Numerical simulation of heat transfer turbulent flow for non-Newtonian nano fluid in a double pipe helical heat exchanger

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ABSTRACT

In this research, the thermal and hydrodynamic behavior of a non-Newtonian nanofluid turbulent flow in the counterflow arrangement in a double pipe helical heat exchanger is numerically simulated. A solution of carboxymethyl cellulose powder in water with a mass percentage of 0.1% with a nanoparticle of aluminum oxide as a working fluid has been used. The CFD commercial software Fluent was used to solve the governing equations, the results were in a good agreement with experimental data. The effect of important parameters such as curvature, Reynolds number and volume percentage of aluminum oxide nanoparticles on the heat transfer has been investigated. The results show that as the curvature ratio increases in constant Dean (Dn) numbers, the Nu number and the coefficient of friction increase. The addition of nanoparticles of aluminum oxide to the base fluid for the flow with the constant Reynolds and Dn number increases the heat transfer and increases the pressure drop in the helically coiled tubes. The centrifugal force generated by the curvature of the coiled tubes results in a secondary flow in the heat exchanger so that the heat transfer and pressure drop increased up to 35% and 30%, respectively, compared to the straight tubes. The effect of heat transfer enhancement methods on the hydrodynamic index has also been studied, so that in the helical coils, the amount of hydrodynamic index increased with decreasing curvature ratio and increasing the volume concentration of nanoparticles.

KEYWORDS

Double pipe helical heat exchanger, Numerical simulation, Heat transfer, Nano fluid, Turbulent flow.

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1. Introduction

The use of extensive surfaces and nanoparticles is an effective way to increase heat transfer in the heat exchangers, which attracted the attention of many researchers in the last two decades. Todays, the recognition of the thermal behavior of a double pipe helical heat exchanger is important because of its wide application in nuclear reactors, food processing, electronics, air-conditioning and etc. So far, researching on thermal characteristics of nanofluids in helically coiled heat exchangers are scarce. Majidi et al [1] evaluated experimentally the heat transfer in a double pipe helical heat exchanger with a copper-wire fin around the inner tube. The results showed an enhancement in overall heat transfer coefficient due to the presence of fin in annulus section. Narrein and Mohammed [2] investigated numerically the effects of different geometrical parameters, material, diameter and volume concentration of nanoparticles on the hydrodynamic and thermal characteristics in helically coiled tube heat exchangers for laminar flow. A review on heat transfer in helical coil heat exchangers are provided in ref [3].

2. Methodology

A double pipe helical heat exchanger (DPHE) is simulated numerically with a nanofluid flowing in the annulus side. The schematic of DPHE is represented in Fig. 1. The configuration details of the heat exchanger are presented in Table 1.

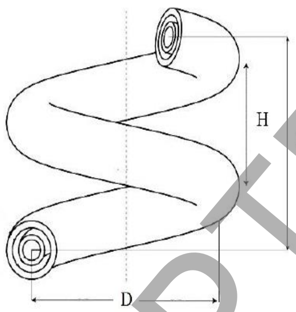

Fig. 1. Schematic of helical coil DPHE

The governing equations including, conservation of mass, momentum and energy are solved numerically using the commercial software Fluent. A k-ε turbulent model was used to analyze the nanofluid turbulent flow. Further information for mathematical and numerical turbulent modeling is available in [4, 5] . The no slip boundary condition is applied to all walls while the outer surface of annulus is assumed to be adiabatic. Physical properties of nanofluid are a function of the physical properties of nanoparticles and base fluid which are calculated as ref [6].

Table 1. Geometric parameters of the heat exchanger

	Inner pipe	Outer pipe
Outer diameter (mm)	6.35	15.87
Inner diameter (mm)	4.75	14.07
Coil diameter (mm)	180-240-300	180-240-300
Coil pitch (mm)	31.74	31.74
Curvature	0.026-0.020-0.016	0.043-0.032-0.025
Flow rate (L/min)	2-5	10-25
Inlet temperature (°C)	50	20

The following equations and dimensionless numbers are defined to present the characteristic of turbulent convection heat transfer and pressure drop in a double pipe helical heat exchanger [7] .

