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Characteristics of Gas Flow through Bend Pipes of Different Angles

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Abstract: *Pipelines are used to convey fluid materials not only in the industrial process but also in the place of residence and agriculture. Pipes are simple and convenient to use. But the numerical modeling and estimation of flows inside pipes is challenging. Due to this, the investigation of flow behaviors of fluid through pipes is absolutely fascinating for researchers. We have met with various pipe flow analysis at the literature which have been conducted with laboratory experimental techniques. Bend pipe is often used in pipe line transportation, fluid flow velocity and pressure change dramatically when passing through the bend pipe, therefore the bend pipe influences the efficiency of pipeline transportation. In this study, we have taken different bend pipes of different angles with constant diameter and length for geometry. Steady, laminar and fully developed flow with no-slip wall condition has been solved applying control volume technique using ANSYS FLUENT. Water vapor is used as working fluid with the assumption that the fluid is continuum. The continuity equation and Navier-Stokes equations are solved. The results obtained from our simulations agree with the results published in literature. The aim of the simulations is to investigate the behavior of the pressure and the velocity distributions in different sizes of bend pipes. Our results show a change of the pressure and the velocity distributions in different bend pipes for the same boundary conditions.*

Keywords: *No-slip conditions, Reynolds number, Steady, Laminar, incompressible, CFD simulation, bend pipe, FLUENT.*

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I. Introduction

A comprehensive understanding of good pipe design and pipe line arrangement is essential for this process. Also these analyses are costly and lengthy. The flow in complex pipe system is impossible to solve analytically. This is where the computational approach needs which reduces time, costs in design phases and bears useful results. The useful results and information can be used against pipes corrosion and erosion or for the optimization of pipes design in the manufacturing processes. In order to transport fluid to the desired delivery position, bends are frequently used to change the direction of a pipe. A bend will always be considered with relation to the straight pipes connected to its two ends. These straight pipes are long due to stabilize the fluid downstream of bends. The bend pipes are most important part of any pipeline network system as these provide flexibility in routing. The bend pipes in 90 degree perhaps the most frequently used fitting in piping systems. Within research, the bend pipes analysis or the simulation approach has great significance in understanding and improving fluid flow performance and minimizing their losses.

Several researchers have approached the analyses of laminar flow with different views. Soundalgekar et al. [1], analyzed laminar flow in bend pipes by perturbation theory, in which flow parameters such as axial and radial velocity profile, skin friction, axial pressure and mass flow were considered. They discovered that skin friction decreases with increase in pressure gradient, while the mass flow increases with increase in pressure drop and flows inside bend pipes high interest presents the prediction or localization of corrosion and erosion where important numerical approaches are presented giving much information for the velocity and pressure distribution.

Toda et al.[14] experimentally determined the pressure drop over a length of 5.0 m including the bend pipe either in horizontal plane or vertical upward plane for the flow of glass beads of diameter 0.5–2.0 mm and polystyrene of diameter 1.0 mm, separately, using water as the carrier fluid. The four 90 degree bend pipes studied had R/r of 0, 2.4, 4.8 and 9.6, where r is the pipe radius and R is the bend radius. For the bend in horizontal plane, they observed the sand particles move up along the inside wall at low velocity, while in straight pipe the flow is a sliding bed. They also found that even when a stationary bed was formed on the bottom of straight pipe, almost all particles were suspended in the bend pipe. At higher velocities, they observed that the particles were forced towards the outer wall as a result of centrifugal forces generated in the bend. For bends in vertical plane, they observed that almost all the particles were travelling along the outside of the bend pipe. The solids were re-distributed downstream of the bend, the distance increasing with increase in velocity. Some researchers have discussed the pressure drop caused by a bend based on the experimental or simulation results. They constructed some models to predict the pressure drop for engineering design.

The objective of this paper is to investigate the pressure drop and the fluid flow properties in different bend pipes of different angles with constant diameter and length for geometry and we observed that the less 90 degree bend pipe is more useful to convey fluid than 90 degree and greater 90 degree bend pipes.

II. Model Development

Problem Statement: We considered water vapor flow through the bend pipes in Cartesian coordinates systems. Fig.1 shows the geometry and coordinates of the bend pipes.

