Comparative Pressure Drop in Laminar and Turbulent Flows in Circular Pipe with and without Baffles using FEV

Ashu Pandey[1] , Rahul Patil[2]

[1]M.Tech. Scholar, Mechanical Engineering Department, Christian College of Engineering & Technology, Bhilai, India.
[2]Assistant Professor, Mechanical Engineering Department, Christian College Of Engineering & Technology, Bhilai, India.

Abstract— *The study of Turbulent flow characteristics in complex geometries receives considerable attention due to its Importance in many engineering applications and has been the subject of interest for researchers. Some of these include the energy conversion systems found in same design of heat exchangers, nuclear reactor, solar collectors & cooling of industrial machines and electronic components. Flow in channels with baffle plates occurs in many industrial applications such as heat exchangers, filtration, chemical reactors, and desalination. These baffles cause turbulence which leads to increases friction within the pipe or duct and leads significant pressure drop.*

This work is concern with the comparative flow and pressure distribution analysis of a smooth and segmented Baffles pipe. In which pressure drop during the flow is examined and with the help of hydrodynamic characteristics performance is predicted with the help of Finite element volume tool ANSYS- Fluent, where simulation is been done. The goal is to carry out evaluating pressure drop across the pipe using different turbulent model and at simulation is done for wide range of Reynolds number in both laminar and turbulent flow regimes. The FEV results are validated with well published results in literature and furthermore with experimentation. The FEV and experimental results show good agreement.

***Keywords— Baffles, Pressure Drop, Turbulence*.**

I. INTRODUCTION

In Laminar-Turbulent is often cause flow instability, which is an essential process towards fully turbulent flow. In many engineering applications, suppressing or triggering turbulent is widely used depending upon the desired nature of flow, laminar or turbulent, required by the particular application. Therefore understanding the flow visualization of laminar and turbulent is very important in flow control and must be preceded by a study of the flow instability associated with the specific flow configuration. When flow takes place in laminar and turbulent adequate pressure drop takes place throughout the length of pipe this is due to presence of friction in pipe or channel surface which result in various loss of pipe. In order to overcome this loss various techniques are been adopted as per desired. In heat exchanger the main aim is to achieve better effectiveness in heat transfer this can be achieve be using extended surface i.e. baffles or using artificial roughness. In form of thin plates Baffles are mounted on channel walls play an important role in enhancing the heat transfer not only by enlarging the fluid contact area but also by destabilizing the flow field. The flow instability caused by the baffles triggers laminar–turbulent transition. Consequently, mixing enormously increases in the disturbed flow field, resulting in more effective heat transfer.

In case of laminar flow when the flow is constraint and a desirable turbulence is required baffles acts a major role in creating turbulence in laminar flow. In this work a comparative Flow analysis have in carried out between straight pipe and segmented baffled pipe at various Reynolds number (10<Re<10,000). The effect of baffles in hydrodynamic performance is been visualized.

II. LITERATURE REVIEW

In 1973 Richman and azad perform numerical and experimental investigation for analyzing steady incompressible developing turbulent flow behavior in smooth pipes. [1] A modified Van driest viscosity model is adopted to solve governing equation to determine vorticity transport and stream function.

Lissenburg et. al 1975 experimentally examine the effect of a constriction on turbulent pipe flow be evaluating velocity and the axial turbulence velocity distributions in a cross-section of a circular tube at various distances downstream at selected internal of constriction. [2] A point very close to wall and in the axis of tube a spectral distributions of the turbulence velocity has been gauged. It has found that on reducing constriction contraction ratio vibrations of hose takes place.

Quader and Wilkinson 1980 investigate Isothermal and non-isothermal flow rate-pressure drop result in turbulent flow through smooth pipes for non-Newtonian fluids.[3] It has observed that friction factor plays a significant role with Reynolds number during fluid flow. And other papramters such as pipe diameter, mean velocity, Bowen's correlation are experimentally derived parameters which characterize the fluid.

In 1987 Hartnett and Rao measures Heat transfer and Friction factor for the Turbulent flow of purely viscous Non-Newtonian fluids in a 2:1 rectangular channel. [4] The obtained result is compared with previously reported circular tube geometrical result. It has found that the rectangular duct fully established friction factor measurements are within ± 5% of the Dodge-Metzner prediction if the Kozicki generalized Reynolds number has employed.

Chevrin et. al 1992 examine Reynolds stress in the near-wall region of a fully developed turbulent pipe flow. Glycerine is adopted as working fluid Because of closed circuit tunnel and Two laser Doppler velocimeter (LDV) systems has been employed for measuring the two point spatial correlation, R 12, between the Stream wise and Radial velocities in a radial plane of the pipe.[5]

In 1994 Linden and Hoogendoorn perform experimental to visualize the effect of a pressure wave on the turbulent flow and heat transfer in rectangular air flow channel. Hot film sensor, hot wire and pressure transducer are used for instant measuring heat flux, velocity and pressure. It has been found that heat transfer is function of thermal boundary layer thickness and Reynolds number. [6] The results are compared with simple numerical turbulent flow and heat transfer model.

