# Modelling Erosion using Computational Fluid Dynamics – ANSYS

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# CERTIFICATE OF APPROVAL

**MODELLING EROSION USING COMPUTATIONAL FLUID DYNAMIC - ANSYS**

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A project dissertation submitted to the

Petroleum Engineering Department

Universiti Teknologi PETRONAS

In partial fulfillment of the requirements for the

BACHELOR OF ENGINEERING (Hons)

PETROLEUM ENGINEERING

Approved by,

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(Mr. Titus Ntow Ofei)

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TRONOH, PERAK

MAY 2015

## 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 that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(AHMAD FARIS B HUSNIN)

# ABSTRACT

A numerical simulation is proposed of erosion–corrosion phenomena in two-phase flows comprising of immiscible liquid and particulate solid. The simulation geometries are a pipe bend and bean choke the evaluated quantity is the wall erosion–corrosion brought about by the flow of a fluid mixture of liquid phase and a solid phase. A computational fluid dynamic tool has been adopted for the simulation of the flow field inside the piping and for the simulation of the particle trajectories and impact rates. As far as corrosion is concerned, a passivating and an actively corroding metallic material have been considered. Erosion model parameters have been derived from experiments correlating particle impact angle and erosion rate. Corrosion model parameters have been obtained from electrochemical measurements. The effects of the key operating parameters (fluid flow velocity and particulate content) have been evaluated by a two-level design of experiments approach. The single most important effects on synergistic damaging and on the ratio of corrosive to overall damaging have been identified. Erosion-enhanced and erosion-limited effects of flow conditions have been highlighted for the passivating and for the actively corroding alloys, respectively

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background Study

Degradation of pipe fittings and related supplies in oil and gas pipelines is a constant issue experienced by pipeline engineers (Kumar, P. G. et al., 2014). Numerous sand management frameworks have been executed over a time of time to prohibit sand at its source down hole of the well. These sand exclusion strategies include gravel packing at the well head and/or utilizing screens to avoid sand from entering the pipeline. These sand exclusion systems alongside continuous sand observing and control have been fruitful in chopping down the production of sand in the pipelines lines to a vast degree and are widely utilized as a part of oil and gas production wells. Hydrocarbon wells produce a complex multiphase mixture of components including hydrocarbon liquids, solids and gases and with that it create an erosion damages to the pipelines. Example of the damages are particulate erosion, liquid droplet erosion, erosion-corrosion and last but not least cavitation.

Transport phenomena in oil & gas pipeline is a multi-phase particulate modelling problem. The issues like slugging, hydrates, wax, erosion & corrosion, gel, flow induced vibration and sand transport is of immense impact on flow assurance. It is generally accepted that particulate (sand and proppants) are the common source for erosion. Particulate erosion is a function of impact velocity, density and viscosity.

For this project, ANSYS software is used to model the erosion process in oil & gas pipes and therefore predict the pitting and estimate the mechanical strength. The geometry of the pipe and fitting on the flow assurance will also be study and see effect to the erosion damage.

## 1.2 Problem Statement

Qualitative and quantitative erosion prediction equations have been attempted since the times of Finnie in 1960, who developed an erosion model based on the cutting of material of construction by sand particles. This model could not predict the erosion occurring at higher impact angles and hence Bitter, modified Finnie's equation by adding deformation wear to Finnie's cutting action. Fluid flow phenomena of the sand particles are based on the impact location and also velocity, thus Computational Fluid Dynamics (CFD) is widely used to predict the dynamic of the flow field. CFD also takes account of erosion rates of the pipes and therefore the expectant lifespan of the pipe can be evaluated. The geometry of the pipe and fitting can also be design and modified using CFD, thus predict its effect on the flow assurance. By prediction of erosion we not only be able to estimate the service life of the pipe, but also we can see where the location in the geometry is much more severe to erosion.

## 1.3 Objectives

The objectives of this project are:

- To model the erosion process in oil and gas pipes.
- To predict the erosion rate of the pipes.

## 1.4 Scope of Study

This project is oriented towards the understanding of corrosion and erosion using Computational Fluid Dynamics (CFD) – ANSYS Software. The scope for this project included the analysis of degradation of the pipelines over time, for example, horizontal pipeline, pipe bend and choke bend. This is sufficient enough to in determining the flow assurance of the fluids. From the CFD test, the corrosion or erosion rate can simply be acquired by simulating the fluid flow throughout the pipelines. On the other hand, the mechanical strength and pitting of the pipelines also been tested on the simulation mentioned above.

## 1.5 Relevancy of Project

This project highly involves in a comprehensive technical investigation and covers most of the petroleum engineering scope. Knowledge of corrosion engineering and ANSYS software are mostly in use in order to solve this project. Precision and accuracy are very important aspect when doing this project.

Company regards that the determination of a corrosion is a very important because most of the company need to know how much corrosion will occur at the pipe and from there, we can reduce the amount of corrosion and thus will increase the efficiency of it. Therefore gives the company more profits because the cost to repair is very high. Company also apply the concept of prevention is better than cure. Thus from ANSYS software we can predict and prevent any type of corrosion.

Throughout this project, the author has been closely and directly involved with the progress of the operations. The author has been also been able to communicate directly with the supervisors and lecturers related to the project. By involving himself directly to the project, the author is able to improve on his knowledge and skills in related to corrosion and also ANSYS software in general.

After going through with all the circumstances of this project, the author also expands his foundation on the understanding of the corrosion based on ANSYS software.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Erosion

Sand erosion is usually experienced in the oil and gas industry (Kulkarni, G., et al., 2012). Serious harm to the production facilities can happen if the sand is not taken care of appropriately. The sand produced with oil and gas is ordinarily sifted down hole and observed at different discriminating areas in the pipeline. The down hole sand screen restricts the size and measure of sand that can travel through it.