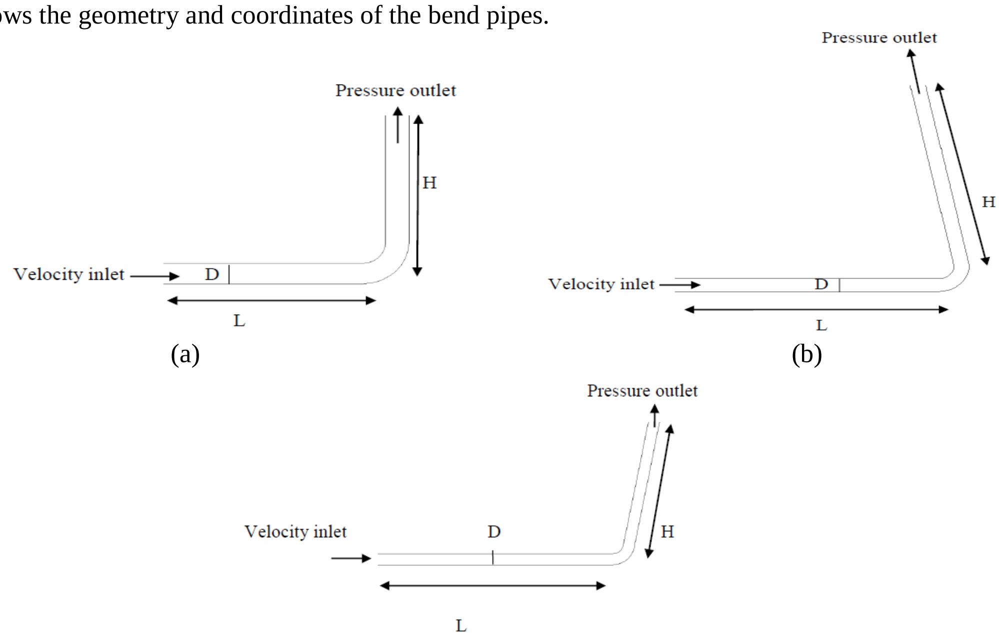

Figure.1: 1(a) 90 degree bend pipe 1(b) Greater 90 degree bend pipe (G90)
1(c) Less 90 degree bend pipe (L90)

Where $L = 1500$ mm (1.500 m) and H =500 mm (0.500 m) are the length and height of the bend pipes and $D = 2$ mm is the constant diameter of the bend pipes .A number of investigations are performed with no slip boundary conditions on the walls. This model geometry constructed by using Gambit 2.2.30 component of the Fluent package as shown in the above figures. The meshing is scheme is composed of elements and type.
The elements selected were quadrilateral defines the shape of the element used to mesh and the type parameter defines the meshing algorithm which in our case was pave. After the geometry is successfully meshed, the zone types are specified. A mesh file is exported for use in Fluent 6.3.26.
Governing Equations: The 2D water vapor flow is assumed to be steady and laminar. The two basic laws of conservation of mass or continuity equation and Navier-Stokes equations are solved for incompressible flows for Newtonian fluid. The incompressible forms of the governing equations are expressed in following forms. The equation of conservation of mass or continuity equation can be expressed as:
The continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

The Navier-Stokes equations:

$$\rho(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \rho g_x \tag{2}$$

$$\rho(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \rho g_y \tag{3}$$

Where $\rho$is the density of the fluid and u , v are the x and y velocity components of the flow field and p is the pressure andρg_x and $\rho g_y$are the gravitational body forces (per unit volume) acting on the fluid.

Boundary Conditions: Boundary conditions were specified at the inlet, outlet and no-slip boundary condition is implied on the walls. As inlet boundary condition the initial velocity ($v = 1$ m/s) of the pipe were specified. The static pressure at the outlet was set 0 Pa and the other settings that have been made are compiled in table 2.

