tube.

Studies are carried out in CFD tool for the effects of several geometrical parameters on heat transfer characteristics for water and the effect of different nanofluids SiO_2, CuO, and Al_2O_3 with different volume fractions (1-5%).on heat transfer characteristics.

Characteristics of helical coils

Stretching of the flow through the coils is the key point of helical coil heat exchanger which produces the secondary flow due to the effect of centrifugal forces. For the analysis of flow in helical pipe, Dean (De) number is used defined as follows,

$$De_{in} = \left(\frac{\rho V d_{in}}{\mu}\right)\left(\frac{d_{oi}}{D}\right)^{1/2}$$

As turbulent flow is used in double tube helical heat exchangers, thus in this work, turbulent flow ranges were chosen for flow rates. Therefore, to know about the type of flow, the obtained Reynolds number can be compared with critical Reynolds number (Re_{cr}):

$$Re_{cr} = 2300[1+8.6(d / D)^{0.45}]$$

Where δ is curvature ratio and defined as:

$$\frac{d_{oi}}{D}$$

2. CFD Methodology

2.1 Geometry and Boundary Conditions

The model used in this analysis is the double tube helical heat exchanger (fig 1) shows schematic cross section of used model, it consists of two tubes with two turns in which nanofluid flows through inner tube and water flows through outer tube. Both fluids flow in the same direction. Copper is used for tubes to maximize the heat transfer rate. The end of tubes acts as the entry and exit for hot as well as cold fluid .The temperature for nanofluid and water are taken as 348^0C and 283^0C respectively.

In the present study, velocity inlet boundary condition is enforced at the inlet of inner and outer tubes and pressure outlet boundary condition is enforced at the outlet of inner and outer tubes. The flow is assumed to be Newtonian, turbulent and incompressible. As there are two walls in double tube helical heat exchanger so insulated outer wall condition is used at outer wall and bilateral wall is used for inner wall for the heat transfer to be occurred on both sides.

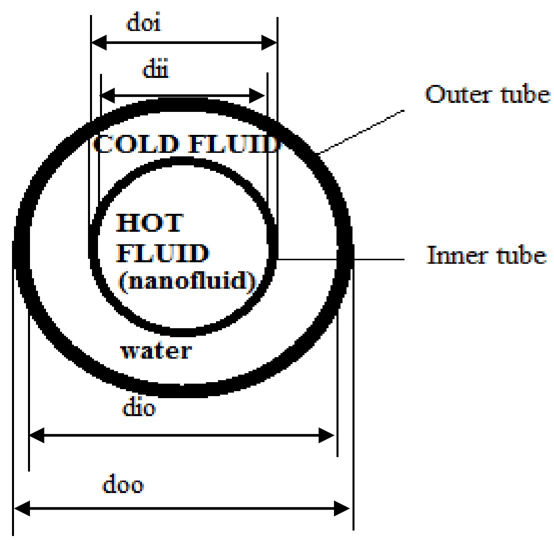

Fig. (1) Schematic cross section of used model (double tube helical coil heat exchanger)

Table 1, 2, and 3 shows the dimensional parameters, properties of base fluid and nanoparticle and Properties of copper respectively.

Table 1: The dimensional parameters of helically coiled tube heat exchanger

Helically coiled tube	Value (inch)
Inner diameter of inner tube (d_{ii})	0.545
Outer diameter of inner tube (d_{oi})	0.625
Inner diameter of outer tube (d_{io})	0.785
Outer diameter of outer tube (d_{oo})	0.875
Pitch of coil	2

Table 2: The thermo - physical properties of base fluid and nano particles at T = 300k

Thermo-physical Properties	Water	Al_2O_3	CuO	SiO_2
Density, ρ (Kg/m^3)	996.5	3600	6500	2220
Specific Heat, C_p (J/Kg K)	4181	765	533	495.2
Thermal Conductivity, K (W/m K)	0.0103	36	17.65	13
Viscosity, μ (mpa s)	0.001003	-	-	-

Table 3: Properties of copper

Description	Value	Unit
Densit,y ρ (Kg/m^3)	8978	Kg/m^3
Specific Heat Capacity, C_p (J/Kg K)	381	J/Kg-K
Thermal Conductivity, K (W/m K)	387.6	W/m-K

