Design and Simulation of SmartBall for Pipeline Inspection

by

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13728

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

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Dr Aklilu Tesfamichael

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources or person.

(PUTERA NAZREEN SHAH BIN MOHAMAD ZAKI)

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Finally, I would like to also express my gratitude to my fellow friends for their help throughout my time here. Thank you for being there through thick and thin!

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ABSTRACT

According to KROHNE, a 1% oil leak in a 20 inch oil pipeline can cost 450, 000 barrels and contaminate 10 m^2 within 24 hours. Thus, it is compulsory to have a leak detection system in some jurisdictions. Despite there are various method of leak detection for a pipeline, yet there is no a solution that can fit all. This is due to the fact that different pipelines have different orientations and require different approaches. SmartBall, a pipeline leak detection device, utilizes acoustic for detecting leaks. It moves along the pipeline and detects a distinct leak noise. This device is different from a pig in the sense that it does not occupy the whole pipeline inner diameter and it is possible to launch it through either a pig launcher or a receive fittings. The ball was designed to accommodate sensors for data acquisition, memory card for storage and processor for data conversion. Dynamics of the SmartBall moving in a pipe that contains a flowing fluid was studied with different bends. For this analysis CFD ANSYS Fluent was used. Generally, the results show that as angle of inclination increases, the oil velocity required to propel the SmartBall increases.

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CHAPTER 1

1 INTRODUCTION

1.1 Background Study

An undetected leak in a pipeline is a serious matter. According to KROHNE, a 1% leak in a 20 inch line can cost 450, 000 barrels and contaminate 10 square metre within 24 hours and due to the severity of the consequences, it is compulsory to have some kind of leak detection system in some jurisdictions. Despite the various method of detecting leaks within a pipeline, there is yet a solution that can fits all. This is due to the fact that different pipelines have different orientation and requires different approach.

There are various methods of detecting leaks. Among them are:

- Self-Propelled Type Tools
- Pumping/Wire Line Tools
- Computational Method
- Free Floater

Pipeline inspection gauge also known as ‘pig’ is the most popular choice. Pig is a type of pumping/wire line tools as it will occupy the whole diameter of the pipeline and propulsion depends on the pressure of the product in the pipeline. However, with the rapid development in the pipeline leak detection system, there are now a lot of new technologies in the market.

On the other hand, SmartBall, a pipeline leak detection device, utilize acoustic in detecting leaks. The SmartBall is a device that floats along the pipelines detecting a distinct leak noise. This device is different with a pig in the sense that it does not occupy the whole pipeline inner diameter and it is possible to launch it through a pig launcher or a receive fittings.

1.2 Problem Statements

Leaks within a pipeline can be very challenging to detect. One of the reasons is because pipelines designs and configurations can be very complex; hence it is very important for us to have a method that is capable to meet the challenge. While pigging, a method that uses Pipeline Inspection Gauge or more known as PIG, is a very popular choice, there are limitations and sometimes can be troublesome.

This is because occasionally during an operation a pig can get stuck due to inconsistency in diameter from wax build up. On top of that, since pigs require a certain amount of product pressure to propel it, it will be a problem when the pressure is not up to the requirement.

Since the most common method to detect leaks are through inline inspection and there are very likely to be stuck in the pipeline, tracking an inline inspection device while inspection is very important. In this study, the author will used an inline inspection device called SmartBall and study its trajectory and minimum velocity required to push it through the pipeline.

1.3 Objectives of the Study

- To design a SmartBall for pipeline inspection
- To study the dynamics of SmartBall along oil pipeline with different inclinations

1.4 Scopes of the Study

The main scope of study for this project was to identify the velocity required to propel the SmartBall through various inclinations. This study covered the fluid dynamics of the oil travelling at the speed needed to propel the SmartBall and movement of the SmartBall along the pipeline. To achieve the scopes, the project had been divided into two important parts;

The first part was study on SmartBall's capabilities and applications and also the study on fundamental of fluid mechanics in a pipeline.

The second part of this project was to construct a simulation using ANSYS Fluent to simulate the SmartBall movements. The simulation was able to determine the oil velocity required to propel the SmartBall along pipeline with multiple inclinations. Besides that, the simulation was also be able to convey the dynamics of the fluid and SmartBall along the pipeline.

CHAPTER 2

2 Literature Review

2.1 Overview of the SmartBall

SmartBall was first introduced in the water pipeline industry. The technology was introduced by Pure Technologies, a Canadian technology company. After years of experiences in the water pipeline industry, the company had decided to venture in oil and gas [20]. While this is fairly a new method of pipeline inspection, the company had undergo many projects in the oil and gas industry all over the world and recently, they had appointed Applus+ VELOSI Malaysia as their representative in Malaysia. Applus+ VELOSI Malaysia is a company that provides asset integrity, quality assurance, quality control and various other engineering services to leading oil and gas industry worldwide.

SmartBall is a pipeline inspection device that utilizes acoustic as it method to detect pinholes along pipelines [21]. This is because when a pressurized pipelines have leaks, a distinct anomalous acoustic activity is produced [20]. The SmartBall will then record the acoustic activities that will be analyze once the SmartBall had been retrieved.

The SmartBall consist of two components *(refer Figure 2.1).* The first component is the core, it is fitted with instruments such as acoustic sensors, tri-axial accelerometer, tri-axial magnetometer; GPS synchronized ultrasonic transmitter, temperature and pressure transmitter. This instruments will be capsulated in an aluminum shell. The second component of the SmartBall is the outer layer which will primarily act as a protective measures and it is usually made of polyurethane. Besides providing protection, the outer layer will also reduce noise produced from the movement of the SmartBall and will also create a larger surface area for propulsion of the SmartBall.

Although SmartBall characteristics seem similar with intelligent pigs, it is actually not. While pigs normally occupy the whole diameter of the pipe that it is travelling in, the SmartBall does not and instead it is designed to be smaller than the pipe’s diameter. Other than that, the SmartBall travels along the pipeline with some help from the pipeline product propulsion to roll through the pipeline it is required to do the inspection which in contrast to a pig that will occupy the whole diameter in order to generate enough pressure to propel it through the pipeline [20].

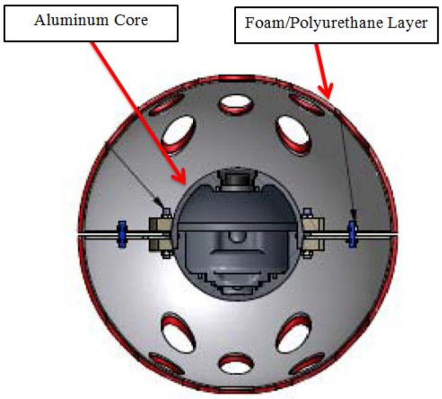

Figure 2.1 SmartBall Components [20]

2.2 SmartBall Deployment and Retrieval

Since SmartBall is deployed into the flow of pipelines, it will be collected at the downstream receiver after inspection is complete *(refer Figure 2.2).* The location of the SmartBall is monitored at known bench marked locations along the pipeline. This is to correlate the inspection data with position along the pipeline. There are 2 standard methods of deployment of the SmartBall [15];

Figure 2.2 SmartBall core and foam shell after extraction [15]

2.2.1 Launching through a PIG launcher

The aluminum core is encapsulated inside a protective outer foam shell *(refer Figure 2.3)*, which allows the device to be propelled through the pipeline by creating a larger surface area for the product flow to make contact with. This method is typically used for pipelines that is 16 inch in diameter or larger [15].

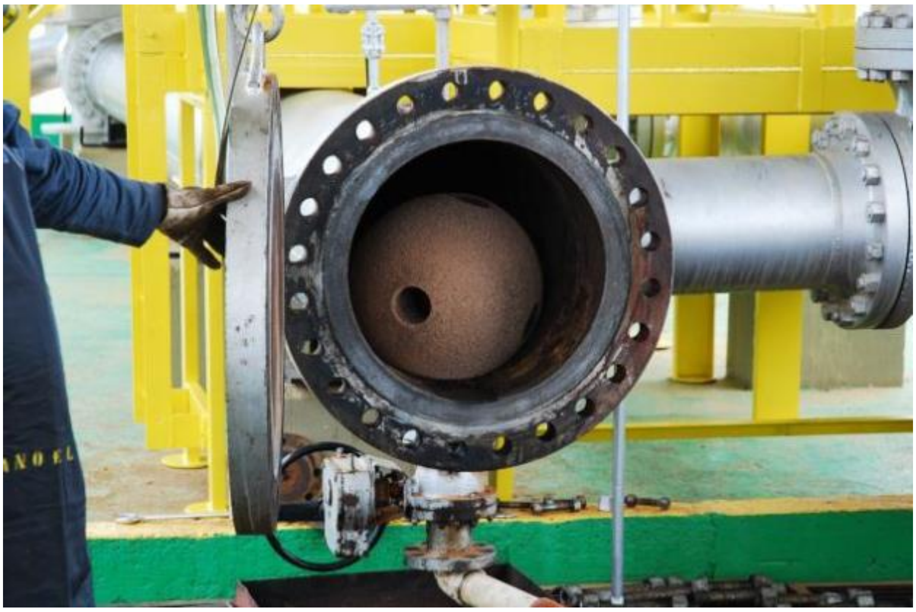

Figure 2.3 SmartBall tool with foam over shell at extraction [15]

2.2.2 Launching through a Receive Fittings

The aluminum core is encapsulated in a polyurethane coating *(refer Figure 2.4)* and is suitable for deployment into pipelines ranging from 4” to 14” in diameter [15].

Figure 2.4 Polyurethane coated SmartBall tool at extraction [15]

2.3 Tracking the SmartBall within a Pipeline

Tracking the location of the SmartBall position is very important in order to produce an accurate location of the leak. One of the components that being used to track the location of leaks is the accelerometer data. The accelerometer is located in the core and it will record the rotation of the SmartBall and then the data will be used to determine the angular velocity of the SmartBall *(refer Figure 2.5) [15]*.

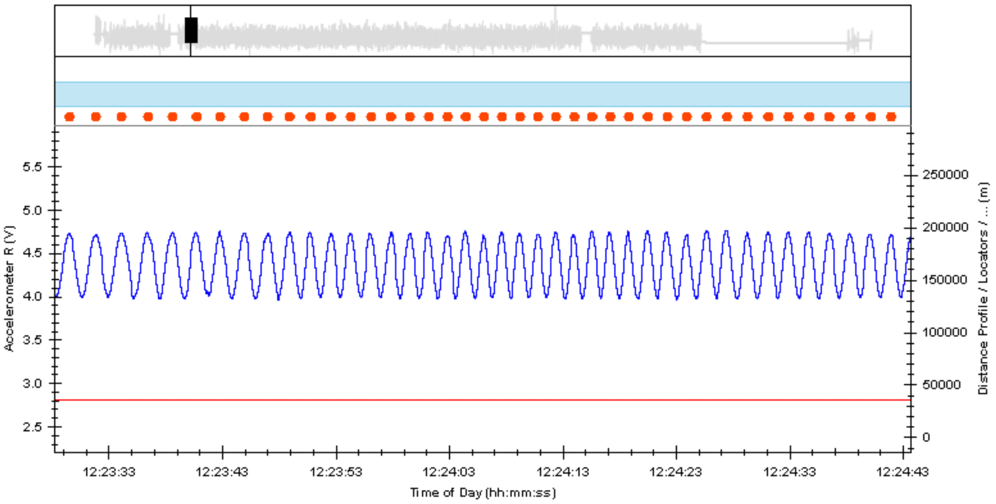

Figure 2.5 Data from the Accelerometer [15]

In order to get the location of the leak, the angular velocity will be used to produce velocity profile and then will be aligned with the acoustic recording. In fact, to improve the precision of the leak location, reference points need to be established. This reference points (also referred as markers) will be place along the pipelines. Below are the 2 devices that commonly used as markers [15]:

2.3.1 SmartBall Receivers (SBR)

A number of these devices will be placed along the pipeline and the function of this device is to detect ultrasonic pulses emitted from the SmartBall. The position of the SBR along the pipeline will act as a checkpoint because it will records the time the SmartBall travels passed it and calculate approximate location of the SmartBall with respect to time. SBRs are mounted at the outer surface of the pipeline *(refer Figure 2.6) [15]*.

Figure 2.6 The SBR that is connected to Acoustic Sensor [15]

2.3.2 Above Ground Markers (AGM)

Any benchmarking device that is range 22 Hz can be used as a marker. The AGMs should be placed directly above the pipeline so that the SmartBall's global positioning system (GPS) will be able to log the passage time by measuring the 22 Hz signal emitted by the SmartBall. Since the AGMs will act as a checkpoint, the data will then be analyzed and then location of the leaks will be able to be determined [15].

2.4 SmartBall Data Gathering and Interpretations

In the event of leaks within a pressurized pipeline, an acoustic signal will be produced. This is because as the pressurized product inside the pipeline escapes to the lower pressure atmosphere outside the pipeline which produces a distinct acoustic noise [20].

As the SmartBall travels, it will continuously record the acoustic data of the pipeline. When the SmartBall approaches a leak, the intensity of the noise increases and exactly at the leak, the acoustic data will reach its peak *(refer Figure 2.7)*. Then, as the SmartBall travels away from the leak, the noise intensity will be decreased [15].

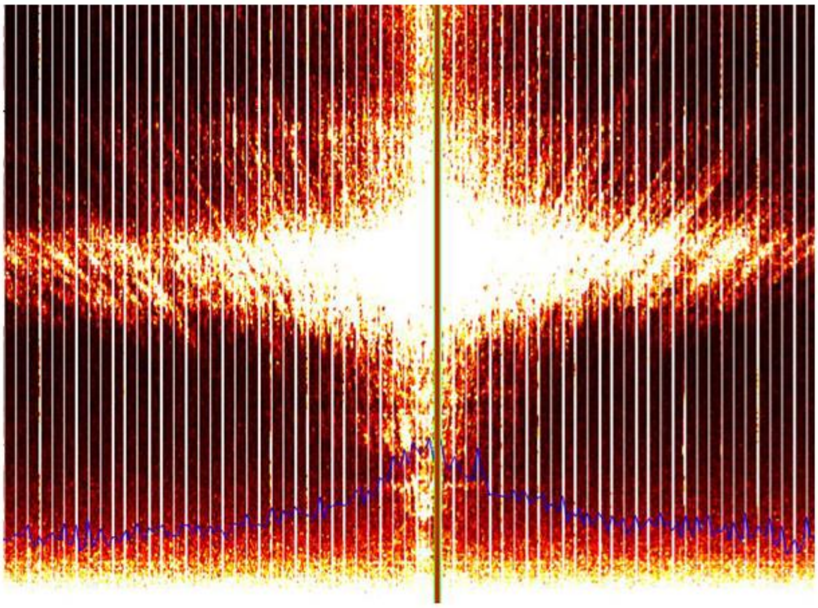

Figure 2.7 The acoustic data recorded [15]

This acoustic data obtained then compared with the velocity profile deduce from the data from the accelerometer. In order to determine the accurate location of the leak, the velocity profile will be aligned with the acoustic data so that the location of the peak of the acoustic signal which indicates the leak can be determined.