Table no. 1: Material specific settings

Material	Water-vapor
Density(kg/m^3)	0.5542
Specific heat at constant pressure (J/kg-k)	2014
Conductivity K(w/m-k)	0.0261
Fluid viscosity (kg/m-s)	1.34×10^{-5}

Numerical Method: The control volume method is used to discretize the governing equations. FLUENT solves the governing equations for continuity and Navier-Stokes equations in order to obtain the velocity filed .To do this control volume based technique is used .The pressure based solver was used due to modeling of laminar flow. The continuity and Navier-Stokes equations are solved with first order up-wind scheme to interpolate the corresponding cell center variables to the faces of the cells. For the pressure-velocity coupling The SIMPLE (Semi – Implicit Method for Pressure-Linked Equations) algorithm was used for introducing velocity and pressure into continuity and Navier-Stokes equations. The computation are considered to be converged when the residues for continuity and momentum are less than 10^{-6}.

Grid dependency Test: To evaluate the grid size effect, grid dependency tests are carried out. Three different sizes of grid 10×2000, 20×4000 and 40×8000 are tested for bend pipes and laminar flow with no slip boundary conditions and the results are listed in the following table. The table shows that the difference of average velocity at outlet for grid sizes 10×2000, 20×4000 and 40×8000 respectively. For convenience, we used grid size 20×4000.

Table no.2: Grid dependency test of the average velocity under three sizes of grids.

Grid size	Average velocity
10×2000	0.992931
20×4000	0.9923801
40×8000	0.9987421

Validity and Verification: To valid our model, we simulated 2D steady, laminar flow through 90 degree bend pipe with the boundary conditions as was done by Christina G. Georgantopoulou et al. [20]. We compared velocity distribution with that of Christina G. Georgantopoulou et al. [20] along the vertical line at $x = 4$ m and $y = 0$ to 0.7620 m. The results are displayed in figure.2. The square symbols represents the Christina G. Georgantopoulou et al. [20] results and the solid line represents the results from current work. The results show good agreement which validate our model.

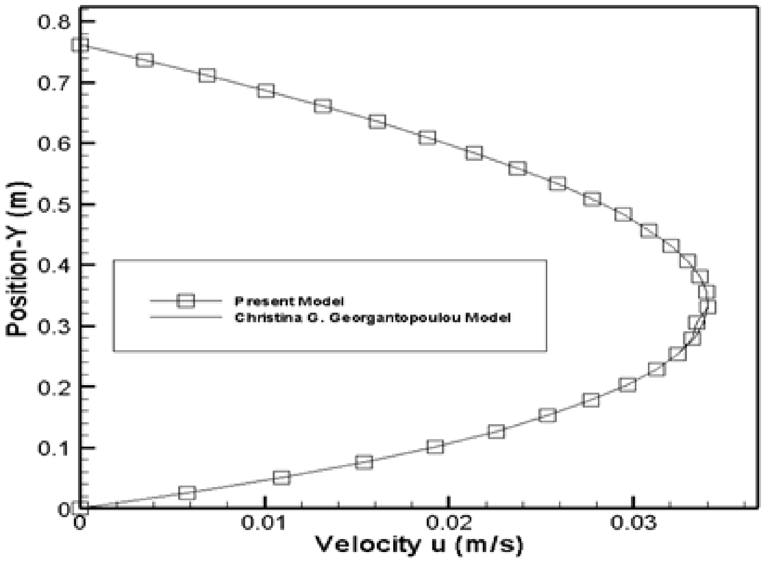

Figure.2: The velocity distributions along the vertical line at $y = 0$ to 0.7620 m.

III. Result and Discussion

In this section, the effect of bend on flow properties have been illustrated for the less 90 degree bend pipe case as well as 90 degree bend pipe case and greater 90 degree bend pipe case respectively.