Habib et.al 1999 analyzed the Heat Transfer characteristics of pulsated Turbulent Pipe flow under different conditions of Pulsation frequency, Amplitude and Reynolds number keeping uniform heat flux at pipe wall and revealed that the effect of pulsation on the mean Nusselt numbers is insignificant at low values of Reynolds number.[7]

Pavelyev et. al 2003 conducts experiment to evaluate resistance coefficients at critical Reynolds number from Blasius formula for laminar flow and from the Prandtl formula for turbulent flow are identical and the effect of insert has also been investigated. From this it can be concluded that insertion of the rod led to a decrease in the critical Reynolds number.[8]

Galinat et. al 2005 analyzed the drop fragmentation process caused by a cross-sectional restriction in a pipe. Using Trajecto-graphy Drop break-up downstream of the restriction has been studied and found that mean drop diameter downstream of restriction linearly increases as a function of the inverse of the square root of the pressure drop. [9]

Tandiroglu 2006-07 computes the effect of the flow geometry parameters on Transient Forced Convection Heat transfer for turbulent flow in a circular tube with baffle inserts. Several parametric configurations are used such as inlet diameter ratio, baffle orientation angle etc and proposed a empirical correlations of Nusselt number and pressure drop as a function of Reynolds number corresponding to the baffle geometry in transient flow conditions.[10]

Promvonge 2010 experimentally examined heat transfer characteristic for a multiple 60° V-baffle turbulator with parametric aspect ratio. The obtained result shows remarkable increases thermal performance and gives optimal value of applied aspect ratio aspect. [11]

Katsuhide er. Al 2011 investigates the effect of pipe diameter in pressure drop and heat transfer of Cryogenic slush fluids. It has observed that larger pipe diameter produces a higher onset velocity for reducing pressure drop and worsening heat-transfer characteristics [13]

Kang and yang 2012 investigates the flow instability in presence of baffles in channel of heat exchanger instability through which time-periodic two-dimensional flow bifurcates into three-dimensional flow [14]

George et. al 2013 perform numerical simulation for turbulent flow across smooth circular pipe at high Reynolds number. A comprehensive report set of data is put into perspective with other simulation data sets, obtained in pipe, channel and boundary layer geometry. [15]

Dosunmu and Subhash 2014 studied the turbulent flow behavior of surfactant test solutions by measuring pressure drop across a straight pipe at various flow rates. [17]] It has found that affect of concentration, pipe diameter, pipe roughness, and solvent type significantly reduces drag within pipe. The percentage of drag reduction is high at higher Concentrations in larger pipes with negligible Surface Roughness.

Wenbin et. al 2014 analyzed the influence of small pipe inserts Heat transfer performance and pressure drop in a circular tube. By employing pipe inserts at relatively low flow resistance high heat transfer coefficient can be archived.[18]] The effect on Nusselt number and friction factor increases with the decrease in spacer length and arc radius.

Shiniji et. al 2015 explore drag reduction and degradation of nonionic surfactant (Aromox) solutions by computing the Pressure drop and Flow rate in the circuit pipe flow system using a pump. It has found that on addition of organic acids to the solution the significant reduction in drag.[19]

III. MATHEMATICAL MODEL

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:

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

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

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

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

Moody's Chart

R: radius of the pipe

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

$\mathrm{Re} \to \infty$: Completely rough pipe

IV. METHODOLOGY

The equation of motion (Navier stokes Equation) for Straight pipe and Segmented baffled pipes is solved by using ANSYS Fluent. The computational model of Straight pipe and segmented baffled pipes was discretized into 38841 elements with 39726 nodes by proper defining the boundary condition at inlet, outlet, topwall bottom wall, Baffles. In figure 1 the Schematic of the circular pipe with segmental baffles is shown and figure 2 shows the mesh model in ANSYS FLUENT

