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Original Research Article

INVESTIGATION OF EFFECT OF BAFFLES IN PIPE FLOW CHARACTERISTICS USING FEV

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ABSTRACT

In the field of fluid flow and heat transfer utilization of complex geometries in from of extended surface such fins, baffles, artificial roughness gaining attention of researchers due to having significant application in the field of heat and mass transfer, specially baffles are exercised in various thermal application in order to increase thermal performance and hydrodynamic performance characteristics. . Application such as Heat exchanger, solar air heater, photovoltaic ducts or channel, nuclear reactor etc. these baffles leads to obstacle in flow through which turbulence generates which help in promotion of fluid mixing, heat transfer, enhancement un friction factor etc.

This work focuses on hydrodynamic performance analysis of pipe with presence of fragmented baffles. The performance characteristics of baffled pipe have been compared with smooth pipe for a wide range of Reynolds number. The governing equation has been solved by using ANSYS Fluent and for high Reynolds number k-turbulence model has been used along with SIMPLE algorithm. The obtained results have been compared with available literature and show good agreement with the computational an experimental work..

KEYWORDS: Baffles, Hydrodynamic characteristics, Pressure coefficient, Reynolds number.

INTRODUCTION

In the field of heat transfer and fluid flow implementation of baffles and the extended surface the effectively techniques of enhancing heat transfer in numerous engineering applications of the micro- and nano-fluids including chemical catalytic reactors, pumping systems, plate-fin heat exchangers, electronic system cooling, etc.

Due to presence of obstacle in the flow region leads to break boundary layer and creates turbulence this phenomenon is of substantial significance because it may strongly affect pressure drop, wall friction, heat transfer, occurrence of extreme temperatures, and stability of the flow.

LITERATURE SURVEY

Riccardo et. al 1973 presented modeling of break-up in an inhomogeneous flow which develops in concentric restriction in a pipe. Euler-Lagrange is used for simulations of the drop motion of interface deformation model. Turbulent flow downstream is solved by direct numerical simulation firstly then single drop trajectories are calculated.

Howes et al. 1991 numerically investigates the flow of an incompressible Newtonian fluid within a two-dimensional channel with periodic baffles. For uneven flows in this geometry a regime of chaotic advection was observed when baffles are used.

Yuyan et al. 1994 simulated the cross-flow filtration for baffled tubular channels and pulsatile flow by solving the time-dependent Navier-Stokes equations and evaluate local flux, pressure and the wall concentration along the membrane are determined by an osmotic pressure model and mass balances using the pre-generated flow field.

Gaddis and Gnielinski 1997 presented a novel procedure for calculating the shell side pressure drop in shell-and-tube heat exchangers with segmental baffles. The method was based on correlations for calculating the pressure drop in an ideal tube bank coupled with correction factors, which take into consideration where the influence of bypass streams and leakages, and on equations for calculating the pressure drop in a window section from the Delaware method.

Ko and Anand 2003 experimentally investigates the heat transfer coefficients in uniformly heated rectangular channel with wall mounted porous baffles. It has found that employing porous baffles heat transfer can be enhanced by 300 compared to heat transfer in straight channel with no baffles.

Smith and Mackley 2006 describe the scale-up of oscillatory behavior mixing in baffled tubes experimentally. The dispersion coefficient has been evaluated for wide range of tube diameter and length and on that basis developed an empirical correlation which predicts the mixing behavior of fluids..Jian Zhang et al. 2009 performed 3D simulation of a whole heat exchanger with middle-overlapped helical baffles using Fleunt 6.3. in their model six different configuration of helical baffles has been investigated and compared with experimental work and fond that they are within acceptable limit.

Wang et al. 2011 computation investigates the thermal characteristics of H-shape baffle heat exchanger. In their work comparative analysis has been done between segmental baffle, rod baffle and H-shape baffle and found that H shapes yields better performance in cross fluid flow and longitudinal fluid flow in shell type heat exchanger.

Solano et al. 2012 numerically studied the flow pattern and heat transfer characteristics of oscillatory baffled reactors with helical coil inserts. The obtained result shows that the heat transfer for the helical baffled tube could be improved by a factor of 4 as compared to smooth tube.

Xin et al. 2012 numerically examined the flow resistance and heat transfer of Specially-Shaped (triangle, circular, rhombic) rod baffle heat exchangers. The result shows that the trigonal and rhombic cross section rod baffles in the shell side give more optional structure forms for expanding the application scope of rod baffle heat exchangers and for rhombic cross section has 10% higher heat transfer rate as compared to other configuration.

