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MODELING CUTTINGS TRANSPORT MECHANISM IN HORIZONTAL WELL

By

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(10712)

DISSERTATION

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Submitted to the Petroleum Engineering Programme
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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ABSTRACT

Cuttings transport becomes a major problem to handle in oil and gas industry. It is a complex process to transport cuttings from vertical well and it is become more complex if the well is horizontal. Transporting cuttings from wellbore is important because if the well is inadequate in hole cleaning, it can lead to many serious problem. Since then, for the past few decades, many researches and studies have been made, objectively to understand in detail the mechanism of cuttings transport in wellbore. The problem was identified and researchers tried to come out with possible methods to overcome this problem.

There are many models and methods have been developed to investigate the cuttings transport in wellbore. Mathematical model, empirical model, theoretical model, and also experimental work have been done in order to solve the problem. Some characteristics and parameters that affect the transportation process have been identified. In this project, the modeling using simulation's software is a new method used in study the cuttings transport mechanism in horizontal well. ANSYS 11.0 is used in this project as a tool in modeling and simulating the cuttings transport mechanism.

The use of ANSYS 11.0 in modeling cuttings transport mechanism in horizontal well provides a simple workable method compared to experimental work. ANSYS 11.0 allowed user to investigate the unlimited parameters and the operational conditions of the wellbores also can be designed at any conditions. It means that, using this software eliminates all physical difficulties in study the cuttings transport mechanism.

The main purpose of this project is to model a cuttings transport mechanism in horizontal well using ANSYS. The wellbore conditions will be design in this software and the investigation of the parameters that effect the transportation is done by comparing various set of parameters. Using two different sizes of particles, 0.185 inches and 0.274 inches, the simulation simulate three type of fluid with different density, 998.2 kg/m^3, 1198 kg/m^3, and 1497 kg/m^3 by setting its annular velocity to 20 m/s, 40 m/s, and 60 m/s. The result of the project is expected to be in graph diagram, where it compares all parameters.

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I would like to express special gratitude and thank to my sincere supervisor, Mr Elias B Abllah for his full support, advice, constant supervision, strength, courage, and valuable guidance throughout this project. I would also like to thank the head, lecturers, and stuff of geosciences and petroleum engineering for all their support and providing me with a good environment and facilities to graduate as a petroleum engineer. It is a great pleasure to express my deepest appreciation to my parents, Mahad b Hassan and Zubidah bt Abdullah who prayed for me and stood by my side in a long this journey of studies.

TABLE OF CONTENT

Figures	Page

CHAPTER 1

INTRODUCTION

1.1 Background Study

Nowadays, there are many horizontal wells being drilled from all over the world. In this growing numbers of drilling well, it is found that hole cleaning and transporting the cuttings from well is the most common problem that occurred and it is very costly problem to handle. Inadequate hole cleaning in horizontal well can lead to many costly problems such as mechanical pipe sticking, slow drilling rate, formation fracture, poor cement job, high torque and drag, difficulties in casing/cementing and in logging, and even worse lose of the well.

In hole cleaning and transportation of the cuttings, the study showed that there are few parameters that control and effect the process such as hole angle, hole size, flow rate, rotary speed, rate of penetration (ROP), pipe eccentricity, cuttings size, pump pressure, bit type, weight on bit, and also rotating weight. Besides that, the fluid properties such as density, viscosity, annular velocity, Newtonian and Non-Newtonian type, and flow regimes have significant effect on the cuttings transport process.

Since the problem of the cuttings transport is become the major problem in oil and gas industry, there are many studies and researches had been done in past few decades. For example, Tulsa University Drilling Research Project (TUDRP) had done many researches and experimental work to study the mechanism of cuttings transport in wellbore. There are also numbers of paper that been presented in international conference and meeting, where it presenting the current problem and proposing a new method to overcome the problem.

Some of the studies and experimental works had come out with new developed models and correlations, where objectively to overcome the cuttings transport problem. As example, Larsen, Azar, and Pilehvari developed a model for cuttings transport in highly inclined wellbore (50° – 90° angles). The model predicts critical velocity and cuttings bed thickness when the flow rate is below critical flow. Martin, Georges, Bisson, and Konirsch published a numerical correlation based on the data they collected in laboratory and field. Gavignet and Sobey presented a model known as double layer model, where it relates equations and parameters in horizontal well. Zamora and Hanson compiled 28 rules of thumb to improve high angle hole cleaning based on laboratory observations. Luo, Berns, Kellingray, and Chamber presented charts to determine hole cleaning requirements in deviated well. Also, Clark and Bickham presented a cuttings transport model based on fluid mechanics relationship, which they assume three cuttings transport mode, settling, lifting, and rolling, each dominant within a certain range of angle.