2.5 The SmartBall Specifications

The SmartBall will be operating in a very challenging environment. Hence it is important that SmartBall is designed in such a way that it is up to the challenge. The SmartBall can operates at maximum pressure of 2000 psi and at the temperature range of -10 degree Celsius to 70 degree Celsius. Moreover, SmartBall will be able to operate in crude oil, synthetic crude, and natural gas.

In order to be able to detect leaks effectively, SmartBall needs to have a leak detection threshold of leaks as small as 0.06 LPM and since pipeline can be have a very long terrain, the SmartBall requires a battery that can last throughout the inspection and for this case, SmartBall can be deploy up to 400 hours [22]. On top of that, SmartBall also have different diameters which have different features and the evaluation on which one to be deploy is based on the pipe size and length. Table 2.1 shows the different specifications of the SmartBall.

SmartBall® Diameter	**4”**	**6”**	**8”**	**10”**	**12”**
Outer Diameter of Tool	3.15” (80 mm)	5.3” (135 mm)	7.125” (180 mm)	8.75” (220 mm)	10.75” (275 mm)
Suitable pipe diameter	4” (100 mm)	6” (150 mm)	8” (200 mm)	10” (>250 mm)	12” (>300mm)
Power Source	Lithium primary	Lithium rechargeable			
Maximum Run Time	29.5 hours	55 hours	115 hours	115 hours	400 hours
Memory Capacity	4 GB	32 GB	32 GB	32 GB	128 GB

Table 2.1 SmartBall Specifications [22]

2.6 Fundamental Concepts of Fluid Flow

2.6.1 Continuity

The principle states that the total amount of the fluid travelling throughout the pipe will be constant. The principle is similar to conservation of mass where the liquid can be created nor destroyed as it flows through a pipeline. Therefore:

$$\boldsymbol{M = Vol\ x\ \rho = Constant} \qquad \text{(Equation 2.1)}$$

Where;

$M = mass\ flow\ rate\ at\ any\ point\ in\ the\ pipeline, kg/s$

$Vol = volume\ flow\ rate\ at\ any\ point\ in\ the\ pipeline, m^3/s$

$\rho = density\ of\ fluid\ at\ any\ point\ in\ the\ pipeline, kg/m^3$

From equation *2.1*, if we consider the volume flow rate of the product in the pipeline as the product of the area of cross section of the pipe and the average liquid velocity, the equation can be rewritten as below:

$$\boldsymbol{M = A\ x\ V\ x\ \rho = constant} \qquad \text{(Equation 2.2)}$$

Where;

$M = mass\ flow\ rate\ at\ any\ point\ in\ the\ pipeline, kg/s$

$A = area\ of\ the\ cross\ section\ of\ the\ pipe, m^2$

$V = average\ liquid\ velocity, m/s$

$\rho = density\ of\ fluid\ at\ any\ point\ in\ the\ pipeline, kg/m^3$

Since liquids are generally incompressible, density will not change appreciably hence reducing the equation to

$$\boldsymbol{AV = constant} \qquad \text{(Equation 2.3)}$$

2.7 Energy Equation

Consider *Figure 2.8* below as an elevated pipeline with fluid flowing from point 1 to point 2, elevation at point 1 and 2 are denoted as $z_1 and\ z_2$ respectively. Besides that, $p_1 and\ p_2$ will denote the pressure at point 1 and 2 and assuming a typical case where diameter 1 is different that diameter 2, we will discuss the velocity at 1 and 2.

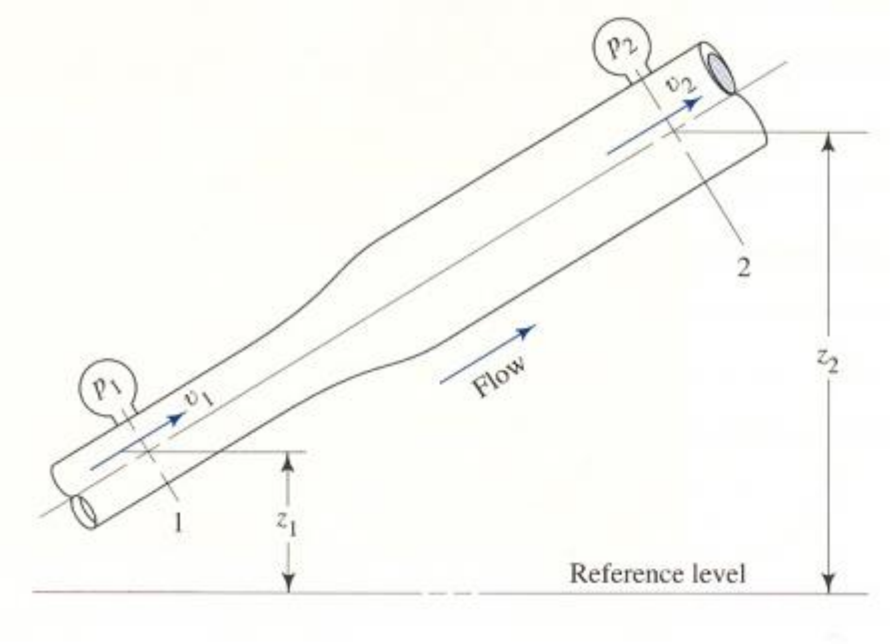

Figure 2.8 Energy of liquid in pipe flow

Consider a particle of liquid flowing from point 1 with a weight W, this particle can be considered to possess a total energy E that have 3 components:

$$Energy\ due\ to\ position, or\ potential\ energy = WZ_1$$

$$Energy\ due\ to\ pressure, or\ pressure\ energy = \frac{WP_1}{\gamma}$$

$$Energy\ due\ to\ velocity, or\ kinetic\ energy = \frac{W(V_1^2)}{2g}$$

Where:

$$\gamma = specific\ weight\ of\ the\ liquid$$

Therefore:

$$E = WZ_1 + \frac{WP_1}{\gamma} + \frac{W(V_1^2)}{2g} \qquad \textit{(Equation 2.4)}$$

Dividing equation *2.4* by W to get total energy per unit weight at point 1:

$$H_1 = Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} \qquad \textit{(Equation 2.5)}$$

Where:

$$H_1 = total\ energy\ per\ unit\ weight\ at\ point\ 1$$

Considering the same amount of energy of liquid particle at point 2, the total energy per unit weight at point 2 will be:

$$H_2 = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} \qquad \textit{(Equation 2.6)}$$

Where:

$$H_2 = total\ energy\ per\ unit\ weight\ at\ point\ 2$$

Due to conservation energy:

$$H_1 = H_2$$

Therefore:

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} \qquad \textit{(Equation 2.7)}$$

Equation 2.7 is one of the form of a Bernoulli's Equation and in the real practice we will need to consider friction loss to the pipe surface and also energy added to the system through pumps. Therefore modifying *equation 2.7* will result in:

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} + H_p = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + \sum H_L \qquad \textit{(Equation 2.8)}$$

Where:

$$H_p = pump\ head\ added\ to\ the\ liquid\ at\ point\ 1$$

$$\sum H_L = all\ head\ loss\ between\ point\ 1\ and\ 2\ due\ to\ friction$$

2.8 Inspection Device Malfunctions

A stuck inspection device can be very costly due to the fact that for a retrieval to be done, a shutdown must be initiated and this can cost a huge loss to a company. If the inline inspection device does not arrive at its intended destination, most likely it is stuck in the pipeline [23]. On June 11, 2004, a pig was stuck in the BP deep-water Gulf of Mexico Marlin Tension Leg Platform (TLP) oil export pipeline. The pig was stuck approximately nine miles from the Marlin TLP in 1200 feet of water depth and it took 10 days to remove the pig.

There are various reasons a pig can get stuck during an operation and among them are [23]:

i. Pipe, flange or a gasket misalignment
ii. Wax build up causing inconsistency in pipe diameters
iii. The pig was strongly worn out causing the propellant to flow through it resulting in insufficient propulsion.
iv. Insufficient pressure to propel the pig

Besides that, tracking an inspection device is very crucial as it used either to locate deformities or in case of stuck pig, a location can be determined to retrieve the pig.

CHAPTER 3

3 Methodology

3.1 Project Methodology

Throughout this project, the author had designed a method in order to achieve the objectives of the project:

Step 1: Identifying Problem Statements

In order for a research to initiate, problems need to be identified. This is important because it will give the research a purpose to fulfill at the end of the day. Besides that, by knowing the problems it will help steer the research into the right direction. In this paper, the main problem statement that the author had underlined was about the need to study the dynamics of an inline pipeline inspection device and its trajectory during inspection.

Step 2: Setting Up Objectives and Scope of Study

Once problems were identified, objectives of the research were underlined. For this study, the author had underlined a few objectives that he aims to achieve at the end of the day. One of his main objective is to design a SmartBall for pipeline inspection and the minimum oil velocity required to push the SmartBall through various inclinations. Besides that, the author had specified his scope of study for this project.

Step 3: Information Gathering

Once problem statement and objectives had been identified, the author gathered as much information as possible related to the field of study. Then, he was able to understand the field he is studying. In this process, the author gathered the information necessary for his study from materials such as research papers, conference paper, journals, and books. At the end of the day, the author identified necessary parameters (flow related) that will ensure the SmartBall travel throughout the pipeline.

Step 4: Design and Run the SmartBall Simulation

From the information obtained on previous step, the author was able to run simulations to study the oil velocity required to propel the SmartBall throughout the pipeline. Besides that, the simulation was a tool to study the behavior of the SmartBall movement in a pipeline and with the aid of the simulation, the author was able to study different scenario of the movement of the SmartBall such as at an elevation and a bent.

Step 5: Data Interpretations

Once the simulation had been done, the data collected from the simulation were interpreted. This is important as it will determine the outcome of the study. The result from the interpretation was used to deduce whether future study need to be done in order to refine the study.

Step 6: Developing Conclusion and Recommendations

Based on the outcome of the simulation, the author developed conclusions of his study and recommendations. This will be crucial as this is where the author decides whether the objectives set in the initial stage of his study are met or not. Besides, based on his study, the author will also be able to make recommendations that will improve the outcome of future study.

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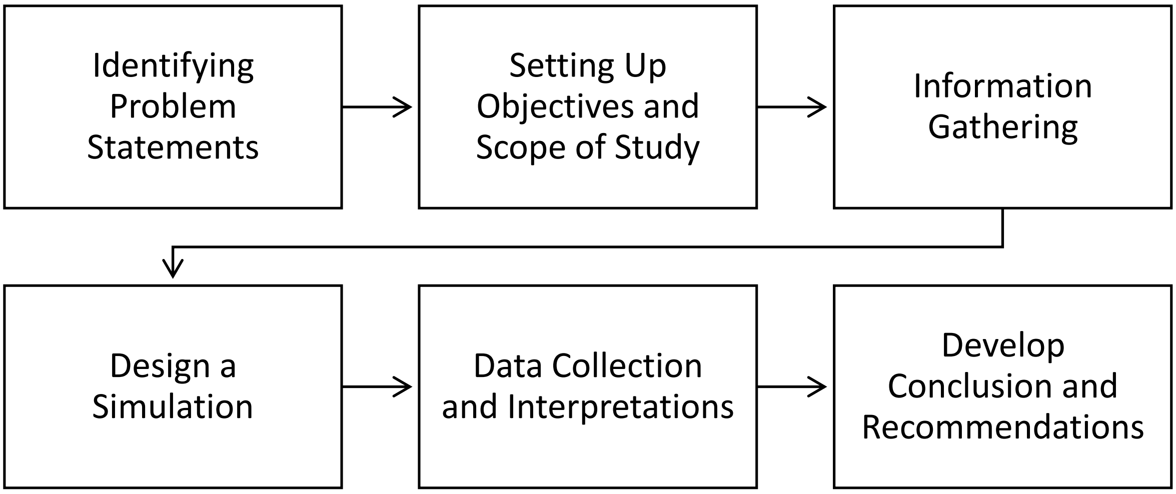

Figure 3.1 Summary of Project Methodology

3.2 Simulation Methodology

For this project, the author had used ANSYS Fluent as his simulation tool. One of the main aim of the simulation was to predict the trajectory of the SmartBall being propel by oil flow along a pipeline. The flow was assumed to be fully developed and the software uses Lagrangian reference frame to analyze the model.

Step 1: Drawing the Geometries

For this project the author had created seven pipe geometries; basically a pipe section of one meter length with 7 angles of inclination. The angles that he had designed for are 0°, 15°, 30°, 45°, 60°, 75°, and 90° *(refer Figure 3.2 to 3.8).* The pipe diameter is set to be 4.026 inch and total length is 2 meter with bend starting after 1 meter.