2.2 Numerical Simulation

In this study, commercial software ANSYS 15 is used to create the geometry and meshing of double tube helical coil heat exchanger. MAPPED FACE MESH with Tetra and Hexahedral cells is done for creating fine mesh. The number of nodes used in this analysis is 53710. A numerical analysis with standard (k-ε) k-epsilon model as a turbulent model is used to understand the flow characteristics. A mixture model is used for this analysis. Inlet and outlet are defined as velocity inlet and pressure outlet with insulated outer wall condition. Dean number is used to calculate the input value. The coupled scheme with second order upwind is used to deal with pressure-velocity coupling problem and to solve governing equations. The relaxation factor has been set to default values. The normalized residual values are set to 10^{-5} for all the variables to converge the solution.

The governing differential equations for the fluid flow are given by Continuity equation, Navier Stokes equation and energy conservation equation. These can be written in the following form [15]:

2.2.1 Continuity Equation:

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \qquad (2.1)$$

2.2.2 Navier Stokes equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho X-\frac{\partial p}{\partial x}+\frac{1}{3}\mu\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 u \quad (2.2)$$

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=\rho Y-\frac{\partial p}{\partial y}+\frac{1}{3}\mu\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 v \quad (2.3)$$

$$\rho\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=\rho Z-\frac{\partial p}{\partial z}+\frac{1}{3}\mu\frac{\partial}{\partial z}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 w \quad (2.4)$$

2.2.3 Energy Equation:

$$\rho C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\left(u\frac{\partial p}{\partial x}+v\frac{\partial p}{\partial y}+w\frac{\partial p}{\partial z}\right)+k\nabla^2 T+\mu\phi \quad (2.5)$$

Where,

$$\phi=2\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]+\left[\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)^2+\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)^2\right]-\frac{2}{3}\left[\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right]^2$$

2.2.4 Turbulent kinetic energy (k) equation:

$$\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k-\rho\varepsilon \quad (2.6)$$

2.2.5 Turbulent kinetic energy dissipation (ε) equation:

$$\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\left(\varepsilon/k\right)G_k+C_{2\varepsilon}\rho\left(\varepsilon^2/k\right) \quad (2.7)$$

In the above equations, G_k represents the generation of turbulent kinetic energy due to mean velocity gradients, σ_k and σ_ε are effective Prandtl numbers for turbulent kinetic energy and rate of dissipation, respectively; $C1\varepsilon$ and $C2\varepsilon$ are constants and μ_t is the eddy viscosity and is modeled as

$$\mu_t = (\rho C_\mu k^2)/\varepsilon \quad (2.8)$$

The empirical constants for the turbulence model are arrived by comprehensive data fitting for a wide range of turbulent flow.

$$C_\mu = 0.09,\ C_{\varepsilon 1} = 1.47,\ C_{\varepsilon 2} = 1.92,\ \sigma_k = 1.0,\ \sigma_\varepsilon = 1.3 \quad (2.9)$$

The governing differential equation for solid domain is only the Energy equation which is given by;

$$\nabla^2 T = 0 \quad (2.10)$$

Heat transfer coefficient is obtained by equating the conduction heat transfer to the convection heat transfer;

$$q_{cond} = q_{conv} \quad (2.11)$$

Local Nusselt number is given by;

$$Nu_X = hD/k \quad (2.12)$$

3. Result and discussion

For the helically coiled heat exchanger, the heat is also transferred due to the effect of secondary flow. In this work, the effects of several geometrical parameters and different nanoparticles with different volume fractions on heat transfer characteristics were studied.

3.1 Effect of curvature ratio (δ)

Curvature ratio defined by δ (d_{oi} / D) is the most important parameter for the analysis of helical heat exchanger. Dean Number includes curvature ratio and both parameters d_{oi} and D can change curvature ratio. Here, to avoid the variation of Dean Number in annulus, just outer diameter of the tube was changed. In this figure (2) it is observed that increasing of curvature ratio makes reducing of heat transfer coefficient significantly.

As the tube thickness increases, the heat transfer rate decreases due to the increasing resistance offered by the tube.