Faith et al. 2013 analysis performance of porous baffles inserted solar air heaters using 1st and 2nd law approach. At thickness of 6mm and air flow rate of 0.025kg/s optimum efficiency has been achieved and similarly for non-baffle collectors optimum air mass flow rate is 0.016 kg/s.

Kumar and umavathi 2015 present 2D natural convection analysis for open-ended vertical porous wavy channel with perfectly conductive thin baffles and evaluate the effect of various parameters such as wall temperature ratio, grashof number, porous parameters, etc. in their work.

Eshita et al. 2016 explore the complex flow and temperature pattern in shell-and-tube heat exchanger using CFD code OpenFOAM-2.2.0 for wide range of mass flow rates. it has been observed that there is significant heat transfer near the nozzle region therefore, the conventional heat transfer correlations are not valid. Therefore a new correlation has been develop and validated with analytical model.

MATHEMATICAL MODELLING

the **Navier–Stokes equations** can be written in the most useful form for the development of the finite volume method:

$$\rho\frac{Du}{Dt} = -\frac{\partial p}{\partial x} + div(\mu\, grad\, u) + S_{Mx} \qquad (1)$$

$$\rho\frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + div(\mu\, grad\, v) + S_{My} \qquad (2)$$

$$\rho\frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + div(\mu\, grad\, w) + S_{Mz} \qquad (3)$$

Governing equations of the flow of a compressible Newtonian fluid

Continuity $$\frac{\partial \rho}{\partial x} + div(\rho u) = 0 \; ($$

x-momentum $$\frac{\partial(\rho u)}{\partial x} + div(\rho u u) = -\frac{\partial p}{\partial x} + div(\mu\, grad\, u) + S_{Mx} \qquad (4)$$

y-momentum $$\frac{\partial(\rho v)}{\partial y} + div(\rho v u) = -\frac{\partial p}{\partial y} + div(\mu\, grad\, v) + S_{My} \qquad (5)$$

z-momentum $$\frac{\partial(\rho w)}{\partial z} + div(\rho w u) = -\frac{\partial p}{\partial z} + div(\mu\, grad\, w) + S_{Mz} \qquad (6)$$

Energy $$\frac{\partial(\rho i)}{\partial t} + div(\rho i u) = -p\, div\, u + div(k\, grad\, T) + \Phi + S_i \qquad (7)$$

Using various correlation FEV results are been compared analytically

$$h_f = f\frac{LV^2}{D_h 2g}$$

Where,

f is the friction factor for fully developed laminar flow

L: length of the pipe

V: mean velocity of the flow

d: diameter of the pipe

f is the friction factor for fully developed laminar flow:

$$f = \frac{64}{\text{Re}} \text{ (For Re<2000) } \text{Re} = \frac{\rho u_{avg} d}{\mu}$$

C_f is the skin friction coefficient or Fanning's friction factor.

For Hagen-Poiseuille flow: $C_f = \tau_{wall} / \frac{1}{2}\rho u_{avg}^2 = \frac{16}{Re}$

For turbulent flow: $\frac{1}{\sqrt{f}} = 1.74 - 2.0\log_{10}\left[\frac{\varepsilon_p}{R} + \frac{18.7}{Re\sqrt{f}}\right]$ Moody's Chart

R: radius of the pipe

ε_p: degree of roughness (for smooth pipe, $\varepsilon_{p=0}$)

$Re \to \infty$: Completely rough pipe

METHODOLOGY

The ANSYS 14.5 finite element program was used for analyzing Segmented Baffles. For this purpose, a 2 dimensional flow region has been developed which include baffles at a few distance and a separate geometry of pipe without baffles having same length has been developed. A 20-node three-dimensional structural solid element was selected to model the Baffled pipe. The Pipe with Segmented Baffles was discretized into 38841 elements with 39726 nodes.. The Pipe surface boundary conditions can also be provided in mesh section through naming the portion of modeled Pipe i.e Inlet, Outlet, Top wall, Bottom Wall, Baffles.