In this project, the investigation of the cuttings transport mechanism will be focus in horizontal well (90° well) only. The parameters used and its fluid properties will be discussed in next section. This is an approach to study the transportation of cuttings using software simulation and done in laboratory.

1.2 Problem Statement

Problem identification:

- The study of cuttings transport mechanism in wellbore mostly done by using physical model development and in laboratory work.
- An experiment using physical model is limited and not many parameters can be studied.
- The construction of the model also takes time and need high operating and laboratory cost.

From these problems, it is clear that the physical model development take long time and limited by construction limitations. So that, this project proposed a much easier and workable method in study the cuttings transport mechanism in horizontal well.

1.3 Objective

The main objective of this project is to model the cuttings transport mechanism in horizontal well using ANSYS software.

The second objective of this project is to conduct the model simulation and comparison using different parameters that effect cuttings transportation.

1.4 Scope of Study

- The study involves literature review on modeling cuttings transport mechanism in horizontal well.

- Modeling the cutting transport mechanism using ANSYS 11.0 and CATIA 5.0 software that are available in university lab. The simulation investigates effect of fluid density, annular velocity, and cuttings size to transportation of cuttings in horizontal well.

1.5 Project Relevancy

Modeling cuttings transport mechanism using ANSYS is applicable at all level of researches. Since ANSYS is available at the market and there is corporation that supplies the software and provides the latest upgrade of the software, it means that using ANSYS as mechanism in study the cuttings transport is relevant and can widely used. Being more focused on this project, this software will be used to model the mechanism of the cuttings transport in horizontal well, specifically at horizontal segment. Using the exact value of investigated parameters, the mechanism of cuttings transport will be visualized and this step can be repeated as much time as required.

1.6 Feasibility of the Project within the Scope and Time Frame

- With proper planning beforehand to project will be kept inside to scope of the project and the project can be finished within the timeframe.

- Gantt chart created will assist in planning of the activities done during whole planning course of project.

- Besides, under the supervision and guidance of m supervisor, I am confidence this project would be achieved the scope and time frame set beforehand.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Drilling Fluid

Drilling fluid is a fluid used to aid the drilling of boreholes into the earth. There are three (3) categories of drilling fluid that are usually used in drilling process, which are water-based mud, oil-based mud, and gaseous drilling fluid.

Water-based Mud: Mud where the continuous phase is water. In this phase, any additives are dispersed in the water.

Oil-based Mud: Mud where the continuous phase is oil and contains less than 2 per cent (2%) up to 5 per cent (5%) water. This water is spread out, or dispersed, in the oil as small droplets. This type of mud is used for many reasons likes enhanced shale inhibition, increased lubricity, and for greater cleaning abilities with less viscosity.

Drilling fluid provides some important functions in drilling and hole cleaning operation, such as:

1. **Remove cuttings from well**
2. Suspend and release cuttings
3. Control formation pressure
4. Seal permeable formation
5. Maintain wellbore stability
6. Cool, lubricate, and support the bit

Remove cuttings from well – drilling fluid carries the cuttings in the wellbore up to the surface. The effectiveness of the fluid to do so is depends on parameters likes' cuttings size, shape, and density, and its annular velocity. Some other drilling mud properties that important in transporting cuttings include:

- Most drilling mud will become gel under static conditions. This characteristic of mud keeps the cuttings suspended when it is not moving.
- Drilling mud that has higher annular velocity give positive effect on cuttings transport.
- Drilling mud with high density may clean the hole better even with lower annular velocity.

For the next section, the drilling fluid parameters such as viscosity, density, shear stress, and shear rate will be explained. Some other theory like flow regimes and Newtonian and Non-Newtonian fluid will be discussed.

2.2 Annular Velocity and Density

Annular velocity is the speed at which drilling fluid moves in the annulus. It is commonly expressed in units of feet per minute (ft/min) or meter per minute (m/min) and also called apparent velocity (AV). Annular velocity is major parameters in cuttings transport process. By maintaining the annular velocity at certain rates, the drill cuttings will be kept to prevent it from settling down to the bottom and cause drilling problems.