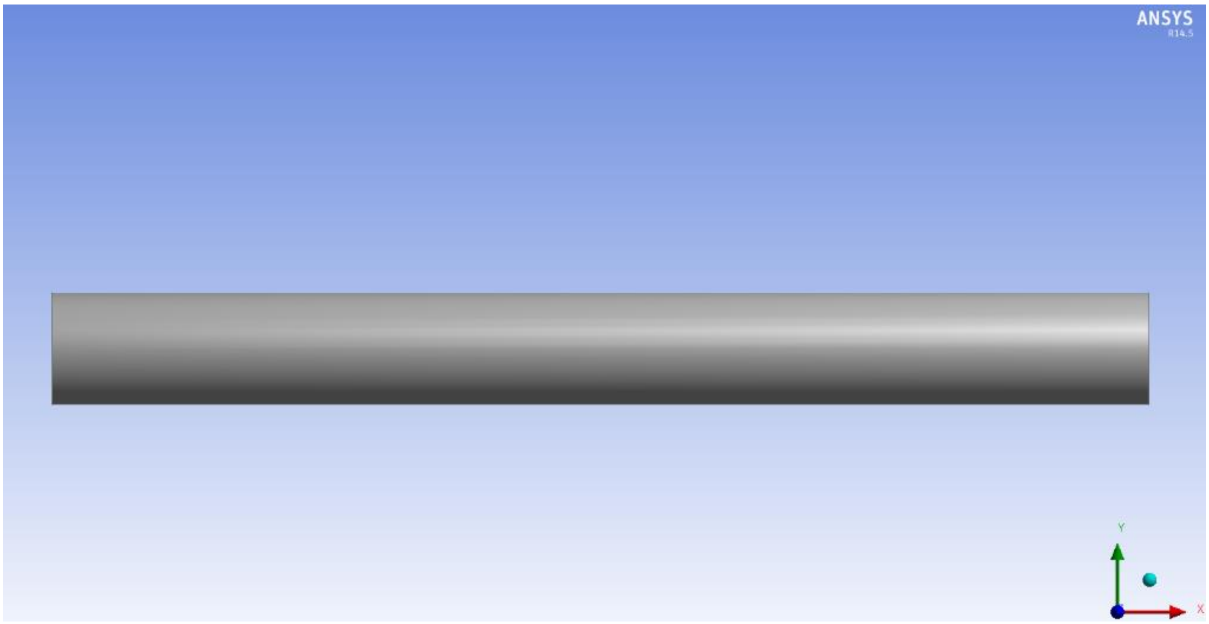

Figure 3.2 Geometry 1 with 0° degrees inclination

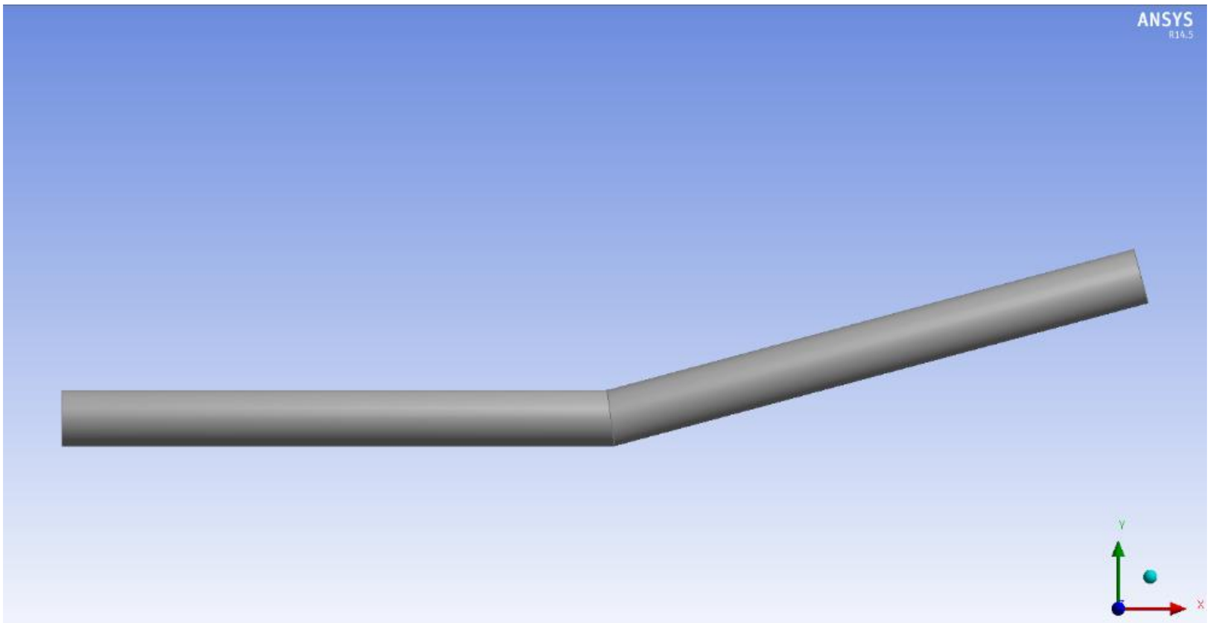

Figure 3.3 Geometry 2 with 15° degrees inclination

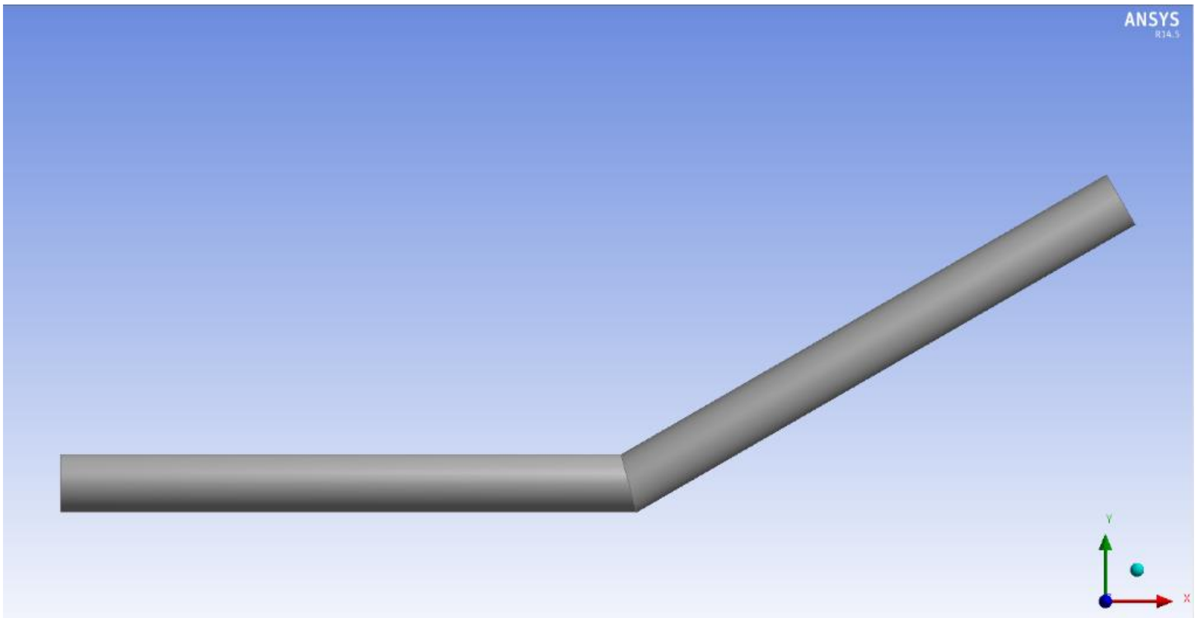

Figure 3.4 Geometry 3 with 30° degrees inclination

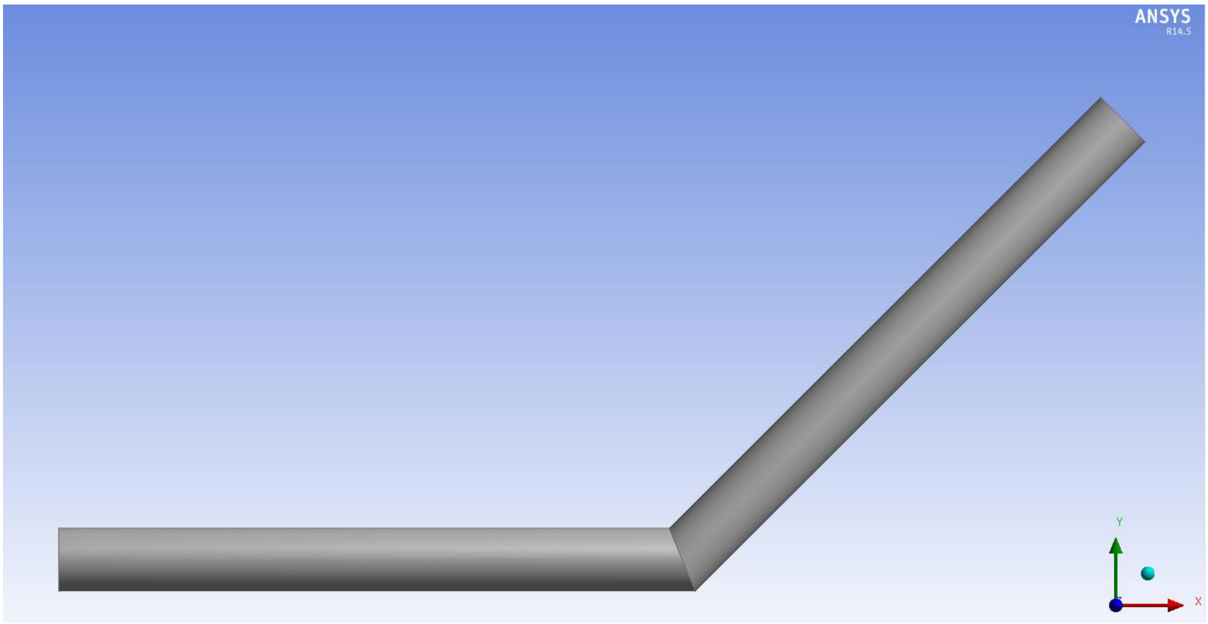

Figure 3.5 Geometry 4 with 45° degrees inclination

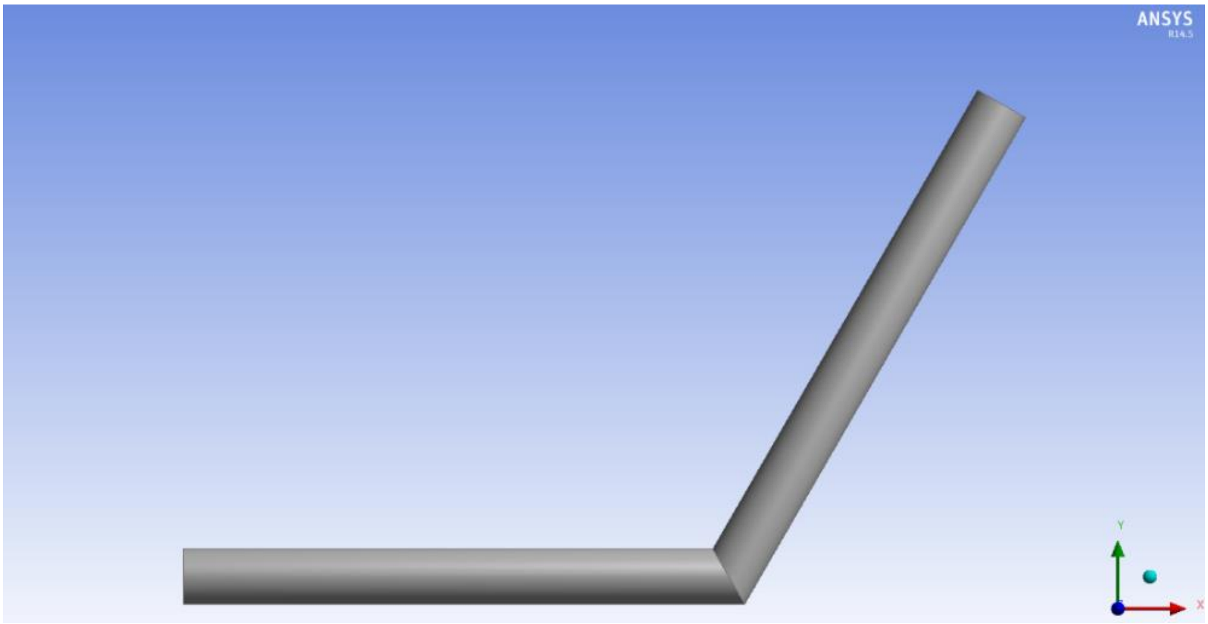

Figure 3.6 Geometry 5 with 60° degrees inclination

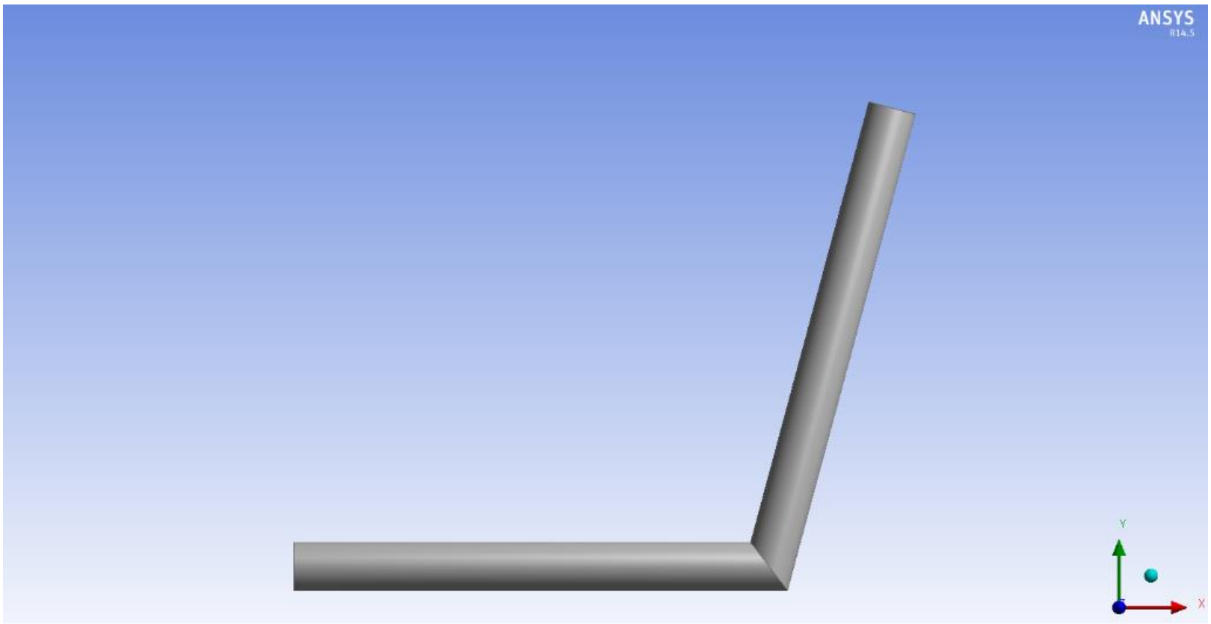

Figure 3.7 Geometry 6 with 75° degrees inclination

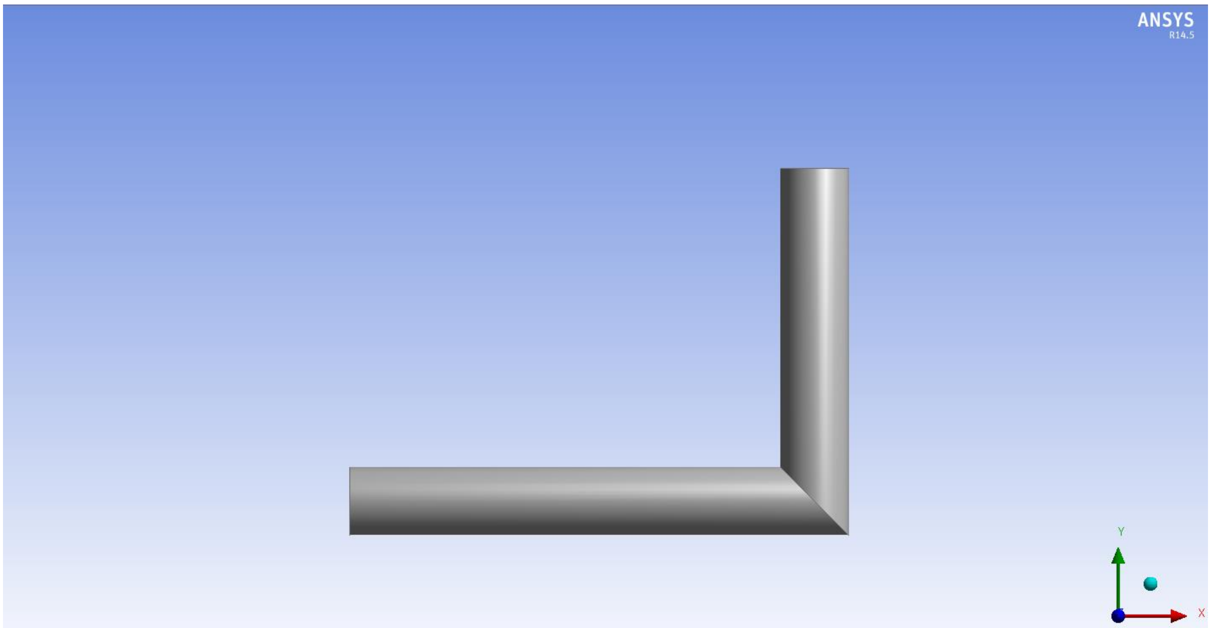

Figure 3.8 Geometry 6 with 90° degrees inclination

Step 2: Meshing the Geometries

Meshing is one of the most critical steps in a simulation. In order to yield the best result for the simulation, a right meshing approach need to be done, too many number of cells will result in long solving duration while too few will result in inaccurate results.