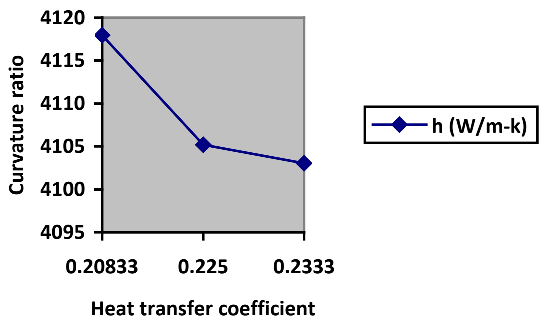

Fig. (2) Variation of Heat transfer coefficient with respect to curvature ratio

3.2 Effect of different nanoparticles:

In this section, three different types of nanoparticles: Al_2O_3, CuO, and SiO_2 with water as a base fluid are used. The graph is plotted between Nusselt Number and Dean Number for different nanoparticles at 4 % volume fraction and 20 nm particle sizes. It can be seen from the fig. (3) that for different nanofluids, Nusselt Number increases with the increase in Dean Number. These results also indicate that all the four types of nanofluids are comparatively richer in heat transfer rate than the pure water because all the nanofluids possess higher Nusselt number compared to pure water. It is clearly seen that SiO_2 – water nanofluid shows the best nanofluid and posses the higher Nusselt Number compared to pure water. It is clear that the SiO_2 nanofluid has the highest value, followed by CuO and Al_2O_3.

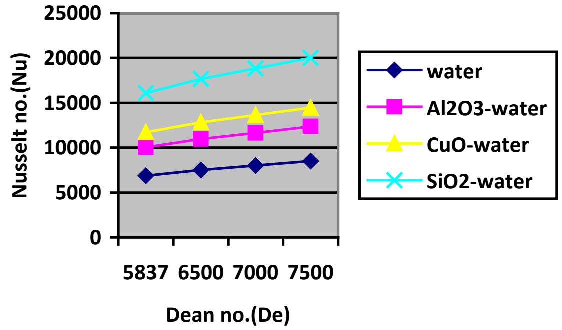

Fig. (3) Variation of the effect of different nanofluids under the range of Dean Number on the average Nusselt Number

3.3 Influence of Dean Number (De) :

For the analysis of flow in helical tube, Dean Number is used. The values of Nusselt Number for different Dean Number are shown in fig (4) and these values increases with increase in Dean Number. As Dean Number is directly related to the velocity of the flow. At higher flow rates, mixing fluctuations intensifies due to the dispersion effects and chaotic movement of the nanoparticles and results in increased heat transfer coefficient. In this way the Nusselt Number will also increase.

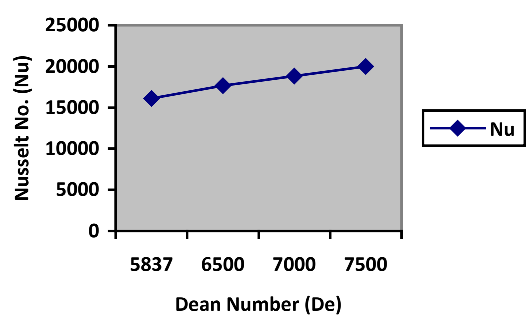

Fig. (4) Variation of the Nusselt number with respect to Dean Number

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3.4 Effect of different nanoparticle volume fraction

In this section, the graph is plotted between Nusselt Number and Dean Number at different volume fraction range (0.01-0.05). It is clear from the fig. (5) that by adding low volume fraction of nanoparticle with 20 nm particle size to the water as base fluid, enhancement in Nusselt Number can be achieved. Because larger surface area for molecular collisions is achieved by the presence of nanoparticle and higher momentum is achieved by increasing concentration of nanoparticles. This momentum transfers thermal energy more efficiently to the coolant and enhances the heat absorption of it, causing its temperature to increase. It is clear that the Nusselt number increases with increased value of volume fraction.

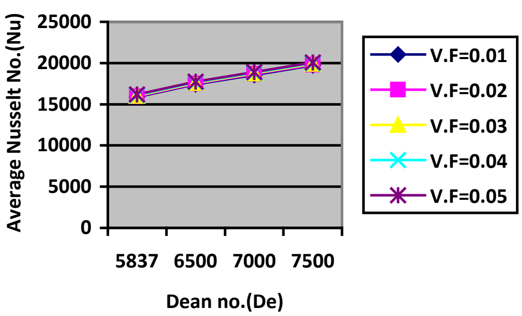

Fig. (5) The effect of different volume fraction under the range of Dean Number on the average Nusselt Number