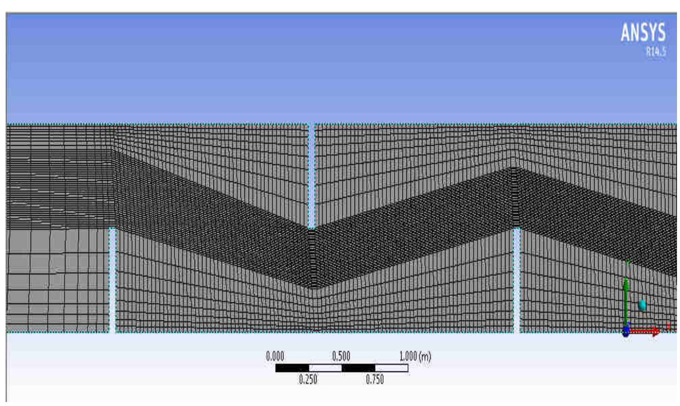


Figure 1 Model Geometry

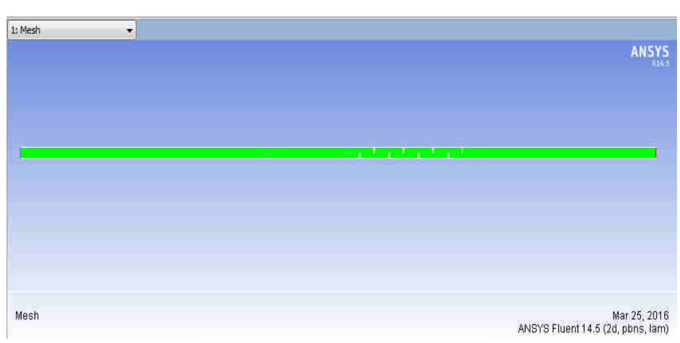


Figure 2 Mesh Model

Table 1 The boundary condition for pipe flow [12,7, 13]

Working Fluid	Value	unit
Density, ρ	998.2	kg/m^3
Viscosity, μ	0.001003	kg/m.s
Diameter	1	m
Specific heat, cp	4182	j/kg-k
Thermal Conductivity	0.6	w/m-k

RESULT AND DISCUSSION

VALIDATION

Using Ansys fluent the governing equation of pipe and pipe with baffles i.e. The Navier stokes continuity equation has been solved. On the basis of this FEV work the hydrodynamic characteristic of pipe and pipe with baffles has been evaluated with a grid size of 106 shows good agreement during the grid dependence test. Moreover, the performance of pipe and pipe with baffles are illustrated in the corresponding results. The precision of obtained results has been validated by comparing the present result with available literature of Al-Atabi et al. [7], Muhammad [12], Jim [13] whose works are based on experimental, analytical and FVM results.

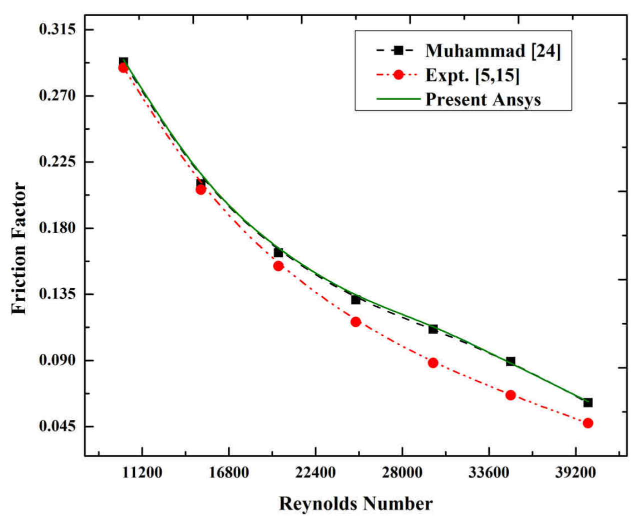


Figure 3 Validation of Coefficient of friction with respect to varying Reynolds Number

The validation of present computational work has been illustrated in figure 3 to 6, and it is found that the present result shows good agreement with mentioned researchers works. The minor variation in the results is primarily due to varying operating parameters, assumptions taken during experimentation and simulation.

The small variation is results are due to variation in grid sizing, operating condition, material properties, etc. But the obtained result shows the same trend so that the results are suitably verified.

