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Computational Investigation of Flow Stability of Baffled Pipe

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***Abstract:** In this paper, comparative flow stability within the straight pipe and the baffled pipe has been investigated using computational fluid dynamics (CFD). The k-ε turbulence model has been used to simulate high turbulent flow within the pipe. The flow stability has been analyzed in terms of skin friction coefficient and wall shear stress for a wide range of Reynolds number. The effect of baffle orientation has also been seen. It has been found that on increasing baffle orientation angle, the flow gets reversed at low Reynolds number and the flow is quite unstable.*
***Keywords:** Computational fluid dynamics, Baffles, Stability, CFD, Reynolds Number*

I. INTRODUCTION

Baffles are the important structural element of shell and tube type heat exchanger, which acts as an obstruction and/or flow-directing panel or vanes employed in some industrial process ducts, vessels and pipes, mostly in case of tube and shell heat exchangers, static mixers and chemical reactors to take the advantage of mixing, momentum transfer and formation of secondary flow. It is generally used in various engineering applications. Baffles are designed to direct the flow of fluids in order to maximize the thermal efficiency and to support tube bundles.

There are three basic modes of heat transfer; Conduction, Convection, and Radiation. Conduction is practically involved in all operations in which heat interaction taking place. Baffles are the commonly used structural element, which is applied in transmitting heat by the mode of conduction especially in channels and ducts in process industries.

II. LITERATURE REVIEW

Howe's et al. (1991) has been numerically simulated the natural and forced unsteadiness of flow in the baffled pipe for the periodic flow and illustrated the chaotic advection, the mixing mechanism and fouling rates of the flow. Gaddis and Gnilinski (1997) using the novel method to calculate the pressure drop within shell and tube heat exchanger in presence of baffles; based on correlations. The obtained results have been compared with experimental work and get ± 35% variations. Sun and Emery (1997) applied finite volume method to solve the governing equations and investigated the convective heat transfer of a two-dimensional enclosure filled with air along with having internal baffles, which acts as internal heat sources. The obtained experimental and numerical result using window calorimeter is compared in terms of temperature distribution. Kang and Yang (2012) examined the flow instability of channel with the baffle in three-dimensional flows. They have been observed the influence of aspect ratio of baffles, baffle spacing, and baffle height for the given range of Reynolds number.

Salahudd in et al. (2015) presented a comprehensive comparative report on the performance of helical and segmental baffles in shell and tube heat exchanger and found that helical baffles have superior performance as compared to helical baffles. A novel approach has been represented by Mehdi et al. (2015) for improving the energy efficiency of shell and tube heat exchanger using helical baffles with nano-fluid. The influences of overlapping and decrease in helix angle of baffles have been examined and found that pressure drop and heat transfer increases as the concentration of nano fluid increases. The results have been optimized by single-objective optimization using Neural Network.

Bin et al. (2015) experimentally examined the performance of baffle helix angle along with discontinuous helical baffles in shell tube heat exchanger. The analysis based on the second law of thermodynamics represents, the superior performance in terms of heat transfer for smaller helix angle. The effect of the baffle on flow distribution of an electrostatic precipitator has been presented by Sayema et al. (2015) for the coal based power plant. The result shows that residence time of flue gas in electrostatic precipitator increases, which ultimately increases the collection efficiency and effective mixing of particles.

Cong et al. (2017) studied the thermal performance of trisection helical baffles heat exchangers with diverse inclination angles and baffle structures. They represented that the sector baffles have better performance as compared to ellipse baffles and concluded that overlapping of baffles is not beneficial.

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III. MATHEMATICAL MODELING

Navier-stokes equation has been used for fluid flow in baffled channel, duct, pipe etc. and governed by the Bernoulli's equation of flow (Yadav et al., 2017). For analyzing the fluid flow across the pipe Navier–Stokes equations are solved by using ANSYS Fluent solver. The details of equations are as follows:

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

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

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

Governing equations of the flow of a compressible Newtonian fluid

Continuity $$\frac{\partial \rho}{\partial x} + div(\rho u) = 0 \quad \text{......... (4)}$$

x-momentum $$\frac{\partial(\rho u)}{\partial x} + div(\rho u u) = -\frac{\partial p}{\partial x} + div(\mu grad u) + S_{Mx} \quad \text{..........(5)}$$

y-momentum $$\frac{\partial(\rho v)}{\partial y} + div(\rho v u) = -\frac{\partial p}{\partial y} + div(\mu grad v) + S_{My} \quad \text{........... (6)}$$

z-momentum $$\frac{\partial(\rho w)}{\partial z} + div(\rho w u) = -\frac{\partial p}{\partial z} + div(\mu grad w) + S_{Mz} \quad \text{........... (7)}$$

