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Heat Transfer of Pulsating Turbulent Flow in Pipes

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ABSTRACT

Pulsating flow has a significant impact on heat and mass transfer in sterling engines, electronic cooling, nuclear reactors, gas turbines, and arterial blood flow. Flow characteristics of pulsating flows in different channels have received extensive attention in recent years. The effects of the pulsation amplitude and frequency, the Prandtl number and Reynolds number on heat transfer are characterized by variation in temperature, heat flux, and Nusselt number. In this study, pulsating turbulent flow in a pipe is analyzed using a transient ANSYS CFX simulation. The results are plotted against time and discussed considering different flow conditions such as pulsating frequency, amplitude, Reynolds number and Prandtl number to analyze the effect on heat transfer.

Key words: Heat Transfer, Computational Fluid dynamics, Turbulent Flow etc.

INTRODUCTION

Pulsating flow is defined as the flow where the velocity of the flow changes with time. It has a great magnitude of importance as it contributes positively to heat transfer by a fluid flowing through a pipe. When any fluid oscillates axially in a pipe under induced heat flux, two types of boundary layer forms namely the thermal boundary layer and the velocity boundary layer and as these boundary layers vary with time, the cross-sectional interaction between them contributes in enhanced heat transfer in the pipe flow. The application of pulsating flow heat transfer made the researchers all over the world to expand the research on the thermal behavior of pulsating flow in different flow conditions. Miniaturization of Higher chip density in electronics devices need faster heat removal system, future space shuttle needs lightweight and enhanced heat removal system, power generation, and industrial process need cost effective and easy to set up heat removal system, furthermore the modern nuclear reactors need effective heat removal for proper operation. These heat removal urgencies led the researchers to go beyond the conventional system and consider the pulsating flow heat transfer system as it has great potential of removing heat efficiently and effectively. Theoretical study along with numerical and experimental study had been done on pulsating laminar and turbulent flow and the results are often inconsistent and sometimes conflicting in nature. Yuan *et al* [1] concluded Heat transfer decreases in pulsating laminar flow. The effect is more prominent in case of flow in pipes than parallel plates because of difference in hydraulic and thermal performance of the pipes and parallel plates. Zohir *et al* [2] showed in their study that pulsating turbulent flow can increase the heat transfer and concluded that the heat transfer increases with the increase in pulsating amplitude. Yuan *et al* [3] concluded in their study on the effect of pulsating laminar flow in a pipe that pulsating Laminar flow weakens heat transfer. Elsayed *et al* [4] showed in their experimental study, the Nusselt number decreases with increasing frequency of the pulsating flow. The aim of this study is to carry out a numerical simulation to understand and analyze the heat transfer characteristics of pulsating flow in a pipe with constant heat flux on the outer pipe wall.

Nomenclature

A = amplitude of pulsating flow
f = frequency of pulsating flow
Nu = Nusselt number

Pr = Prandtl number
D = diameter of the pipe
L = length of the pipe
µ = dynamic viscosity
V = *pulsating velocity*
U_0 = *non-pulsating velocity*
Re = Reynolds number
C_p = specific heat capacity
K = thermal conductivity
T = time
Q'' = heat flux

FLOW DOMAIN AND BOUNDARY CONDITION

Using ANSYS design modular, a simple pipe geometry is created. The flow domain consists of an inlet, an outlet, and the wall. The pipe diameter is 25 mm and length are 1000 mm. Geometry is shown in figure 1.

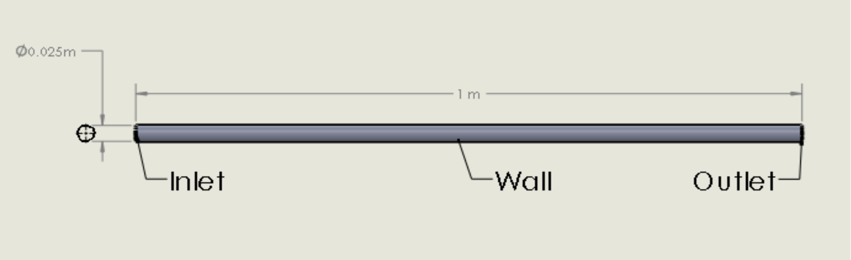

Fig. 1 Geometry

Table -1 Boundary conditions

Boundary Conditions	
Inlet	Velocity Inlet (V m/s)
Wall	Constant Heat Flux
Outlet	Pressure Outlet