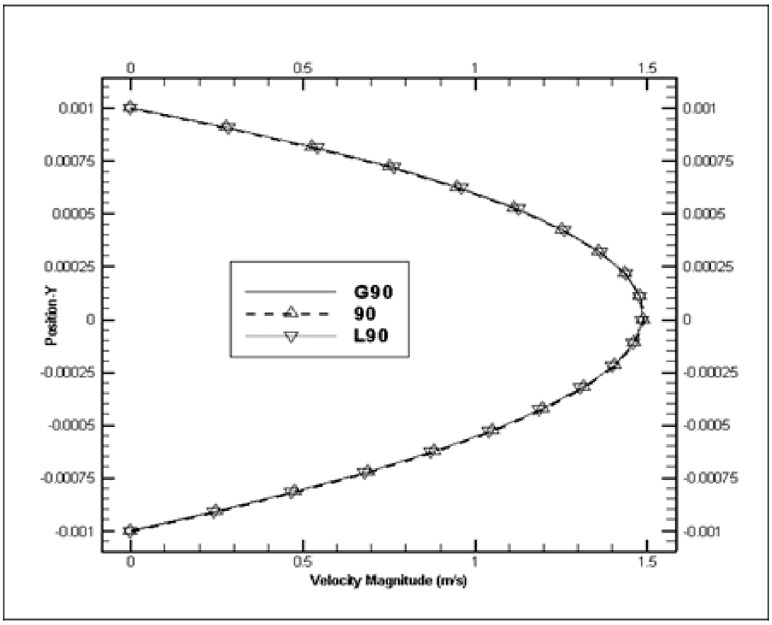

Figure.3: Velocity distribution along the vertical line at x=1.494m

A comparison of velocity distribution for the three cases is shown in figure.3. The velocity distribution is taken along the vertical line at $x = 1.494$ m for the three cases respectively. Since the peek position is in the horizontal section of pipe and far from the bend so the velocity profiles are the same for all the three cases. For this figure.3 depicts an equal magnitude of velocity profile for the three cases.

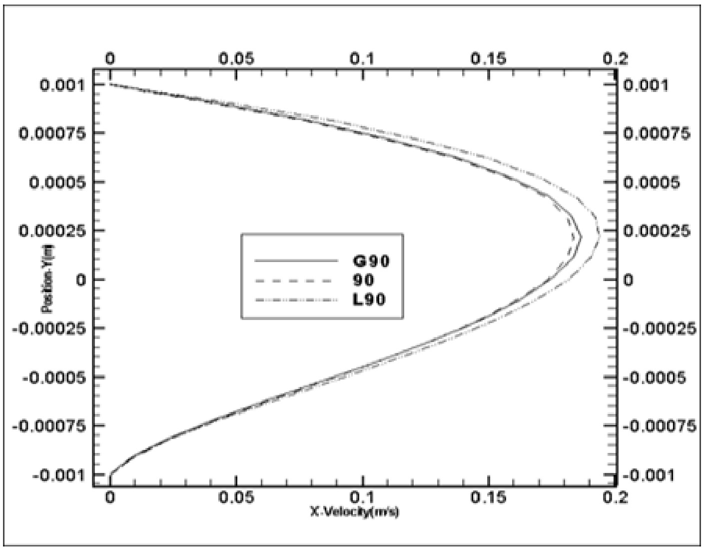

Figure.4: Velocity distribution along the vertical line at $x = 1.494$ m

Figure.4 shows a comparison of velocity distribution along the vertical line at $x = 1.494$ m, after that bend starts, for the three cases. Here we observe that unlike the result discussed above, the velocity through the pipe with bend less than 90 degree is the highest but for the other two cases the velocity profiles are almost the same. It is because for the case with bend 90 degree and greater 90 degree, there are stagnation points where the velocity is zero and at that position the flow changes its direction through the upward section of the pipe. But in case of with bend less than 90 degree, the flow changes it direction with an angle less than that of the other cases. Also there is no stagnation point. Consequently, the velocity of flow through the pipe with bend less than 90 degree is the highest.

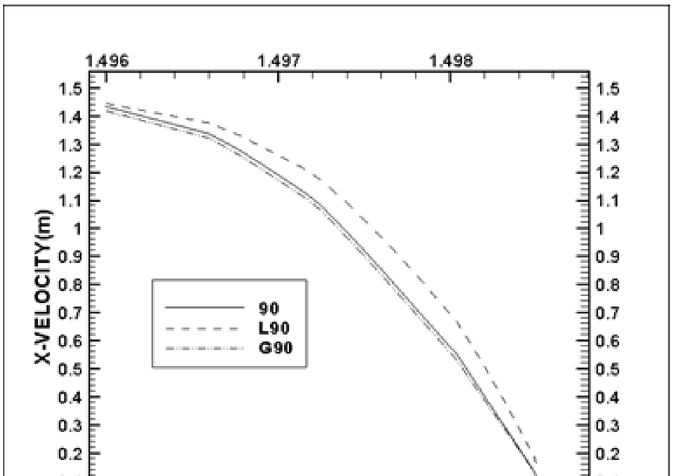

Figure.5: Velocity distribution along the horizontal line at x=1.496m to x=1.4985m