The material of the pipeline and different segments is likewise critical for relieving the sand erosion damage. Most of the time, the oil and gas production rate must be restricted because of intemperate sand erosion. The outline of the oil and gas production systems to securely withstand sand erosion and all the while advance production obliges a dependable sand erosion prediction tools

## 2.2 Corrosion

Corrosion is the ruinous assault of a material by reaction with its surroundings and a regular potential peril connected with oil and gas production and transportation facilities (Brondel, D., et al., 1987). Pretty much any watery environment can advance erosion, which happens under various complex conditions in oil and gas generation, transforming, and pipeline frameworks. On account of oil and gas wells and pipelines, such very corrosive media are carbon dioxide ($CO_2$), hydrogen sulfide ($H_2S$), and free water. Nonstop extraction of $CO_2$, $H_2S$, and free water through oil and gas parts can over the long run make the internal surfaces of these segments to experience the ill effects of corrosion impacts.

Corrosion costs US commercial ventures alone an expected $170 billion a year. The oil business, with its unpredictable and demanding production methods, and the environmental danger ought to parts come up short, takes an above normal share of these expense. Corrosion attacks each part at every stage in the life of oil and gas field. From casing strings to production platforms, from drilling to abandonment, corrosion is a foe worth of all the high innovation and research we can toss at it.

## 2.3 CFD Approach

A computational fluid dynamic software has been chosen for the simulation of the stream field inside the piping and for the simulation of the particle directions and their effect on the curve dividers. CFD is right now one of the more refined and guaranteeing methodologies for the investigation and arrangement of a wide class of issues including flow areas and in a wide set of exploration and industrial application fields.

Turbulence can be approximated by distinctive models. Specifically, the CFX code brought for this study solves the balance equation through discretisation, utilizing a control volume methodology to change the balance partial differential equations (PDEs) into algebraic equations fathomed numerically. The CFX code has been utilized as a part of the investigation of solid particle erosion in gas flow in components of complex geometry.

The balance equations will therefore integrates the solution procedure in each of the control volume and therefore the discrete equations can be obtain via control volume basis that conserve primary quantities. Flow field quantities can be define by numerical solution that most possibly used by routines implementing models for further flow-related quantities, for example phases transported by a given fluid phase. One of the big contribution for this class of fluid dynamic codes is the capability to simulate and identify the flows and geometric domains of the complex fluid, both in two- and three-dimensions without forgetting the turbulence effects.

Therefore CFD modelling provides the user with detailed information on the exact location and magnitude of the erosive wear. In CFD, there are two types of simulations that can be done which are:

- Single phase Computational Fluid Dynamics simulation
    - Applicable for dilute particle phase
    - Based on Eulerian-Lagrangian methodology
        - Single phase simulation + DPM
    - Lots of literature and many erosion models
    - Provides detailed information on the exact location and magnitude of the erosive wear
    - Potential to allow design to be optimized prior to testing
- Multiphase Computational Fluid Dynamics simulation
    - More realistic for full particle loading from low, medium to high range
    - Based on Eulerian-Granular multi-fluid approach
    - Captures four-way couplings including fluid-particle, particle-fluid, particle-particle and turbulence interactions
    - Capture particle shielding and liquid damping effects.

## 2.4 Model Description

The generalized erosion prediction procedure consists of three separate models or simulations: 1) flow modeling, 2) tracking of a large number of sand particles, and 3) application of empirical erosion equations. CFX contains the ability to couple the equations governing fluid motion and the particle equation of motion. This ability has not been employed in this work due to the low particle concentrations that are used. The flow simulation contains the information necessary to perform all subsequent calculations. Velocity components, turbulence quantities (turbulent kinetic energy and dissipation rate), as well as the carrier fluid properties (density and viscosity) are all contained within the flow field simulation.

Once a simulated flow field is obtained using the CFD code, the solution is seeded with a large number of sand particles at the inlet to the geometry. A large number of particles, on the order of several thousand, is normally required in order to obtain a reasonable distribution and to reduce scatter in the erosion predictions. Each particle is tracked separately through the flow field and particle impingement information (velocity and location) is gathered as particles strike the walls. For each particle impingement, a set of empirical erosion equations is applied. These relations are used to determine the mass loss resulting from that impingement. These erosion equations account for the impingement speed and angle, as well as the particle shape and mechanical properties of the wall material. In order to visualize erosion predictions in a convenient manner, predicted erosion data is transferred to a postprocessor. This postprocessor is used to generate contour plots of predicted erosion quantities. This allows not only the simultaneous examination of the flow solution, particle trajectories, and erosion predictions, but also provides the ability to identify areas of high erosion.

# CHAPTER 3

# METHODOLOGY

## 3.1 Preliminary Study

The project started by doing a background study research on the topic related to further my understandings about it. All the information and details regarding the fluid flow and properties of hydrocarbon used are very important for this topic because all this sample will influence the simulation later. The author usually obtained all the information from journal and research papers done by previous authors and also through the books that author borrowed from UTP library. Not to be forget author's supervisor also helped in gathering the information related to the topic.

## 3.2 Pre-Simulation Work

This subtopic represents the preparation for the simulation and listing all the parameters and properties of the fluid involved in this experiment. Below are the lists of parameters proposed in this simulation:-

- Liquid particles : Oil and water
- Solid particles : Sand
- Velocity of the fluid flow
- Diameter of the Pipe
- ANSYS Software – CFX

### 3.3 Simulation Work

For this simulation project to be begin, first the author need to download the ANSYS software into his laptop so that it will be easier for the author to do the simulation since the corrosion lab in the UTP is always occupied with other more important project. Then the model is created into pipe bend and venturi tube to be stimulate using CFX

#### 3.3.1 Pipe Bend

Pipe bend with a radius of curvature of 4D with a vertical inlet and horizontal outlet is created and modelled, as shown in **Figure 1**. A multi-phase parameters are used in this model to determine the erosion rate. The parameters are as below:

- Inlet velocity : 20 m/s
- Mixture viscosity : $1.5 \times 10^{-5}$ kg/(ms)
- Mixture density : 65 $kg/m^3$
- Pipe ID : 25 mm
- Radius of curvature : 4 D
- Particle size : 0.25 mm

#### 3.3.2 Bean Choke

While for a bean choke, a model is sketched and created and the inlet flow and outlet flow also shown in **Figure 1**. The particle parameters and fluid flow used are as mentioned below:

- Inlet velocity : 10 m/s
- Mixture viscosity : $1.5 \times 10^{-5}$ kg/(ms)