Density is defined as mass per unit volume and symbolize by unit ρ (rho). For some cases, density is also defined as weight per unit volume and it is called specific weight. In wellbore, temperature and pressure changes can affect the drilling fluid density. At low pressure, the density of drilling fluid increases and at high temperature the drilling fluid density decreases. While when pressure increases, the drilling fluid density will increase. Mathematically, density can be shown by:

$$\rho = \frac{m}{V}$$

Where, ρ = density,

m = mass,

V = volume

2.3 Shear rate, Shear Stress, and Viscosity

Shear stress: The force per unit area required to sustain a constant rate of fluid movement.

$$\tau = \frac{F}{A}$$

Where, τ = shear stress,

F = force,

A = area of surface subjected to the force

Shear rate: The velocity gradient measured across the diameter of fluid flow channel. It is a rate of change of velocity.

Viscosity: A property of fluids that indicates their resistance to flow. Unit for viscosity is dyne-s/cm2 and symbolize by Poise (P).

$$\mu = \frac{\tau}{\gamma}$$

Where, μ = viscosity,

τ = shear stress,

γ = shear rate

2.4 Newtonian and Non-Newtonian Fluid

In this project, the drilling fluid used to transport the cuttings from horizontal well will be water and other drilling mud (to be expressed in density value). The comparison between these drilling muds based on their fluid characteristics. Generally, the drilling mud used in this project can be categorized in two (2) categories, which are Newtonian drilling fluid and Non-Newtonian drilling fluid.

Newtonian Drilling Fluid

Newtonian Fluid is a fluid that has a constant viscosity at all shear stress rates at constant temperature and pressure. In common terms, this mean that the fluid continues to flow regardless of the forces acting on it. Water, sugar solutions, silicone oils, and glycerin are Newtonian fluids. For Newtonian fluid, the stress versus strain rate curve is linear and the constant of proportionality is called viscosity.

Non-Newtonian Drilling Fluid

Non-Newtonian Fluid is a fluid whose viscosity is variable based on applied stress. Salt solutions, ketchup, custard, paint, blood, and shampoo are example of Non-Newtonian fluids. In drilling industry, most drilling mud used is non-Newtonian fluid. For Non-Newtonian fluid, the relation between the shear stress and the shear rate is different from Newtonian fluid. So, the constant coefficient of viscosity cannot be identified.

Comparison between Newtonian and Non-Newtonian Fluid

(Figures sources: http://en.wikipedia.org)

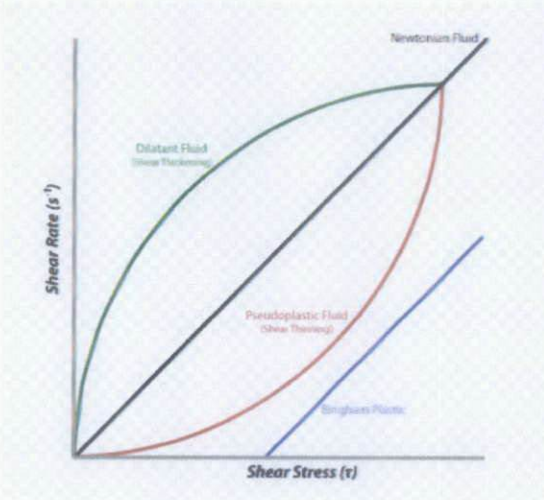

Figure 1: Behavior comparison of Newtonian and Non-Newtonian Fluids

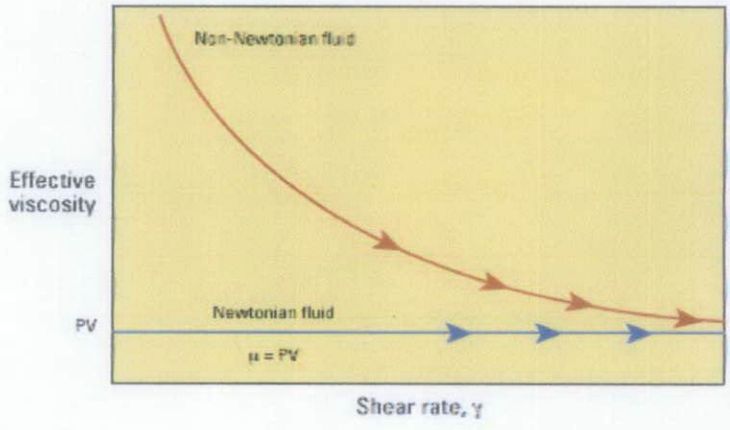

Figure 2: Newtonian versus Non-Newtonian Effective Viscosity Comparison

2.5 Flow Regimes

The cuttings transport is very much affected by flow regimes, which the flow can be turbulent or laminar. From the previous study conducted, it is found that the flow regime is dependent on the fluid density, size and shape of annulus, and fluid viscosity. Transition region is a flow regime between laminar and turbulent flow where it has both laminar and turbulent characteristics.