For this project, the author had used the cut cell Cartesian meshing which will generates a high percentage of hexahedral cells to produce accurate fluid flow results.

Besides that, to verify the meshing accuracy, the author had done analysis on the statistics of mesh element quality and aspect ratio for each case. If the result of the analysis is unsatisfactory, the author reduced the mesh size until a satisfactory meshing is achieved. The aspect ratio need to be as minimum as possible while element quality need to be as maximum as possible. *Figure 3.10 and 3.11* is the analysis run for geometry 1.

Step 3: Setting Up Simulation Parameters and Run Calculations

Once meshing had been satisfactory, the simulation parameters is being set up. The SmartBall has a diameter of 0.08 meter and mass of 0.5 kg and was injected at the horizontal end of the pipe section (inlet). The velocity of the oil flow was initialized as 0.25 m/s and increases 0.01 m/s until the SmartBall managed to travel through the pipe section. Once parameters had been set up, the calculation had been run until solution is converged.

Step 4: Yielding Results

Once calculation is done, the results can be yield. For this project the result needed is the fluid velocity contour, fluid pressure contour and the SmartBall velocity contour. *Figure 3.9* shows the flow chart of the simulation process.

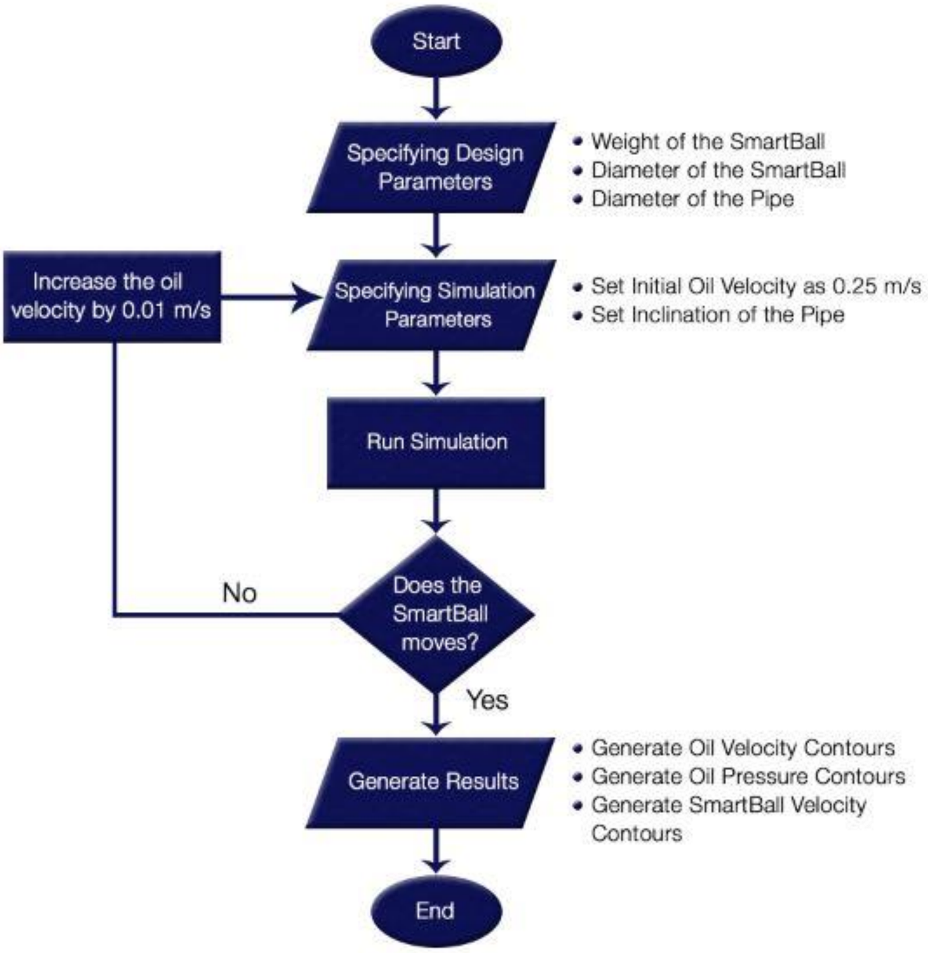

Figure 3.9 Simulation Process

3.3 The Design of SmartBall

The design process of the project was done in two phases: conceptual design and detailed design. Conceptual design was done by drawing multiple hand sketches and the best design concept will be selected. The best conceptual design was used to create a detailed design using CATIA.

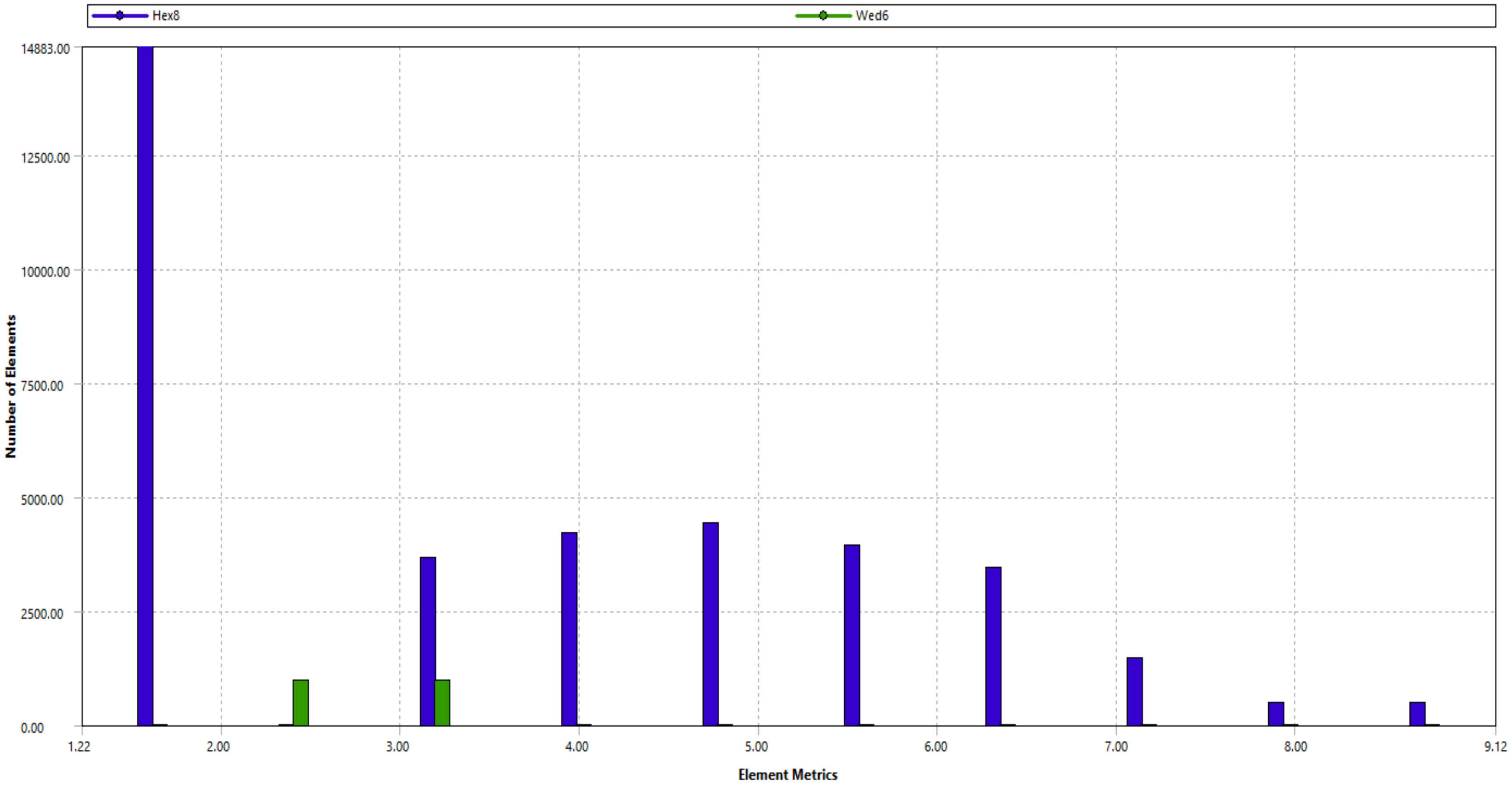

Figure 3.10 Bar chart of Aspect Ratio VS Number of Elements for Geometry 1

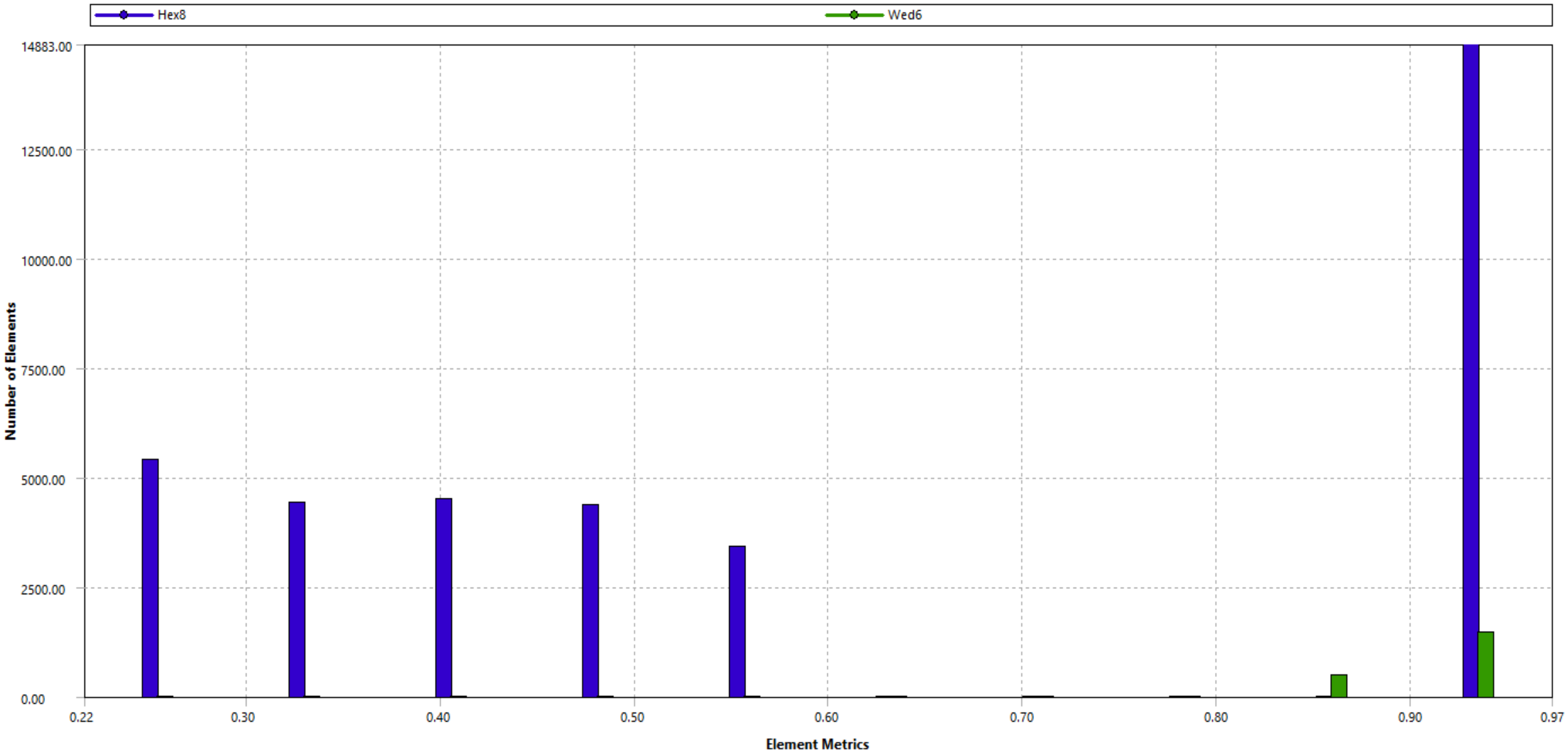

Figure 3.11 Bar chart of Element Quality VS Number of Elements for Geometry 1

3.4 Project Milestones

Milestone 1	**Determining Necessary Parameters for Simulation**
Duration	18th – 20th of June 2014
Description	The author will established and finalize the key parameters for his study before running simulations

Milestone 2	**Design and Run the SmartBall Simulation**
Duration	20th – 30th of June 2014
Description	The author will design and run the SmartBall simulation in order to study the behavior of the SmartBall movement within a pipeline.

Milestone 3	**Data Interpretation**
Duration	30th of June – 15th of July 2014
Description	The author will interpret the data obtained from the simulation executed and will determine the outcome of the study

Milestone 4	**Develop Conclusion and Recommendations**
Duration	15th – 25th of July 2014
Description	The author will finalize the outcome of the experiment and decide whether the objectives set are met or not. He will also make recommendations in order to refine the experiment.