- Inlet ID : 60 mm
- Outlet ID : 30 mm
- Particle size : 0.25 mm

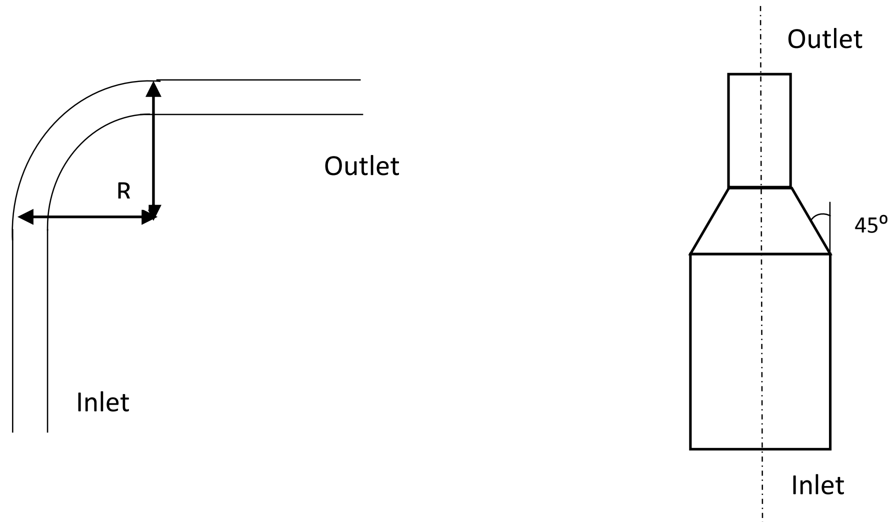



**Figure 1 Pipe Bend and Bean Choke Schematic Diagram**

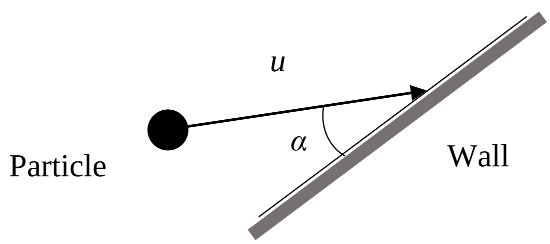
### 3.5 Method of Analysis

The sand erosion simulation is performed in four stages; grid generation, flow solution, particle track calculation and erosion rate computation. The initial three stages are performed with CFX, though the models developed by DNV perform the fourth step. The methodology connected in the initial three stages and the DNV erosion model is outlined beneath.

The CFD program CFX contains the greater part of the elements that are of significance for erosion issues. The grid system is suited to model complex streamlined, or irregular fluid domains. With a multi-block grid system, optimized grid might likewise be made, making computational times well disposed. On the other hand, care must be taken when making the grid. The standard k-e technique is petitioned the turbulence modelling, and a merged turbulence field must be accomplished keeping in mind the end goal to anticipate the correct particle movement. Just a grid that has adequate resolution, orthogonality close to the walls, and a sensible grid expansion guarantees a merged turbulence field.

During the flow calculations a steady state one-phase flowfield is produced. The flow may be either incompressible, or compressible. By accepting mixture amounts for the flow parameters, (for example, velocity, density, viscosity, and so on.), multi-phase flows are approximated. At the point when the flow and turbulence fields are met, the molecule tracks are tackled on the steady state flowfield. Up to 10 000 particles are discharged at self-assertive areas at the domain inlet, where the molecule tracking routine inside CFX is connected.

Erosion calculations are performed with a general method taking into account the circumstance indicated beneath, where *u* is the hit velocity and *α* is the hit angle (Det Norske, 1996):



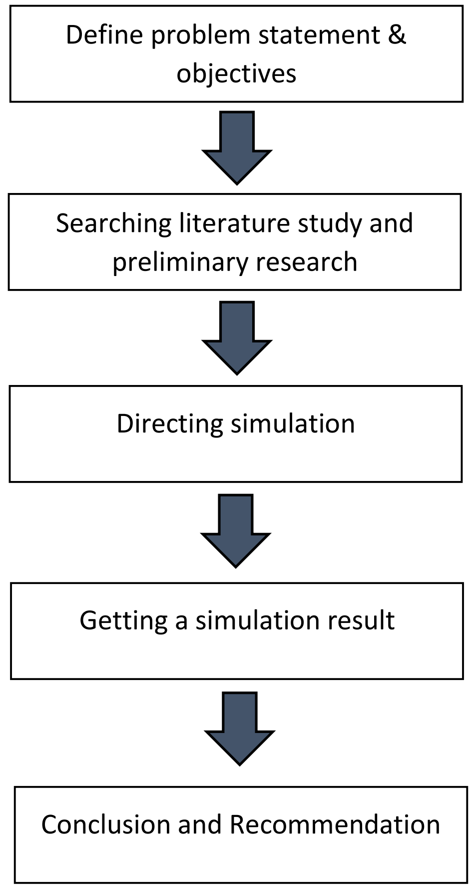

The general equation for the erosion rate is written as follow (W. F. Adler, 1979):

$$E_L = C_{unit} \frac{K u^n \dot{m}_p F(\alpha)}{\rho_w A} \tag{1}$$

Here $E_L$ is the erosion rate in mm/year, $C_{unit}$ = 3.15×1010 is a converting factor from m/s to mm/year, *K* is a material constant, *p m*& (kg/s) is the massflow of sand that hit the area, *A* ($m^2$) is the size of the area exposed to erosion, *rw* ($kg/m^3$) is the wall material density, *n* is the velocity exponent which is dependent of the material, and *F*(*a*) is a number between 0 and 1 given by a functional relationship dependant of the material.

### 3.4 Flowchart

Figure below is the flowchart for my given project.




### 3.5 Gantt Chart

In this section, the author had planned the project timeline throughout the whole 8 months. **Figure 2** and **Figure 3** are the project timeline starting from FYP 1 until FYP 2.