The fluid enters through the pipe inlet at a pulsating velocity V with varying amplitudes of A = 0.1, 0.2 and 0.3 and varying frequency of f = 0.2, 0.3 and 0.4. A constant heat flux Q'' = 15000 w/m2 is acting on the wall of the pipe. For studying the effect of pulsating frequency and amplitude, the time-averaged Reynolds number is kept constant at 10000. While simulating for studying the effect of Reynolds number, two different Reynolds number 10000 and 15000 are considered. Again, while simulating for two different Prandtl numbers, the Reynolds number is kept constant at 10000. Transient simulation is done using a time step of 0.1s. To getting convergence, the Courant number is kept at the order of 1.

$$V = U_0(1 + Asin2\pi fT) \quad (1)$$
$$Re = \rho vD/\mu \quad (2)$$
$$Pr = \mu C_p/K \quad (3)$$
$$Nu = 0.023Re^{0.8}Pr^{0.4} \quad (4)$$

Table -2 Transient Parameters

Transient Parameters	
Time Step	0.1s
End Time	10s
Iteration	236

Table -3 Transient Solution Parameters

Transient Solution Parameters	
Max. Loop Iteration	10

The transient simulation parameters and the transient solutions parameters are shown in table 2 and table 3 above. The time step is set to 100ms and the simulation is run for 10s. The time step is kept small enough to make sure that the solution converges and to keep the Courant number in the order of 1. The total number of iteration is 236 for the varying frequency and 200 for varying amplitude for the constant frequency of the flow. The maximum loop iteration is set at 10 and the minimum is set at 2. Each solution takes around 100 minutes to converge. There is no need to run the simulation for higher end time as the pulsating flow repeat itself after a maximum of 5s for the lowest value of frequency f = 0.2.

MESH STUDY

In case of coarse mesh, the less number of nodes and elements have been used. As we know that low nodal elements give much less accurate results due to discretization error and therefore it is tough to predict or anticipate results using coarse mesh. Here, the number of nodes for the coarse mesh is 208236 and number of elements are 342000. Considering no bias in coarse mesh, the face size and element sizes used are 0.002 m and 0.0007 m respectively. The inflation the growth rate is 1.2 and the first layer height is 0.0001 m. Figure 2 shows the mesh that is used in this study.

