Design of a Pipeline Leakage Detection System

Maidala. A Y, Odujoko A.O., Sadjere E.G., Ariavie G.O

Department of Mechanical Engineering, University of Benin, Nigeria

Abstract— *Pipeline leakage has both economical and environmental effect. This research work is aimed at the design of a pipeline leakage detection system. In this research work, pressure analysis and K-epsilon turbulence model is one of the common turbulence models used by star CCM+ in resolving fluid flow and is used in this simulation. The parameters used were velocity of fluid (crude oil and gas) and pressure. Different velocities (5m/s, 20m/s, etc.) were used to determined increase or drop pressure. The results from the research work show that excessive drop in pressure is as a result of pipeline leakage and this is mostly likely to occur at the highest bent in the pipeline.*

Keywords—Pipeline leakage, Star CCM+, Pressure and Simulation.

I. INTRODUCTION

Hydrocarbons (CH), is a very important sources of energy and it is produced from oil or gas reservoirs. It comprises of carbon and it compound and it is main sources of crude oil. Even inintermediate processing of these hydrocarbons until they are present in useable form, there is requirement for atleast one or two unit operations. The operations will require connections with one another through the aids ofpipelines. Pipelines are media required for the transportation of crude oil from reservoir, wellbore and otherstations to be delivered to destination point such as separator, storage tanks etc.Over time in operation, these pipelines due to ageing, corrosion and wear, design faults, operationoutside design limit or deliberate damage in act of vandalism etc. are caused to leak (Teal, 2003). Considering the vast mileage ofpipelines throughout the nation, it is vital that dependable leak detection systems are used to promptlyidentify when a leak has occurred so that appropriate response actions are initiated quickly. The swiftness ofthese actions can help reduce the consequences of accidents or incidents to the public, environment, and facilities.

Leak detection systems capable of locating the position of the leak are obviously of an environmental kind. Considering the environment of oil spillage, the hazard of gas leakage, pipeline detection system design cannot be neglected. Butthe economical aspect of it is also important. In fact, pipeline leaks are also frequent problems to the producersand transporters of these hydrocarbons and failure to detect it can result in loss of life and facilities, direct cost ofloss product and lie downtime, environmental cleanup cost and possible fines and legal suits from habitants.Various leak detection systems including both the hardware- and software- based methods are beingemployed by pipeline operators are in existence (Zhang, 1997; Wang et al., 2001; Theakston and Larnaes 2002; Liu et al. 2005;Batzias et al., 2011) and also biological based detection method. Of the hardware-based methods is the use ofacoustics, fiber optics, ultrasonics, infrared radiometrics, vapour or liquid sensing tubes, and cable sensors, whilemass/volume balance, transient modeling, statistical/hypothetical analysis, and pressure analysis are examples ofsoftware-based methods. By software-based detection methods, the leak is identified as a result of severaldetectable effects in terms of fluctuations in the monitoring pressures and/or flow rates (Mastandrea et al. 1990;Bonn 1998). Figure 1.1 shows classification of oil/gas Leak detection systems based on their technical nature.