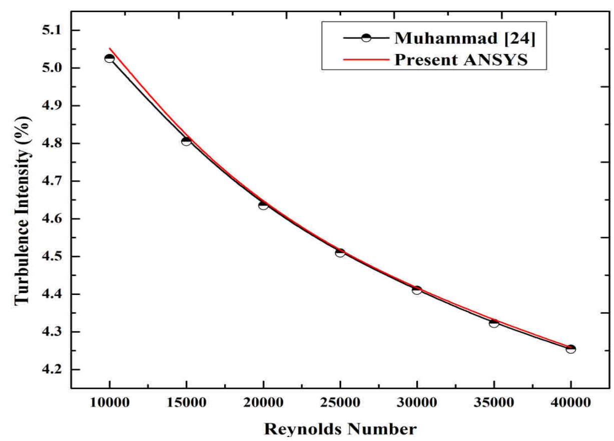


Figure 4 Validation of Turbulence Intensity with respect to varying Reynolds Number

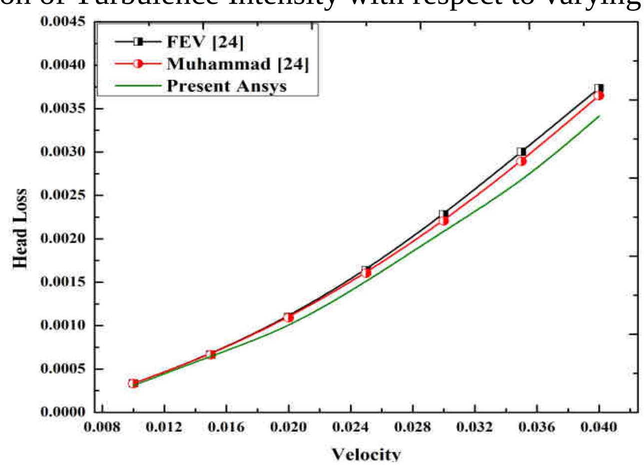


Figure 5 Validation of Head loss with respect to varying Velocity

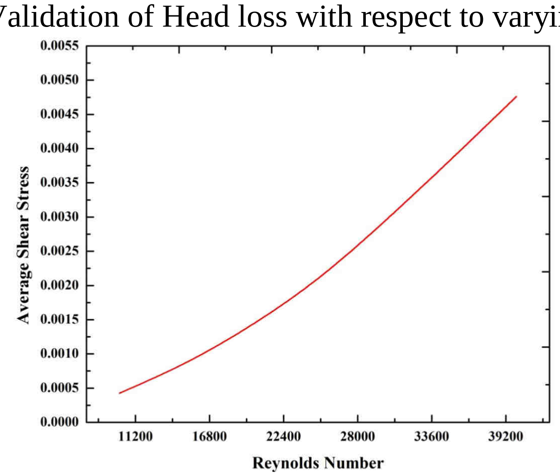


Figure 6 Variation of Shear Stress with varying Reynolds Number

In Fig. 7 to 14 the contour plot of pipe (smooth) and pipe with baffles for various process parameters has been demonstrated. In the contour plot the fluid visualization within the pipe and pipe with baffles has been carried out and on the basis of it various result outcome i.e. Pressure drop, turbulent intensity, skin friction, shear stress has been discussed.

Figure 9-12 illustrates the change in pressure in the pipe and it is observed that it only occurs along the axial direction. This means that the pressure across the centre line and wall are consequently same. The static pressure continuously goes on decreasing because the is not going during this stagnation process anywhere. It is worth noting that there is an increase in the dynamic and total pressures at the pipe center relative to the walls of the pipe due to higher velocity, on the other hand again, the static pressure is constant because the flow isn't going through a stagnation process.

Because of the existence of baffles in flow the pressure drop marginally increases as Reynolds number changes. The baffles create turbulence in the flow when mass flow rate increases, which results in an increase in a friction factor. Furthermore, augmentation in friction correspondingly affects the shear stress across the wall.