4. Conclusion

Numerical simulation has been carried out for double tube helical coil heat exchanger subjected to insulated outer wall condition using ANSYS FLUENT 15. The graphs are plotted for Nusselt number and heat transfer coefficient for the water and nanofluids in which flow condition is taken as turbulent. Following are the outcomes of the above study;

- It is observed that heat transfer coefficient decreases with increasing curvature ratio. Because by increasing the coil diameter (d_{oi}), torsional behavior approaches towards linear behavior.
- Heat transfer coefficient increases with increase in Dean Number for convective heat transfer. Because at higher flow rates, the dispersion effects and chaotic movement of the nanoparticles intensifies the mixing fluctuations and causes increase in heat transfer coefficient.

Nanofluid containing small amount of nanoparticles have substantially higher heat transfer coefficient than those of base fluids. And it increases with increase in particle volume fraction. Because increase in the nanoparticle volume fractions intensifies the interaction and collision of nanoparticles

5. References

[1] D. Wu, H. Zhu, L. Wang, L. Liua, Critical issues in nanofluids preparation, characterization and thermal conductivity, Curr. Nanosci. 5 (2009) 103–112.

[2] A. Ghadimi, R. Saidur, H.S.C.Metselaar, A review of nanofluid stability properties and characterization in stationary conditions, Int. J. Heat Mass Transf. 54 (17) (2011) 4051–4068.

[3] Yu. Wei, Huaqing Xie, A review on nanofluids: preparation, stability mechanisms, and applications, J. Nanomater. 2012 (2012) 1–17.

[4] P. Naphon, S. Wongwises, A review of flow and heat transfer characteristics in curved tubes, J. Renew. Sustain. Energy Rev. 10 (2006) 463–490.

[5] R.A. Seban, E.F. McLaughlin, Heat transfer in tube coils with laminar and turbulent flow, Int. J. Heat Mass Transf. 6 (1963) 387–395.

[6] D.G. Prabhanjan, G.S.V. Raghavan, T.J. Rennie, Comparison of heat transfer rates between a straight tube heat exchanger and a helically coiled heat exchanger, Int. Commun. Heat Mass Transfer 29 185-191, 2002.

[7] S.Wongwises ,M. Polsongkram, “Condensation heat transfer and pressure drop of HFC-134a in a helically coiled concentric tube-in-tube heat exchanger,” Int. J.Heat Mass Transfer 29 4386-4398, 2006.

[8] J.S. Jayakumar, S.M. Mahajani, J.C. Mandal, Kannan N. Iyer, P.K. Vijayan, CFD analysis of single-phase flows inside helically coiled tubes, J. Comput. Chem. Eng. 34 (2010) 430–446.

[9] Rennie T.J, Raghavan G.S.V. (2002) “Laminar parallel flow in a tube-in-tube helical heat exchange”; AIC2002 Meeting CSAE/SCGR Program, Saskatchwan.14-17.

[10] Y. Vermahmoudi S.M. Peyghambarzadeh S.H. Hashemabadi, M. Naraki⁻ , “Experimental investigation on heat transfer performance of Fe_2O_3/water nanofluid in an air-finned heat exchanger,” European Journal of Mechanics - B/Fluids 44, 32–41,2014.

[11] Rohit S. Khedkar, Shriram S. Sonawane, Kailas L. Wasewar, “Heat transfer study on concentric tube heat exchanger using TiO_2–water based nanofluid,” International Communications in Heat and Mass Transfer,57, 163-169,2014.

[12] M.M. Elias, I.M. Shahrul, I.M. Mahbubul, R. Saidur, N.A. Rahim, “Effect of different nanoparticle shapes on shell and tube heat exchanger using different baffle angles and operated with nanofluid,” International Journal of Heat and Mass Transfer 70, 289-297 , 2014

[13] Mir Hatef Seyyedvalilu and S.F.Ranjbar, “The Effect of Geometrical Parameters on Heat Transfer and Hydro Dynamical Characteristics of Helical Exchanger”. International Journal of Recent advances in Mechanical Engineering (IJMECH) Vol.4, No.1, 2015.

[14] Thesis , Satyabrata Kanungo, “Numerical Analysis To Optimize The Heat Transfer Rate Of Tube-In-Tube Helical Coil Heat Exchanger” .National Institute Of Technology, Raourkela Odissa, 2014.