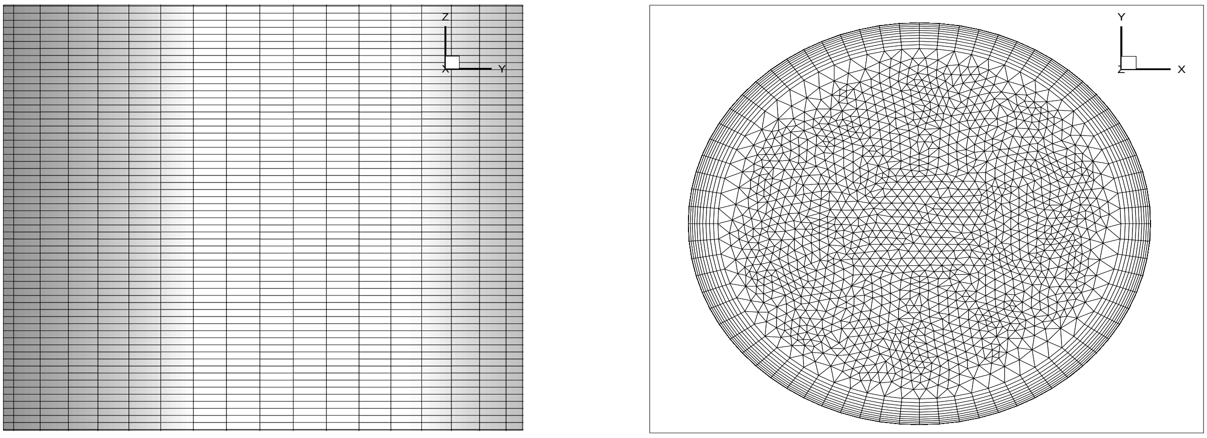

Fig. 2 Mesh

Table -4 Mesh Details

Mesh Refinement					
Coarse Mesh		Intermediate Mesh		Fine Mesh	
Face sizing		**Face sizing**		**Face sizing**	
Element size	0.002 m	Element size	0.0015 m	Element size	0.0011 m
Face sizing 2		**Face sizing 2**		**Face sizing 2**	
Sphere of influence radius	0.01 m	Sphere of influence radius	0.01 m	Sphere of influence radius	0.01 m
Element size	0.0007 m	Element size	0.0005	Element size	0.0005
Sweep method		**Sweep method**		**Sweep method**	
Divisions number	200	Divisions number	200	Divisions number	200
Bias	No bias	Bias	No bias	Bias	No bias
Inflation		**Inflation**		**Inflation**	
Maximum layers	8	Maximum layers	8	Maximum layers	10
Growth rate	1.2	Growth rate	1.2	Growth rate	1.1
First layer height	0.0001 m	First layer height	0.0001 m	First layer height	0.0001
Total nodes	208236	**Total nodes**	367629	**Total nodes**	432351
Total elements	342000	**Total elements**	635800	**Total elements**	701600

In case of intermediate mesh, Sphere of influence radius was kept as same as the coarse mesh though the element size is changed to 0.0015 m. Also, for the face sizing 2, the element size is reduced to 0.0005 m. the other parameters are kept as same as the coarse mesh. The number of nodes for the intermediate mesh is 367629 and number of elements are 635800.

Finally, in case of a fine mesh much greater number of nodal elements and element sizes have been used compared with the other two meshes (coarse and intermediate). For fine mesh, the face sizing element size is reduced to .0011 m but for face sizing 2 the element size is kept same as the intermediate mesh. For inflation layers, maximum layers are changed to 10 from 8 and growth rate is changed to 1.1 to 1.2. The number of nodes and elements for the fine mesh is 432351 and 701600 respectively. The details of mesh refinement are summarized in table 4.

RESULTS AND DISSCUSSIONS

Graphs in figure 3 show the variation in velocity with time. The amplitude of the flow velocity is varied as 0.1, 0.2 and 0.3 and the frequency of the flow is varied as 0.2, 0.3 and 0.4. The plots also contain the non-pulsating flow profile. The non-pulsating flow has a constant velocity of 0.4 m/s. In figure 3 the velocity profile pulsates more frequently with higher frequency whereas the velocity reaches its peak for higher amplitude.

The velocity contours are also shown in figure 4 below corresponding to a plane through the centerline of the flow field for A = 0.2 and f = 0.3. At T = 1s, the velocity is .48 m/s which is the highest in the pipe. It is also evident from the velocity profile shown above as it reaches the peak value. At T = 1.75s, form the velocity contour we can see that various velocity layer is created in the flow field. This is due to the pulsation of the velocity with respect to time. It is also important to note that none of the profile is fully developed at this time. But at T = 2.5s, the velocity reaches its lowest value. We can observe this also on the velocity plot. After this point, the velocity begins to increase again and repeat itself with time.