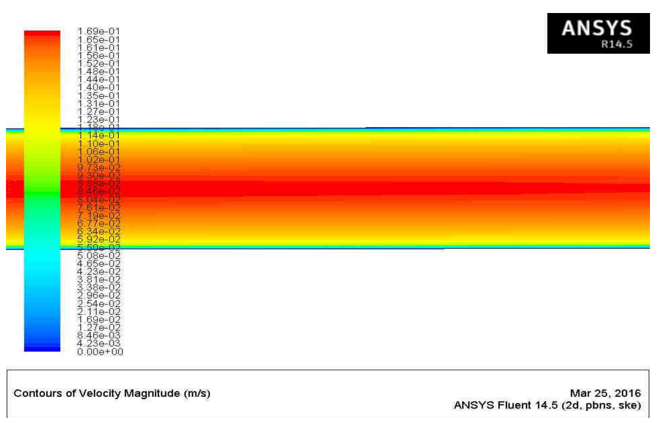


Figure 7: Contour Plot of Velocity Magnitude of Pipe without Baffles

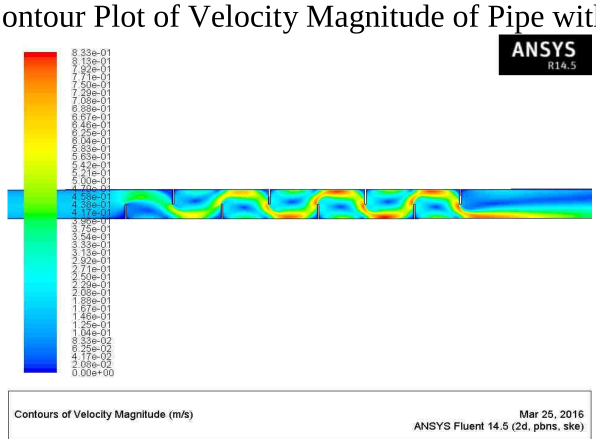


Figure 8 Contour Plot of Velocity Magnitude of Pipe with Baffles

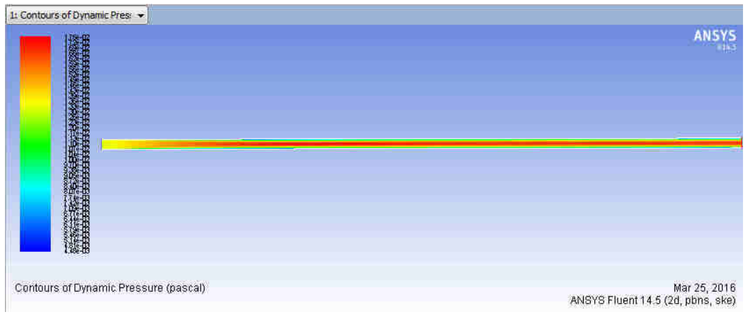


Figure 9 Contour Plot of Dynamic Pressure of smooth pipe

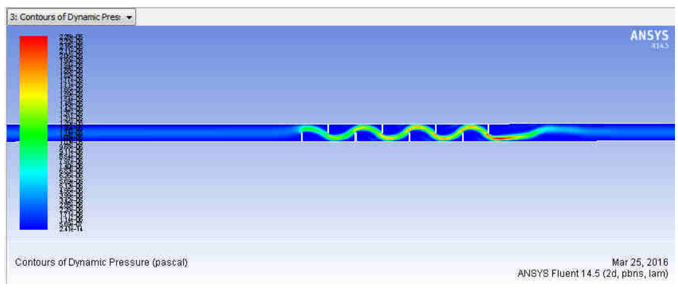


Figure 10 Contour Plot of Dynamic Pressure of Pipe with Baffles

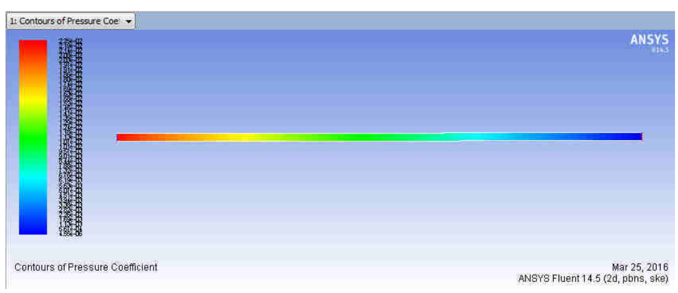