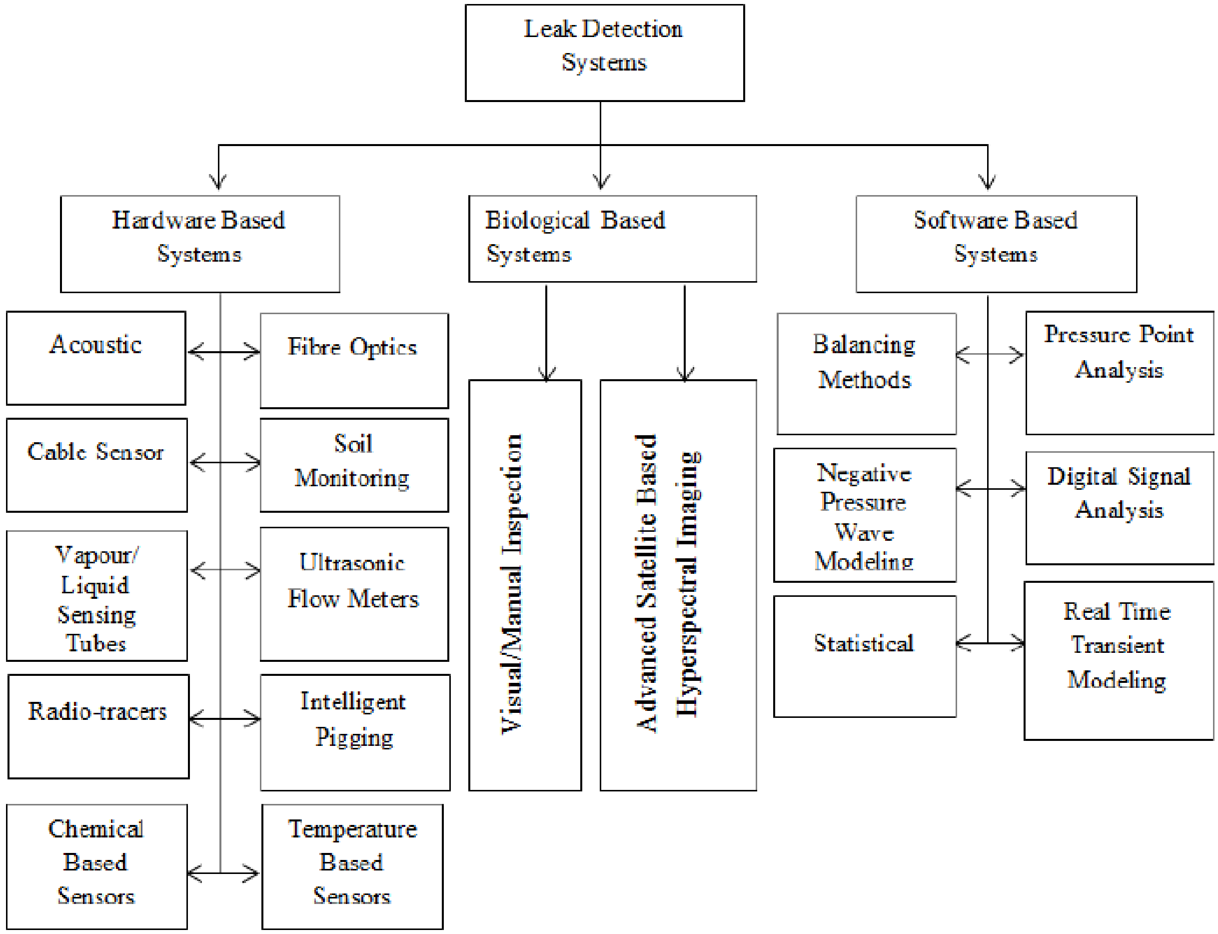

Fig.1.1:Classification of oil/gas Leak detection systems based on their technical nature

In this research work, pressure point analysis and K-epsilon turbulence model software will be used to model pipeline leakage detection system. The K-epsilon turbulence model is one of the common turbulence models used by Star CCM+ in resolving turbulent flow and is used in this simulation. The model is recommended for use for flows that assume net zero heat transfer but variation in pressure (Cenjel, et al., 2012; Adapco, 2013). The letter “k” is the turbulent kinetic energy while ε is the rate of dispersion of the turbulent energy. K- Epsilon model resolves turbulence by finding the amount of kinetic energy per unit mass present in the turbulent fluctuations (Barati 2012; Scott-Pomerantz 2004). Table 1.1 shows the Star CCM+ Parameters used for the analysis.

II. RESEARCH METHODOLOGY

Table 2.1 shows the Star CCM+ Parameters used for the analysis.