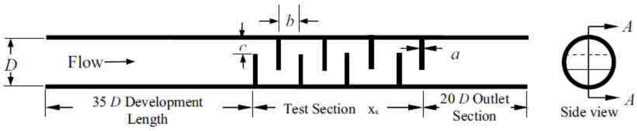

Fig. 1 Schematic of the circular pipe with segmental baffles

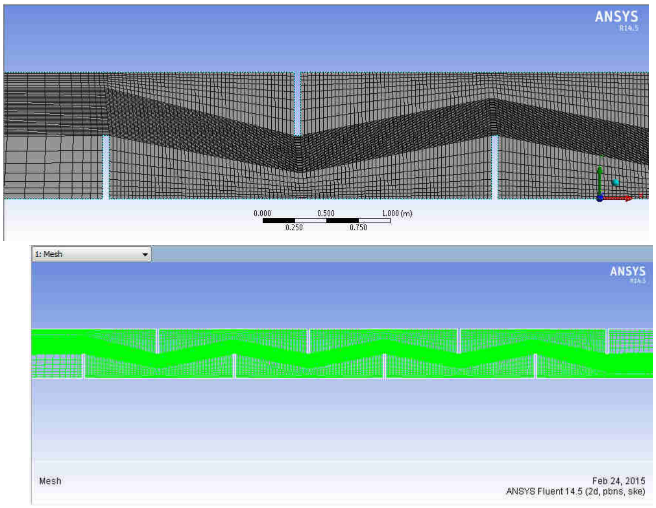

Fig. 2 Mesh model

V. RESULT AND DISCUSSION

The governing equations of the problem were solved, numerically, using a Element method, and finite Volume method (FVM) used in order to calculate the Hydrodynamic characteristics of a Pipe with Segmented Baffles. As a result

of a grid independence study, a grid size of 106 was found to model accurately the Hydrodynamic performance characteristics are described in the corresponding results.
The accuracy of the computational model was verified by comparing results from the present study with those obtained by, Ahsan [16], McGovern [12] Experimental, and Analytical and FVM results.

Table 1 Validation of Friction Factor with respect to varying Reynolds Number

Reynolds Number	**FEV Ref. [16]**	**Expt Ref.[20,12]**	**Present (Ansys)**
10000	0.29301	0.28902	0.29453
15000	0.21012	0.2061	0.21245
20000	0.16315	0.15415	0.16383
25000	0.13118	0.11619	0.13319
30000	0.1112	0.08822	0.10841
35000	0.08923	0.06624	0.08945
40000	0.06125	0.04726	0.06312

Table 2 Validation of Turbulence Intensity with respect to varying Reynolds Number

Reynolds Number	**FEV Ref. [16]**	**Present (Ansys)**
10000	5.02512	**5.05149**
15000	4.80467	4.81107
20000	4.63471	4.64019
25000	4.50895	4.51219
30000	4.41011	4.41423
35000	4.32211	4.33015
40000	4.25401	4.25891

Table 3 Validation of Head loss with respect to varying Velocity

Velocity m/s	**Ahsan Ref.[16]**	**FEV Ref. [16]**	**Present (Ansys)**
0.01	0.000334703	0.000332691	0.000310147
0.015	0.000666083	0.000662879	0.000649214
0.02	0.00110107	0.001088384	0.000974123
0.025	0.00163702	0.0016041	0.001501762
0.03	0.002281783	0.002206522	0.00209149
0.035	0.003002964	0.002890919	0.00264951
0.04	0.003734905	0.003648788	0.00357463

In table 1 to table 3 and figure 3-5 shows the validation of FEV result obtained from the ANSYS tool. It has been seen that the obtained result shows good agreement with the analalytical, Experimental and FEM of avalilable literature.
The small variation is results is due to variation in grid sizing, operating condition, material properites, etc. but the obtained result shows the same trend so that the results are suitably verified.

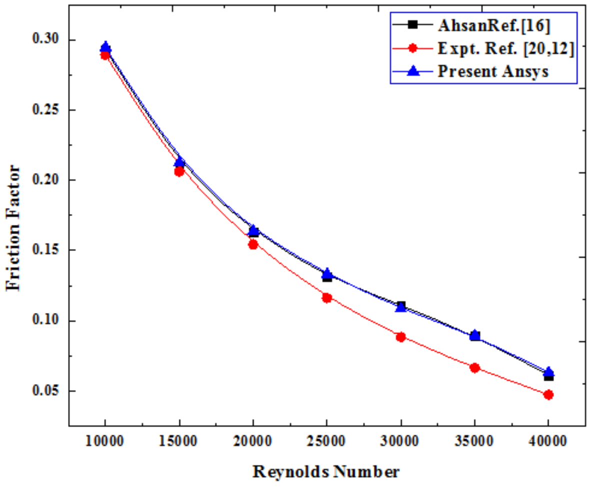

Fig. 3 Validation of Friction Factor with respect to varying Reynolds Number

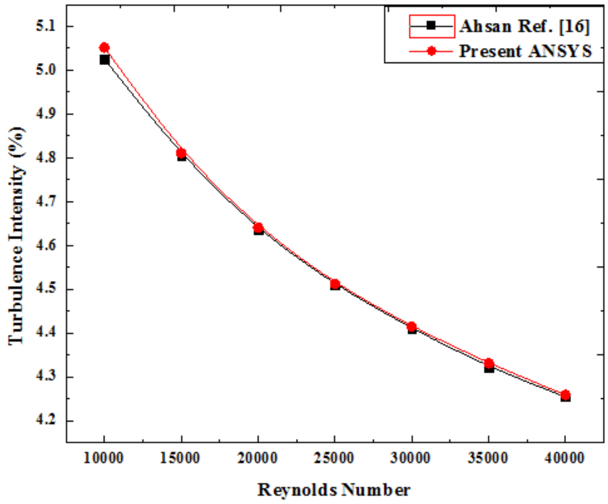

Fig. 4 Validation of Turbulence Intensity with respect to varying Reynolds Number

Figure 6 to 17 shows the contour plot of an pipe which illustrates the flow pattern across the Straight pipe and pipe with segemented baffles. On the basis of this hydrodynamic characteristics various graphs has been ploted and dissued there significance in hydrodynamic performance has been stated.