Figure 11 Contour Plot of Pressure Coefficient of Pipe without Baffles

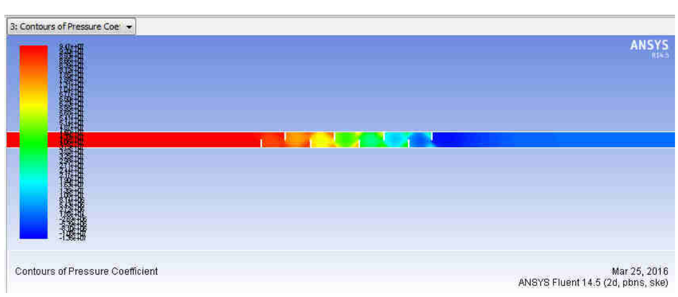


Figure 12 Contour Plot of Pressure Coefficient of Pipe with Baffles

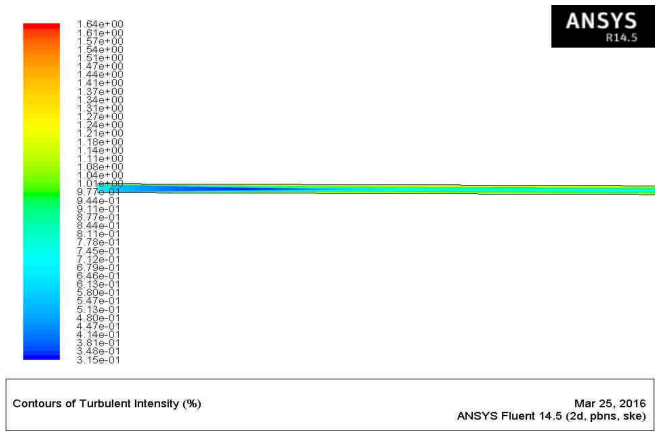


Figure 13 Contour Plot of Turbulence Intensity in smooth pipe

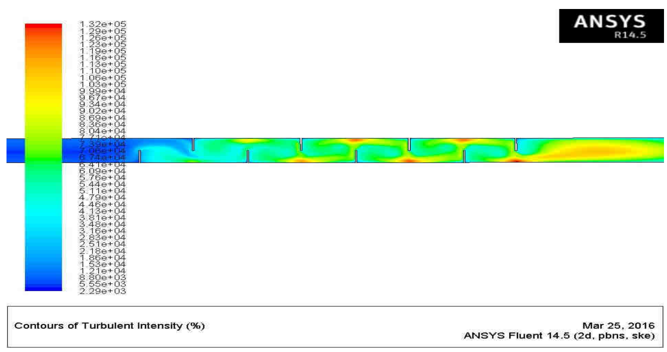


Figure 14 Contour Plot of Turbulence Intensity of Pipe with Baffles

Figure 15 Contour Plot of Wall Shear Stress of smooth pipe

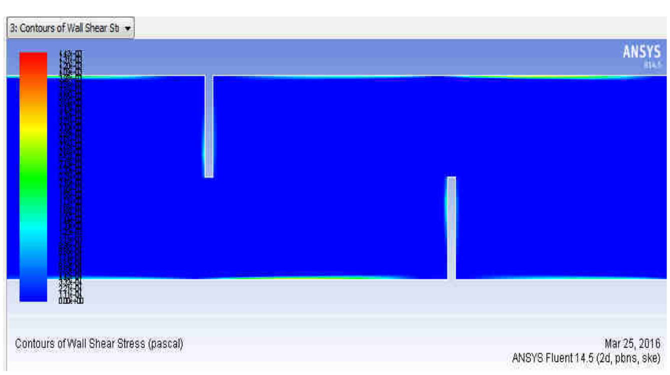
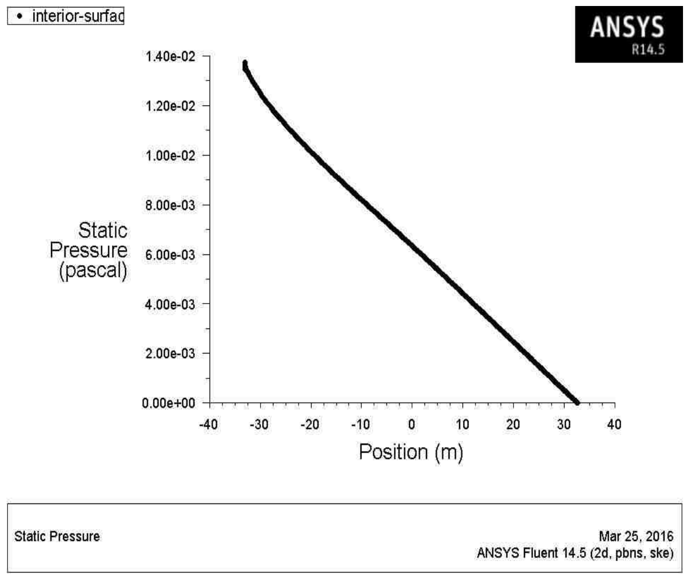