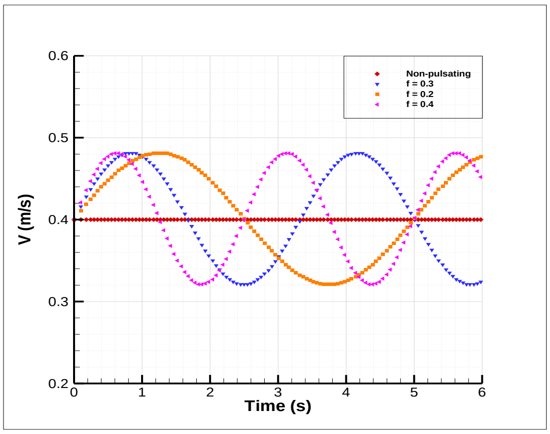

Fig. 3 Velocity vs. Time for A = 0.2

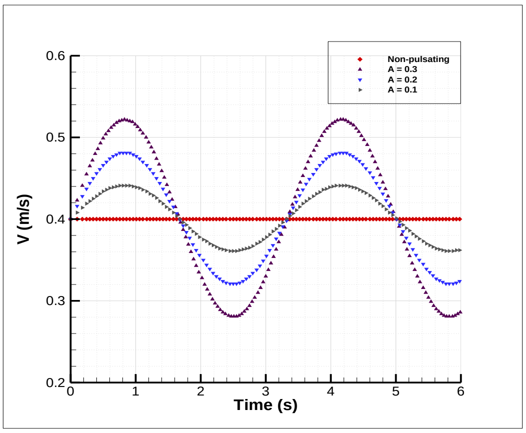

Fig. 4 Velocity vs. Time for f = 0.3

The velocity contours are also shown in figure 4 above corresponding to a plane through the centerline of the flow field for A = 0.2 and f = 0.3. At T = 1s, the velocity is .48 m/s which is the highest in the pipe. It is also evident from the velocity profile shown above as it reaches the peak value. At T = 1.75s, form the velocity contour we can see that various velocity layer is created in the flow field. This is due to the pulsation of the velocity with respect to time. It is also important to note that none of the profile is fully developed at this time. But at T = 2.5s, the velocity reaches its lowest value. We can observe this also on the velocity plot. After this point, the velocity begins to increase again and repeat itself with time.