3.5.1 Project Timeline (FYP 1)

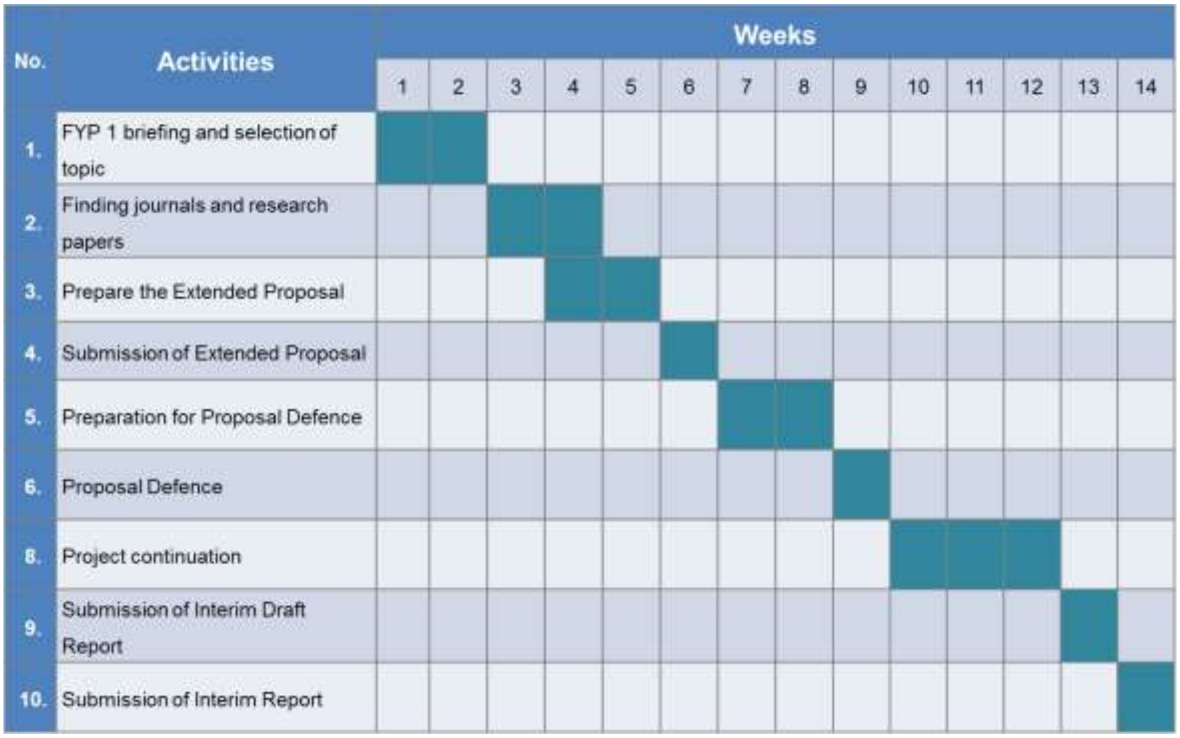



**Figure 2 Gantt chart for FYP 1**

3.5.2 Project Timeline (FYP 2)


**Figure 3 Gantt chart for FYP 2**

# CHAPTER 4

# RESULT

The space domain for the CFD analysis refers to a 90◦ pipe bend and bean choke. A three-dimensional mesh has been set up, by adding further volumes both at the inlet and the outlet of the bend. The former, corresponding to several tens of diameters in length with respect to the Reynolds number of the flow, in order to reach both a steady, fully developed flow and a sufficient dispersion of the particles injected in the stream, prior to reaching the bend zone. The latter in order to avoid possible recirculation flow paths at the outlet surface of the domain, thus leading to numerical convergence errors or unphysical results. A scheme of the regular, hexahedral mesh made up by 111,000(before optimum value calculated) volumes is depicted in figure below. A preliminary sensitivity study on the mesh size led to an acceptable compromise between accuracy in flow field simulation and computational time required by the code runs.

## 4.1 Pipe Bend

After a several meshing upon the pipe bend and bean choke, an optimum number of elements at each materials can be achieved. A graph below shows the optimum number of elements for pipe bend, at 300,000 number of elements is the optimum