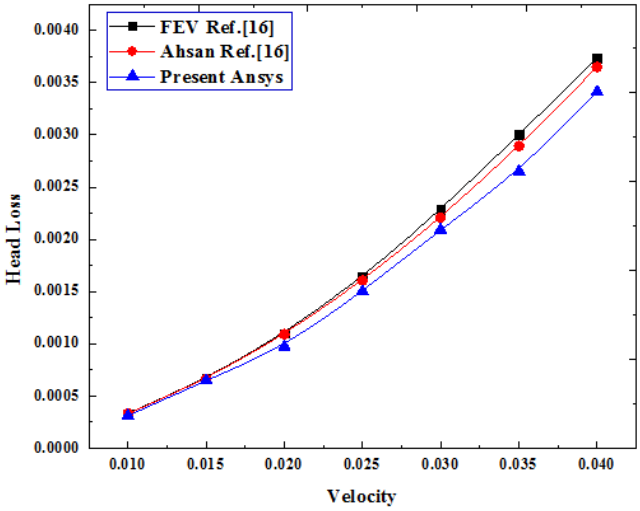

Fig. 5 Validation of Head loss with respect to varying Velocity

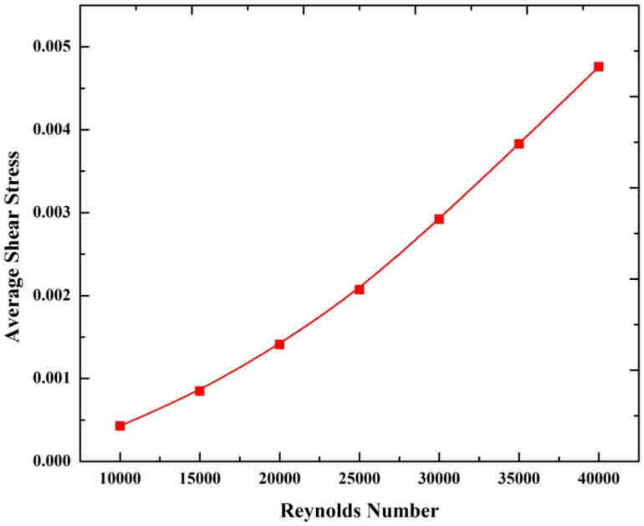

Fig. 6 Variation of Shear Stress with varying Reynolds Number

In figure 7 it can be shown that there is only changes in pressure in the axial direction. This represents that the pressure in the center of the pipe is equal to the pressure on the walls of the pipe. There is not an augmentation in the static pressure because the flow 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, however again, the static pressure is constant because the flow isn't going through a stagnation process.

Due to pressure of baffels pressure drop significantly incrases as reynolds number increases. This baffles creates turbulence in fluid flow asvelocity raises and cause friction with leads to increases in friction factor. Moreover, increaes in friction factor correspongly affects the shear stress across the wall.