Energy $$\frac{\partial(\rho i)}{\partial t} + div(\rho i u) = -p\,div u + div(k\,grad T) + \Phi + S_i \quad \text{........... (8)}$$

Using various correlation FEV results are been compared analytically

$$h_f = f\frac{LV^2}{D_h 2g} \quad \text{........... (9)}$$

$$f = \frac{64}{Re} \text{ (For Re<2000)} \quad \text{............ (10)}$$

$$Re = \frac{\rho u_{avg} d}{\mu} \quad \text{........... (11)}$$

Where, f is the friction factor for fully developed laminar flow; L is the length of the pipe; V is the mean velocity of the flow; d is diameter of the pipe and Re is the Reynold Number

IV. METHODOLOGY

In this work CAD model of Baffled pipe have been developed and the orientation of baffles have been varied at a different angle. The CAD model of baffled pipe has been discretized in a different number of nodes and element which is in order of 10^6. The Geometrical details of baffled pipe are shown in figure 1.

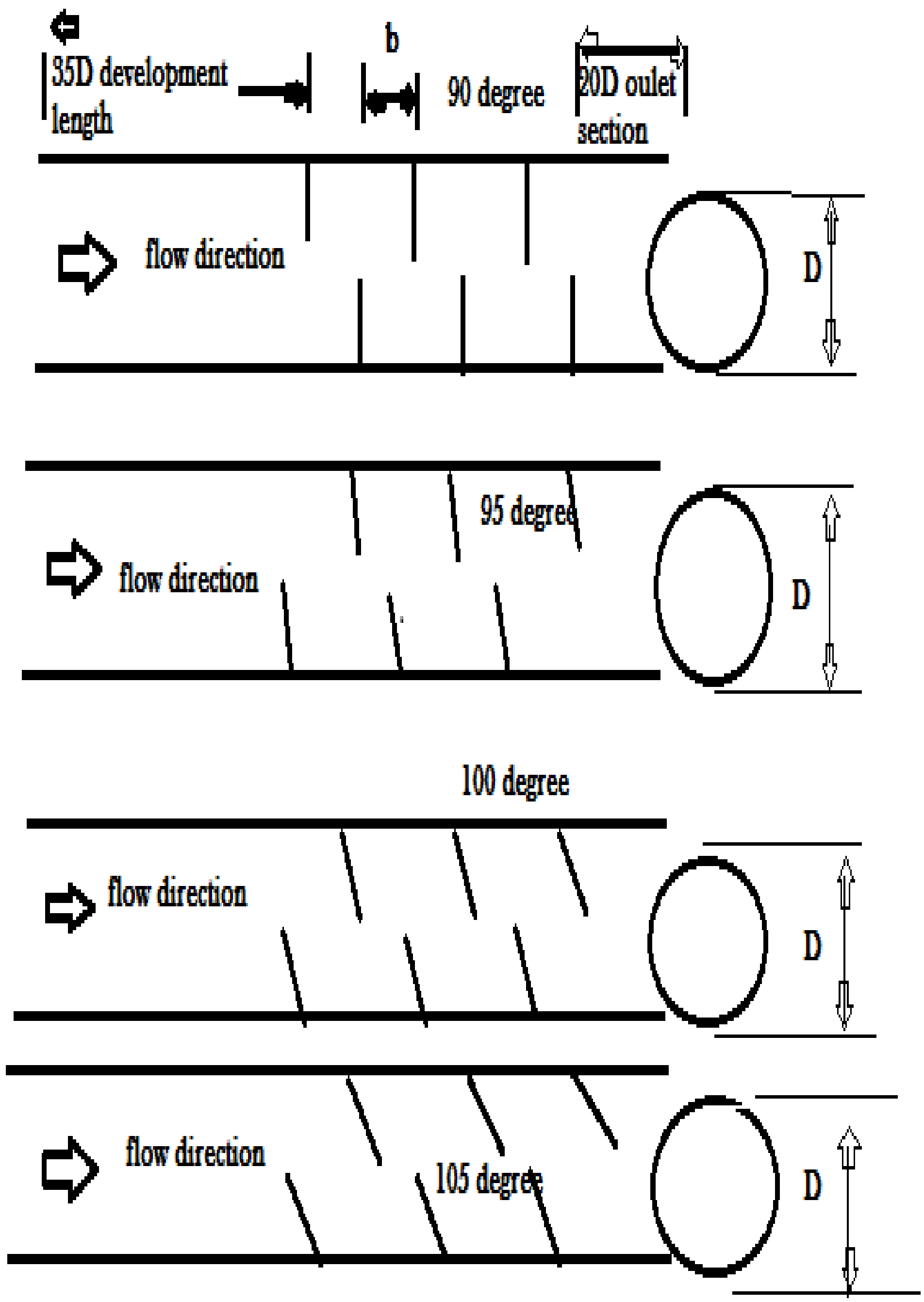
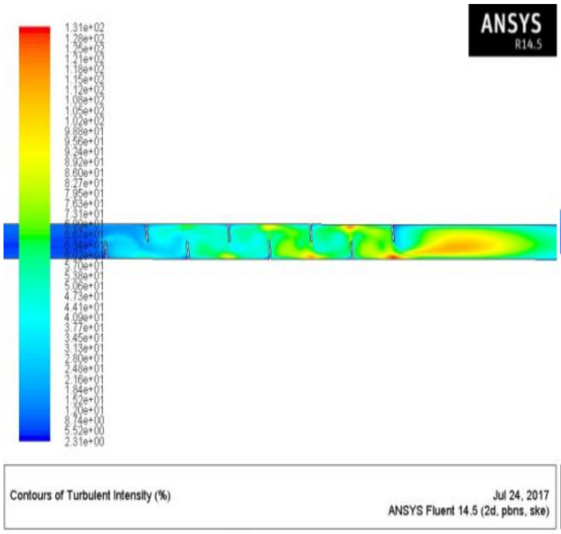