3.4 Project Timeline (FYP 1)

NO	TASK	JANUARY				FEBRUARY				MARCH				APRIL				MAY			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1.0	**Pipeline Leak Detection System Study**																				
	1.1 Outsource Reading Materials			🟥	🟥																
	1.2 Compose Project Proposal					🟥	🟥														
	1.3 Submit Project Proposal to Supervisors							🟥													
2.0	**Project Preliminary**																				
	2.1 Conduct research on software options																				
	2.1.1 Catia (3D Modelling Software)					🟥	🟥														
	2.1.2 AutoCAD (3D CAD Modelling)					🟥	🟥														
	2.1.3 ANSYS (Modelling and Simulation)					🟥	🟥														
	2.2 ANSYS Training					🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥				
	2.3 Background Study of the SmartBall Concept			🟥	🟥	🟥	🟥	🟥	🟥												
	2.4 Identifying Necessary Parameters to Achieve Objectives									🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
3.0	**Project Execution**																				
	3.1 Design the SmartBall																				
	3.2 Run Simulation of the SmartBall																				
4.0	**Project Analysis**																				
	4.1 Data Collection from the Simulation																				
	4.2 Data Analysis																				
5.0	**Project Finalization**																				
	5.1 Develop Conclusion and Recommendations																				
	5.2 Final Report Preparation																				

3.5 Project Timeline (FYP 2)

NO	TASK	MAY				JUNE				JULY				AUGUST				SEPTEMBER			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1.0	**Pipeline Leak Detection System Study**																				
	1.1 Outsource Reading Materials																				
	1.2 Compose Project Proposal																				
	1.3 Submit Project Proposal to Supervisors																				
2.0	**Project Preliminary**																				
	2.1 Conduct research on software options																				
	2.1.1 Catia (3D Modelling Software)																				
	2.1.2 AutoCAD (3D CAD Modelling)																				
	2.1.3 ANSYS (Modelling and Simulation)																				
	2.2 ANSYS Training																				
	2.3 Background Study of the Smartball Concept																				
	2.4 Identifying Necessary Parameters to Achieve Objectives	🟥	🟥	🟥																	
3.0	**Project Execution**																				
	3.1 Design the SmartBall			🟥	🟥																
	3.2 Run Simulation for the SmartBall					🟥	🟥	🟥													
4.0	**Project Analysis**																				
	4.1 Data Collection from the Simulation							🟥													
	4.2 Data Analysis							🟥	🟥												
	Project Finalization																				
	5.1 Develop Conclusion and Recommendations									🟥	🟥										
	5.2 Final Report Preparation											🟥	🟥	🟥							

CHAPTER 4

4 Results and Discussion

4.1 Modelling Development

4.1.1 Geometries Drawing

The author had model a pipe section with seven different inclinations. The pipe sections have 4 inch diameter with one meter in length. The inclination set were 0°, 15°, 30°, 45°, 60°, 75°, and 90°. The reason the angles were chosen is because in a pipeline, the SmartBall may have to travel along various path and one of the most challenging path that the SmartBall needs to travel could be through an incline path. Hence, the author had decided to design a simulation which will test whether the SmartBall will be able to travel through the incline path with specified mass flow rate of fluid in this case oil.

4.1.2 Meshing the Geometries

Meshing is one of the most important steps in a CFD simulation as it will determine the accuracy. Two factors that need to be look at when checking the accuracy of a meshing are aspect ratio and element quality.

4.1.2.1 Aspect Ratio VS Number of Elements

In any CFD simulations, there will be a certain degree of errors due to the evaluation of continuous problems using discrete analysis. Therefore, steps need to be taken in order to minimize this error and one way to judge the errors in a simulation is through aspect ratio. Aspect ratio is defined as the ratio of longest dimension to the shortest dimension of a quadrilateral element in a mesh. As the aspect ratio increases, the accuracy of simulation decreases. Based on *Figure 3.10*, total aspect ratio is less than 9.12 and most of the elements have an aspect ratio between 1.22 and 2. This shows that the simulations were within acceptable range of accuracy and this also applies for the rest of the geometries.

4.1.2.2 Element Quality VS Number of Elements

Besides aspect ratio, element quality can also be used to judge the magnitude of errors in the simulation. Element quality shows the generated mesh quality. A mesh with high percentage of quality will result in better accuracy and hence producing a reliable simulation. Based on *Figure 3.11*, majority of the elements in geometry 1 have more than 90 percent quality which shows that the simulation is within an acceptable margin of errors and this is also the same for the rest of the geometries.

4.1.3 Simulation Calculations and Assumptions

The setup used was the Discrete Phase Model (DPM) in ANSYS Fluent. DPM is designed to track motion of a particle in a flow. The particle can be a fluid, gas or solid. This method is also known as the Lagrangian setup as it is based on Lagrangian reference frame.

Lagrangian reference frame is an approach of tracking position and velocity of each individual particle and take it to be a fixed identity or in other words each particles has its own x,y and z coordinate.

In this setup, the flow was assumed to be a fully developed flow and the movement of the SmartBall is being calculated using *equation 4.1* below:

$$\frac{du_i^p}{dt} = F_D\left(u_i - u_p\right) + \frac{g_i(\rho_p - \rho)}{\rho_p} + \frac{F_i}{\rho_p} \qquad \text{(Equation 4.1)}$$

4.2 SmartBall Design

In order to replicate this technology, the author need to be able to proposed a SmartBall design that will be able to perform its function in detecting leaks. The fundamental part of the SmartBall is its core. *Figure 4.1* is the proposed design of the SmartBall core.

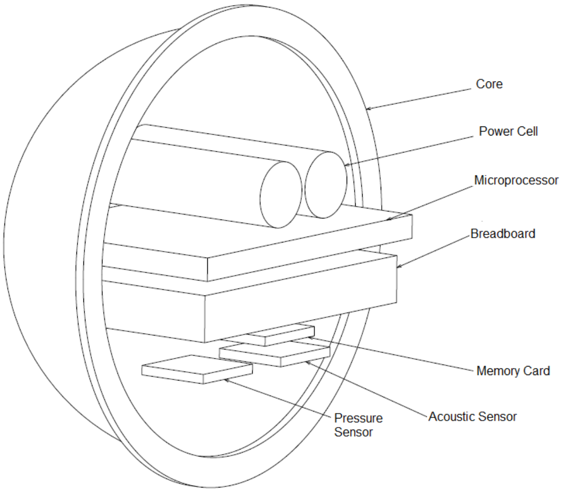

Figure 4.1 The SmartBall Core Design

Based on the design, the author had placed 6 crucial components in the core. The first component was the power cell which is the source of power for the core. There was also a microprocessor in the core to process and converts the data received from the acoustic and pressure sensors to be stored in the memory card.

On top of that, there were 2 sensors which are omnidirectional acoustic sensor to detect the acoustic noise produced by leaks and pressure sensors to get evaluate the pressure along the pipeline. Finally, the breadboard is a construction based where all the electronics component will be mounted.

Since positioning of the SmartBall during an inspection is one of the most critical element in determining the position of a leak, the author would like to suggest that a ‘checkpoint’ being placed along the pipeline. This ‘checkpoint’ is actually the places where we will place frequency emitting device so that the frequency can be pick up by the acoustic sensors to mark the position of the SmartBall in time. The frequency need to be distinct so that it will not be mistaken as a leak.

4.3 Forces Acted on the SmartBall

Figure 4.2 shows the forces acted on the SmartBall as it is being deploy in a pipeline. Force due to gravity and force due to buoyancy are basically constant. On the other hand the lift and drag force depends on the flow conditions.

Lift force are forces acting perpendicular to the direction of the relative motion of the fluid. It is created due to different pressure on opposite sides of an object due to fluid flowing past the object. On the other hand, buoyant force comes from the pressure exerted on the object by the fluid. Because the pressure increases as the depth increases, the pressure on the bottom of an object is always larger than the force on the top - hence the net upward force. Besides that, drag forces are the resistive forces acting on a body moving through a fluid while gravitational forces are the forces resultant from gravity.

In order to move the SmartBall the lift and buoyant force need to be able to overcome the gravitational force. One way to make it possible is by increasing the velocity of oil which will increase lift force.

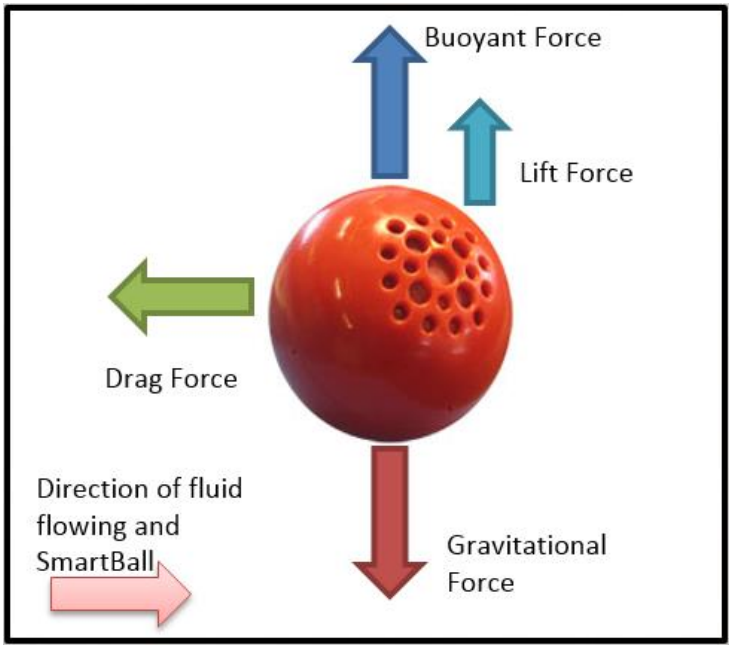

Figure 4.2 Forces acting on the SmartBall

4.4 Simulation Results

For the project, the author had obtain 3 type of results which are:

i. The oil velocity contours
ii. The oil pressure contours
iii. The SmartBall's velocity contours

4.4.1 The Oil Velocity Contours

Based on the result obtained from the simulation, generally for all of the cases, there were no separation of the oil flow on the horizontal part, however for cases with more than 0° degrees of inclinations, there were separation region at the bend. This is because when a flowing fluid approaches a bend, there will be force acting radially inward on the fluid that will caused centripetal acceleration and this is similar to a car that been thrown off the road when entering a corner too fast. After the bend, the faster moving portion of oil is being displaced outward. This is due to inertial effects.

Figure 4.3 Oil Velocity Contour for 0° degrees inclination

The final oil velocity at inlet set for 0° degrees inclination that was able to push the SmartBall through the pipeline was 0.50 m/s. Based on the contour in *Figure 4.3*, the high velocity region was at the middle section of the pipe while the region near the walls has lower velocity. This is due to friction loss between the oil and the wall.

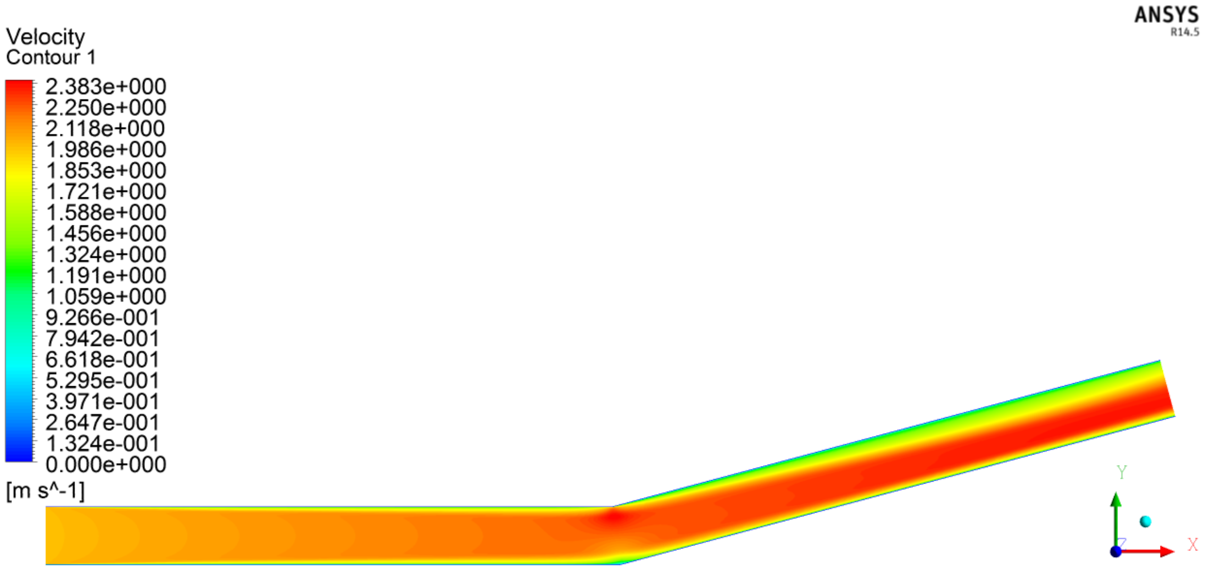

Figure 4.4 Oil Velocity Contour for 15° degrees inclination

The final oil velocity at inlet set for 15° degrees inclination that was able to push the SmartBall through the pipeline was 1.75 m/s. Based on the contour in *Figure 4.4*, on the horizontal part, the high velocity region was at the middle section of the pipe while the region near the walls has lower velocity. This is due to friction loss between the oil and the wall. However, at the bend, separation occurs. Since the inclination angle was small the separation region is relatively small.

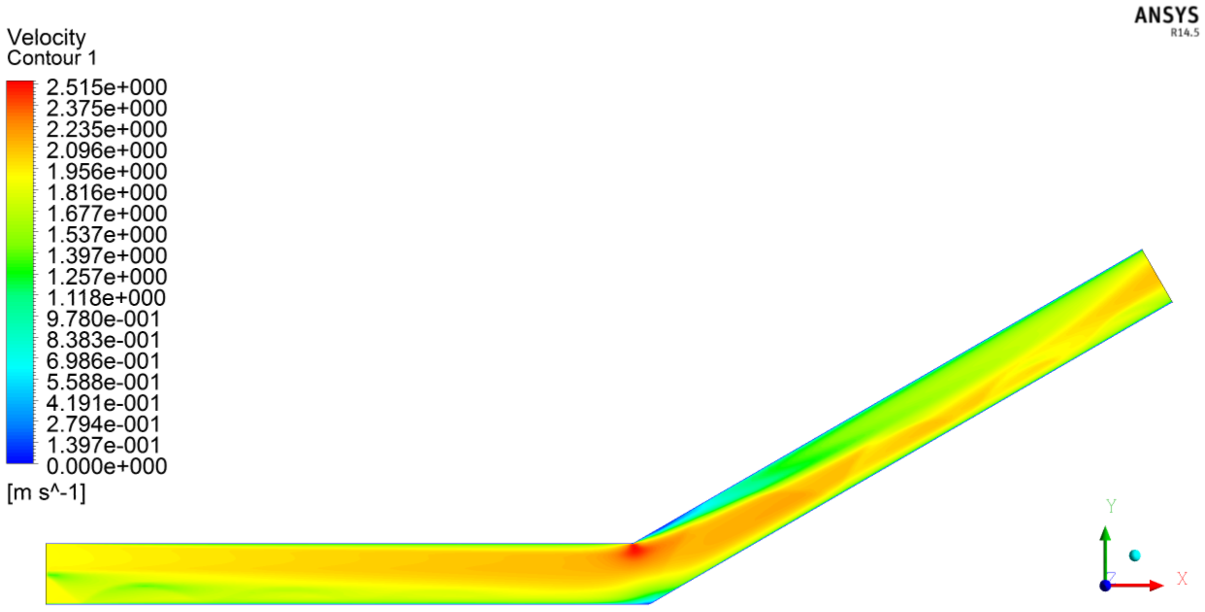

Figure 4.5 Oil Velocity Contour for 30° degrees inclination

The final oil velocity at inlet set for 30° degrees inclination that was able to push the SmartBall through the pipeline was 1.90 m/s. Based on the contour in *Figure 4.5*, on the horizontal part, the high velocity region was at the middle section of the pipe while the region near the walls has lower velocity. This is due to friction loss between the oil and the wall. However, at the bend, separation occurs. Since the inclination angle was bigger compared to 15° degrees inclination, the separation region is relatively bigger.