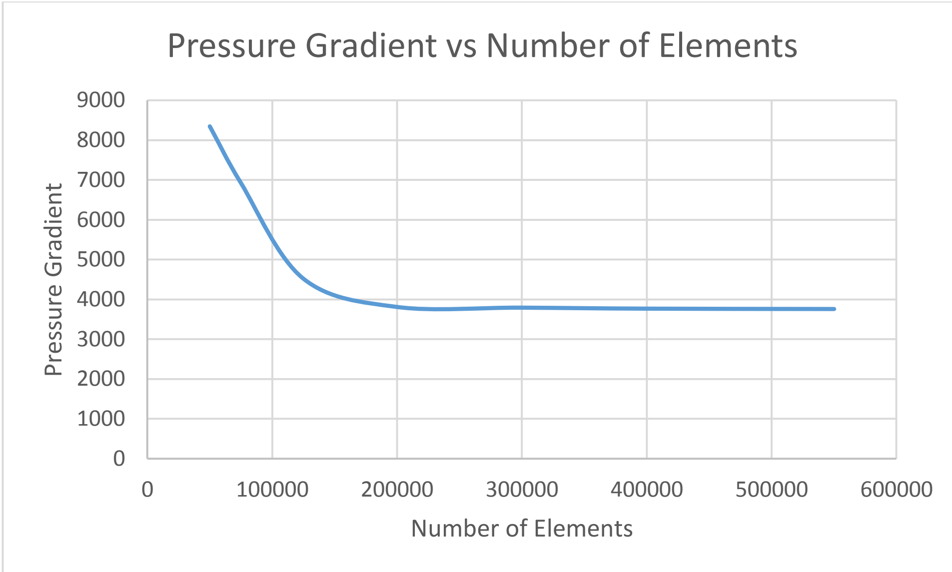



**Figure 4 Pressure Gradient vs Number of Element Graph**

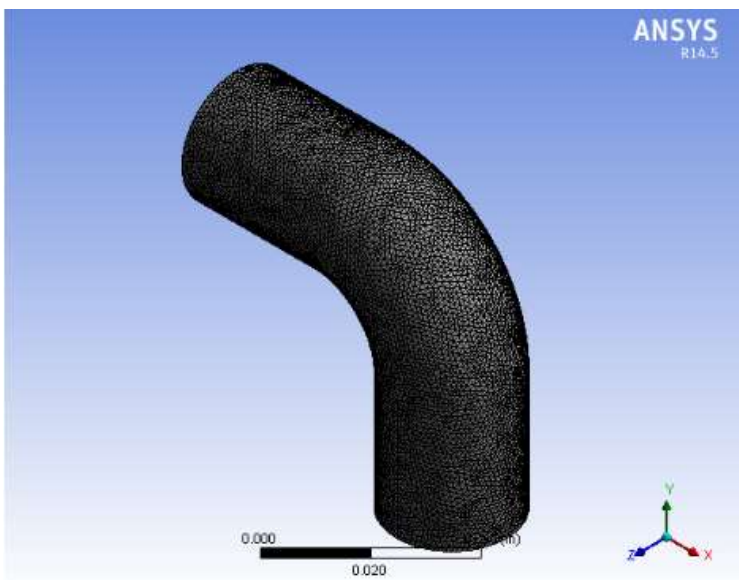



**Figure 5 Pipe Bend**

**Figure 4** above shows the result of the optimized meshing on the pipe bend with the number of elements of approximately 350,000. The reason we optimized the meshing is to get an accurate result and at the same time it takes lesser time. We also can obtained a more accurate result by increasing the number of elements of meshing but it will consume a much longer time. But upon reaching the optimized value, the difference of the accuracy is not that significant, around only 2%. So it is why optimum value of number of elements is used instead.

After obtained the optimum mesh up on a pipe bend, the author examine the pipe bend to check the pressure contour and velocity profile as shown in **Figure 6** and **Figure 7** respectively.

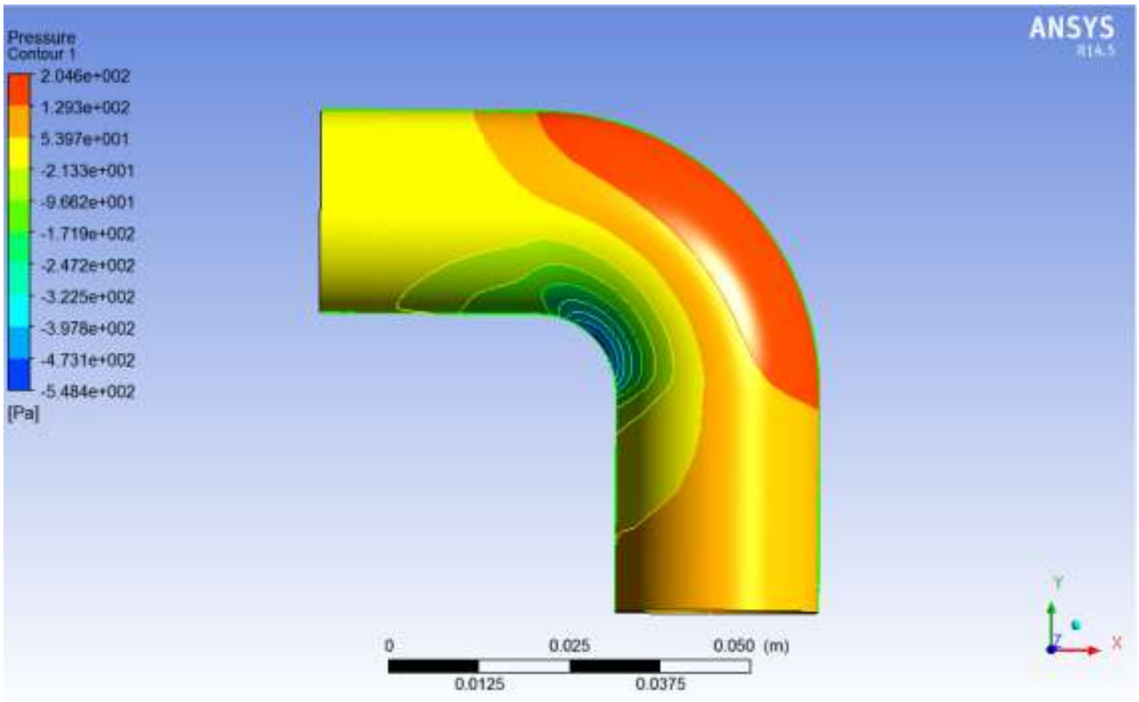



**Figure 6 Pressure Contour of Pipe Bend**

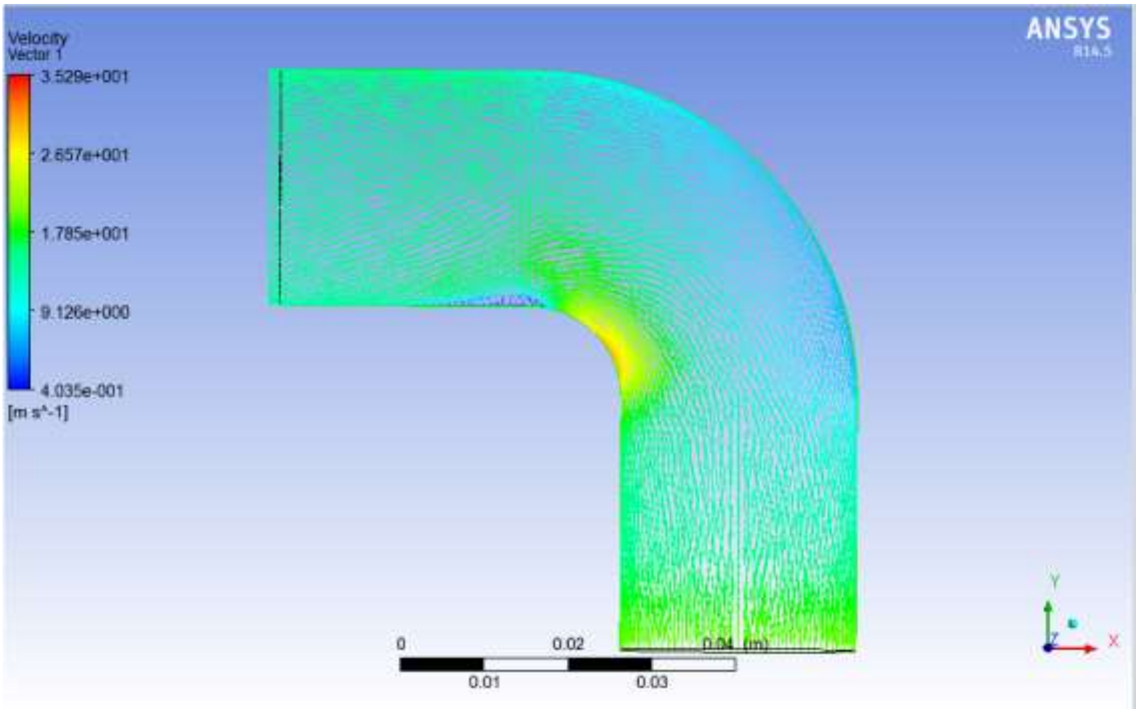



**Figure 7 Velocity Profile of Pipe Bend**

### 4.2 Bean Choke

For a bean choke, the author also make a several experiment to determine the optimum value for the number of elements. This is a same procedure as for a pipe bend. The graph below shows the result of the optimum value determined by plotting a pressure gradient vs number of elements graph.