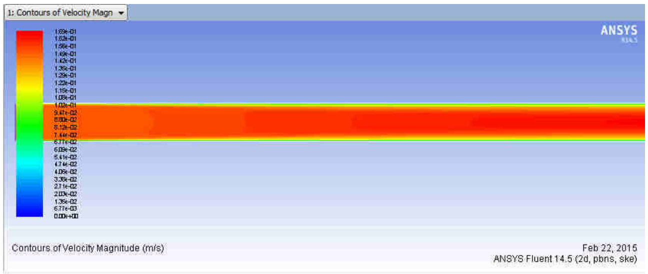

Fig. 7 Contour Plot of Velocity Magnitude of Pipe without Baffles

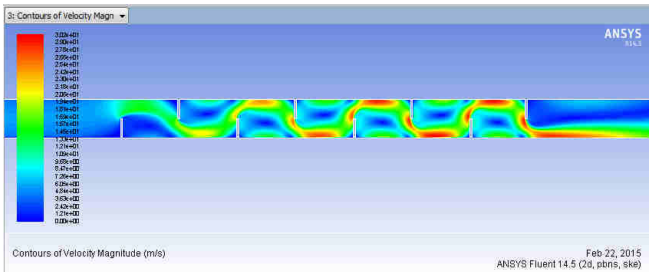

Fig. 8 Contour Plot of Velocity Magnitude of Pipe with Baffles

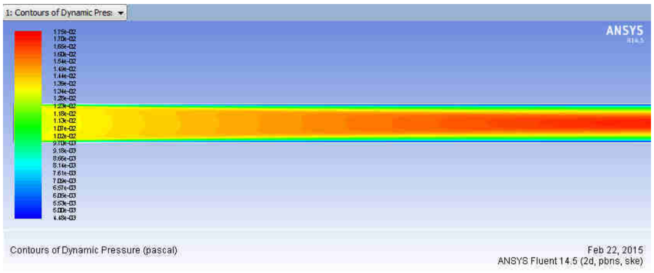

Fig. 9 Contour Plot of Dynamic Pressure of Pipe without Baffles

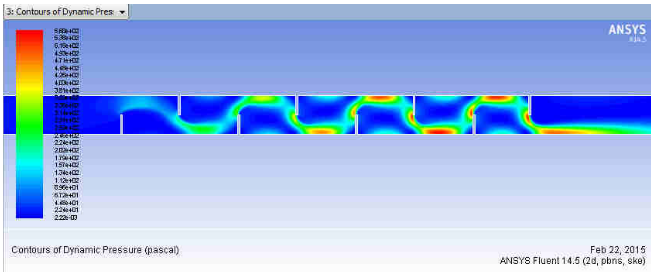

Fig. 10 Contour Plot of Dynamic Pressure of Pipe with Baffles

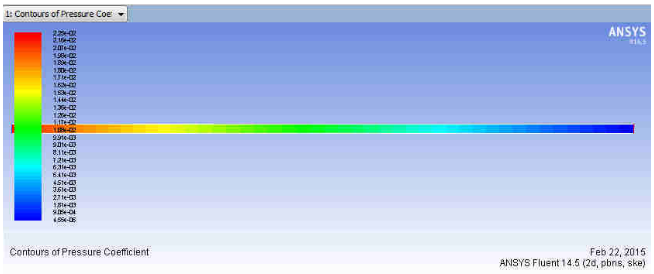

Fig. 11 Contour Plot of Pressure Coefficient of Pipe without Baffles

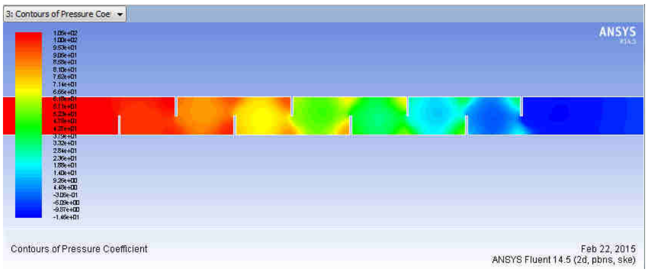

Fig. 12 Contour Plot of Pressure Coefficient of Pipe with Baffles

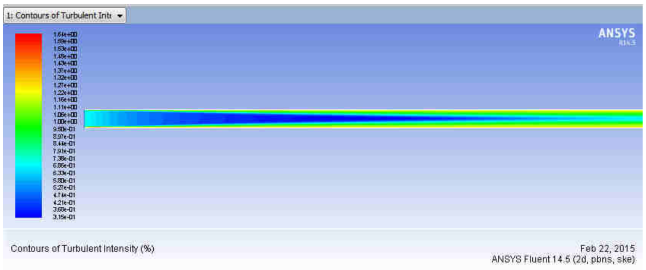

Fig. 13 Contour Plot of Turbulence Intensity of Pipe without Baffles

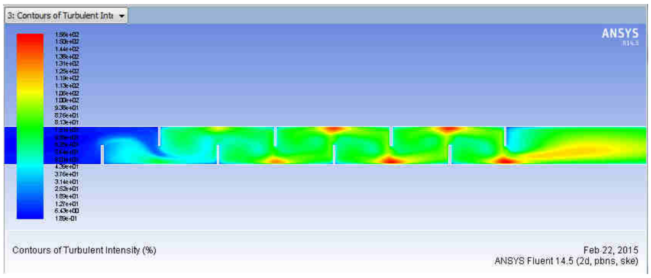

Fig. 14 Contour Plot of Turbulence Intensity of Pipe with Baffles

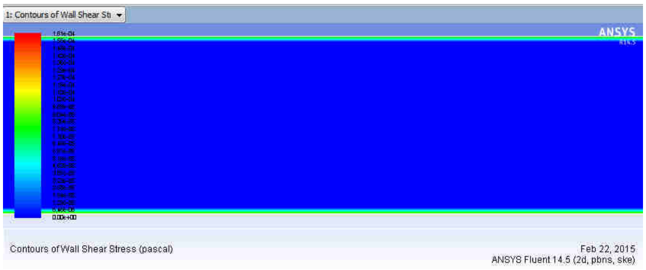

Fig. 15 Contour Plot of Wall Shear Stress of Pipe without Baffles

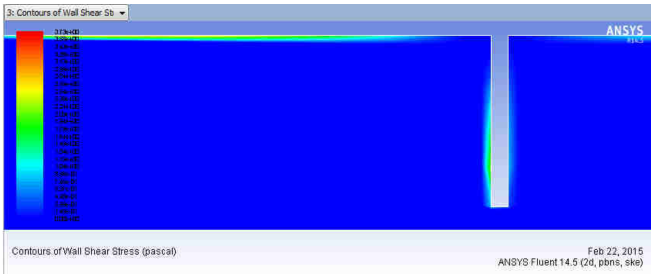

Fig. 16 Contour Plot of Wall Shear Stress of Pipe with Baffles

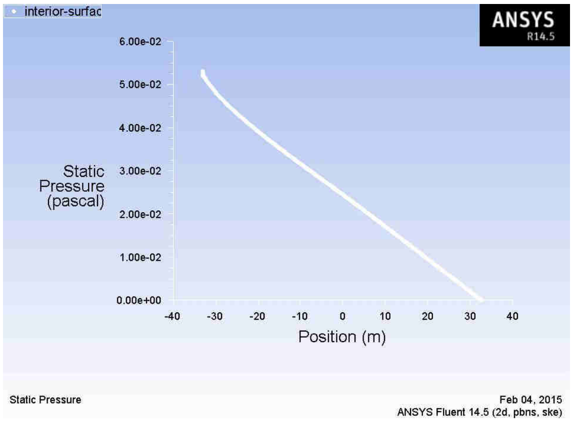

Fig. 17 Static Pressure distributions throughout the pipe