Figure 1: Geometrical details

V. RESULT AND DISCUSSIONS

To study the flow instability within the baffled pipe at different baffle arrangement; the velocity distribution, turbulent intensity, and the pressure distribution have investigated in detail along the channel length. Figure 2 shows the comparison of turbulent intensity along the pipe length. It has been shown that when the fluid flows in a straight pipe, the turbulent intensity increases linearly but when the fluid flows in the baffled section, the turbulent intensity is increased at a higher rate. This trend has been shown that the baffled pipes gives effective turbulence and increase of heat transfer in pipe flow.



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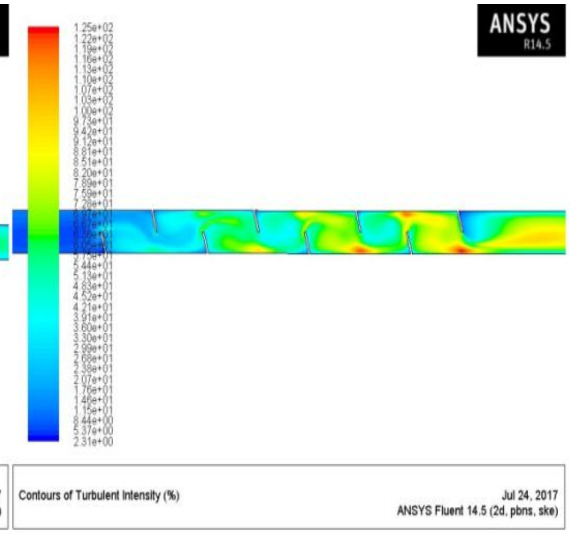

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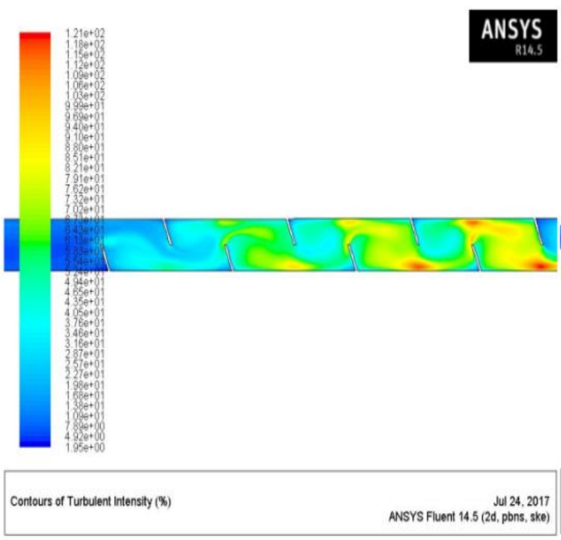