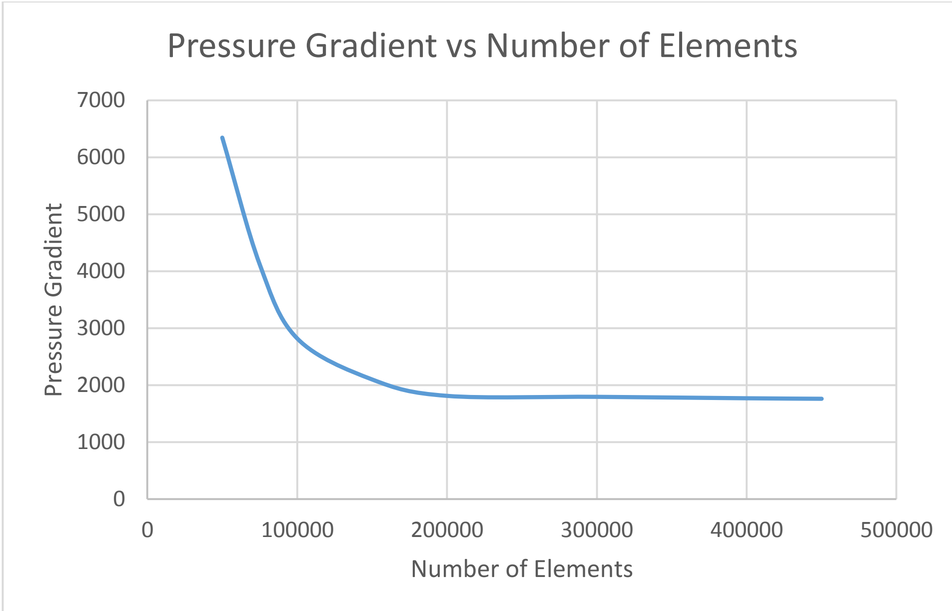



**Figure 8 Pressure Gradient vs Number of Elements**

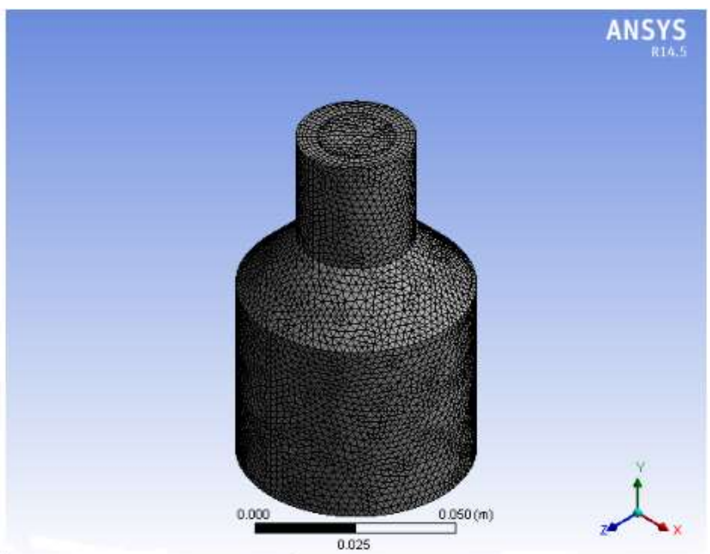



**Figure 9 Bean Choke**

**Figure 8** shows that at approximately of 200,000 is where the bean choke reached the optimum value and figure 6 shows the end result of meshing, Next, the author can also see the pressure gradient and vector profile across the bean choke as shown in the **Figure 10** and **Figure 11** respectively.