Table.2.1: Star CCM+ Parameters used for the analysis (Janna 1993; Scott-Pomerantz 2004; Barati 2012)

	Parameter/Menu choice	**Selection/ Value Inputted**
Mesh Selection	Mesh type	Trimmer (for Volume Mesh); Surface Remesher (Surface mesh); Prism Layer Mesh (For the prism layer)
	Base size	15 mm
	Prism Layer thickness	Equal to the Boundary layer thickness for the given velocity
	Number of layers	20
	Prism layer stretching	1
Physics	Space	2D flow

Selection	Time	Steady
	Material	Gas
	Flow	Segregated flow
	Equation of State	Constant density
	Viscous Regime	Turbulent
	Reynolds-Averaged Turbulence	K-epsilon
Boundary condition selection	Inlet	Inlet Velocity
	Outlet	Outlet Pressure
	Wall	Wall
	Turbulent Intensity	10%
	Turbulence Specification	Intensity + Length scale
	Turbulent length scale	7% of the Hydraulic diameter
	Turbulent velocity scale	5% of the free steam velocity
	Temperature	293K
	Wall condition	No-slip

The pipeline was analyzed with fluid flow in a given duct to determine flow parameters and characteristics. The analysis was done in 2D using CFD package-Star CCM+ software. In general, flow in a two dimensional plane is considered as a special case of a 3D if the geometry is symmetrical in one coordinate (Jiyuan et al 2005). Experiments have shown that 2D models give a very close approximation to 3D model for symmetrical model (Ekambara et al 2005).It has the following steps:

i. Creation of the model in 3D (Figure 2.1). This could be done in star CCM+ or with CAE software and then imported to Star CCM+. Since the given model has a simple geometry, it was drawn in Star CCM+
ii. The 3D model was then converted to part; follow by assigning of regions to parts (Figure 2.2).

