International Journal of Advance Industrial Engineering
ISSN 2320 –5539

Research Article

Pulsating Flow and Heat Transfer in a Helical Tube With Constant Heat Flux

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Accepted 09June 2013, Available online 15 June 2013, **Vol.1, No.2 (June 2013)**

Abstract

In the present study the effect of pulsation was investigated on the heat transfer in a helical tube. The flow is laminar, Newtonian, unsteady and three dimensional. The governing equation is solved in the commercial software Fluent 6.3 and the results are discussed by temperature, and pressure contours and Nusselt number. The effect of amplitude and frequency of pulsation, tube pitch and tube helix ratio were investigated on the Nusselt number. The results show that as the pulsation amplitude increases, the amplitude of Nusselt curves experience a significant augmentation. The increase of frequency yields the increase of average Nusselt number. The heat transfer rate increase as the ratio of helix to the tube diameter decreases. The pitch of helical tube has no significant effect on the heat transfer.

***Keywords**: Heat Transfer, Helical Tube, Pulsating Flow, Nusselt Number, Helix Ratio.*

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1. Introduction

Coiled tubes are used in compact heat exchangers, condensers and evaporators in the food, pharmaceutical, modern energy conversion and power utility systems, heating ventilating and air conditioning (HVAC) chemical industries (Chingulpitak, et al, 2010,2011 and Zhao, et al, 2011). The heat transfer coefficient increases In coiled tubes because of centrifugal force that makes a pair of longitudinal vortices and secondary flow. The effect of secondary flow studied by (Dravid, et al, 1971) numerically on laminar flow heat transfer in helically coiled tubes. They presented a correlation for the Nusselt number. Patankar et al. discussed the effect of the Dean number on heat transfer and friction coefficient in the helically coiled pipes. Kubiar and Kuloor studied experimentally the glycerol flowing inside a vertical helical coil at constant wall temperature. They proposed new correlations for laminar flow regime. A correlation presented for outside Nusselt number of a helical tube (Rahul, et al, 1997). Their results indicated that the coil pitch affects the heat transfer coefficient. Prabhanjan et al. compared Helical and straight tubes. The results showed that a helical coil heat exchanger increases the heat transfer and the temperature rise of fluid depends on the coil geometry and the flow rate. Xin and Ebadian studied the effect of Prandtl number and geometric parameters on heat transfer. Ko studied the entropy generation in helical coils at constant wall flux. In his analysis of second thermodynamic law, he found that optimum Reynolds number and curvature ratio are related to wall heat flux. Naphon and Wongwises reviewed the heat transfer in curved tubes and tabled the proposed correlations at the applicable ranges of effective parameters.

Heat transfer under pulsating inlet condition is often encountered in different engineering practices such as mixing, bio-fluid systems and electronics thermal management etc.

Moschandreou and Zamir performed a research on pulsating flow in a tube and found that the heat transfer of the flow has increased in the frequency range between 5 Hz to 25 Hz. The enhancement was more pronounced at higher Prandtl number. Shahin investigated the convective heat transfer in a pipe and in the annulus between two concentric tubes both experimentally and theoretically. He reported that pulsating of flow had a 25% enhancement in heat transfer for certain pulsation frequencies. Moreover, he demonstrated that the heat transfer rate starts to drop at higher frequencies compared to the steady flow results. In contrast to Moschandreou and Zamir, the analytical solution of Hemida et al. showed that pulsation produces little changes which are always negative in Nusselt number, i.e. heat transfer decreases for the pulsating systems. Chattopadhyay et al. numerically analyzed laminar pulsating flow in a pipe with constant temperature. The flow at the inlet for their problem consisted of a fixed part and a pulsating component, which varies sinusoidally in time. They had observed that in the considered rang of pulsation frequency and amplitude, pulsating has no positive effect in heat transfer. However their research was limited to 0–20 Hz for pulsating frequency and 0–1 for amplitude. The effect of the Nanofluid was investigated on laminar flow in helical tubes experimentally and numerically (Jamshidi et al., 2012 and Jamshidi et al.,

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2013). they optimize the effective parameter for design a industrial helical heat exchanger.

The objective of present study is to investigate the pulsating heat transfer of laminar flow in a helical tube. The study is performed to study the effect of pulsation amplitude and frequency and helical tube characteristics on the flow field and heat transfer.