Figure.5 presents the comparison of velocity distribution along the downstream direction ranges from x=1.496m to x=1.4985m, positioned within the bend, for the three cases. Here we see that the velocity through the pipe with bend less than 90 degree is the highest than other two cases. Because when fluid flow through bend pipes they find wall in front of it in the right side in the case of 90 degree bend pipe and greater 90 degree bend pipe and also for the case with bend 90 degree and greater 90 degree, there are stagnation points and at that position the flow changes its direction through the upward section of the pipe. So the velocity components interact with wall and lose values. But when fluid flow through less 90 degree bend pipe, the flow changes it direction with an angle less than that of the other cases. Also there is no stagnation point. Therefore, the velocity of flow through the pipe with bend less than 90 degree is the highest.

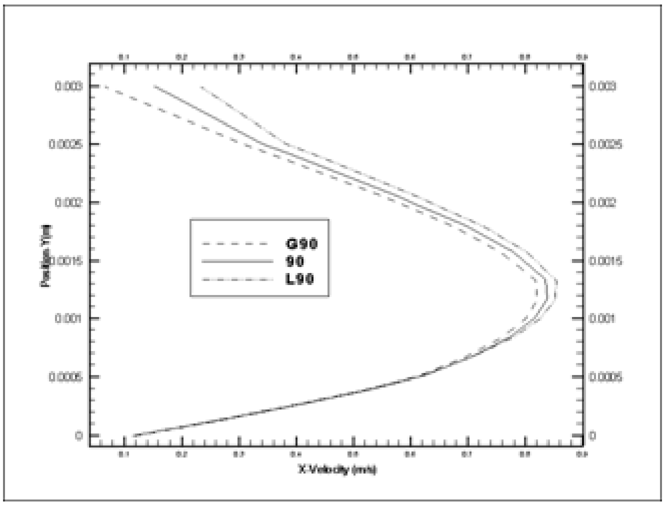

Figure.6: Comparison of velocity distribution along the vertical line within the bend.

Figure.6 reveals the assimilation of velocity profiles along the vertical line ranges from y=0 to y=0.003m, positioned in the bend, for the less 90 degree case as well as the 90 degree and the greater 90 degree bend pipe cases respectively. A discordant of flow profile is visible in this figure. The reason is that fluid changes its velocity direction rapidly when fluid flow through the bending section. There must be a force acting inwards on the fluid to provide the inward acceleration which leads to cause the change of flow direction. Also the pipes contain different vertically positioned sections so the elevation must influence the changes of velocity direction. Since the bend section of less 90 degree bend pipe is small so the velocity is greater for this case compared with the other cases.

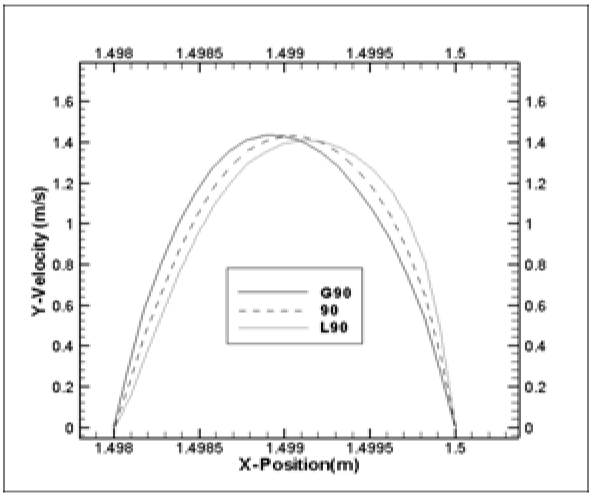

Figure.7: Velocity comparisons for the three cases along the horizontal line after the bend.