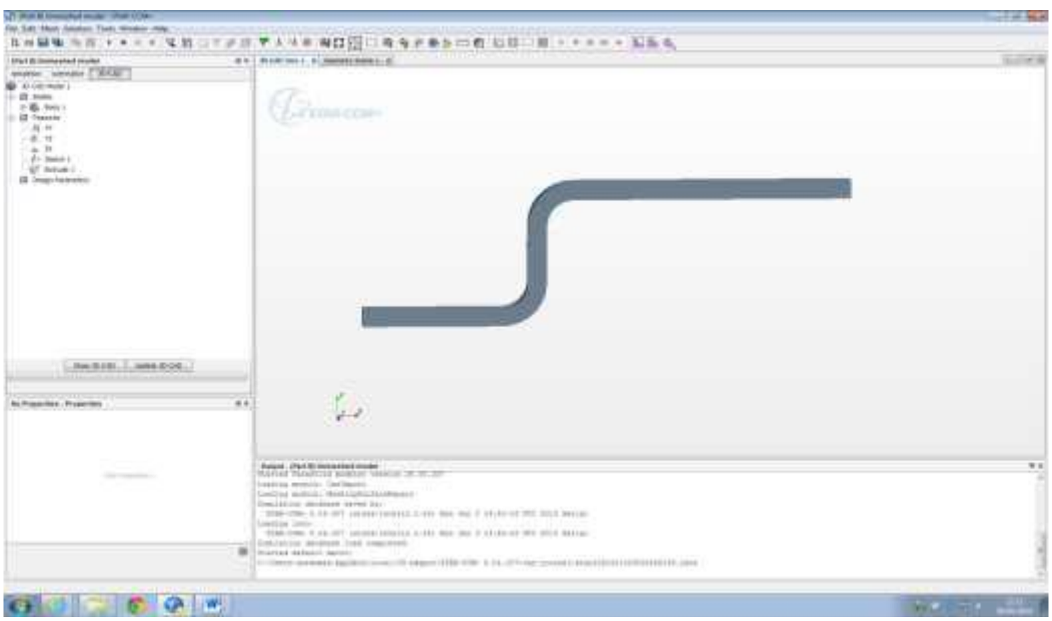

Fig.2.1: Creating the geometry in 3D

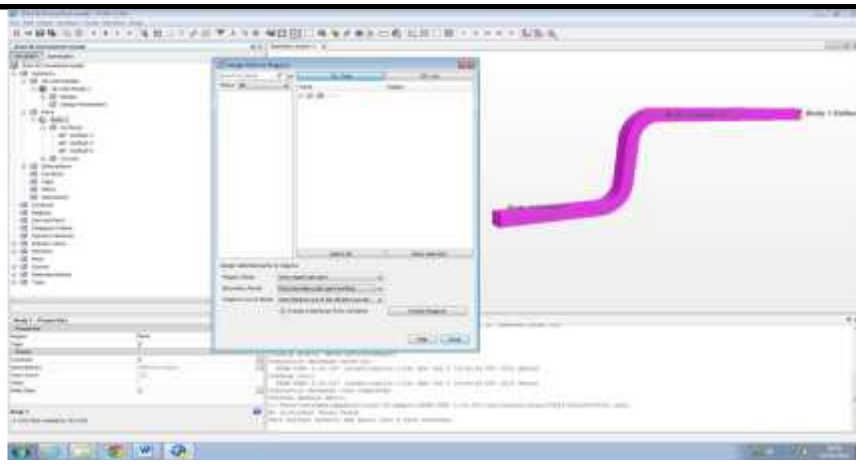

Fig.2.2: Creating the geometry in 3D

iii. The model was then meshed and converted to 2D.

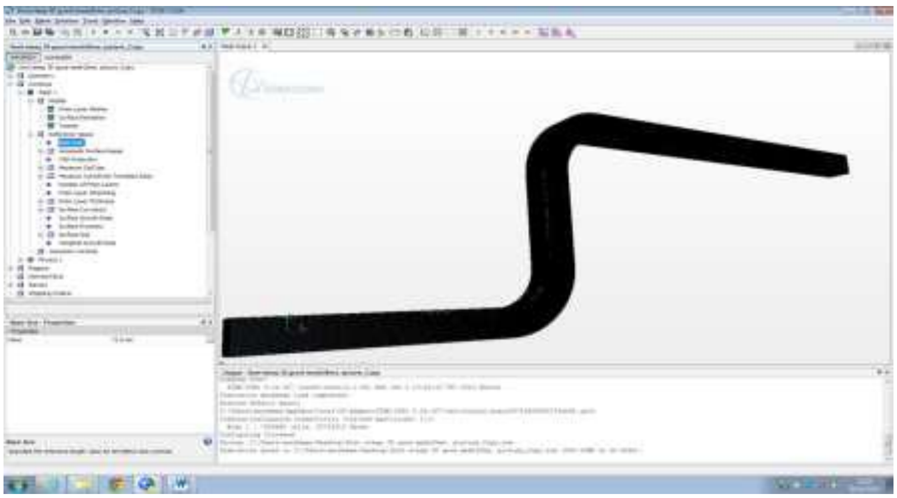

Fig.2.3: Creation of 3D mesh

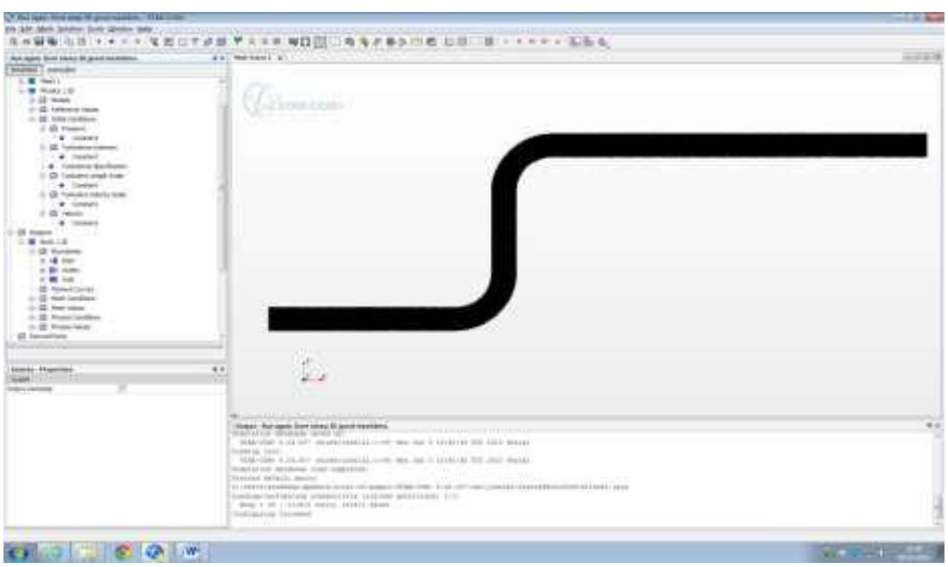

Fig.2.4: Converting 3D mesh to 2D mesh

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iv. The next step was setup the physics for the simulation after which the boundary conditions were specified.