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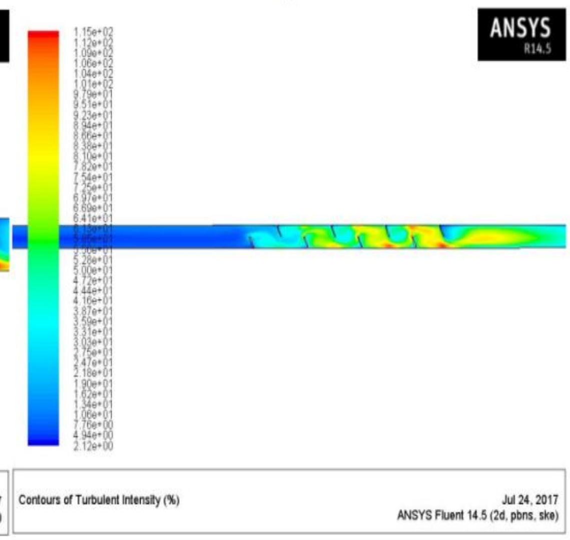

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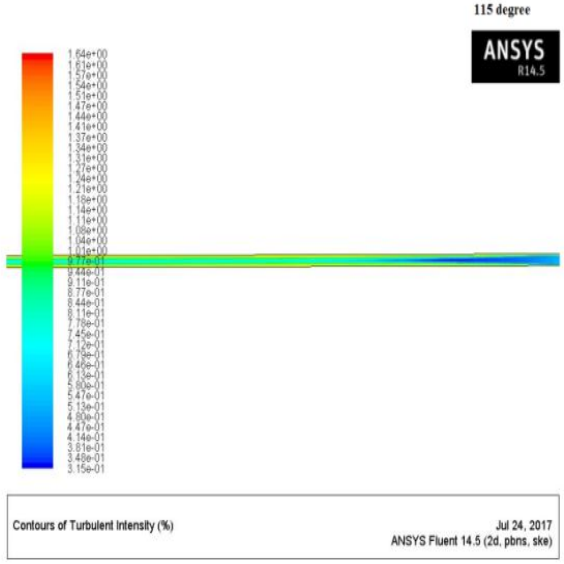


