International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-9, Issue-2S2, December 2019

Oscillating Flows in Circular Pipes

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Abstract – Pulsation flows in pipes heated externally produces oscillating temperature field. This type of unsteady flow happens in heat exchangers. Simulating this type of flows is complex in engineering. In this present study the field variables like velocity and temperature are calculated by numerical control volume scheme. Velocity pulsation is applied at inlet of pipe to produce oscillations. Simulation variables like lengths, diameter and thickness of the pipe are considered as parameters for this study. Also additionsl structural constraints has been added to see how it influences effective thermal stresses.

Keywords: Temperature, Velocity, Pressure, Oscillation.

I. INTRODUCTION

Increase in heat transfer co-efficient by convection because of pulsation, simulating pulsating flow with correct boundary condition has received significant attention [1], [2] in research. Pulsating field has steady and a time dependent oscillating part. So simulating flow pulsation to predict temperature will help us to study the variation of temperature along the pipe [3]. Chamkha, A., & Selimefendigil [4] studied Velocity and temperature field interactions which reflects the influence of pulsations on enhancing the heat transfer rates. Flow oscillations through Circular tubes arrangement was studied by Jalil S. M [5]. He indicated that heat transfer co-efficient is dependent of frequency of oscillations. Periodic variations of temperature through ducts was studied by Haroun Ragueb, Kacem Mansouri[6]. They found that amplitude of temperature oscillations is dependent on wall heat flux. Oscillating flows and its temperature distribution was studied by Furukawa [7]. They proved that heat transfer due to convection increases as a function of frequency at constant amplitude. Numerical analysis was carried out in circular ducts with periodic variation at inlet by Liu, C., Gao, C., von Wolfersdorf, J., & Zhai, Y[8]. They showed that amplitude of temperature oscillations were a function of system variables only. Heat transfer performance in pulsating constant heat tubes was examined by Roslan, R., Abdulhameed, M., Hashim, I., & Chamkha, A. J[9] .They indicated that only a range of frequency can affect pulsations. Bao-Jing Zheng, Xiao-Wei Gao,Kai Yang, and Chuan-Zeng[10] proposed a novel meshless Petro-Galerkin method for combining thermal and elasticity equations. Mehdi Ghannad & Mohammad Parhizkar Yaghoobi[11] studied thermal stress distribution in hollow cylinder and discussed the effect of inner radius on temperature and thermal stress distribution. Takabi, B investigated transient thermal stress distribution in cylinders and found that time taken to reach steady state depends on diameter ratio and heating period.Al-Zaharnah, B.S Yilbas and M.S.J Hashmi[12] used thermo-elasticity equations and Finite element analysis to compute stresses numerically by using Free-Free structural boundary constraints. In the present study Structural boundary constraints like simply supports and fixed-fixed conditions have been considered to study variations of thermally induced stresses.

Abbreviations and Acronyms

A	velocity amplitude
V_m	mean velocity
V_a	amplitude of velocity
n	oscillatingfrequency
D	inner diameter
L	length
t	thickness
r	radial coordinate
r_o	outer radii
r_i	inner radii
x	axial coordinate
r	radial coordinate
u	axial velocity of fluid
v	radial velocity of fluid
u_w	axial velocity of fluid at pipe wall
v_w	radial velocity of fluid at pipe wall
k_s	thermal conductivity of solid
k_f	thermal conductivity of fluid
cp	specific heat
μ	dynamic viscosity
ν	kinematic viscosity
h_f	heat transfer coefficient of fluid
q	heat flux

Ø = viscous dissipation..

Equations

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial (rv)}{dr}=0 \qquad (1)$$

Momentum equation

$$\frac{du}{dt}+\frac{udu}{dx}+\frac{vdu}{dr}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\left(\frac{1}{r}\right)\partial/\partial r(rv\frac{\partial u}{\partial r}+v\frac{\partial^2 u}{\partial x2}) \qquad (2)$$

Energy equation

$$\rho c_p\frac{\partial T}{\partial t}+\frac{\partial}{\partial x}\left(\rho c_p rvT\right)+\frac{\partial}{\partial x}\left(\rho c_p uT\right)=k\left[\frac{\partial^2 T}{\partial x2}+\left(\frac{1}{r}\right)\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)\right]+\mu Ø$$

where

$$Ø=2[(\frac{\partial v}{\partial r})^2+\frac{1}{r^2}v^2+(\frac{\partial u}{\partial x})^2]+[\frac{\partial u}{\partial r}+\frac{dv}{dx}]^2 \qquad (3)$$

At the pipe inlet:

Revised Manuscript Received on December 30, 2019.