Figure 16 Contour Plot of Wall Shear Stress of Pipe with Baffles



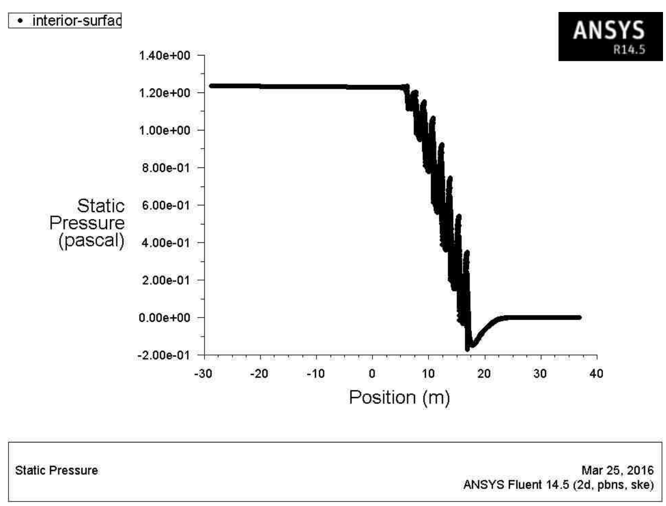


Figure 17 Static Pressure distributions in the pipe and pipe with baffles

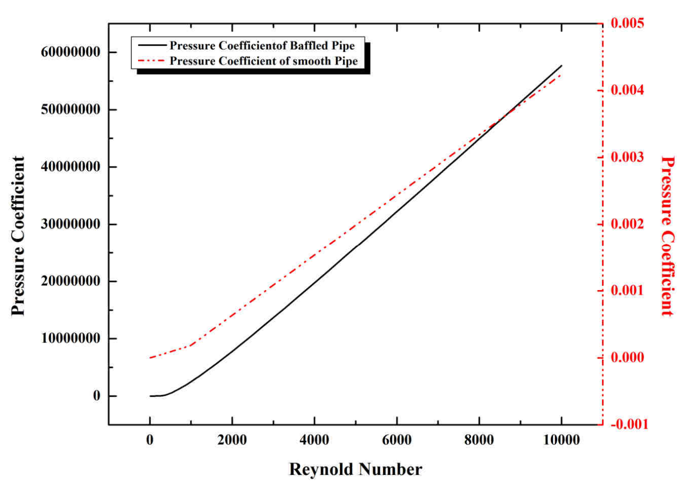


Figure 18 Effect of Reynolds number on pressure coefficient

Figure 18 shows the Effect of Reynolds number on pressure coefficient. It has been observed that pressure coefficient considerably increases linearly as Reynolds number increases. From the figure it can be more evident that the pressure coefficient for pipe with baffles is more is more remarkable.

The Effect of Reynolds number on Wall Shear Stress has detailed in figure 19. It has examined that on increasing Reynolds number the wall shear stress increases significantly

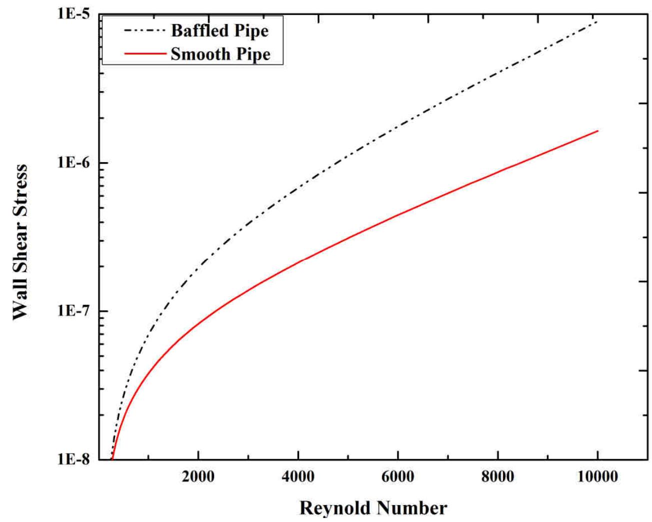


Figure 19 Effect of Reynolds number on Wall Shear Stress

This is because of the fact that friction factor is strong function of Reynolds number. It has also been revealed that the shear stress in pipe without baffles is 81.6% less has compared to pipe with baffles.

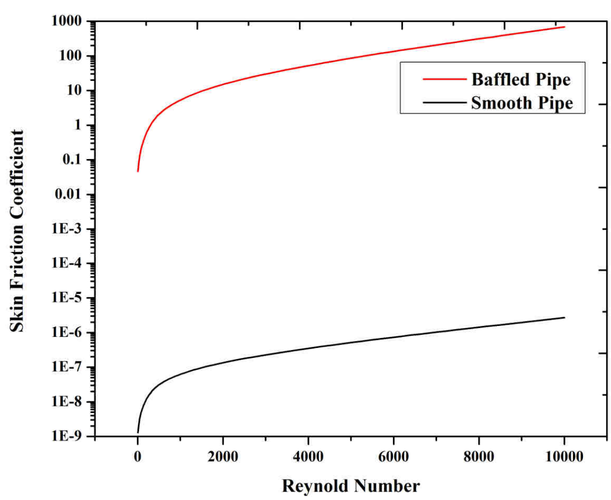


Figure 20 Effect of Reynolds number on Skin Friction

Figure 20 shows the effect of Reynolds number on Skin Friction. It has seen that as Reynolds number increases skin friction increases. This is because of occurrence of turbulence in flow which results in friction. Furthermore the trend of discrepancy is same for both the pipes i.e. pipe with baffles and smooth pipe. But the baffled pipe has higher rate of friction.