2. Numerical simulation

2.1. Mathematical Model

As shown in figure 1 flow enters the domain from left side with pulsating velocity and exits from right side with the boundary condition of pressure outlet. The no-slip was applied as hydrodynamic boundary condition and constant heat flux was used as thermal boundary conditions.
The continuity, momentum and energy equation in 3D Form in Cartesian frame are given by:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

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

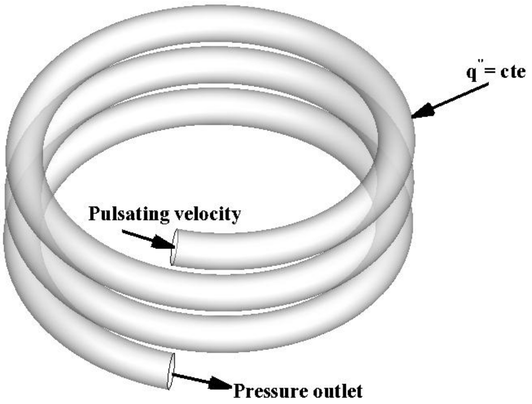

Figure 1- Geometry and boundary conditions

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

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=\frac{1}{\rho}(-\frac{\partial p}{\partial z}+\mu\nabla^2 w) \quad (4)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\frac{\partial}{\partial x}\left[\frac{k}{(\rho c_p)}\frac{\partial T}{\partial x}\right]+\frac{\partial}{\partial y}\left[\frac{k}{(\rho c_p)}\frac{\partial T}{\partial y}\right]+\frac{\partial}{\partial z}\left[\frac{k}{(\rho c_p)}\frac{\partial T}{\partial z}\right] \quad (5)$$

The fluid enters with uniform temperature T0. The velocity profile is combined from a uniform value and a pulsating term as:

$$u_p = U_0(1+A\times\sin(2\pi f t)) \quad (6)$$

Where U0 represent the uniform part of velocity, A and *f* are amplitude and frequency of the pulsation. The frequency is computed by chose a nondimensional frequency (Strouhal number) for the specific case. Strouhal number is defined as:

$$Str=\frac{fd}{U_0} \quad (7)$$

Where d is the tube diameter. The coils are orientated in a horizontal position and the buoyancy forces are not activated. Inlets and outlets are located at each end of the coil. At all solid fluid interfaces, the fluid velocities are set to zero, representing a no-slip condition. The tube wall is subjected to a constant heat flux. The flow regime for all trials is in the laminar region and the fluid is treated as Newtonian.

2.2. Numerical procedure and computational domain

The set of governing equations are solved by a commercial computational fluid dynamics code FLUENT 6.3. The software is a finite volume based solver. The Piso algorithm is employed as the couple of pressure and velocity field. Generally, the accuracy of a numerical solution increases as the number of cells increases. However, the use of a larger number of cells is restricted by the sophistication of the computer hardware and the computing time. The error that arises due to the discretization process can be systematically reduced to zero, at least theoretically, by subsequent grid refinements. In the present simulation the total cell of 65320 was chosen to achieve both accuracy and computing time saving. The boundary layer scheme is used to generate meshes near the wall. The convergence criterion required that the maximum sum of the error for each of the conserved variables be smaller than 1×10^{-5}. The mesh generation procedure is done in Gambit. For validating the numerical results of present work, flow was tested in helical tube without pulsation and results are compared with results of Rogers work as shown in figure 2. Dean number is defined as:

$$De=\mathrm{Re}\sqrt{\frac{r}{R_c}} \quad (8)$$

The present results are in good agreement with the Rogers results.

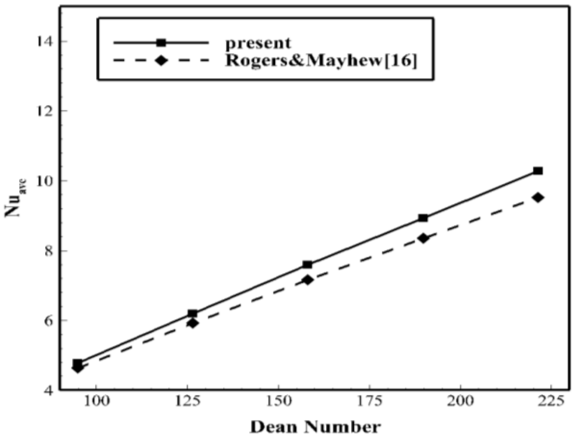

Figure 2-Nusselt number comparison with the work of Rogers and Mayhew

3. Results and Discussion

The simulation is performed for some cases to study the effect of pulsation of inlet velocity on the heat transfer in the helical tube. The Reynolds number is fixed at 8000 for the tube with diameter of 1 cm. The flow is laminar, unsteady and Newtonian. The amplitude of pulsation ranges from 0.1 to 0.5. The pitch ranges from 1.5 to 2.5. The pressure decreasing is shown in figure 3. The range of pressure loss (figure 3) is about 1200 pa for the case without pulsation and pitch of 1.5 cm. The velocity magnitude is shown in figure 4 to point the effect on the helix to form the secondary flow. This phenomenon is also vivid when focusing on the temperature distribution in the various surfaces of the tube (figure 4).