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DOI: 10.35940/ijitee.B1055.1292S219

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

At x =0 ; v = vm + va*sin(0.6283*t)

$$\frac{\partial T}{\partial r}(0,r,t) = 0$$

va= 0.07 m/s Ref [12]
f = 0.1 Hz Ref [12]
Reynolds number = 500 Ref [12]

User defined fuction for velocity pulsation

```
# include "udf.h"
DEFINE_PROFILE (unsteady_velocity, thread, position)
{
face_t f;
  real t = CURRENT_TIME;

begin_f_loop (f, thread)
    {
      F_PROFILE (f, thread, position) = 0.012575 + 0.068*sin
(0.6283*t);
    }
end_f_loop(f, thread)
}
```

For pipe inner radius r = ri
Zero slip condition at pipe inner radius.

$$k_s\frac{\partial T}{\partial r} = k_f\frac{\partial T}{\partial r}$$

$$T_s = T_f$$

At symmetric axis of pipe
at r = 0

$$\frac{\partial u}{\partial r}(x,0,t) = 0$$

v (x,0,t) = 0

$$\frac{\partial T}{\partial r}(x,0,t) = 0$$

At outer surface of pipe r = ro
uniform heat flux Q = 200000 w/m2

Figures and Tables

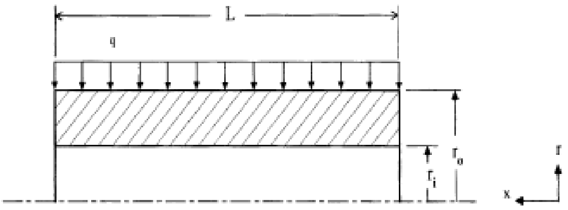

Fig 1: 2D Geometry of Axis symmetric pipe

Table-I : Dimensions of the pipe

S.No	Outer diameter (m)	Inner diameter (m)	Pipe thickness(m)	Pipe length (m)
1.	0.05	0.04	0.01	0.3

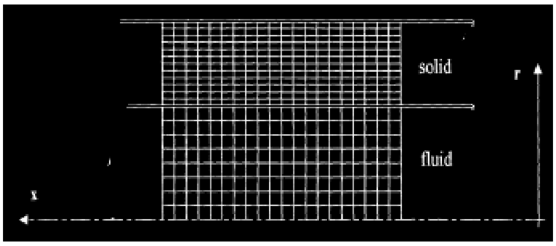

Fig 2: Mesh used in computation

Table-II : Mesh size (No of cells) used in computation

	Solid	Fluid
Radial	60	120
Axial	24	24

Table-III : Materials and Properties used in computation

S.No	Density kg/m^3	Thermal conductivity W/mK	Specific heat J/kg/K	Kinematic viscosity m/s^2
Steel	7800	43	473	-
Water	998.23	0.597	4181.8	$1.006*10^{-6}$