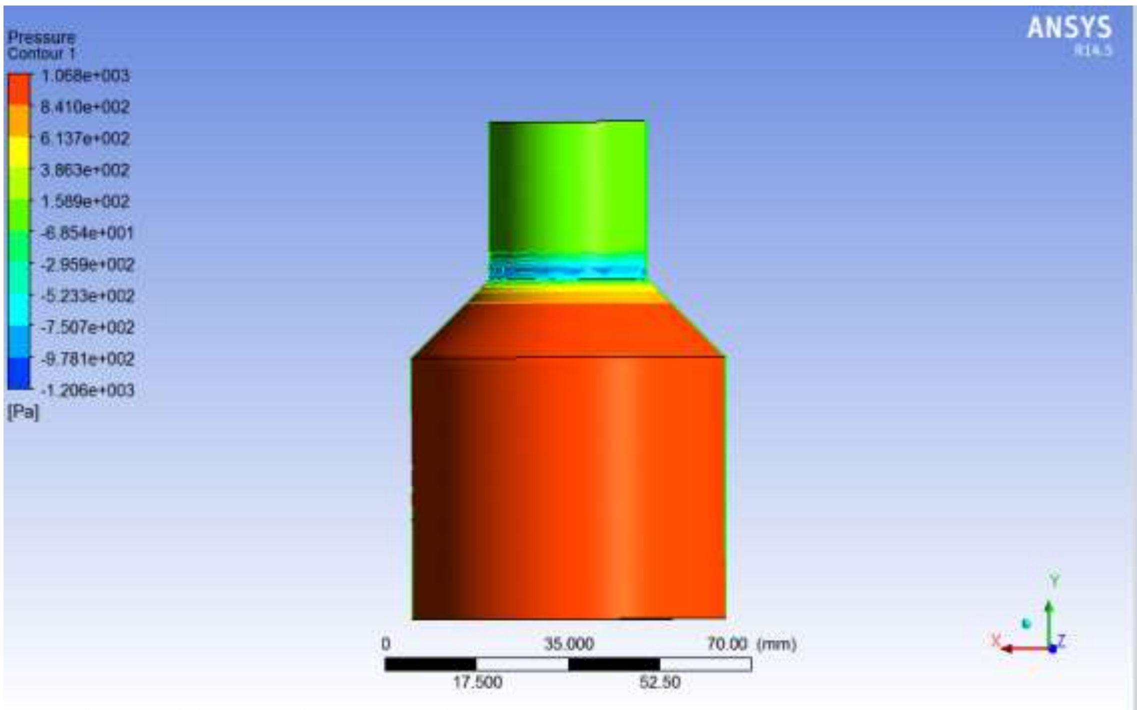



**Figure 10 Pressure Contour of Bean Choke**

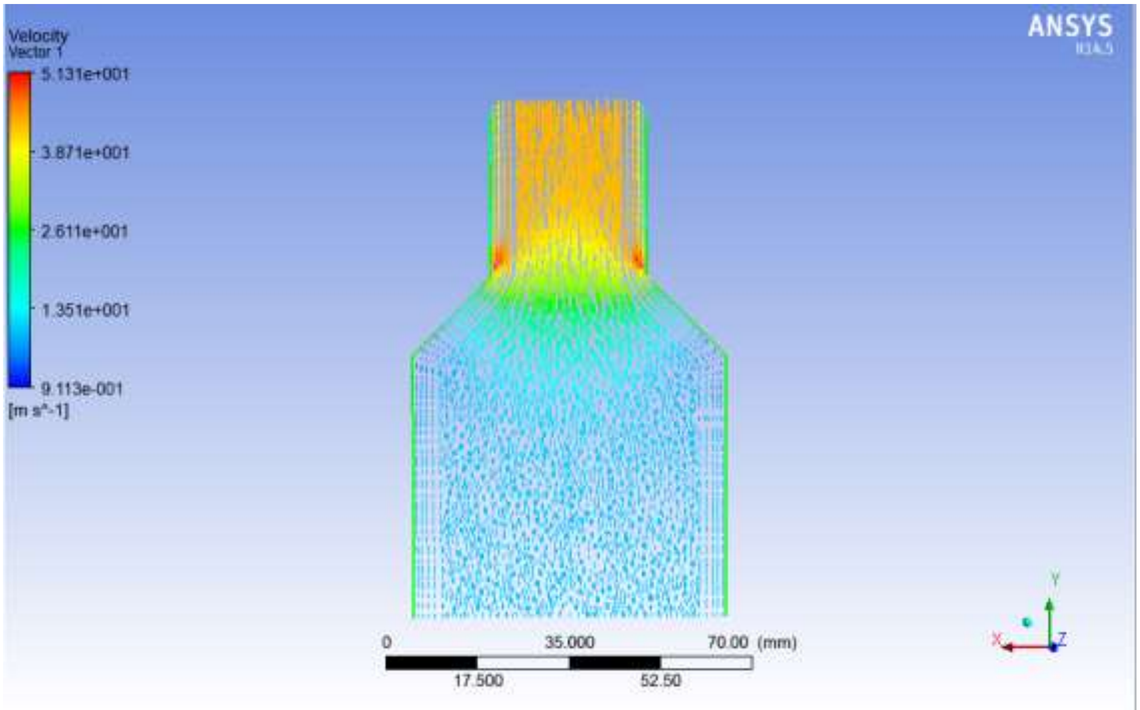



**Figure 11 Velocity Profile of Bean Choke**

## 4.3 Erosion Prediction in Pipe Bend and Bean Choke

A standard elbow and a bean choke are used as application test cases in this work. In order to demonstrate the application of the model, an erosive environment that is representative of actual field conditions is used. All the properties used in this study are mentioned as in the methodology above.

### 4.3.1 Particle Tracking

Representative particle trajectories are examined to determine locations inside the geometry where sand particle impingements are likely to occur. In addition, the velocity at which particles are impinge the walls can be observed. Figures below show the samples of particle trajectories obtained for the pipe bend and bean choke. Entrained particles enter the fitting through the inlet pipe of diameter *D*. It is apparent from each figure that inertial effects cause particles to be distributed more toward the outer wall of the pipe when the flow changes direction. Based on this observation, it is anticipated that the predicted erosion rate will be largest on outer wall of the pipe. **Figure 12** and **Figure** 13 below shows the trajectories of particle when it flows inside a pipe bend and bean choke respectively

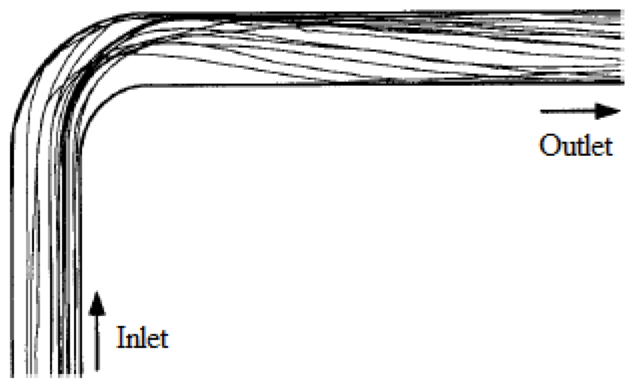



**Figure 12 Particle Trajectories for Pipe Bend**

**Figure 13 Particle Trajectories for Bean Choke**

4.3.2 Erosion Prediction

For the two application test geometries, pipe wall mass is computed using Eq. (1). For these simulations, 10,000 particles were tracked through the geometry and surface erosion contours were generated. In addition, semi-rounded sand particles were assumed. Flow, particle, and pipe wall material parameters are mentioned in the methodology part.

For the Bean Choke, most sand particles hit the 45° contraction and bounces off and hit the second time inside the smaller outlet pipe on the opposite side as the first hit. The maximum erosion rate on the outlet pipe is obtained a small distance from the contraction. In comparison with the experiment, a good agreement on the level of erosion is obtained as shown in **Figure 14** below. The restitution coefficient is $E$ = 0.8 is applied this case. The restitution coefficient does influence the results and may give an explanation of why the location of the maximum point is slightly off.