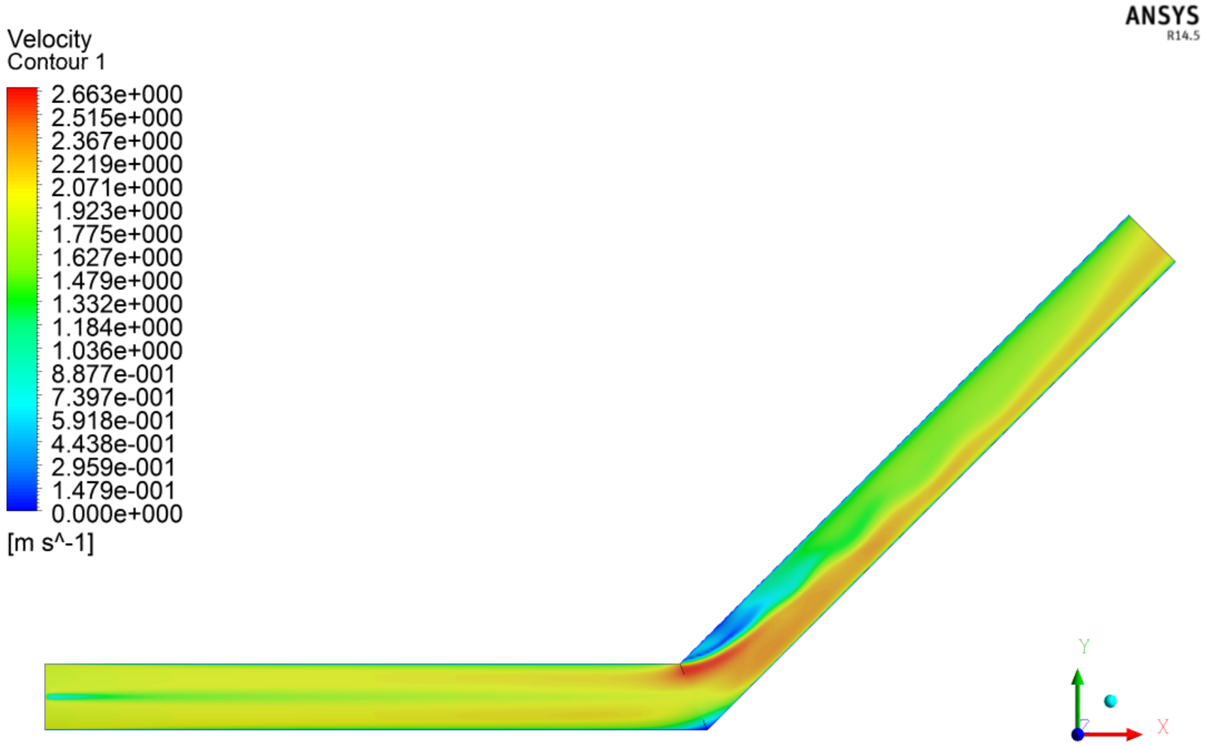

Figure 4.6 Oil Velocity Contour for 45° degrees inclination

The final oil velocity at inlet set for 45° degrees inclination that was able to push the SmartBall through the pipeline was 1.90 m/s. Based on the contour in *Figure 4.6*, on the horizontal part, the high velocity region was at the middle section of the pipe while the region near the walls has lower velocity. This is due to friction loss between the oil and the wall. However, at the bend, separation occurs. Since the inclination angle was bigger compared to previous cases, the separation region was relatively bigger.

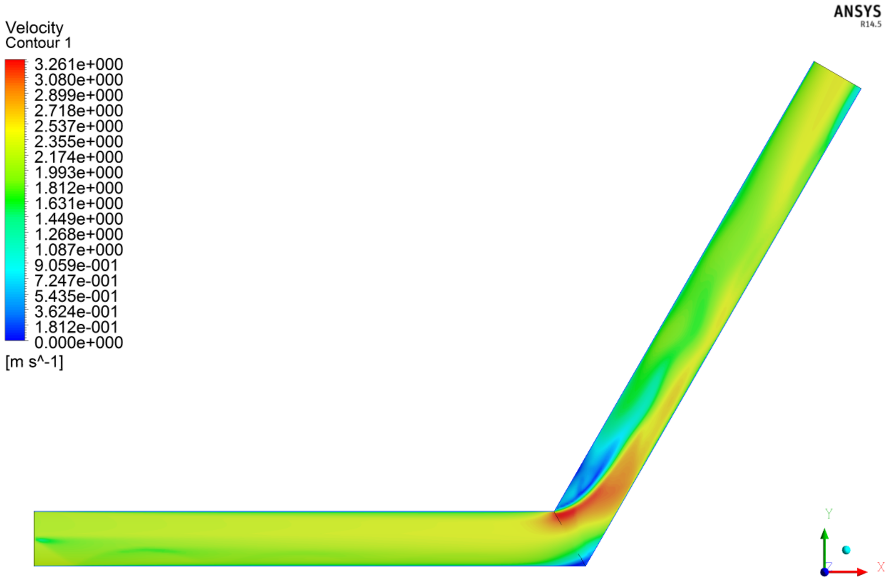

Figure 4.7 Oil Velocity Contour for 60° degrees inclination

The final oil velocity at inlet set for 60° degrees inclination that was able to push the SmartBall through the pipeline was 2.20 m/s. Based on the contour in *Figure 4.7*, on the horizontal part, the high velocity region was at the middle section of the pipe while the region near the walls has lower velocity. This was due to friction loss between the oil and the wall. However, at the bend, separation occurs. Since the inclination angle was bigger compared to previous cases, the separation region was relatively bigger.

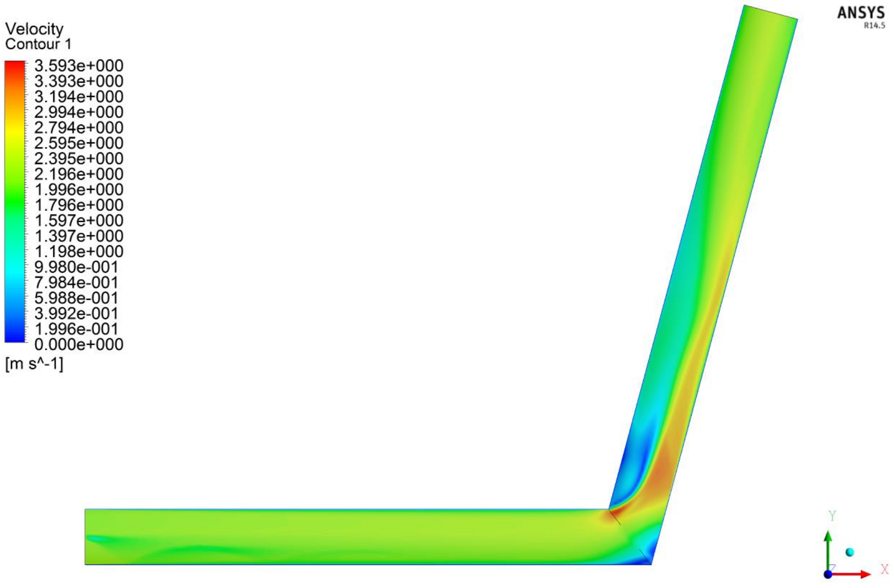

Figure 4.8 Oil Velocity Contour for 75° degrees inclination

The final oil velocity at inlet set for 75° degrees inclination that was able to push the SmartBall through the pipeline was 2.20 m/s. Based on the contour in *Figure 4.8*, on the horizontal part, the high velocity region was at the middle section of the pipe while the region near the walls has lower velocity. This was due to friction loss between the oil and the wall. However, at the bend, separation occurs. Since the inclination angle was bigger compared to previous cases, the separation region is relatively bigger.

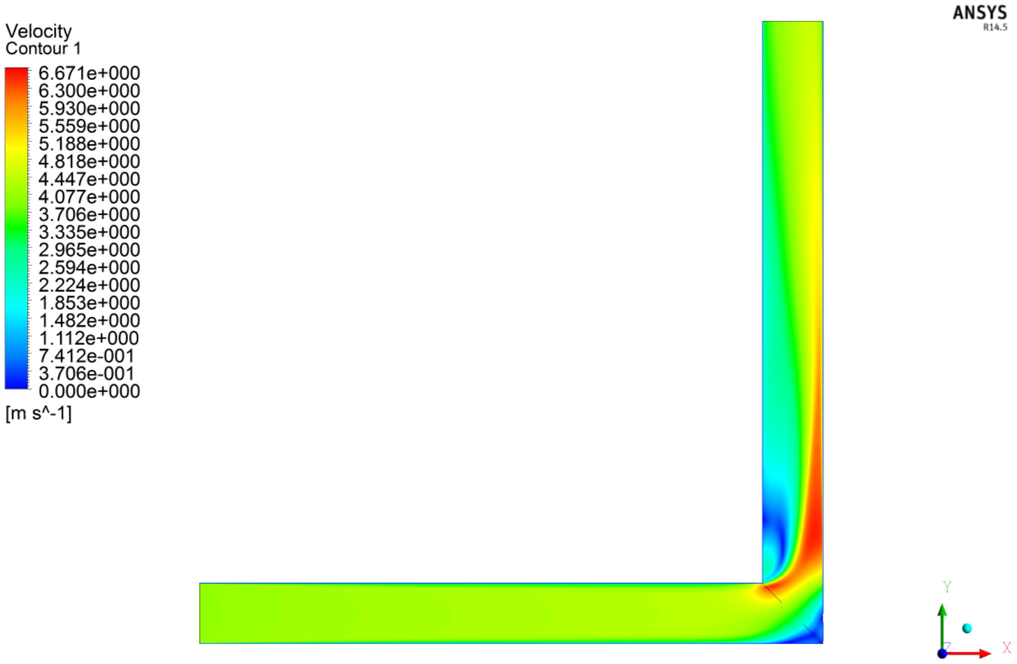

Figure 4.9 Oil Velocity Contour for 90° degrees inclination

The final oil velocity at inlet set for 90° degrees inclination that was able to push the SmartBall through the pipeline was 4.0 m/s. Based on the contour in *Figure 4.9*, on the horizontal part, the high velocity region was at the middle section of the pipe while the region near the walls has lower velocity. This was due to friction loss between the oil and the wall. However, at the bend, separation occurs. Since the inclination angle was bigger compared to previous cases, the separation region was relatively bigger.

4.4.2 The Oil Pressure Contours

For the purpose of this simulation, the pressure was initialized and fixed at 3 bar. Overall, the pressure drop between inlet and outlet were small. However, in all of the pipes with more than 0° degrees inclination, a high pressure region was observed at the bend. This is because the bend causes sudden change of direction and due to inertia, it will be difficult for the fluid to change direction as per the sudden change of direction which causes a high impact collision between the oil particle and the boundary walls at the bend. The greater angle of the bend and the speed of oil, the higher the pressure experienced at the bend.

Figure 4.10 Oil Pressure Contour for 0° degrees inclination

Based on *Figure 4.10,* the pressure across the region decreases as the distance increases. Since there is no elevation or bend, there were minimum pressure drop.

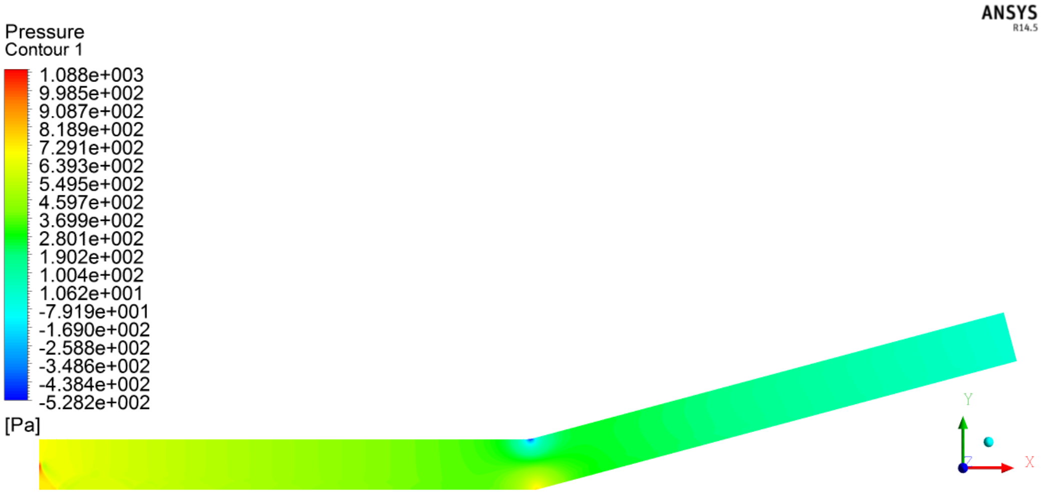

Figure 4.11 Oil Pressure Contour for 15° degrees inclination

Figure 4.11 shows the oil pressure across the pipe with 15° degrees inclination. As the distance increases, the pressure decreases. However, a relatively higher pressure region was developed at the outer part of the bend and as the distance from the bend increases, pressure decreases.

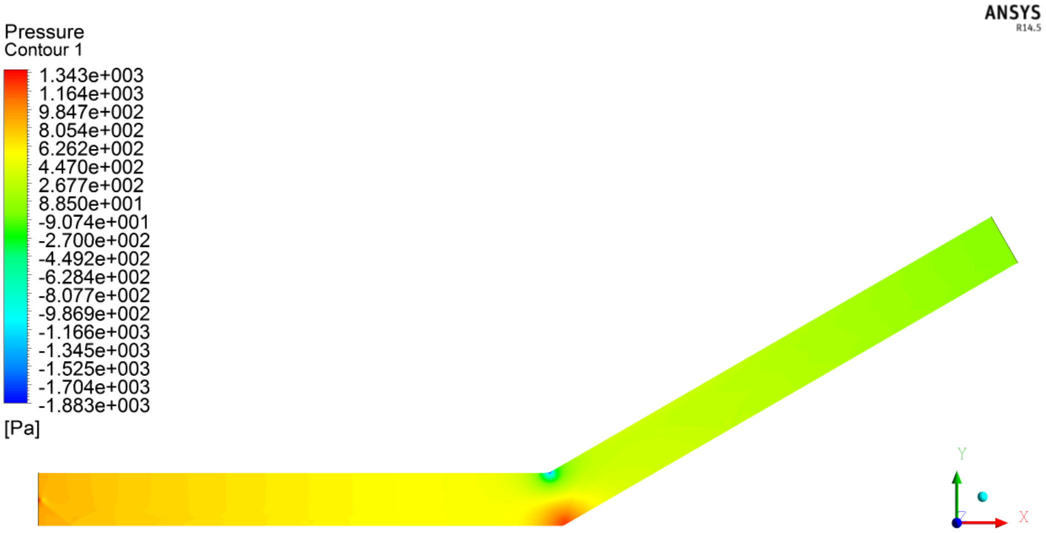

Figure 4.12 Oil Pressure Contour for 30° degrees inclination

Figure 4.12 shows the oil pressure across the pipe with 30° degrees inclination. As the distance increases, the pressure decreases. However, a relatively higher pressure region was developed at the outer part of the bend and as the distance from the bend increases, pressure decreases. Besides that, the high pressure region at the bend was also bigger compared to the previous pipe with smaller inclination.