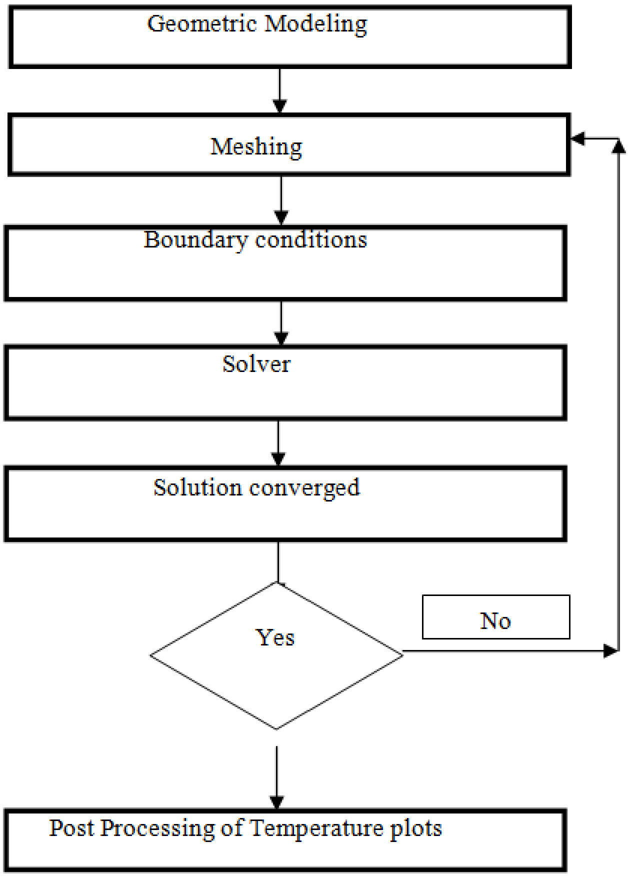

Fig 3: Schematic representation of work flow

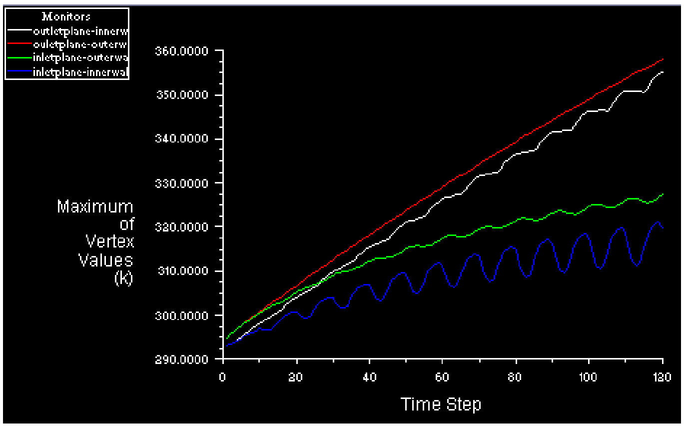

Fig 4:Temperature oscillation at Inlet plane- Inner wall & Outer wall, Outlet plane- Inner wall & Outer wall

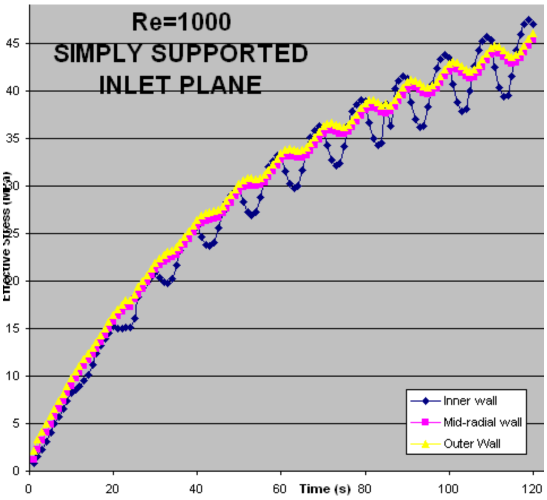

Fig 7: Thermal stress distribution at Inlet planes with simply supported condition.

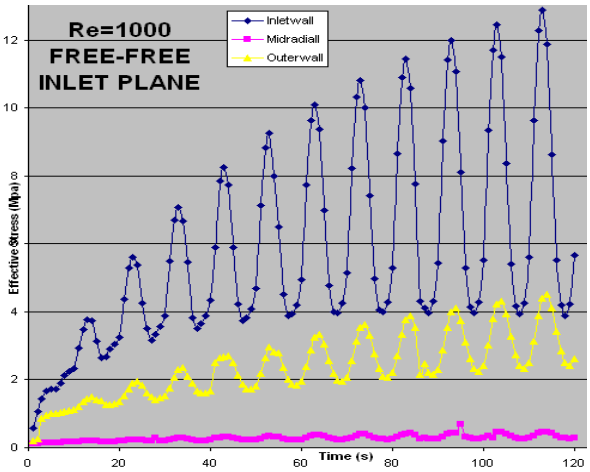

Fig 5: Thermal stress distribution at Inlet planes.

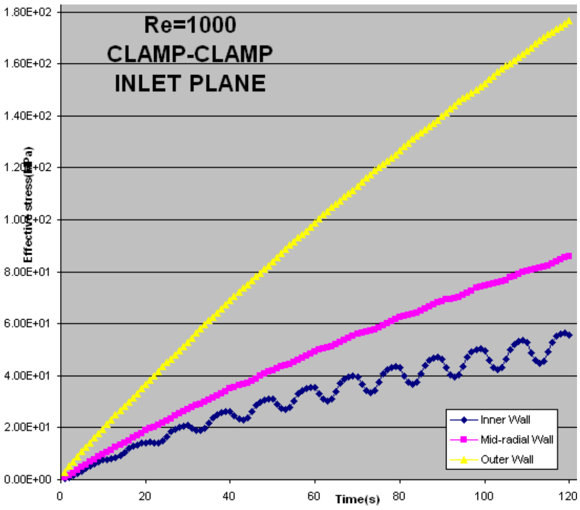

Fig 8: Thermal stress distribution at Inlet planes with Clamp-Clamp condition

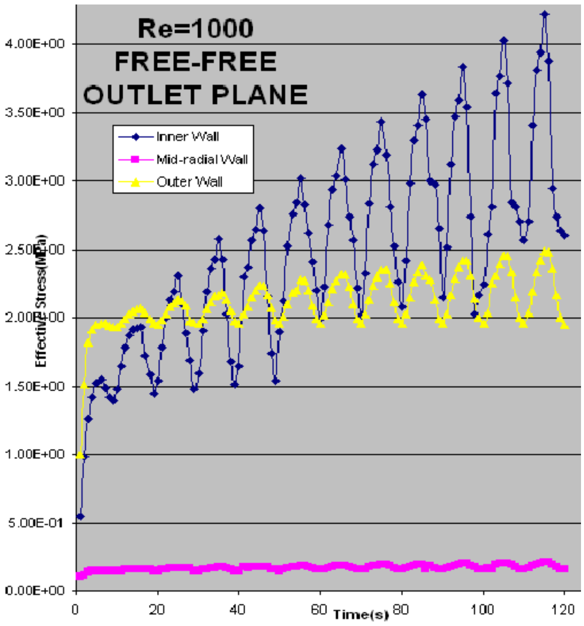

Fig 6: Thermal stress distribution at Inlet planes.