v. Running of simulation and post –processing in which the result obtained was analyze

A number of iterations were done until convergence was achieved. Analysis in CFD is affected by the number of grid points (cells) generated to solve the computation. The number of cell generated is a function of the mesh size. Generally, as the number of cells is increased, the results obtained become more accurate while the computational time increases also. However as the mesh size is made finer and the number of cells increased, a point is reached when the results obtained is not or is marginally affected by the mesh size. At the point the mesh is said to have converged. The results obtained at this point are usually taken as the solution of the computation. Due to the length of time required to obtain solutions using fine mesh, initial analyses were done using coarse mesh. The mesh size was gradually refined until convergence was achieved. Another important parameter which affects the result obtained from the simulation is the number of iteration to convergence. The iteration steps were increased until the results obtained are stabilized(i.e.when the results no longer change with time).

III. RESULTS AND DISCUSSION

Table 3.1 shows the result of mesh convergence study at 20m/s. With a velocity of 20m/s, the solution was found to convergence at a mesh size of 15mm. At that speed of movement of fluid inside the pipeline, pressure drop is taken note of. A drop in pressure is as result of leakage along the pipeline.

Table.3.1: Mesh convergence study at 20m/s

Mesh Size (mm)	Number of Cells (2D)	Total inlet Pressure (Pa)	Inlet Static pressure (Pa)	Max. Mass flow rate at the inlet (Kg/s)	Number of steps taken to stabilize
50	69633	1797.693	143.6292	9.6	2600
40	85628	371.0221	131.0221	9.6	2800
20	105498	399.6862	159.6862	9.6	3000
15	105646	389.2385	149.2442	9.6	2200
10	105646	389.2442	149.2385	9.6	2800

This mesh size was therefore used to run the analysis for other velocity (5m/s, 10m/s, and 40m/s,) cases, and the following boundary conditions were obtained (Table 3.2).

Table.3.2: Boundary conditions obtained after the analysis for the respective velocities.

Inlet Velocity (m/s)	Outlet Velocity (m/s)	Mass Flow rate(Inlet) (kg/s)	Mass Flow rate Inlet) (kg/s)	Static Inlet Pressure (Pa)	Static Outlet Pressure (Pa)	Total Inlet pressure (pa)	Total Outlet Pressure (pa)
5	5.32	2.4	2.4	5.93	0	20.94	17.03
10	10.54	4.8	4.8	21.90	0	81.91	66.67
20	20.91	9.6	9.6	81.58	0	321.58	263.87
40	41.40	1.92	1.92	285.66	0	1245.66	1041.12

Figure 3.1and 3.2 show the plot of total pressure for 20m/s velocity and 40m/s velocity.