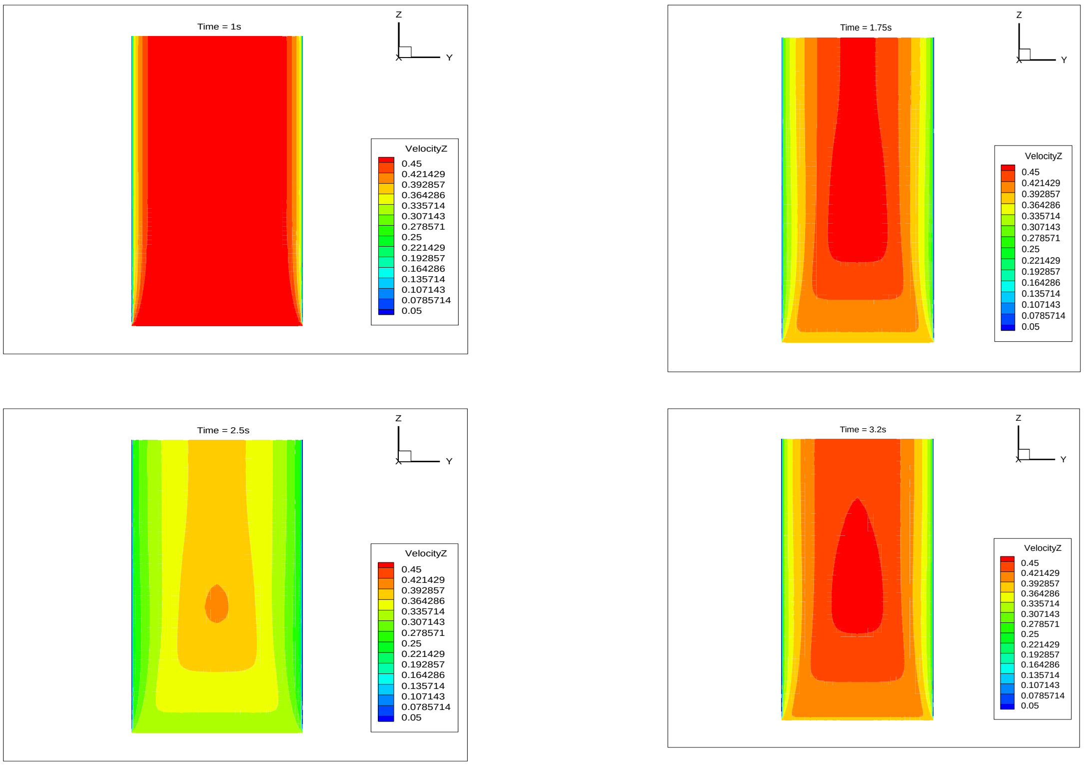

Fig. 5 Velocity Contour for A = 0.2, f = 0.3 at Different Times

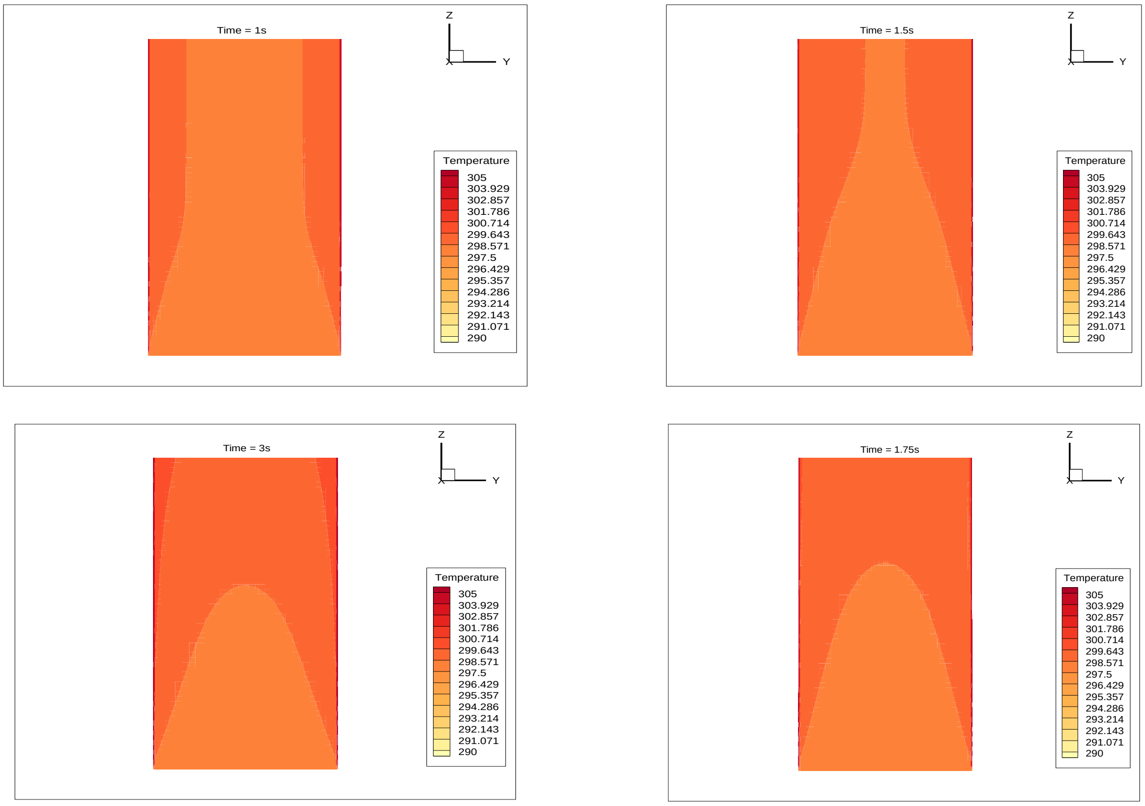

Fig. 6 Temperature Contour for A = 0.2, f = 0.3 at Different Times

The contours above in figure 6 show the variation in temperature at a different time for A = 0.2 and f = 0.3. At T = 1s, the temperature is highly concentrated on the wall due to the applied constant heat flux at the wall. At T = 1.5s, the temperature profile tends to change and becomes more concentrated in the outlet areas. At T = 1.75, the temperature is developed, and a profile is visible in the contour. At T = 3, the temperature profile is fully developed, and it is also observable that a secondary temperature profile with higher temperature is on the rise at the wall near the outlet of the flow domain. After this, the temperature profile repeats itself due to the pulsation of the fluid. Figures below shows the variation in Nusselt number with respect to time for various pulsating amplitude and frequency compared with the non-pulsating flow velocity. For A = 0.2, figure 6, the time-averaged Nusselt number increases with the increase in frequency. For non-pulsating flow,the Nusselt number is constant at approximately 75 whereas for pulsating flow the Nusselt number reaches its peak at 87 for A = 0.2. Most important point to be noted for the case of constant amplitude is that the time-averaged Nusselt number is highest for the highest frequency.