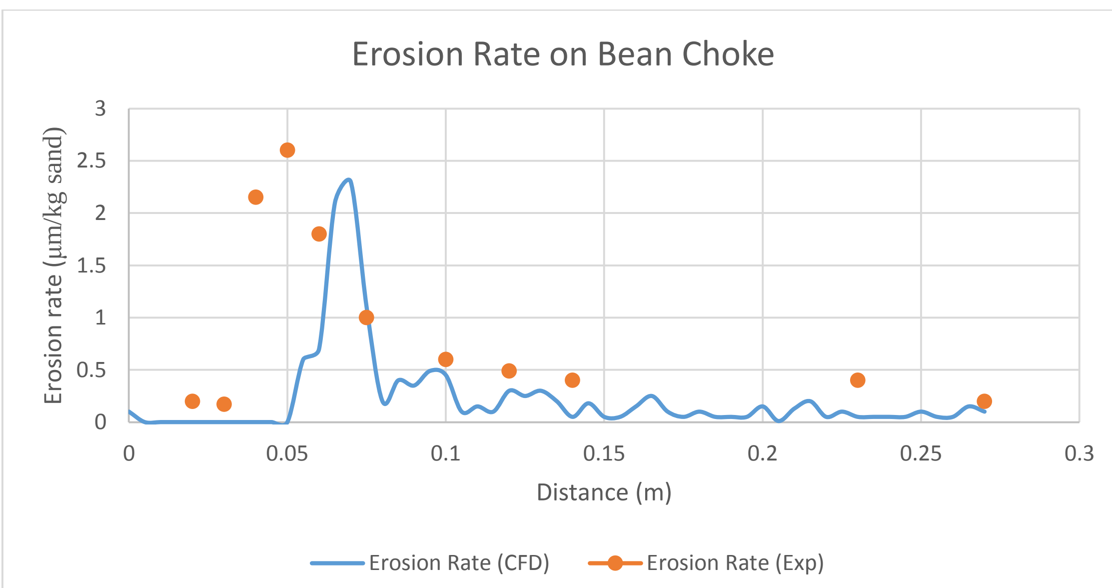



**Figure 14 Erosion Rate along Bean Choke. Comparison with Experimental Results**

For the pipe bend, excellent agreement is obtained when comparing CFD results with the experiment as shown in **Figure 15** below. The highest erosion rate that will occur on the pipe bend is at an angle of approximately of 40° with an erosion rate of 3.5 μm/kg sand. This indicates that the majority of particles are carried nearly completely through the bend before impinging the outside wall of the bend. This can also be detected by careful inspection of the particle trajectories shown in **Figure 12**. The highly eroded zone appears to be localized, indicating that the bulk of the particle impingements occur in roughly the same location.

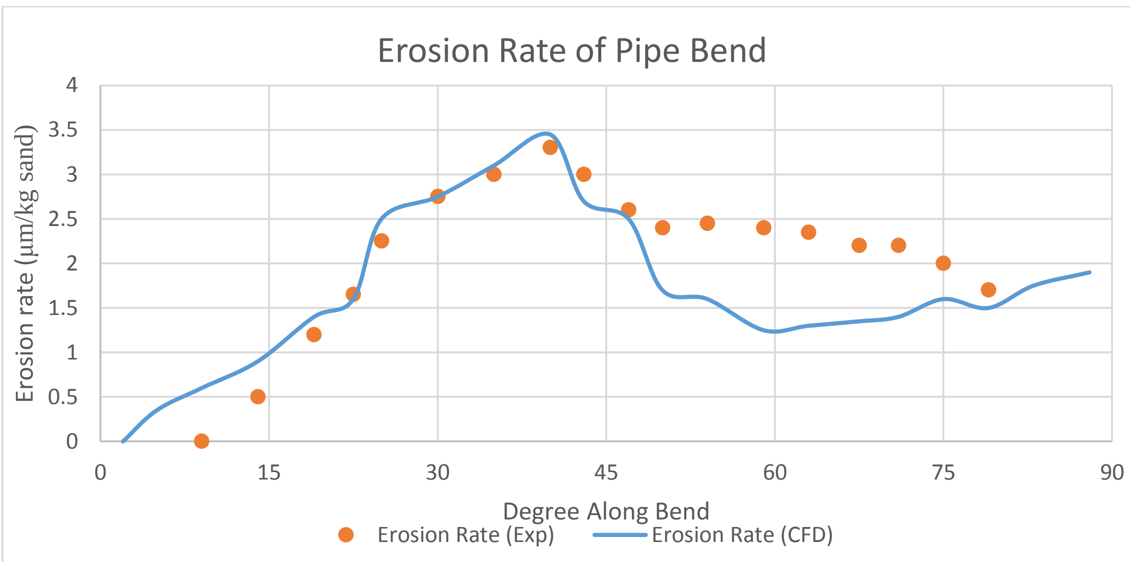



**Figure 15 Erosion Rate along outer side of bend. Comparison with Experimental Results**

# CHAPTER 5

# CONCLUSION & RECOMMENDATION

## 5.1 Conclusion

In a conclusion, Computational Fluid Dynamics (CFD), ANSYS CFX software is very good tool to predict the erosion rate of the pipelines. Other than that, CFD also can estimate the mechanical strength of the given pipelines and pitting of it. The flow assurance of the fluid and the effect of geometry to the pipe can be studied via CFD simulation. Overall, ANSYS CFD provides platform for multi-physics, multi-scale and multi-components configurations of particulate flows. Therefore, the created CFD model is relied upon to be invaluable for assessing crude oil corrosion under new working conditions.

## 5.2 Recommendation

For this section, the author would like to recommend to do an experiment based model instead only relying on the software. This is because experiment we can directly know and see what really happen in the pipeline. In real life, things can happen in many ways and by doing experiment, we can include more factors like pressure and temperature. Last but not least, by doing CFD simulation and also experiment at the same time, we can compare both results and this will give us more effective way in tackling the erosion and corrosion problems.

### 5.3 Future Works

The author had done the project until an optimum value for number of elements for mesh up is achieved for both pipe bend and bean choke. Further project, the author will continue to run the samples with a multiphase flow including fluid and solids. From this, the author will determine the erosion rate (mm/year) and at which part of the pipe will be in contact at most with the solid particles.

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