Reynolds number:

$$Re = \frac{\rho u D_h}{\mu} \tag{1}$$

Where D_h=D_o-D_i hydraulic diameter and u is mean velocity inside the annulus side. Heat transfer coefficient of nanofluid h is defined as:

$$h = \frac{q}{(T_w - T_b)} \tag{2}$$

The local and averaged Nusselt number is determined as follows:

$$Nu = \frac{hD_h}{\lambda}, \quad Nu_{avg} = \frac{1}{L}\int Nu_x dx \tag{3}$$

The non-Newtonian power law model is used to analyze the dynamic viscosity of flow as Eq (4). The rheological properties of non-Newtonian fluid are available in ref [8] :

$$\tau = K\dot{\gamma}^n \tag{4}$$

A helical DPHE was simulated numerically to examine thermo hydrodynamic characteristics in the numerical validation. So the well-known correlations were used to validate the numerical process. Fig. 2 shows the comparison between numerical results and suggested correlations for turbulent flow of water in annulus side of helical DPHE. It's found good agreement with the maximum 5% and %2 relative deviations for Nu number in comparison with Gnielinski [10] and Schmidt [11] correlations.

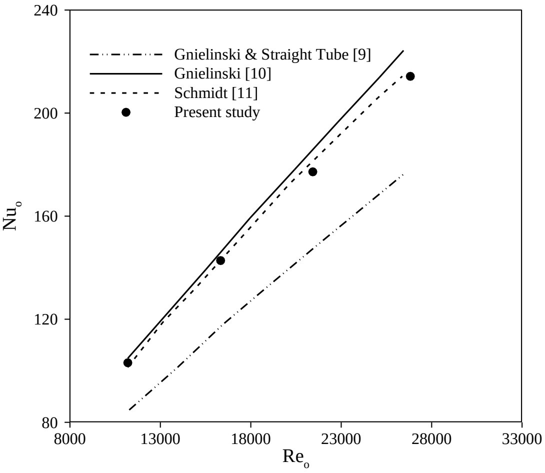

Fig. 2. Validation of Nu number

3. Results and discution

Curvature is one of the main geometric parameter of the helical pipes which induces centrifugal force in fluid results in secondary flow. Fig. 3 shows the streamlines in helical coil for annulus and inner tube. It's expected the secondary flow established by helical coil causes more heat transfer in comparison with straight tubes.

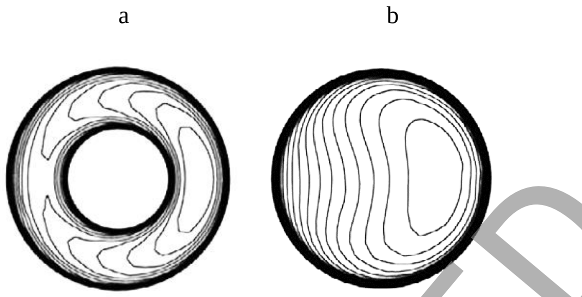

Fig. 3. **The effect of curvature ratio on velocity distribution a) annulus b) inner pipe**

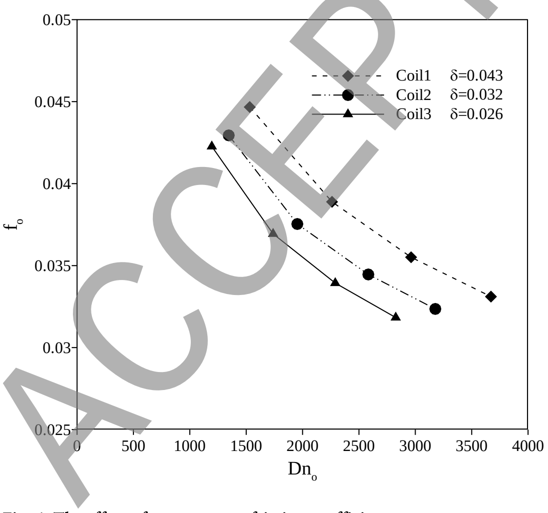

Fig. 4. The effect of curvature on friction coefficient

Fig. 4. shows the effect of curvature on the friction coefficient in annulus side. The higher curvature ratio causes greater friction coefficient in the constant Dean number. Consequently, the increase in the curvature ratio increases the amount of centrifugal force and secondary flow intensity which leads to % 30 enhancements in pressure drop.