In drilling operation, when the flow velocity is low or the fluid has high viscosity, it will create laminar flow. While turbulent flow will appear when the flow velocity is high or the viscosity of fluid is low.

<u>Turbulent Flow (Re > 4000)</u>

Turbulent flow is a type of fluid flow where it characterized by swirling or chaotic motion as the fluid moves along the flow path. This type of flow regime is preferred for drilling mud because it gives result in better removal of cuttings.

<u>Laminar Flow (Re < 2000)</u>

Laminar flow occurs when a fluid flows in parallel layers with no disruption between the layers. There are no cross currents perpendiculars to the direction of flow or swirls of fluids.

$$Re = \frac{\rho V D}{\mu}$$

Where Re = Reynolds Number

ρ = density,

V = velocity,

D = diameter,

μ = viscosity

2.6 Transportation System in Drilling Process

Well drilling is the process of drilling a hole in the ground to extract a natural resource such as ground water, natural gas, or petroleum. The drilling process will used a specific drill bit for the drilling to reach its target. The drilled hole in the ground will leave behind cuttings and these cuttings are important to transport up to the surface to prevent any major problem to happen. Below is the diagram of transportation system in drilling platform.

Table 1: Transportation System Components

1	Mud Tank	15	Monkey Board
2	Shale Shakers	16	Drill Pipe
3	Suction Line	17	Pipe Rack
4	Mud Pump	18	Swivel
5	Power Source / Motor	19	Kelly Drive
6	Vibrating Hose	20	Rotary Table
7	Draw-works	21	Drill Floor
8	Standpipe	22	Bell Nipple
9	Kelly Hose	23	Blowout Preventer Annular
10	Goose Neck	24	Blowout Preventer Pipe and Blind Ram
11	Traveling Block	25	Drill String
12	Drill Line	26	Drill Bit
13	Crown Block	27	Casing Head
14	Derrick	28	Flow Line