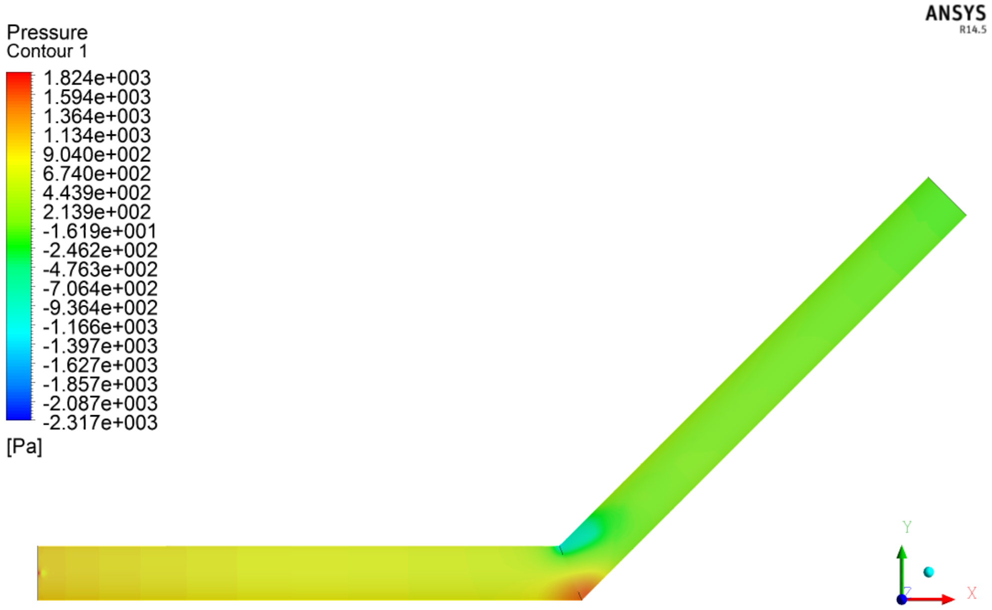

Figure 4.13 Oil Pressure Contour for 45° degrees inclination

Figure 4.13 shows the oil pressure across the pipe with 45° degrees inclination. As the distance increases, the pressure decreases. However, a relatively higher pressure region was developed at the outer part of the bend and as the distance from the bend increases, pressure decreases. Besides that, the high pressure region at the bend was also bigger compared to the previous pipe with smaller inclination.

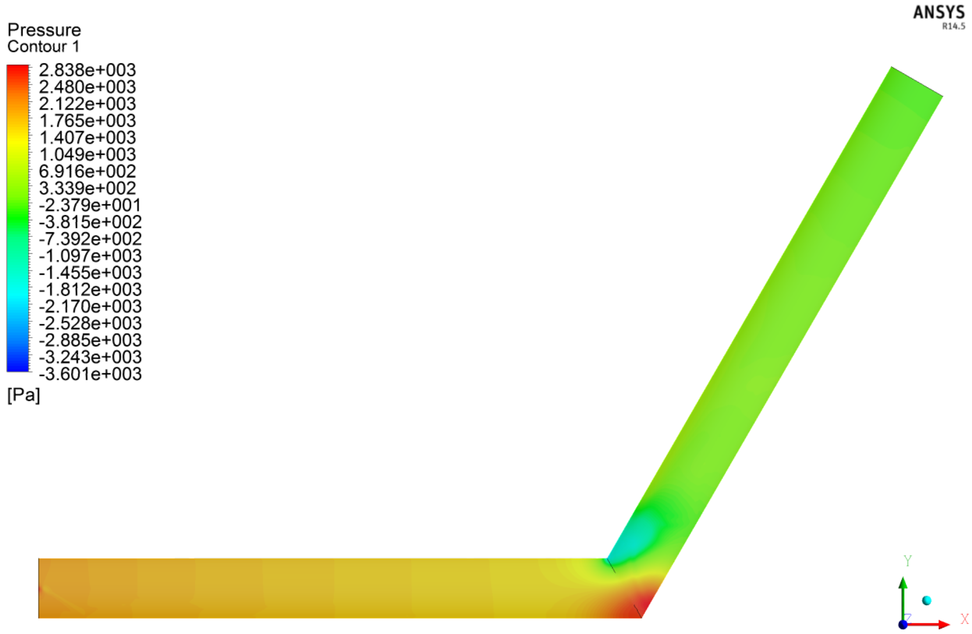

Figure 4.14 Oil Pressure Contour for 60° degrees inclination

Figure 4.14 shows the oil pressure across the pipe with 60° degrees inclination. As the distance increases, the pressure decreases. However, a relatively higher pressure region was developed at the outer part of the bend and as the distance from the bend increases, pressure decreases. Besides that, the high pressure region at the bend was also bigger compared to the previous pipe with smaller inclination.

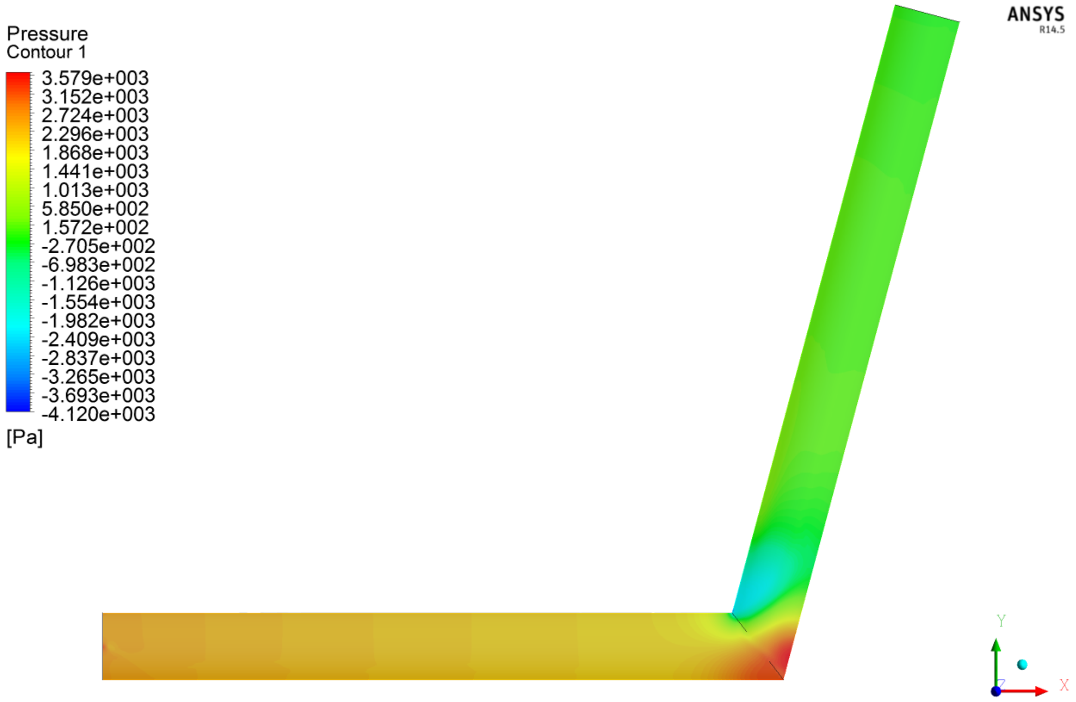

Figure 4.15 Oil Pressure Contour for 75° degrees inclination

Figure 4.15 shows the oil pressure across the pipe with 75° degrees inclination. As the distance increases, the pressure decreases. However, a relatively higher pressure region was developed at the outer part of the bend and as the distance from the bend increases, pressure decreases. Besides that, the high pressure region at the bend was also bigger compared to the previous pipe with smaller inclination.

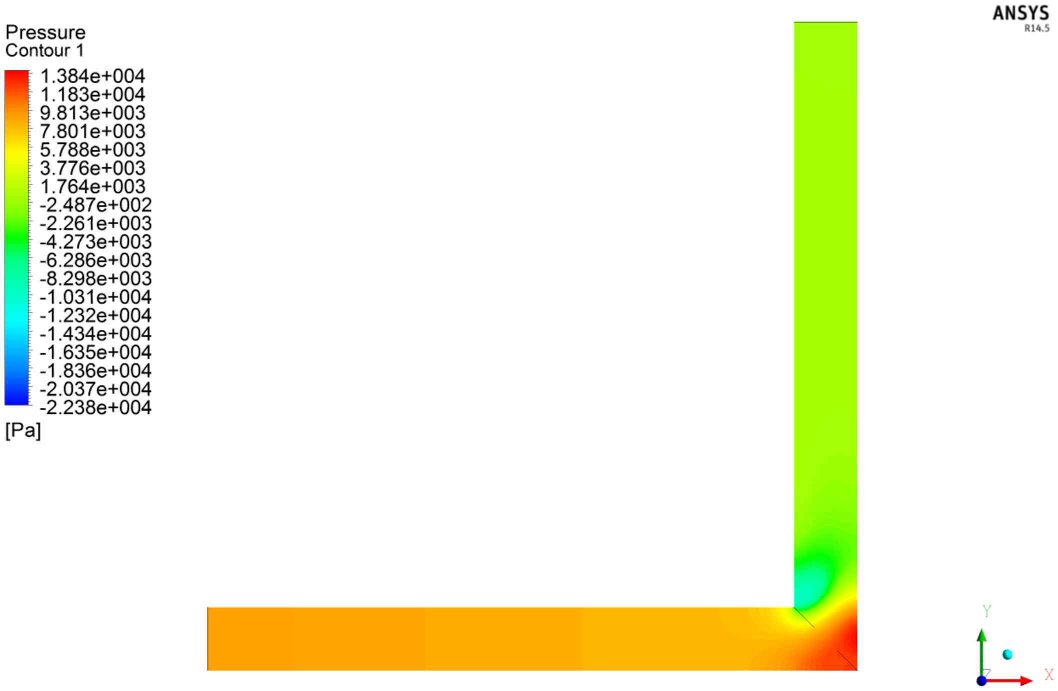

Figure 4.16 Oil Pressure Contour for 90° degrees inclination

Figure 4.16 shows the oil pressure across the pipe with 90° degrees inclination. As the distance increases, the pressure decreases. However, a relatively higher pressure region was developed at the outer part of the bend and as the distance from the bend increases, pressure decreases. Besides that, the high pressure region at the bend was also bigger compared to the previous pipe with smaller inclination.

4.4.3 The SmartBall Velocity Contours

For this simulation, the SmartBall initial velocity was set to be 0 m/s because we want it to rely solely on oil propulsion. SmartBall is different than the conventional PIG because it doesn't occupy the whole pipe diameter and does not rely on pressure propulsion to move along a pipeline. SmartBall is a device which moves freely in a pipeline recording acoustic activities as it travels.

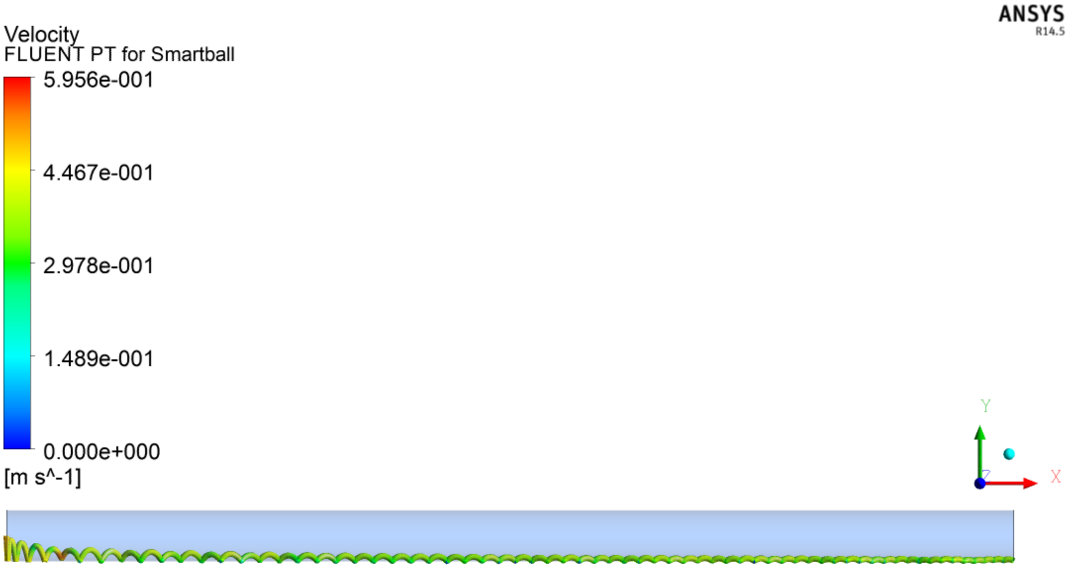

Figure 4.17 The SmartBall Velocity Contour for 0° degrees inclination

Figure 4.17 shows the SmartBall trajectory along the pipeline as it travels with oil flow propulsion. The velocity of oil for this case was 0.5 m/s and based on *Figure 4.17*, the average SmartBall velocity was between 0.29 m/s and 0.40 m/s which was slower than the velocity of oil. This is because the SmartBall is denser than oil, hence it is relatively heavier which results to SmartBall lower velocity compared to oil velocity.