Fig. 5 indicates the heat transfer coefficient of the non-Newtonian Al_2O_3 / CMC (0.1%) nanofluid with the volume concentration of 2%-1% and 0.5% based on the Re number in the annulus region. Adding the nanoparticles increases the thermal conductivity of the fluid, as a result, 10 % enhancement in heat transfer coefficient was observed.

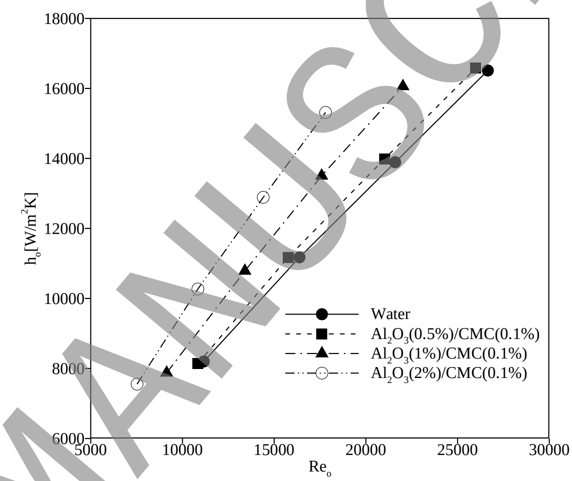

Fig. 5. Annulus side heat transfer coefficient

4. Conclusions

Convection heat transfer and flow characteristics of a non-Newtonian nanofluid were investigated numerically in a double pipe helical heat exchanger. 35 % and 30 % enhancement was observed for heat transfer and pressure drop respectively in comparison to straight tubes. Adding aluminum oxide nanoparticles increased the heat transfer 10 % and pressure drop 8 % for ϕ=2 % in comparison to the base fluid.

5. References

[1] D. Majidi, H. Alighardashi, F. Farhadi, Experimental studies of heat transfer of air in a double-pipe helical heat exchanger, Applied Thermal Engineering, 133 (2018) 276-282.
[2] K. Narrein, H. Mohammed, Influence of nanofluids and rotation on helically coiled tube heat exchanger performance, Thermochimica Acta, 564 (2013) 13–23.
[3] S. Vishvakarma, S. Kumbhare, K.K. Thakur, A review on heat transfer through helical coil heat exchangers, International journal of engineering sciences & research technology, 5 (2016) 607–612.
[4] W.P. Jones, B. Launder, The prediction of laminarization with a two-equation model of turbulence,

International Journal of Heat and Mass Transfer, 15 (1972) 301-314.
[5] Fluent 6.2 user guide, Fluent Inc, New Hampshire, Lebanon, 2005.
[6] M. Heyhat, F. Kowsary, A. Rashidi, M.H. Momenpour, A. Amrollahi, Experimental investigation of laminar convective heat transfer and pressure drop of water-based Al2O3 nanofluids in fully developed flow regime, Experimental Thermal and Fluid Science, 44 (2013) 483–489.
[7] W. Aly, Numerical study on turbulent heat transfer and pressure drop of nanofluid in coiled tube-in-tube heat exchangers, Energy Conversion and Management, 79 (2014) 304-316.
[8] M. Reza Shamsi, O. Akbari, A. Marzban, D. Toghraie, R. Mashayekhi, Increasing heat transfer of non-Newtonian nanofluid in rectangular microchannel with triangular ribs, Physica E: Low-dimensional Systems and Nanostructures, 93 (2017) 167-178.
[9] V. Gnielinski, New equation for heat and mass transfer in turbulent pipe and channel flow, Int Chem Eng 16 (1976) 359-363.

[10] V. Gnielinski, Heat transfer and pressure drop in helically coiled tubes, Heat Transfer, Proceedings of the International Heat Transfer Conference, 6 (1986) 2847-2854.
[11] E. F. Schmidt, Wärmeübergang und Druckverlust in Rohrschlangen, Chemie Ingenieur Technik 39 (1967) 781-789.