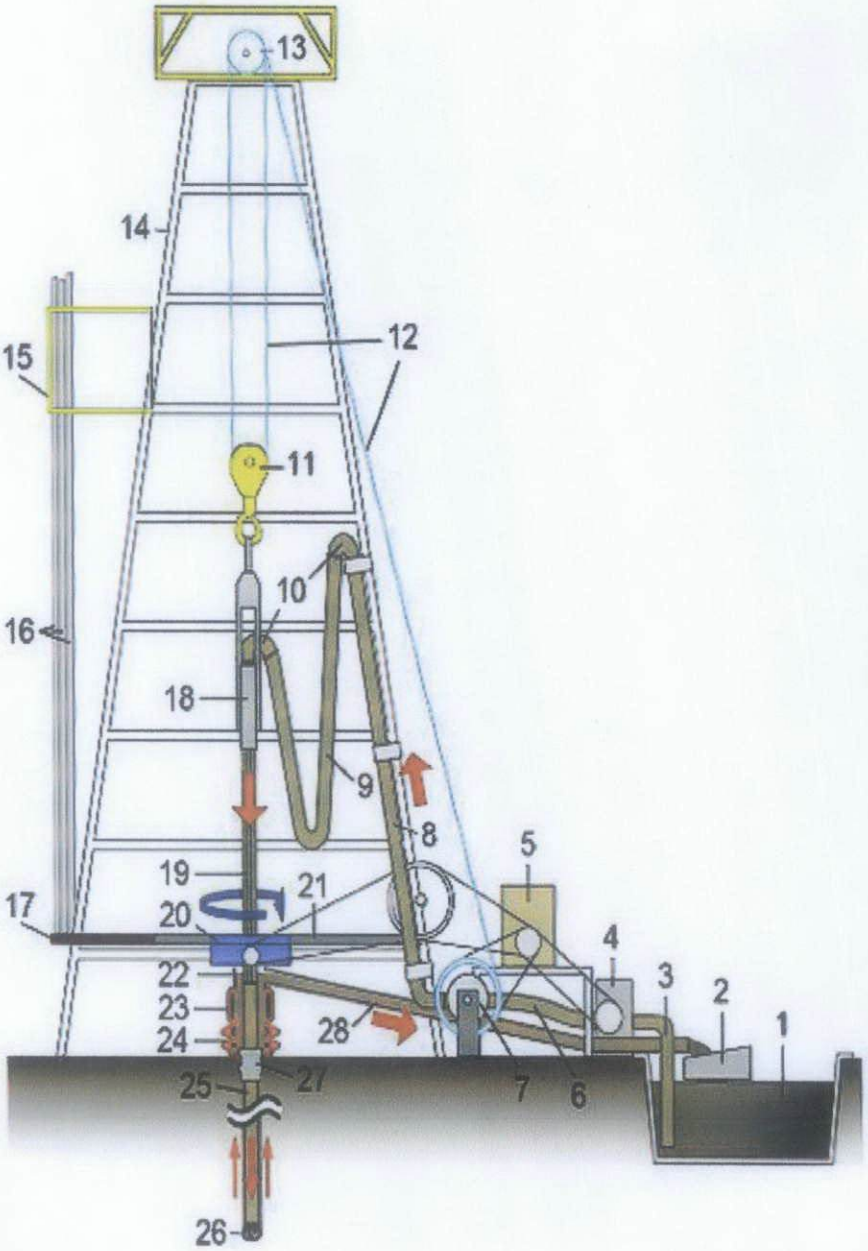

Figure 3: Drilling Rig Transportation System (sources from *oilgasinformation.com*)

2.7 Horizontal Well

Figure 4: Illustration of horizontal well

Drilling horizontal well is the ability to drill wells sideways objectively to reach specific oil and gas reservoir location, which may be located beneath cities or other environments where drilling rig cannot be set up. Multiple wells can be drilled from one drilling platform. This technique also used to expose more surface area of oil bearing rock so that the overall production of the well is increased.

A directional assembly consists of a "mud motor" which contain a rotor and stator inside it and are turned by the force of mud that pumped down. The motor turns the drill bit so instead of turning the entire length of drill pipe, the motor, which is bent at certain angle can remain in a fixed position drilling the aimed direction.

2.8 A Three Segment Model

According to the report by H. CHO, S.N. SHAH, and S.O. OSISANYA, they divided the entire horizontal drilling into three segments, which are vertical and near vertical segment, transient segment, and horizontal and near horizontal segment. The vertical and near vertical segment is range from 0° to 30°, the transient segment between 30° to 60°, and horizontal and near horizontal segment between 60° to 90° deviations. It is stated that the existing of cutting bed is different for each segment and the parameters used also differ for each three of it.

In this project, the focus will be at the horizontal segment only which is the degree of inclination is 90° from vertical direction. The cuttings transportation in the transient and vertical segment will not be study in this project. The parameters that will be used in this project will be discussed in next section.

2.9 Parameters Sensitivity for Horizontal Segment

There are many parameters taken into consideration which give effect in the cuttings transportation process in horizontal well. Based on the recent studies, the parameters such as mud flow rate, mud density, mud type, hole angle, hole size, rotary speed, annular velocity, rate of penetration (ROP), and angle of inclination have certain effect in cuttings transportation, whether it give positive effect or negative effect which mean it helps in transporting the cuttings or not.

In report by Jeff Li and Scott Walker, they used an experimental method to study the cuttings transport mechanism in horizontal well. They came out with the study that there are some parameters that affect the transportation process, which are liquid/gas volume flow rate ratio, annular in-situ liquid velocity, rate of penetration, angle of inclination, and circulation fluid properties.

T. Nazari, G. Hareland, and J.J. Azar also in their report stated about the parameters that effecting the cuttings transportation. The report based on the experiment done in TUDRP where the purposes is to determine the sensitivity of cuttings concentration against various parameters. The parameters such as mud flow rate, mud rheology, hole angle, mud weight, mud type, hole size, rotation speed, eccentricity, rate of penetration, drill bit type, and cutting size were studied in this experiment. And they came out with the results that hole inclination, annular mud velocity, and drill pipe rotation are the most important parameters that affect the cuttings transportation.

For this project, it is decided to study the effects of three parameters, which are *annular velocity, drilling fluid density* (mud type), and *cutting size.*

2.10 ANSYS 11.0 Software

ANSYS 11.0 is software that provides a physical modeling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications.

Based on the previous study, there are numbers of researches that use simulation software to study the cuttings transport mechanism. Mostly all of them used software called Computational Fluid Dynamic (CFD). Using CFD, it enables researchers to simulate drilling conditions by visualizing velocity and pressure gradient for different wellbore and bit geometry. Report by H.I. Bilgesu, M.W. Ali, K. Aminian, and S. Ameri, they conducted a study about cuttings transport in wellbore using CFD software. The main objective of the study is to visualize the velocity gradient in cuttings transport. They made a comparison in results by using four different fluid densities and three different cuttings size. The effectiveness of the software was determined by simulating successfully results from an experiment reported in literature.