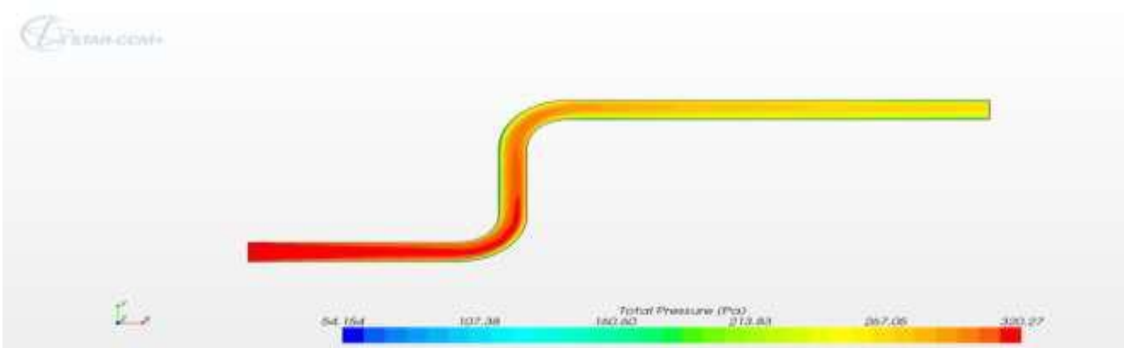

Fig.3.1: plot of total pressure for 20mls

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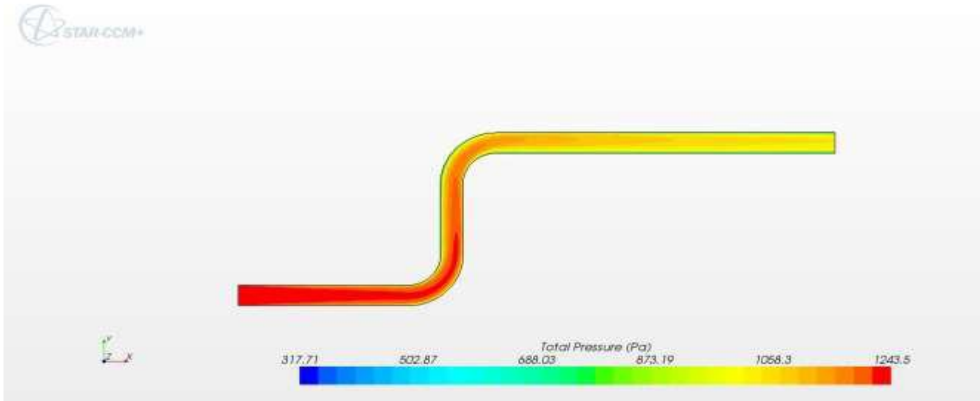
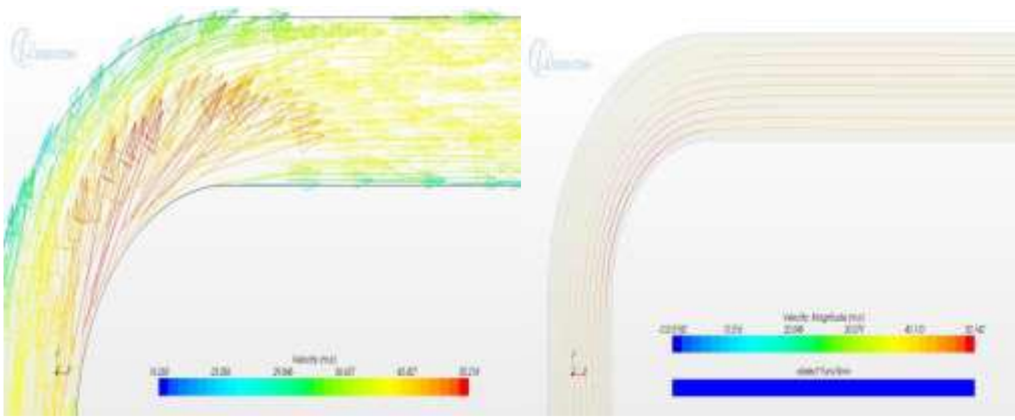


Fig.3.2: Plot of total pressure for 40m/s

Figure 3.3 shows the magnified velocity vector and streamline plots for 40m/s. It can be seen that there was no separation at the bends. The same was observed for other velocities (5m/s, 10m/s, and 20m/s).



(a) (b)

Fig.3.3: Magnified vector plot scene (a) and streamline plot (b) at one of the bends showing that no separation occurred at 40m/s

Figure 3.4 shows that the velocities around the bends are the greatest, and this can be explained by the law of conservation of mass. The bend restricts the movement of the fluid coming from the inlet. As the mass of fluid hit the restriction (i.e. the wall of the bend), the area available for the fluid to flow is reduced. Since the mass flow rate must be maintained, the velocity of the fluid passing through the bend is increased, hence maintaining continuity.