Straight

Figure 2: Comparison contour plot of turbulent intensity along the pipe length

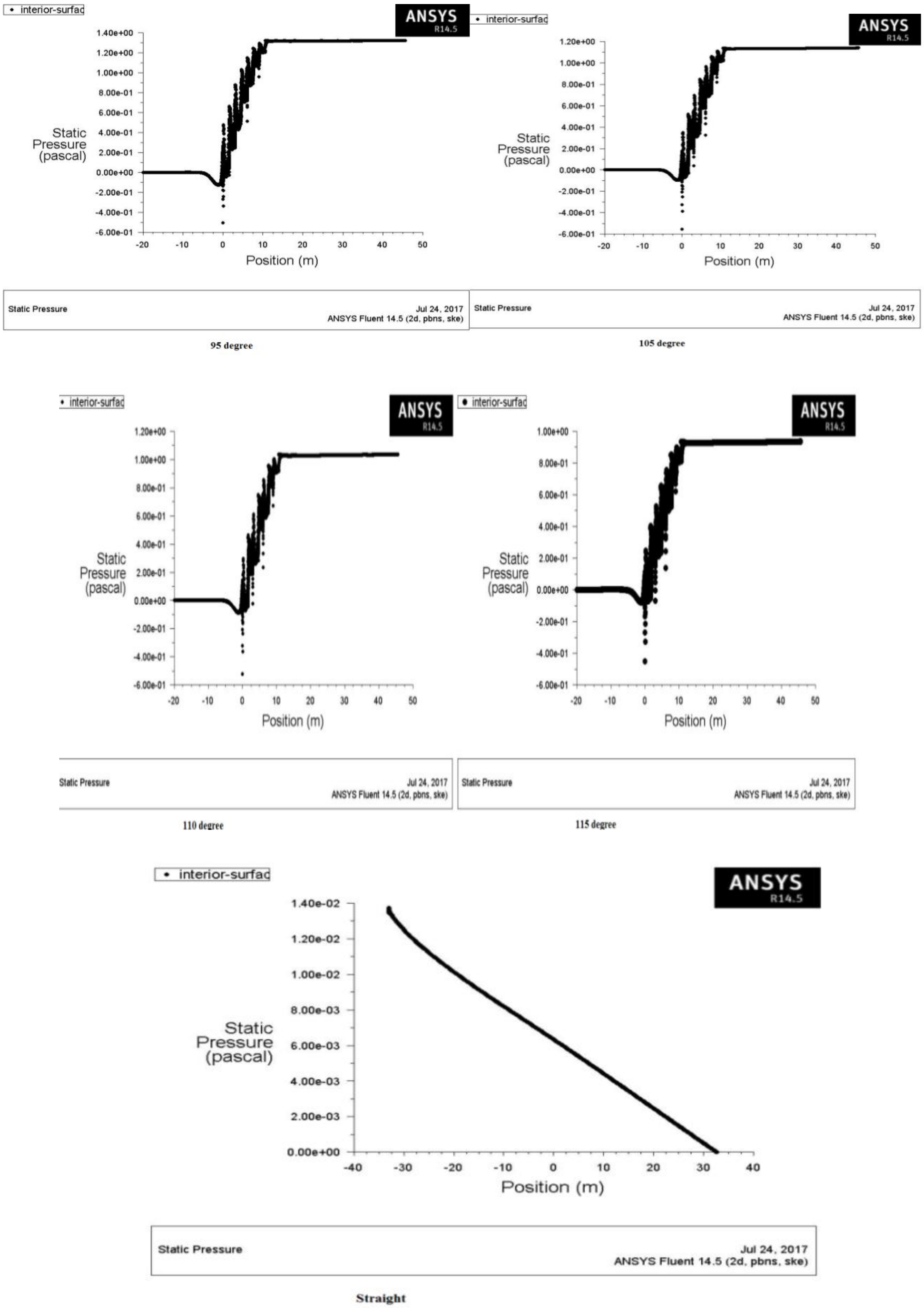


Figure 3: Comparison of pressure distributions along the pipe length

Figure 3 shows the comparison of pressure distribution along the pipe length. It has been shown that when the fluid flows, the flow is stable till it reaches the baffled section. After reaching baffled section, the flow becomes unstable due to mass and momentum transfer and the pressure reduces in a zigzag manner. The same trend has been seen for the entire baffle oriented pipe but the rate of pressure decreases. It has also been seen that the drop in pressure increase as the baffle orientation increases.