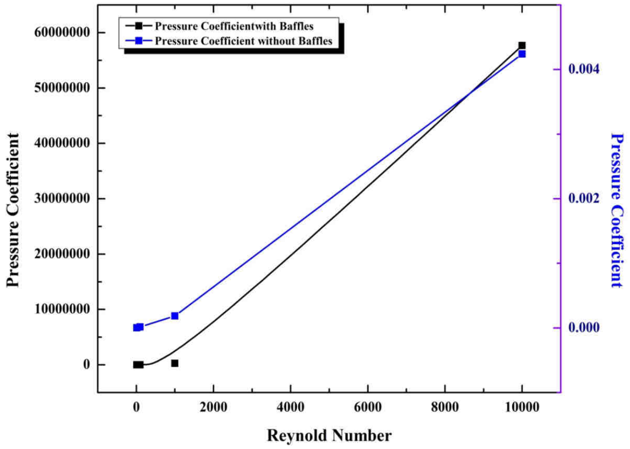

Fig. 18 Variation of Pressure Coefficient with respect to Reynolds Number

Figure 18 shows the Variation of Pressure Coefficient with respect to Reynolds Number. It has been observed that in increasing Reynolds number pressure coefficient significantly increases linearly. It has also seen that the pressure coefficient is more noteworthy for pipe with segmented baffles.

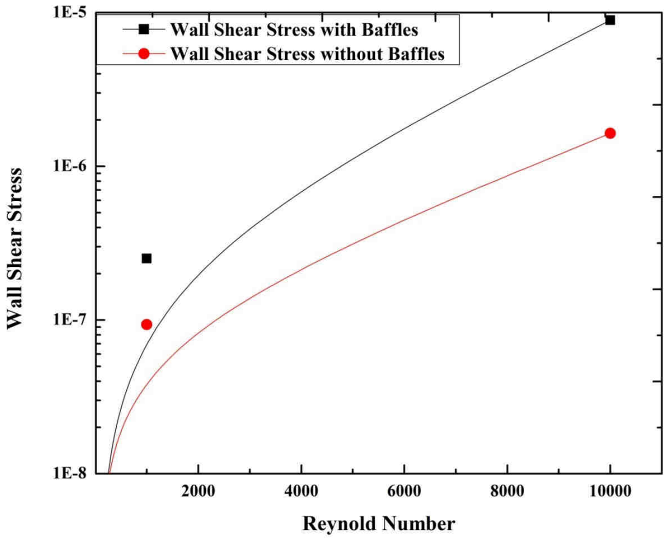

Fig. 19 Variation of Wall Shear Stress with respect to Reynolds Number

The Variation of Wall Shear Stress with respect to Reynolds Number has shown in figure 19. it has observed that shear stress across wall significantly increases are Reynolds number increases. This is due to increases in friction factor at high Reynolds number. Segmented baffles pipes has 4.443 times more in comparison with straight pipe.

Figure 20 shows the Variation of Skin Friction coefficient with respect to Reynolds Number. It has observed that skin friction increases as Reynolds number increases. This is due to presence of turbulence in flow leads to friction. Moreover, the trend of variation is same for straight and baffled pipe but in higher range.