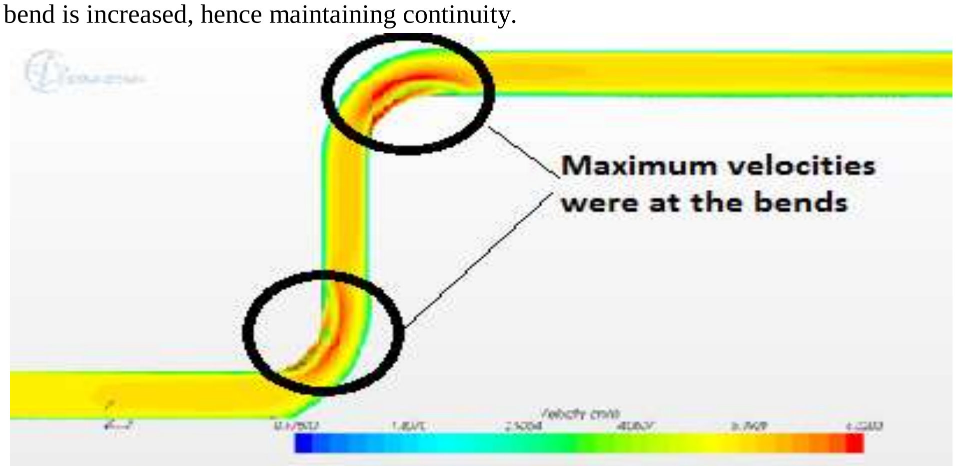


Fig. 3.4: Velocities at the bends at 5m/s

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The velocity at the wall is zero due to the non-slip condition. Due to viscous effect too, the fluids closest to the layers in direct contact with the wall have velocities which are far much less than the velocity of the fluid (their velocity are nearer to the zero velocity at the wall). Because of this less velocity, a laminar sub-layer is created near the wall as shown in Figure 4.5. The flow in the remainder of the duct is turbulent.

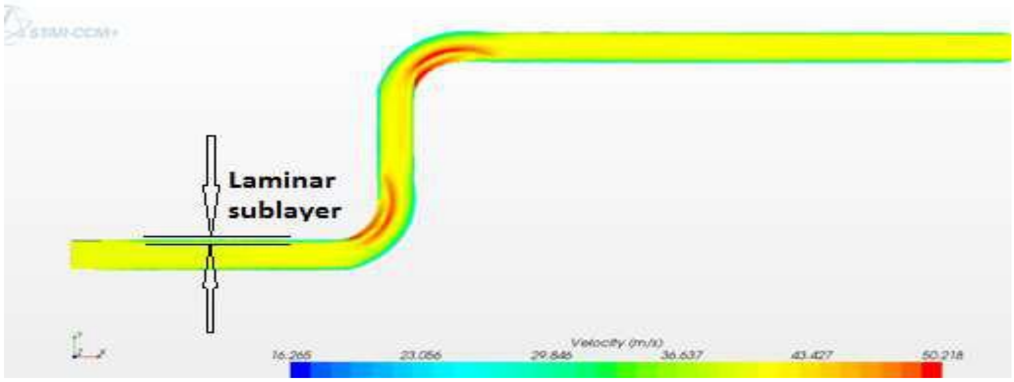

Fig.3.5: Laminar sub-layer at 40m/s

The pressure loss between the inlet and outlet is the difference in pressure between the inlet pressure and the outlet pressure and it can be used to predict leakage in a pipeline. A large drop in values of pressure is as results of pipeline leakage. The static values of pressure have been used in finding the loss (Table 3.3).

Table.3.3: Pressure Loss between the Inlet and Outlet

Case	**Velocity (m/s)**	**Inlet Pressure (P_1) (Pa)**	**Outlet Pressure (P_2) (Pa)**	**Pressure Loss (P_2-P_1) (Pa)**
1	5	5.94	0	5.94
2	10	21.91	0	21.91
3	20	81.58	0	81.58
4	40	285.66	0	285.66

It can be seen that pressures increases as velocity increase. Therefore, high variation in velocity of the fluid in the pipeline might results to leakage. Also, it can be seen that the error decreases as velocity is increased from 5m/s to 40m/s.

IV. CONCLUSION

To avoid pipeline leakage, automated leak detection systems must be installed for new and upgraded pipelines. To design a cost effective system, it is necessary to improve the performance of existing techniques. Intensive research and development at oil facilities must be carried out to model leak detection system. In this research work, a commercial CFD package-Star CCM+ software was used to analyze possible leakage in a pipeline. The results obtained from the simulation shown that the software was able to simulate fluid flow in the pipeline. The outcome of the results obtained can be used to predict the velocity, pressure, mass flow rate, mesh size, etc. An indication of large drop in pressure is as a result of pipeline leakage.

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