In this project, ANSYS 11.0 will be used as a tool in modeling cuttings transport mechanism in horizontal well. It is a same method which is using simulation, but with a new type of software.

2.11 Future Researches and Technology Needs

It is stated in SPE paper presentation titled State-Of-The-Art Cuttings Transport in Horizontal Well by Ali A. Pilehvari, J.J. Azar, and Siamack A. Shirazi, the conclusion of the presentation is mentioning about the future research and technology needed for cuttings cleaning in horizontal well. Although nowadays the problem in horizontal well cleaning is lesser from before, since the problem occurred and the cost to handle it are still very high.

In order to develop a new method and solution to handle this problem, the paper mentioned about the important aspect that need to be carefully study. Two out of four aspects that been mentioned were Fluid Flow Simulation and Mechanistic Modeling. These two aspects are very much related to this project objective, where to simulate the cuttings transport using fluid flow simulation.

1. Fluid Flow Simulation

In understanding the cuttings transport and modeling, the important information that needs to know is fluid flow modeling under the in-situ condition. The fluid behavior, velocity, viscosity, it's laminar and turbulent flow, and both Newtonian and non-Newtonian fluid are very important elements of fluid that need to take serious.

2. Mechanistic Modeling

The important part in modeling the cuttings is to develop a comprehensive cuttings transport mechanistic model verifiable with experimental data. In addition, a fluid-solids interaction model is needed to simulate the whole cuttings transport process.

2.12 Reviews on Previous Study

In report by H. CHO, S.N. SHAH, and S.O. OSISANYA, they proposes a new mathematical model to overcome the limitations in existing hydraulic model used to predict cuttings transport in wellbore. In this study, they divided a well into three sections, which are based on wellbore deviation, cuttings transport characteristics, and cuttings bed. The three segments are vertical and near vertical section (0° to 30° from vertical), transit section (30° to 60° from vertical), and near horizontal to horizontal section (60° to 90° from vertical). A mathematical model for each segments are different based on the parameters used. The simulation was performed and as the results, the found that wellbore deviation has significant effects on cuttings transport. Besides that, they also found that the most dominant parameters affecting cuttings transport are annular velocity and drilling fluid viscosity. Also, they stated that in horizontal section, a high velocity with less viscous fluid, resulting in high turbulence compared to highly viscous fluid.

In journal by M.E. Ozbayouglu, S.Z. Miska, T. Reed, and N. Takach, they conducted a study on using foam in cuttings transport modeling in horizontal well. In their study, they used three-layer model where they assumed that the wellbore is divided into three layers, stationary layer, mixture layer, and fluid layer. At each layer, they developed an equation to represent parameters in it. The experiment was conducted using low pressure-ambient temperature flow loop in TUDRP. As the results, they found out that when foam is used as drilling fluid, a very high annular velocity are required to prevent a thick cuttings bed development in the wellbore. And if the water is used, the development of cuttings bed is lower since its viscosity is less than foam.

In paper presented by H.I. Bilgesu, M.W. Ali, K. Aminian, and S. Ameri, they proposed a new method in study the cuttings transport in wellbore using Computational Fluid Dynamics (CFD). The objective of using CFD was to visualize the velocity gradient in the wellbore. In this study, they used incompressible two-phase flow, Power Law Model to represents drilling mud, Newtonian Model to represent water, and cuttings ware treated as inert particles in wellbore. They also used various types of parameters like four (4) values for drilling fluid density and three (3) values for particles sizes. As the simulation results, they found out that annular velocity plays an important role in hole cleaning.