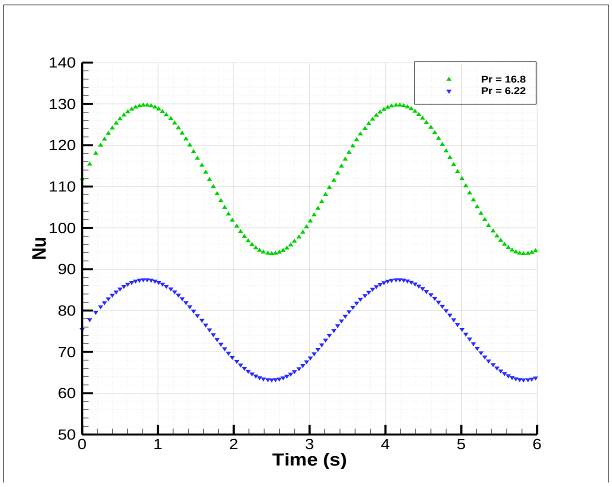

Fig. 7 Nu vs. Time for Pr = 6.22

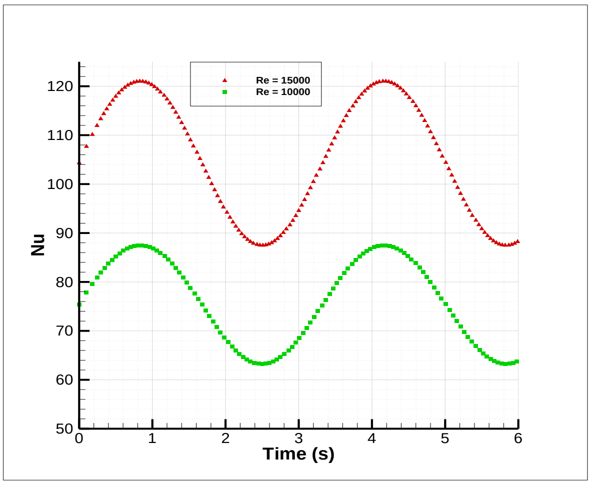

Fig. 8 Nu vs. Time for Re = 10000

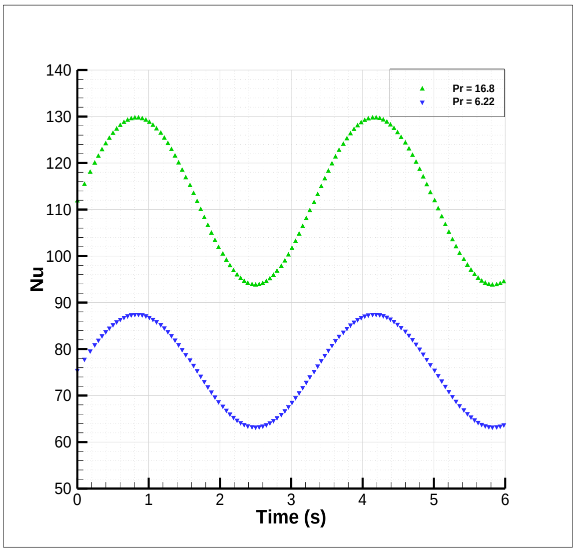

Fig. 9 Nu vs. Time for Pr = 6.22

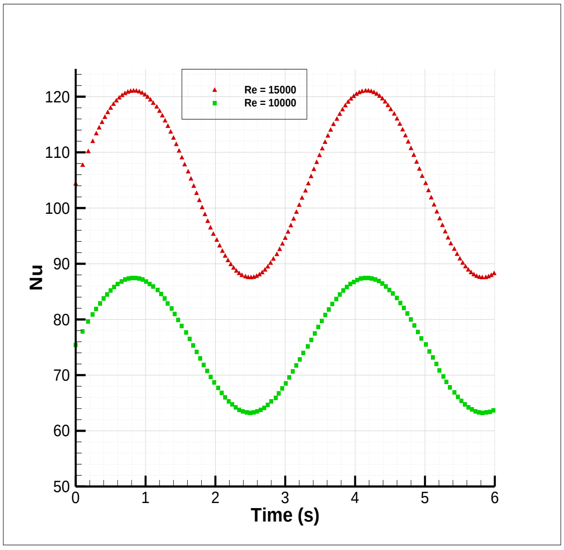

Fig. 10 Nu vs. Time for Re = 10000

On the other hand, figure 8 shows the Nusselt number variation for the constant frequency of f = 0.3 but the varying amplitude of A = 0.1, 0.2 and 0.3. We can see from the graph that the Nusselt number is highest for the highest amplitude and lowest for the lowest amplitude among the pulsating flow. For non-pulsating flow, the Nusselt number is still constant at 75 same as the case of constant amplitude. Point to be noted in this case of varying amplitude velocity that the time average Nusselt number is same for all the amplitudes and which is exactly equal to the non-pulsating flow Nusselt number. So, we can say comparing both the graphs that the Nusselt number is highest for the highest frequency and the amplitude does not have any effect in heat transfer in the pipe flow and the Nusselt number is a function of the frequency of the flow in case of pulsating flow.

Simulation is also done using same fluid with two different Reynolds number of Re = 10000 and Re = 15000. The figure 9 above shows that the Nusselt number increases with the increase in Reynolds number while for both the cases the pulsating amplitude and frequency are kept constant. The maximum Nusselt number is about 122 for Re = 15000, while the maximum Nusselt number is 88 for Re = 10000.

However, figure 10 shows that the Nusselt number increases for the fluids with higher Prandtl number. Two different fluid with Pr = 6.22 and Pr = 16.8 are used in the simulation keeping the Reynolds number constant at Re = 10000. Results show that the Nusselt number is higher for higher Prandtl number fluid. Hence, higher heat transfer. The maximum Nusselt number is about 130 for Pr = 16.8, while the maximum Nusselt number is 88 for Pr = 6.22.