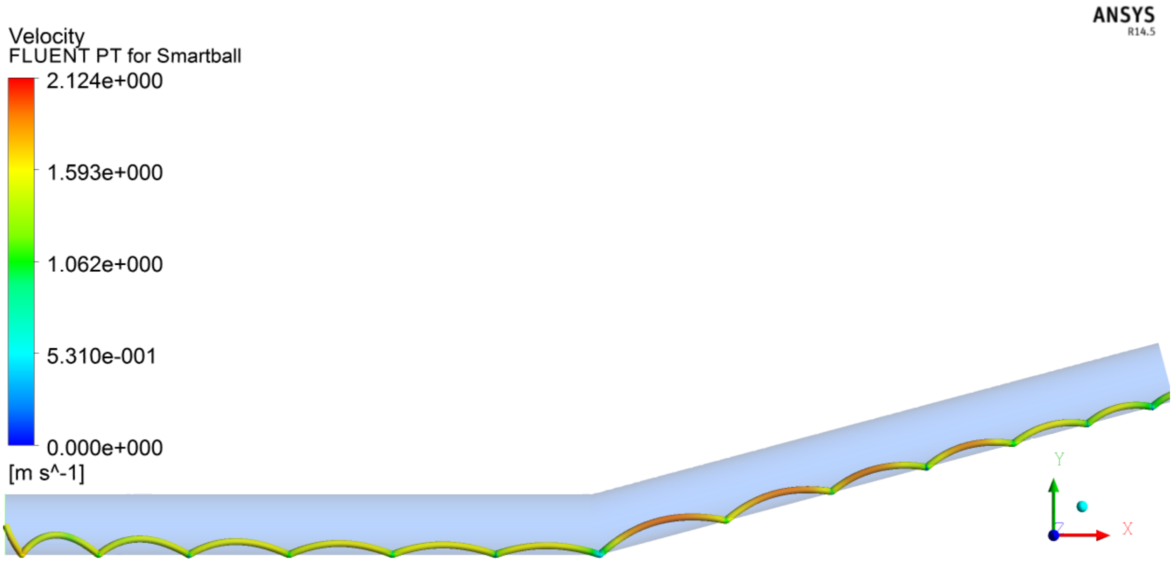

Figure 4.18 The SmartBall Velocity Contour for 15° degrees inclination

Figure 4.18 shows the SmartBall trajectory along the pipeline as it travels with oil flow propulsion. The velocity of oil for this case was1.75 m/s and based on *Figure 4.18*, the average SmartBall velocity was between 1.06 m/s and 1.59 m/s which was slower than the velocity of oil. This is because the SmartBall is denser than oil, hence it is relatively heavier which results to SmartBall lower velocity compared to oil velocity.

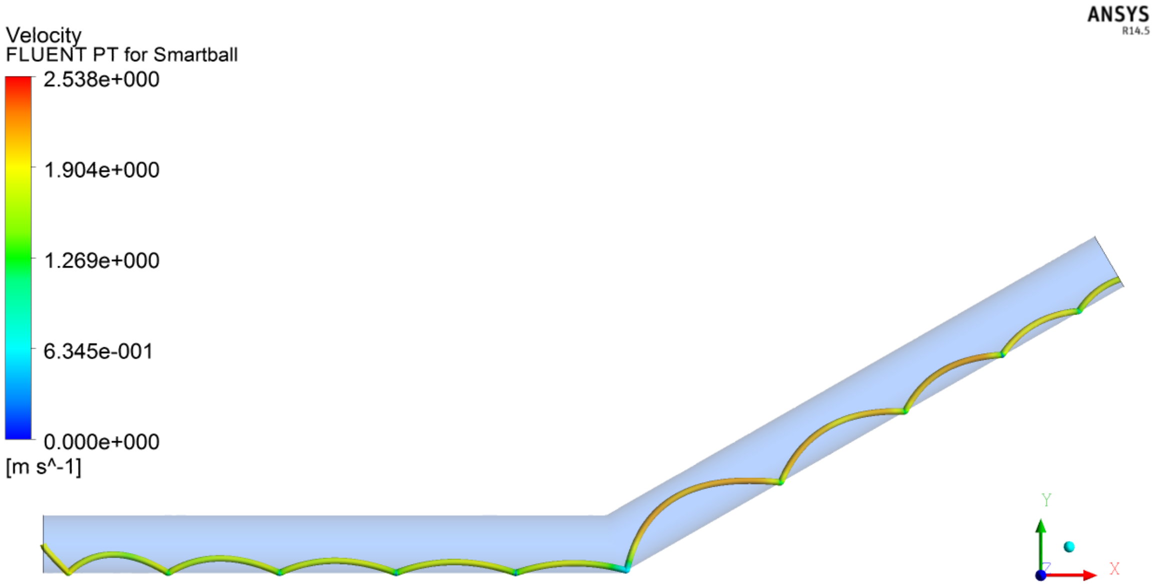

Figure 4.19 The SmartBall Velocity Contour for 30° degrees inclination

Figure 4.19 shows the SmartBall trajectory along the pipeline as it travels with oil flow propulsion. The velocity of oil for this case was 1.90 m/s and based on *Figure 4.19*, the average SmartBall velocity was between 1.27 m/s and 1.90 m/s which was slower than the velocity of oil. This is because the SmartBall is denser than oil, hence it is relatively heavier which results to SmartBall lower velocity compared to oil velocity.

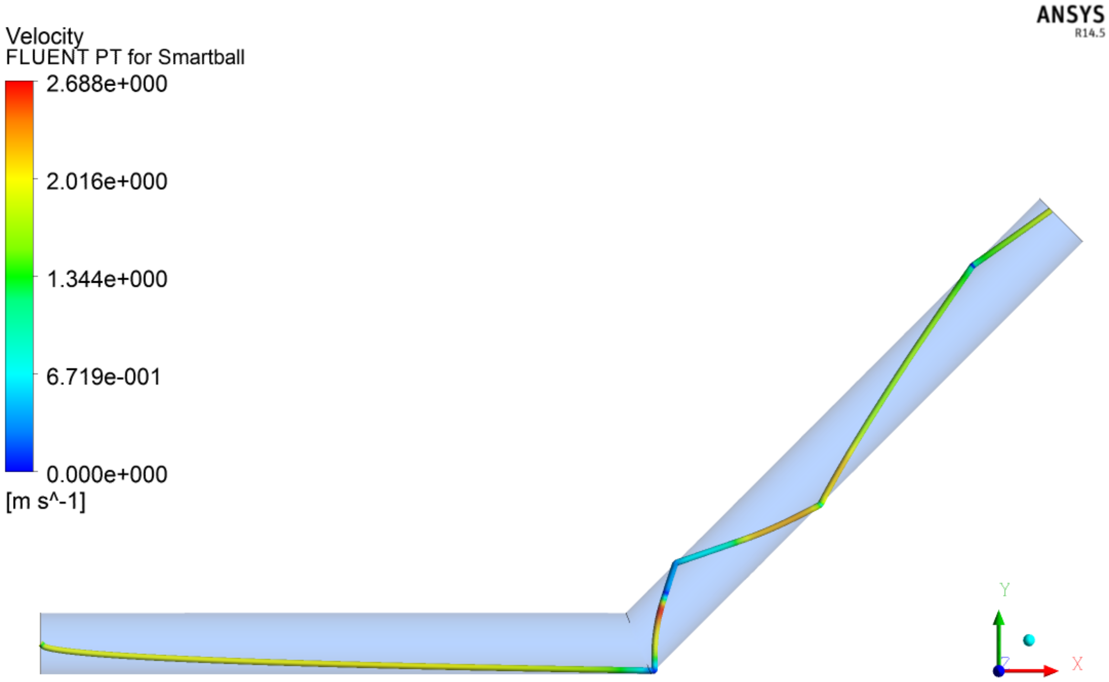

Figure 4.20 The SmartBall Velocity Contour for 45° degrees inclination

Figure 4.20 shows the SmartBall trajectory along the pipeline as it travels with oil flow propulsion. The velocity of oil for this case was 1.90 m/s and based on *Figure 4.20*, the average SmartBall velocity was around 1.34 m/s which was slower than the velocity of oil. This is because the SmartBall is denser than oil, hence it is relatively heavier which results to SmartBall lower velocity compared to oil velocity. However, there were very small regions has a speed around 2.02 m/s, slightly higher than the velocity of the oil because of it travels passed high pressure region at the bend which help propel the SmartBall as based on *Figure 4.13*, the bend experienced a bigger higher pressure region compared to previous cases.

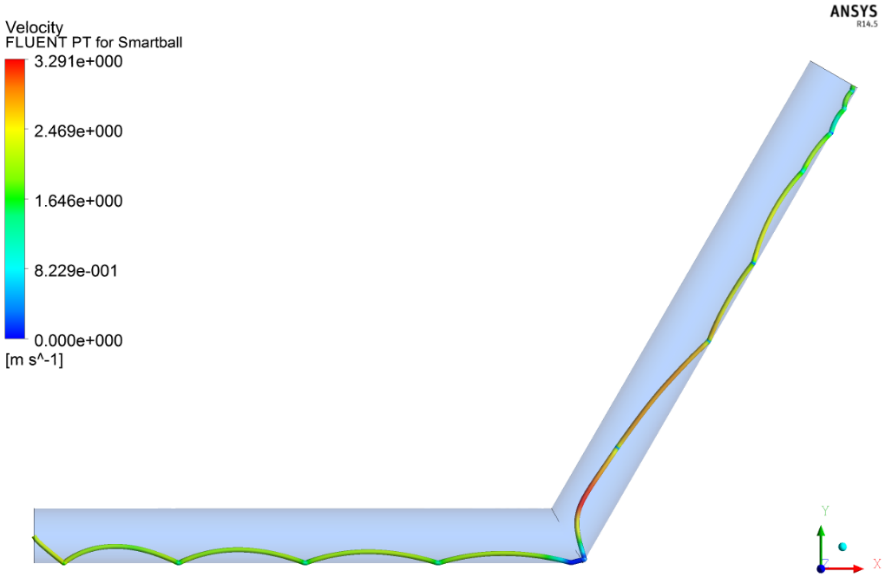

Figure 4.21 The SmartBall Velocity Contour for 60° degrees inclination

Figure 4.21 shows the SmartBall trajectory along the pipeline as it travels with oil flow propulsion. The velocity of oil for this case was 2.20 m/s and based on *Figure 4.21*, the average SmartBall velocity was around 1.64 m/s which was slower than the velocity of oil. This is because the SmartBall is denser than oil, hence it is relatively heavier which results to SmartBall lower velocity compared to oil velocity. However, there were very small regions has a speed around 3.29 m/s, slightly higher than the velocity of the oil because of it travels passed high pressure region at the bend which help propel the SmartBall as based on *Figure 4.14*, the bend experienced a bigger higher pressure region compared to previous cases.

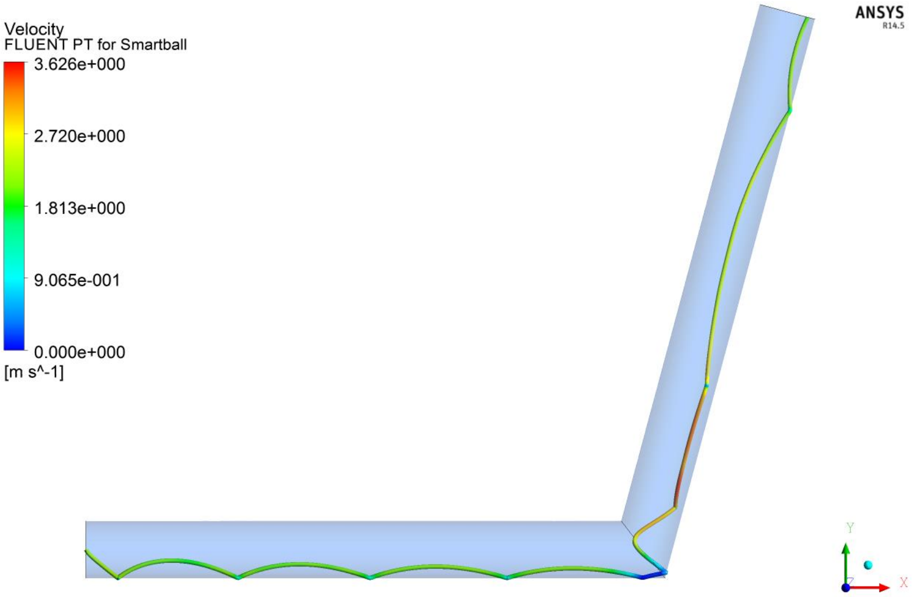

Figure 4.22 The SmartBall Velocity Contour for 75° degrees inclination

Figure 4.22 shows the SmartBall trajectory along the pipeline as it travels with oil flow propulsion. The velocity of oil for this case was 2.20 m/s and based on *Figure 4.22*, the average SmartBall velocity was around 1.81 m/s which was slower than the velocity of oil. This is because the SmartBall is denser than oil, hence it is relatively heavier which results to SmartBall lower velocity compared to oil velocity. However, there are very small regions has a speed around 3.62 m/s, slightly higher than the velocity of the oil because it travels passed high pressure region at the bend which help propel the SmartBall as based on *Figure 4.15*, the bend experienced a bigger higher pressure region compared to previous cases.

Figure 4.23 The SmartBall Velocity Contour for 90° degrees inclination

Figure 4.23 shows the SmartBall trajectory along the pipeline as it travels with oil flow propulsion. The velocity of oil for this case is 4.00 m/s and based on *Figure 4.23*, the average SmartBall velocity was around 3.89 m/s which was slower than the velocity of oil. This is because the SmartBall is denser than oil, hence it is relatively heavier which results to SmartBall lower velocity compared to oil velocity. However, there are very small regions has a speed of around 5.84 m/s, slightly higher than the velocity of the oil probably because it travels passed high pressure region at the bend which help propel the SmartBall as based on *Figure 4.16*, the bend experienced a bigger higher pressure region compared to previous cases.

Table 4.1 shows the summary of the results obtained from the simulation. Generally as the angle of inclination increases, the velocity of oil required to push the ball increases and the average velocity of SmartBall are less than the velocity of oil.

Angle of Inclination (° degree)	**Velocity of Oil (m/s)**	**Average SmartBall Velocity Range (m/s)**
0	**0.5**	**0.29 – 0.40**
15	**1.75**	**1.06 – 1.59**
30	**1.9**	**1.27 – 1.90**
45	**1.9**	**Around 1.34**
60	**2.2**	**Around 1.64**
75	**2.2**	**Around 1.81**
90	**4**	**Around 3.89**

Table 4.1 Summary of the Results

CHAPTER 5

5 Conclusion and Recommendations

5.1 Conclusion

Despite the importance of inspection, steps need to be taken to avoid inspection device malfunction. Tracking an inspection device in this case, the SmartBall will be crucial in order to not only locate the leaks but also to track it in case it got stuck. Since SmartBall doesn’t occupy the whole diameter of the pipe like the conventional PIG, necessary parameters need to be determined to avoid it being stuck in a pipeline.

Besides that, based on observations from the simulation results, the SmartBall work best at inclinations below 60° as it does not wobble too much which may distort the acoustic recordings. However, steps can be taken to ensure it works above 60°, such as increase the diameter of the outer layer to increase propulsion area and reduce wobbling.

From this study, the author had design a SmartBall and was able to predict the velocity required to propel the SmartBall through the pipeline with various inclination. The simulation was also able to display probable trajectory of the SmartBall movement along the pipeline.

5.2 Recommendation

Based on the study conducted, there are a few recommendations that need to be considered in order to improve the foundation of this study:

i. **Conduct a laboratory scale experiment**

   In order to validate the results of this simulation, a prototype need to be constructed and tested in a laboratory. This is important because we need to make sure that the SmartBall will be able to travel along a pipeline in its real-case application.

ii. **Conduct an experiment based on a case study**

   A case study based on a pipeline used in the oil and gas industry need be taken as reference so that a more realistic evaluation can be done.

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