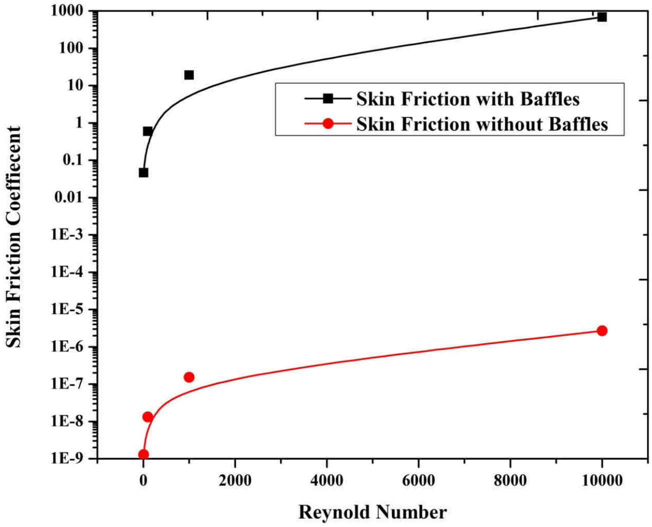

Fig. 20 Variation of Skin Friction coefficients with respect to Reynolds Number

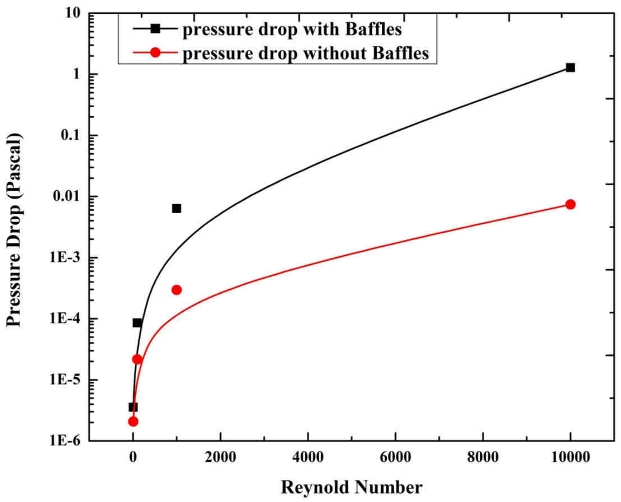

Fig. 21 Variation of Pressure Drop with respect to Reynolds Number

Figure 21 show the Variation of Pressure Drop with respect to Reynolds Number. It has observed that pressure drop raises as Reynolds number increases. This is due to presence of turbulence in flow. In existence of baffles the variation in pressure drop in 70.87% more in laminar regime and 17212.05 % in turbulent regime in comparison with straight pipe.

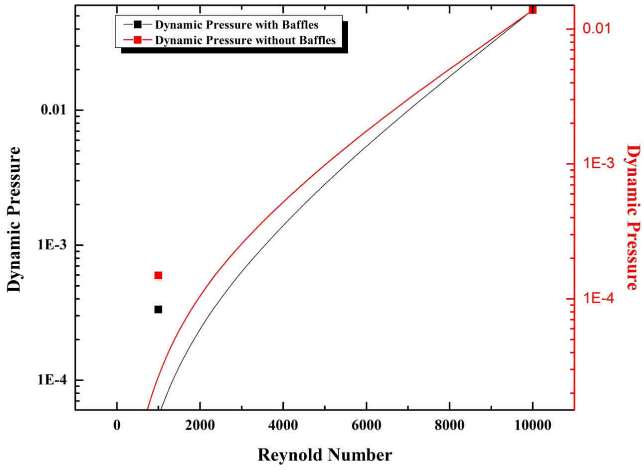

Fig. 22 Variation of Dynamic pressure with respect to Reynolds Number

Figure 22 shows the Variation of Dynamic pressure with respect to Reynolds Number. It has observed that on increasing Reynolds number the dynamic pressure increases gradually in comparison with straight pipe. At the variation is 24.54% and 301.53% more in baffles configuration for low and high Reynolds number. From this it can also be concluded that the variation in dynamic pressure also varies with Reynolds number for both pipes configuration.

VI. CONCLUSION

On implementing Segmented Baffles in pipe pressure drop significantly increases in comparison with straight pipe.Dynamic pressure goes increases as Reynolds number increases but on comparison with straight pipe dynamic pressure is more significant in baffled one.

Skin friction coefficient increases with increases in Reynolds number and in skin friction is more noteworthy in baffled pipe.

In laminar flow the presence of baffles creates turbulence.

On increasing Reynolds number turbulent intensity linearly increases.

On considering temperature affect the baffles gives advantages in improving thermo-hydrodynamic performance.

Wall shear stress drastically enhances more in baffled as Reynolds number increases.

Due to presence of turbulence in pipe friction factor linearly increases along with Reynolds number.

Integrating extended surface in pipe and ducts increases heat transfer characteristics as friction factor increases. Therefore it is widely been used in heat exchanger design.