CHAPTER 3

METHODOLOGY

3.1 Project Activities Flow Chart

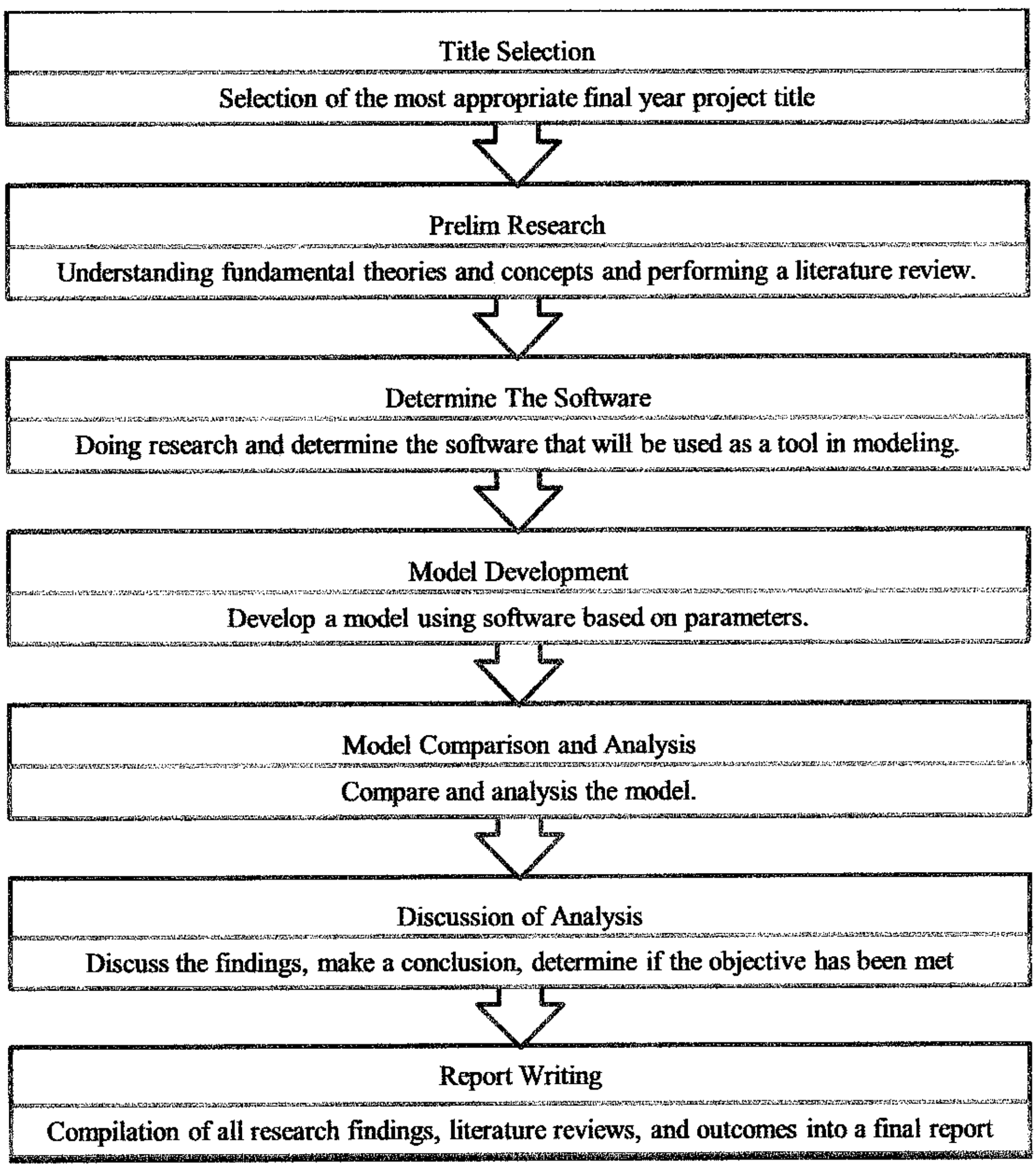

Figure 5: Project Activities Flow Chart

3.2 Model Development

Below is the methodology used in order to complete the model development using software.