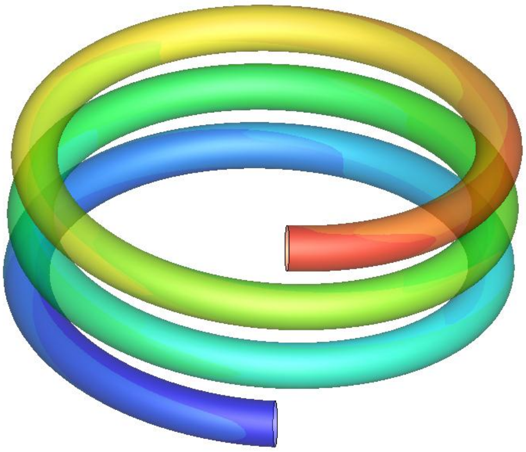

Figure 3-pressure variation in the helical tube for

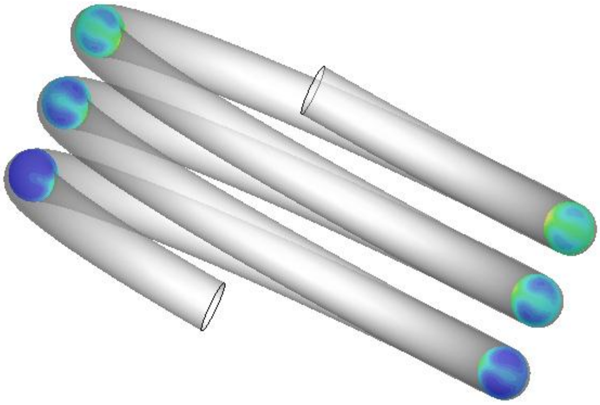

Figure 4- Temperature distribution in the helix

The two recent figures are for the case without pulsation. The contour of Nusselt number that is shown in figure 5 shows the effect of entrainment length on the initial section of tube. The effect of inlet velocity pulsation amplitude and pitch of the helical tube are shown in the figure 5, 6. As it was excepted, the Nusselt number has greater peak by increasing of pulsation amplitude. But the average Nusselt number has no significant changes. However this happens for helix ratio of 0.1. The study the pitch effect on the heat transfer rate three pitch of 1.5, 2 and 2.5 cm are chosen. As mentioned in the recent researches results, the present simulation shows that the increasing in pitch does not have significant effect on the Nusselt number (figure 6). The effect of frequency of pulsation (Str) on Nusselt number is investigated for Re=8000, pitch=1.5 and A=0.1 (figure 7). The fluid in contact with the wall for longer time, so decreasing the frequency of inlet velocity from Str=0.5 to St=0.1, leads to an increase in amplitude of the Nusselt number and its total value.

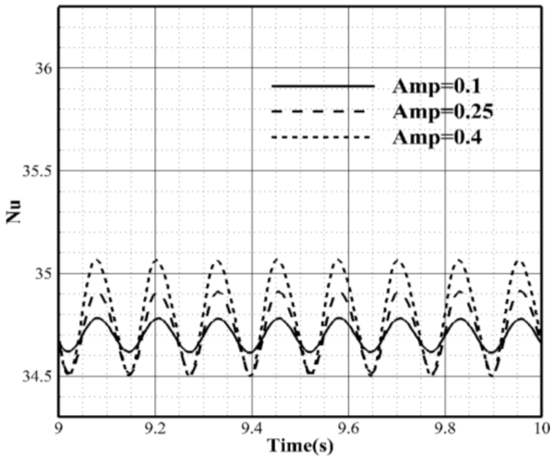

Figure 5- the Nusselt number at P=1.5 cm , Re=8000 and varying pulsation amplitude

For design a heat exchanger it is necessary to compare the effect of various design parameters on overall treatment. The average Nusselt number is shown in figure 8 by increasing of helix ratio for three different amplitude value at Re=8000 and Str=0.1. The effect of pulsation amplitude decreases on average Nusselt number by increasing of the helix ratio. The helical tube experiences greater heat transfer rate by augmentation of amplitude at constant helix ratio.