REFERENCES

[1] J. W. Richman, R. S. Azad, “Developing turbulent flow in smooth pipes”, Applied Scientific Research, 1973, Volume 28, Issue 1, pp 419-441

[2] R. C. D. Lissenburg, J. O. Hinze, H. Leijdens, “An experimental investigation of the effect of a constriction on turbulent pipe flow”, Applied Scientific Research, December 1975, Volume 31, Issue 5, pp 343-362

[3] A.K.M.A. Quader, W.L. Wilkinson, “Correlation of turbulent flow rate-pressure drop data for non-newtonian solutions and slurries in pipes”, International Journal of Multiphase Flow, Volume 6, Issue 6, December 1980, Pages 553-561

[4] J. P. Hartnett, B. K. Rao, “Heat transfer and pressure drop for purely viscous non-Newtonian fluids in turbulent flow through rectangular passages”, Wärme - und Stoffübertragung, 1987, Volume 21, Issue 5, pp 261-267

[5] P. -A. Chevrin, H. L. Petrie, S. Deutsch, “The structure of Reynolds stress in the near-wall region of a fully developed turbulent pipe flow”, Experiments in Fluids, October 1992, Volume 13, Issue 6, pp 405-413

[6] R. J. van der Linden, C. J. Hoogendoorn, "Transients in flow and local heat transfer due to a pressure wave in pipe flow", Applied Scientific Research, June 1994, Volume 52, Issue 4, pp 371-399

[7] M. A. Habib, S. A. M. Said, A. A. Al-Farayedhi, S. A. Al-Dini, A. Asghar, S. A. Gbadebo, "Heat transfer characteristics of pulsated turbulent pipe flow", Heat and Mass Transfer, February 1999, Volume 34, Issue 5, pp 413-421

[8] A. A. Pavelyev, A. I. Reshmin, S. Kh. Teplovodskii, S. G. Fedoseev, "On the Lower Critical Reynolds Number for Flow in a Circular Pipe", Fluid Dynamics, July 2003, Volume 38, Issue 4, pp 545-551

[9] S. Galinat, O. Masbernat, P. Guiraud, C. Dalmazzone, C. Noı¨k, "Drop break-up in turbulent pipe flow downstream of a restriction", Chemical Engineering Science, Volume 60, Issue 23, December 2005, Pages 6511-6528

[10] Ahmet Tandiroglu, "Effect of flow geometry parameters on transient entropy generation for turbulent flow in circular tube with baffle inserts", Energy Conversion and Management, Volume 48, Issue 3, March 2007, Pages 898-906

[11] Pongjet Promvonge, "Heat transfer and pressure drop in a channel with multiple 60° V-baffles", International Communications in Heat and Mass Transfer, Volume 37, Issue 7, August 2010, Pages 835-840

[12] Jim McGovern, "Technical Note: Friction Factor Diagrams for Pipe Flow, Dublin Institute of Technology ARROW@DIT

[13] Katsuhide Ohira, Kei Nakagomi, Norifumi Takahashi, "Pressure-drop reduction and heat-transfer deterioration of slush nitrogen in horizontal pipe flow," Cryogenics, Volume 51, Issue 10, October 2011, Pages 563-574

[14] Changwoo Kang, Kyung-Soo Yang, "Flow instability in baffled channel flow", International Journal of Heat and Fluid Flow, Volume 38, December 2012, Pages 40-49

[15] George K. El Khoury, Philipp Schlatter, Azad Noorani, Paul F. Fischer, Geert Brethouwer, Arne V. Johansson, "Direct Numerical Simulation of Turbulent Pipe Flow at Moderately High Reynolds Numbers" Flow, Turbulence and Combustion, October 2013, Volume 91, Issue 3, pp 475-495, Date: 10 Jul 2013

[16] Muhammad Ahsan, "Numerical analysis of friction factor for a fully developed turbulent flow using keε turbulence model with enhanced wall treatment", beni-suef university journal of basic and applied sciences xxx (2014) 1e9

[17] Idowu T. Dosunmu, Subhash N. Shah, "Turbulent flow behavior of surfactant solutions in straight pipes", Journal of Petroleum Science and Engineering, Volume 124, December 2014, Pages 323-330

[18] Wenbin Tu, Yong Tang, Bo Zhou, Longsheng Lu, "Experimental studies on heat transfer and friction factor characteristics of turbulent flow through a circular tube with small pipe inserts", International Communications in Heat and Mass Transfer, Volume 56, August 2014, Pages 1-7

[19] Shinji Tamano, Hiroki Ikarashi, Yohei Morinishi, Keijiro Taga, "Drag reduction and degradation of nonionic surfactant solutions with organic acid in turbulent pipe flow", Journal of Non-Newtonian Fluid Mechanics, Volume 215, January 2015, Pages 1-7

[20] Lewis F. Moody. Friction factors for pipe flow. Transactions of the A.S.M.E., pages 671–684, November 1944