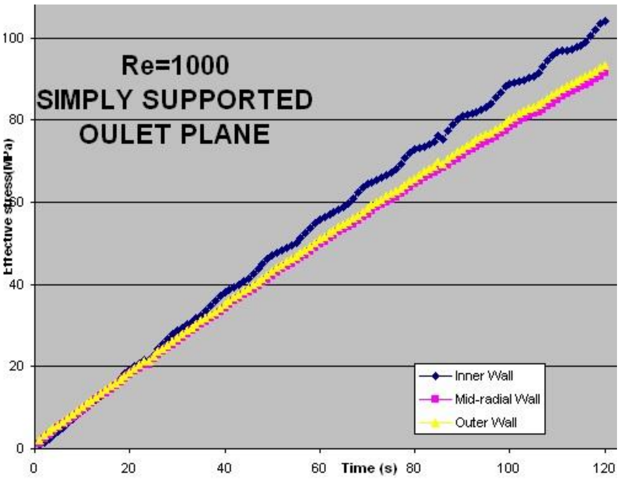

Fig 9: Thermal stress distribution at Outlet planes with simply supported condition.

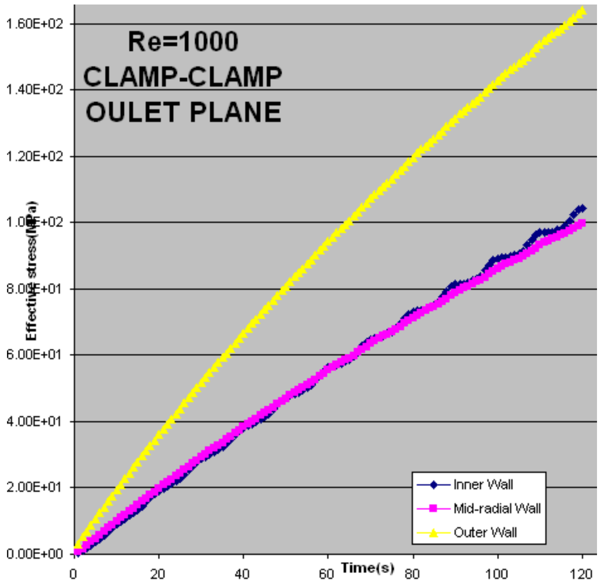

Fig 10: Thermal stress distribution at Outlet planes with Clamp-Clamp condition.

II. RESULT AND DISCUSSION

1) Fig 4,5& 6 shows temperature and thermal stress profiles variations with time in the present study which agrees well with Ref [12] fig 4 case(a) , Fig 11 (a) & (b).The temperature variation at inlet plane inner wall, inlet plane outer wall, outlet plane inner wall and outlet plane outer wall is plotted using monitor points as shown below using FLUENT 6 software. Four monitor points are used to get the time dependent temperatures. Vertex maximum value is employed for getting the temperature values. Monitor point 1 represents Inlet plane inner pipe wall. Monitor point 2 represents Inlet plane outer pipe wall. Monitor point 3 represents Outlet plane pipe inner wall. Monitor point 4 represents Outlet plane pipe outer wall. The thermal stresses that have been shown are von mises effective stresses. Usually in pipes outer wall act as a constraint for inner leading to higher values of stresses at inner wall. Reynolds number of 1000 has been used for simulation.

III. CONCLUSION

The temperature oscillation and its amplitude are more evident at pipe inlet plane of the pipe material and it diminishes as we proceed towards the pipe outlet plane. The reason behind this behavior is due to the high value of amplitude of velocity oscillations at the inlet plane, and due to uniform heating the convective heating of the fluid occurs at lower temperature at inlet of the pipe material. Temperature oscillation decreases as a function of increase in pipe thickness. From this behavior it is clear the material with which the pipe is made of uniformly heats the fluid and dampens the temperature variations in the oscillations at wall portion of the pipe.

The thermal stress values increases in initial period of heating because of wall temperature. Values of thermal stresses are directly related to diameter and thickness of pipe.

If structural boundary conditions are added as constraints thermal stress values increases further as shown in Fig 7,8,9 &10.

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