In figure.7 a comparison of velocity profile after the bend section for the three cases. The velocity is picked along the downstream direction on the line ranges from x=1.498m to x=1.500m which is located after the bend for the three cases. This figure exhibits that the assimilation velocity profiles are met at the point y=1.499m. Before that, in the case of grater 90 degree, velocity initially increase near the left wall of the pipe since there is no stagnation point and then decreases as fluid moves towards the right wall of the pipe for stagnation point where the velocity is zero and at that position the flow changes its direction through the upward section of the pipe. But in the case of less 90 degree bend pipe, velocity initially decreases near the left wall of the pipe since there is stagnation and then increases as fluid moves towards the right wall of the pipe since there is no stagnation point. The 90 degree case has tried to equalize the velocity profile between the left and right wall of the pipe. The reason for this is the bend angle of the pipes. In the 90 degree bend pipe case, the bend is gentle so the fluid flows more easily through the vertical section of pipe. The mean velocity at that positions are

1.013m/s, 1.009m/s and 1.008m/s for the less 90 degree case as well as the 90 degree and the greater 90 degree bend pipe respectively.

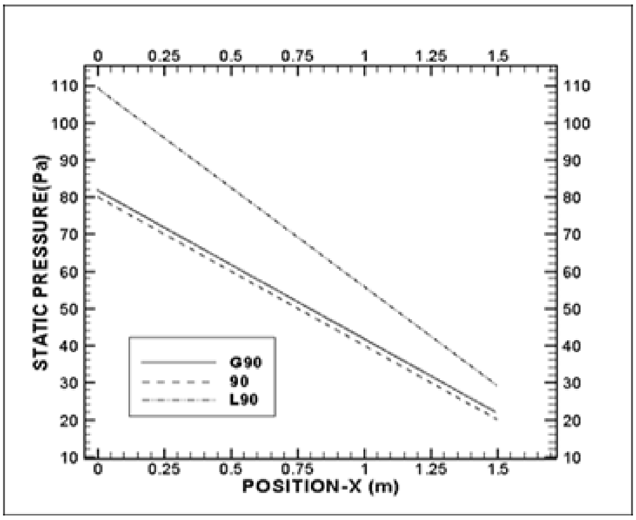

Figure.8: Comparison of static pressure distribution along the horizontal line for the three cases.

The comparison of pressure distribution among three cases is shown by figure.8. The static pressure distribution is taken along the downstream for the three cases ranges from x=0 to x=1.4985m.
The above figure shows that the hightest static pressure is produced with the inlet and gradually decreases with respect to position. Less 90 degree bend pipe case has high pressure in the initial region compared to the other cases. This is due to the impact of the bend angle of the pipe. Since less 90 degree bend pipe has increased of velocity along the pathlines so it must decrease pressure with respect to position.

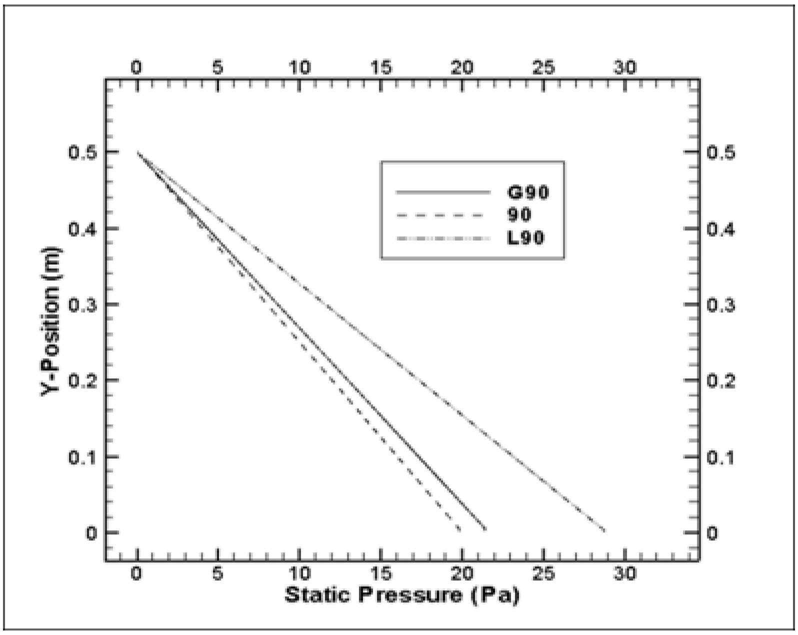

Figure.9: Comparison of static pressure along the vertical line among the three cases.