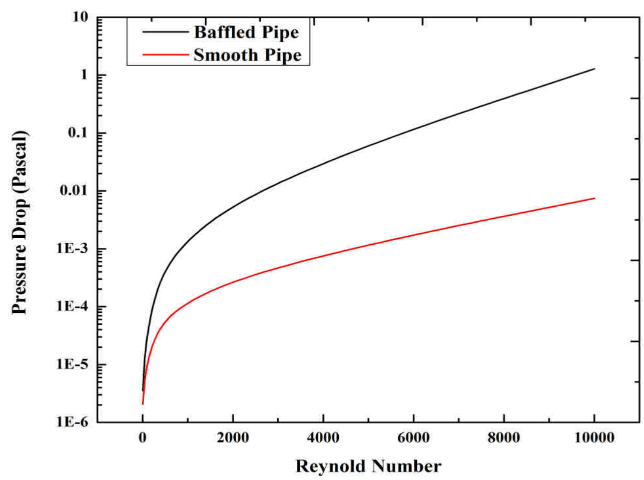


Figure 21 Effect of Reynolds number on Pressure Drop

Figure 21 shows the Effect of Reynolds number on Pressure Drop. It has examined that pressure drop raises as Reynolds number increases. This is because of rise in turbulence in the flow when pipe with baffles has used.

This is due to presence of turbulence in flow. In extinction of baffles the deviation in pressure drop in smooth pipe is 41.47% in laminar regime and 99.42% less in turbulent regime as compared with pipe with baffles.

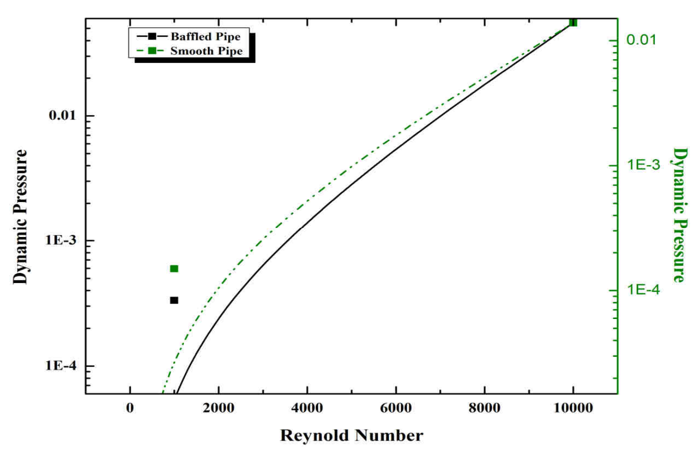


Figure 22 Effect of Reynolds number on Dynamic pressure

Figure 22 shows the Effect of Reynolds number on Dynamic pressure. It has seen that the dynamic pressure progressively increases as the Reynolds number increases. the rate of enhancement of dynamic pressure is comparatively more in pipe with baffles. While in smooth pipe has 75.095% less dynamic pressure than pipe with baffles at high Reynolds number.

CONCLUSION

The pressure drop considerably increases on employing fragmented baffles as compared to smooth pipe.

- On increasing Reynolds number dynamic pressure increases significantly. However, smooth pipe has comparatively low dynamic pressure as compared to baffled pipe.
- Coefficient of skin friction increases as Reynolds number increases. In baffled pipe Coefficient of friction is significantly more due to have more surface area than smooth pipe.
- On realizing baffles in laminar regime turbulence can be created.
- Turbulent intensity is direct function of Reynolds number. In other words, as Reynolds number increases turbulent intensity correspondingly increases.
- Increasing in turbulency promotes the friction factor as Reynolds number increases.
- The thermal performance of any heat exchanger can effectively been increases by employing segmented baffles.
- Shear stress at the wall increases as the fluid flow rate increases.
- The heat transfer characterizes in pipe and ducts are enhanced by using extended surface in form of Fin, baffles, artificial roughness which ultimately, increases the friction factor. Therefore it is extensively been employed in heat exchanger design

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