CONCLUSION

In this study, a three-dimensional transient state numerical simulation is conducted to explore the effects of pulsating turbulent flow with different amplitude and period of heat transfer in a pipe. The overall and local performance in the pipe flow using Nusselt number, Prandtl number, and Reynolds number is compared. The results are analyzed from the point view of heat transfer. Results show that the time-averaged heat transfer through a pipe increases with the increase in pulsating frequency while comparing with the non-pulsating counterpart. Also, the variation in pulsating amplitude has no effect on the heat transfer as the time-averaged value of Nusselt number remains constant and same as the non-pulsating value. On the other hand, heat transfer increases with increase in Reynolds number and Prandtl number. Further study can be done to study the optimum pulsating frequency and Reynolds number conducive for higher heat transfer in a pipe flow.

REFERENCES

[1]. H Yuan, S Tan, J Wen, and N Zhuang, Heat transfer of pulsating laminar flow in pipes with wall thermal inertia, *Int. J. Therm. Sci.*, **2016**, 99, 152–160.

[2]. AE Zohir, AA Aziz, and MA Habib, Heat transfer characteristics and pressure drop of the concentric tube equipped with coiled wires for pulsating turbulent flow,*Exp. Therm. Fluid Sci.*, **2015**,65, 41–51.

[3]. H Yuan, S Tan, N Zhuang, and L Tang, Theoretical analysis of wall thermal inertial effects on heat transfer of pulsating laminar flow in a channel,*Int. Commun. Heat Mass Transf.*, **2014**, 53, 14–17.

[4]. EAM Elshafei, MS Mohamed, H Mansour, and M Sakr, Experimental study of heat transfer in pulsating turbulent flow in a pipe, *Int. J. Heat Fluid Flow*, **2008**, 29(4), 1029–1038.