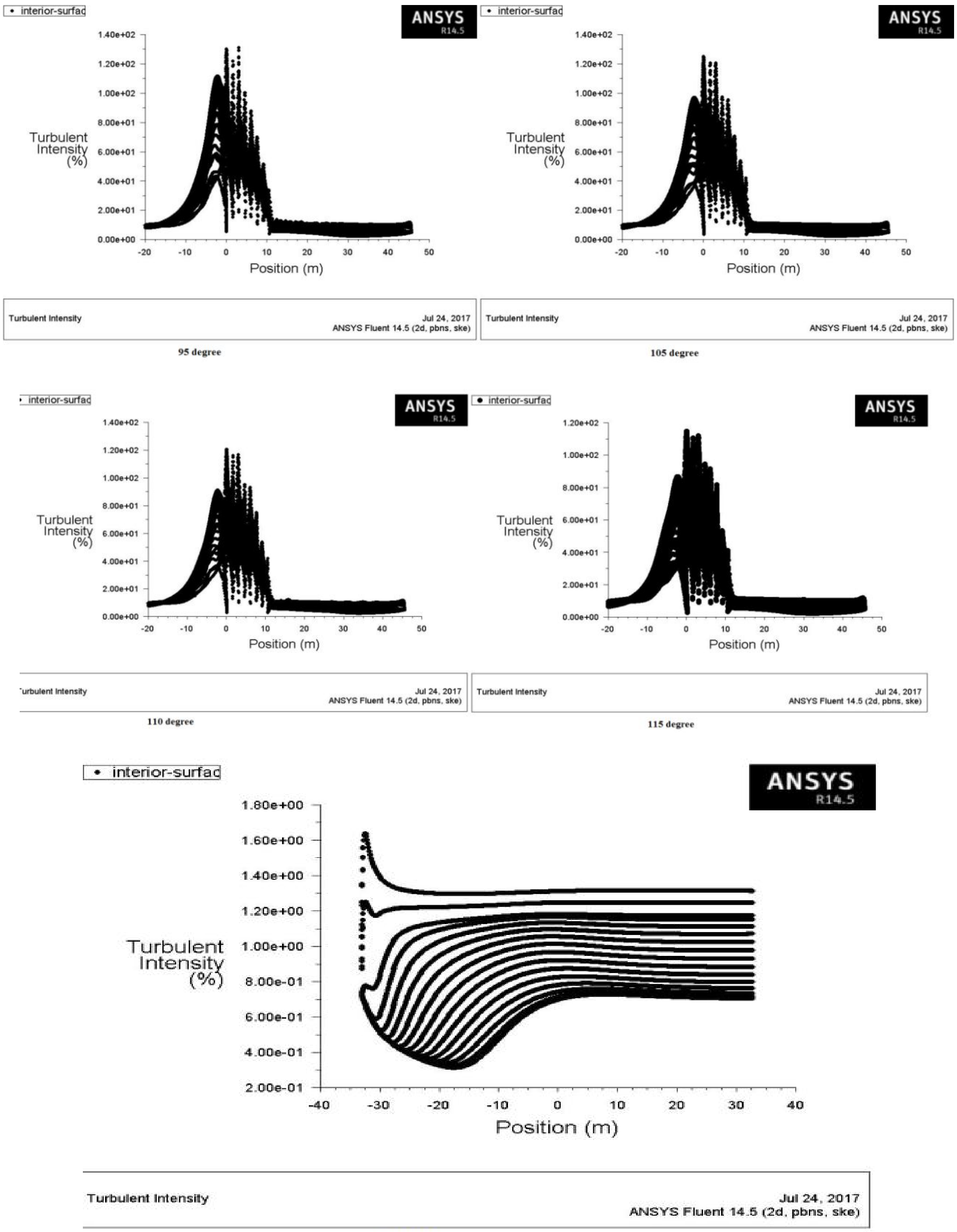
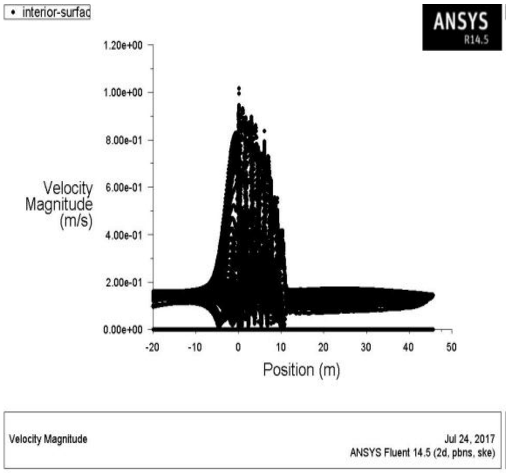


Figure 4: Comparison of turbulent intensity along the pipe length

Figure 4 shows the comparison of turbulent intensity along the pipe length. It has been seen that when the fluid flows, at the baffled section the turbulent intensity increase rapidly. After passing through the baffled section there is a drop in turbulent intensity. The same trend has been seen for the entire baffle oriented pipe but the rate of turbulence changes. Therefore, in heat exchanger cases numbers of the baffle are increased so that the turbulent intensity can be increased significantly which will increase the heat transfer rate.