As it was predictable, the Nusselt number decreases as the helix ratio increases. It is due to the weakness of formed secondary flow by increasing of helix ratio. The augmentation of helix ratio means that the tube behaves like a straight one.

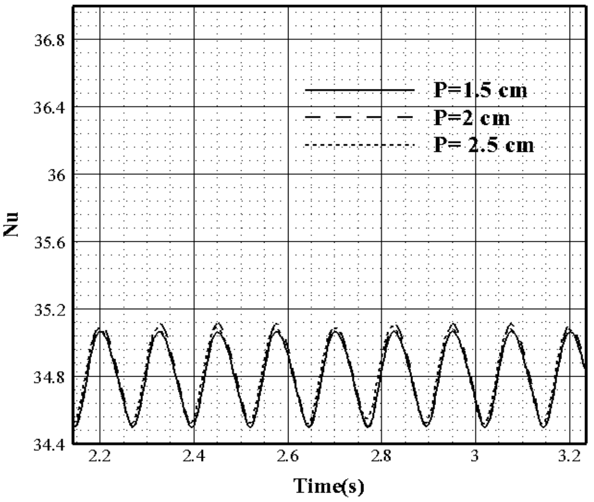

Figure 6- The Nusselt number at P=1.5 cm, Re=8000 and varying pulsation amplitude.

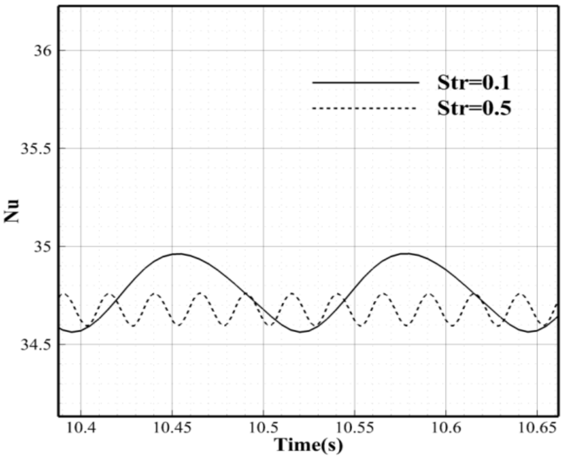

Figure 7- The Nusselt number at P=1.5 cm, Re=8000 and two pulsation frequency.

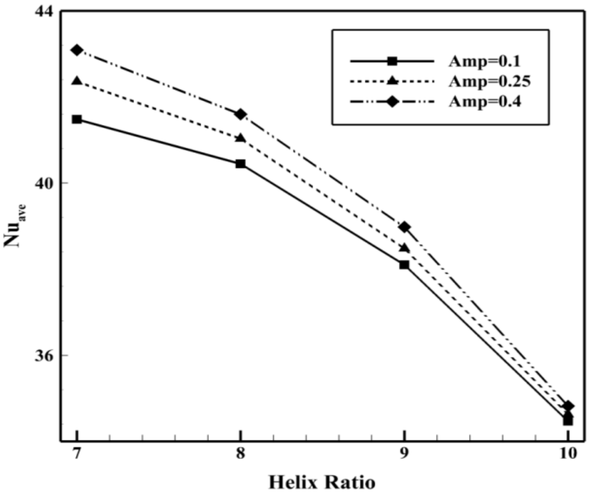

Figure 8- The average Nusselt number at P=1.5 cm, Re=8000 versus helix ratio for different Amplitude..

Conclusion

The effect of inlet pulsation investigated numerically on the flow and heat transfer in a helical tube at constant ---. The numerical procedure was validated by comparing the recent researches results. The effect of pulsation amplitude and frequency and helix ratio was studied. The results show that the frequency has significant effect on the heat transfer rate. The Nusselt number experiences the higher peak by increasing of pulse amplitude. The pitch of helix has not any considerable effect on the heat transfer characteristics. The helix ratio is the key parameter that contributes the flow field and heat transfer in such tubes. The average Nusselt number decreases by increasing of helix ratio at constant amplitude and augments by the increasing of amplitude at constant helix ratio. The effect of nanofluid on heat transfer and pulsating turbulence flow in helical tubes can be some interesting further research.

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