A comparison of static pressure distribution among the three cases is revealed by figure.9. The pressure distribution is picked along the vertical section of the pipe ranges between y=0 to y=0.500m. The figure gives a decrease of pressure distribution along the vertical section of the pipe. The reason behind this is that when fluid changes its direction of flow through bend there acts an inward force to cause the direction change. The impact of this force will change with elevation. Since the pick pressure belongs to three different vertically inclined pipes so impact of this force will give three different scenario of pressure drop. There is a greater pressure in the bend region for the less 90 degree case which is gradually decreased with the change of direction of flow compared to the other cases.

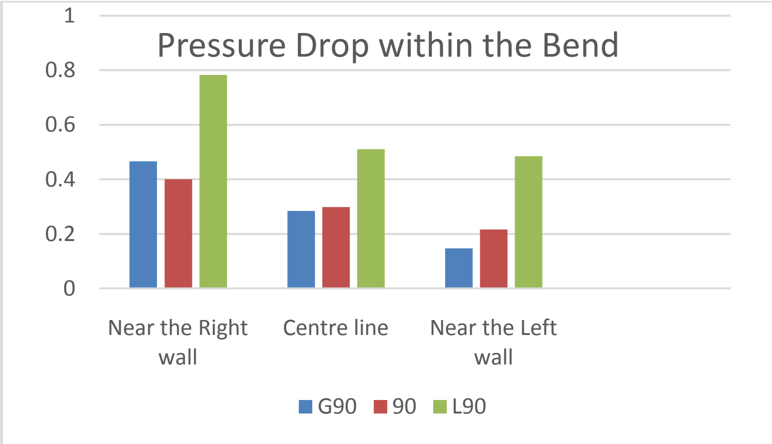

Figure.10: Pressure drop comparison along the bend among the three cases.

Figure.10 represents the comparison of pressure drop within the bend region among the three cases. The pressure drop is taken in three different positions namely near the inner wall as well as middle line and near the outer wall within the bend region for the three cases respectively. It is shown by this figure that the pressure drop in the left side of bending section is greater for the case of grater 90 degree case where as the pressure drop in the right side of bending section is greater for the case of less 90 degree case. The less 90 degree bend pipe gives larger amount of pressure drop within the bend region compared to the other cases. The greater the velocity produces a greater pressure drop across the less 90 degree bend pipe.Table-1 shows the amount of pressure drop due to the bend and the outlet mean velocity for the less 90 degree case as well as 90 degree case and grater 90 degree bend pipe case.

Table no.3: Pressure drop and outlet velocity for the three cases.

	Pressure drop (Pa)	Outlet velocity (m/s)
Less 90 degree bend pipe	108.8700656	1.0191868
90 degree bend pipe	79.73142622	0.999987
Greater 90 degree bend pipe	81.3831892	1.0188967

It is observed from the table that less 90 degree bend pipe has large amount of pressure loss. The pressure losses due to the bend angle of the pipe. The bends of pipe are responsible for momentum exchange resulting from a change in the direction of flow. Since less 90 degree bend pipe has small bend so it produces more pressure drop along the pipe.

IV. Conclusion

From the above discussion we observed that for the same boundary conditions, the magnitude of velocity and pressure drop of less 90 degree bend pipe is greater than the 90 degree and greater 90 degree bend pipe. Less 90 degree bend pipe case has the highest pressure in the inlet region compared to other cases. This is due to the bend angle of the pipe. For this reason we can say that less 90 degree bend pipe is more useful to convey fluid than the 90 degree and greater 90 degree bend pipes. The present findings may be useful to understand the flow behavior inside the bend pipes at any pumping stations or water refineries.

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