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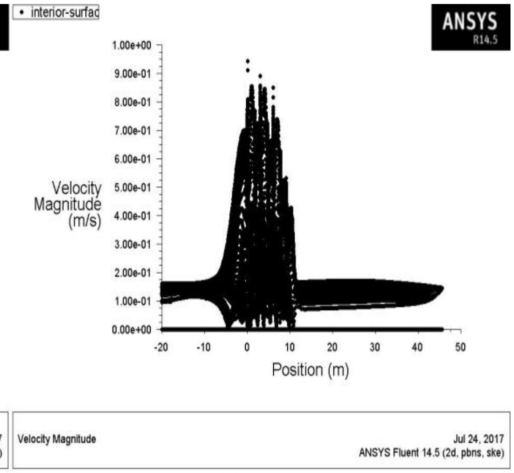

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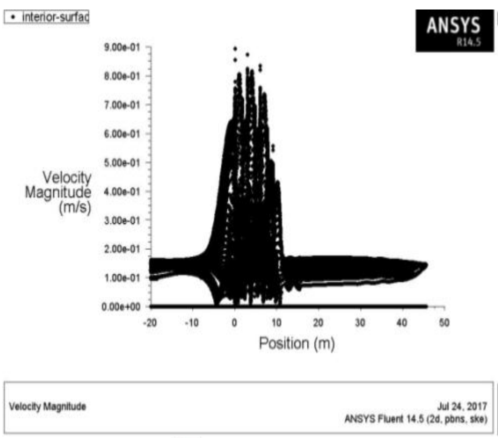

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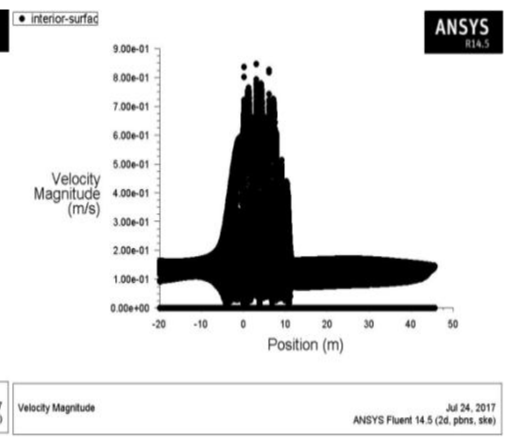

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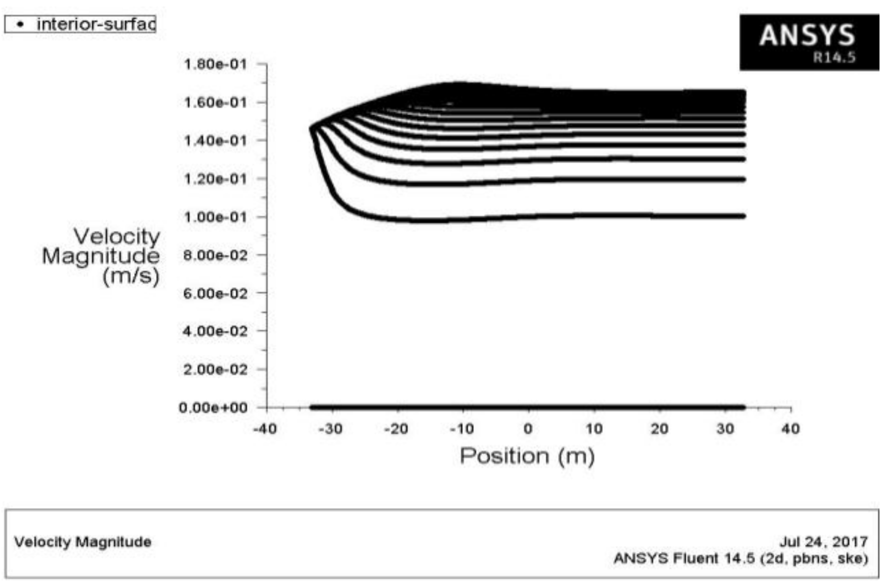

Straight

Figure 5: Comparison of velocity distribution along the pipe length

Figure 5 shows the comparison of velocity distribution along the pipe length. It has been seen that when the fluid flows; the flow is stable till it reaches the baffled section. After reaching baffled section, the flow becomes unstable and the velocity increases because of mass and momentum transfer. The same trend has been seen for the entire baffle oriented pipe but the rate of velocity changes.

VI. CONCLUSIONS

In this work, the flow stability has been examined for fully developed turbulent flow and following conclusions have been drawn:

A. At high Reynolds number due to the presence of baffles, the flow gets unstable which ultimately affect the various parameters such as pressure, velocity, and turbulent intensity.
B. As the baffle orientation varies the parameters such as pressure, velocity, and turbulent intensity varies significantly.
C. The velocity increase within the pipe as it passes over the baffles.
D. The turbulent intensity increase within the pipe as it passes over the baffles.

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