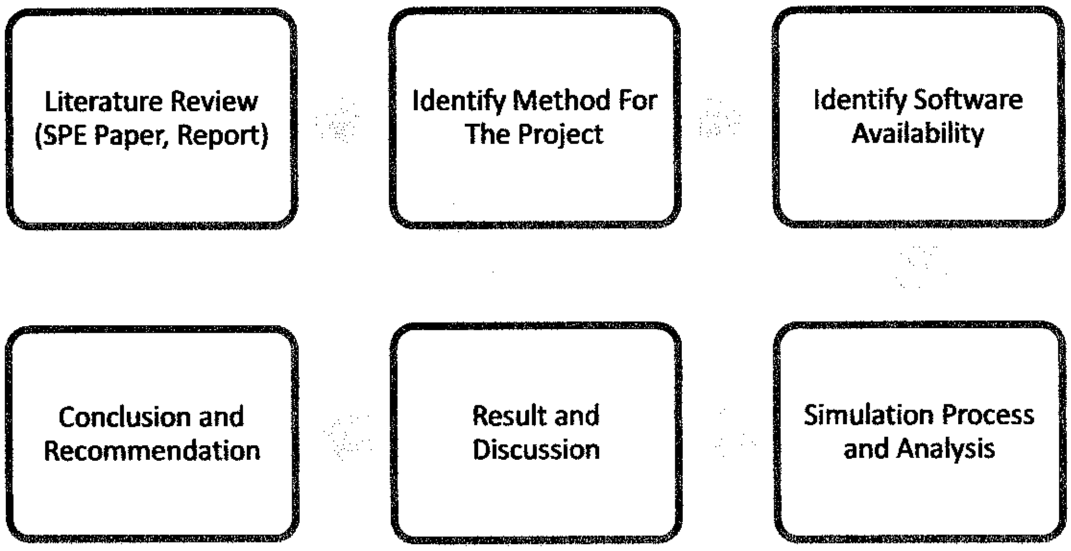

Figure 6: Methodology to Design and Simulate the Cuttings Transport Model

Stimulation Process and Analysis

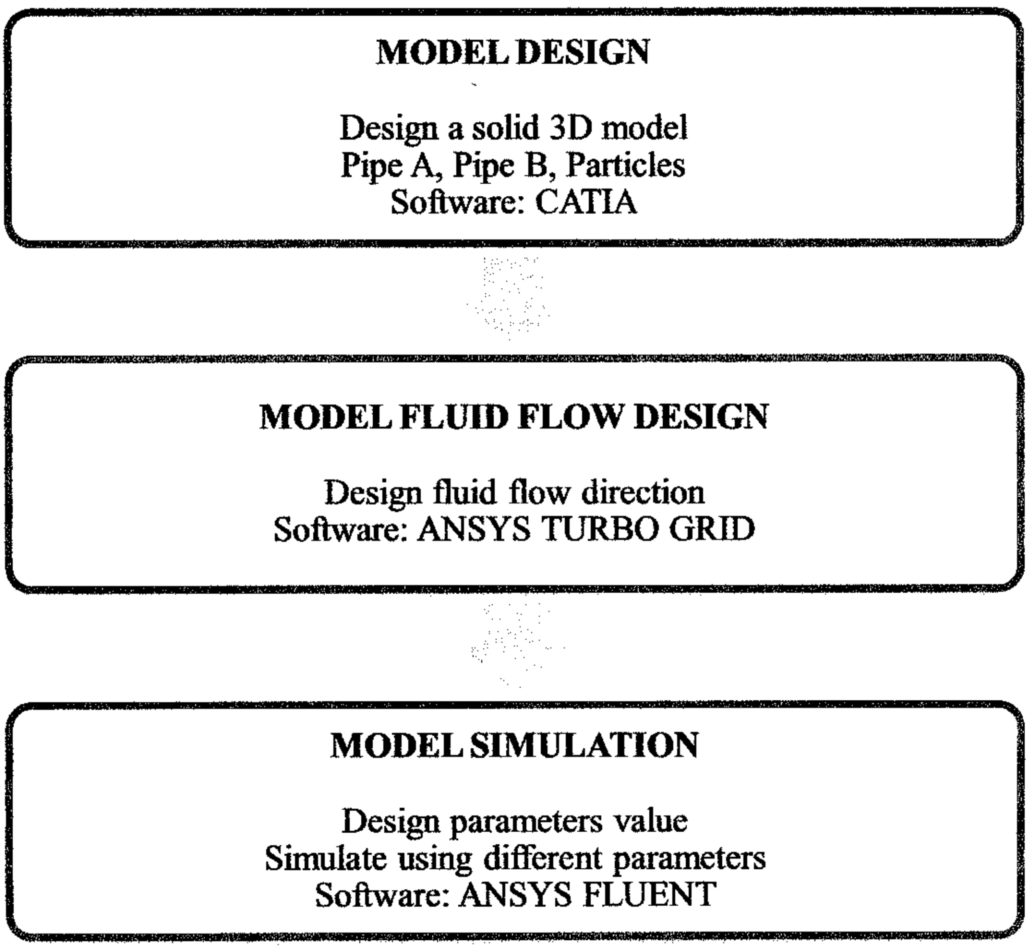

Figure 7: Work Flow for Modeling and Simulating Model

3.3 Model Design

In this project, it needs three (3) weeks of time to complete the design process. Some difficulties were found in this process, and still the author able to overcome it and continue to complete the project. The difficulties are:

1. The author is a first-time user in using the CATIA software. Since it is the first time the author use the CATIA software, it take a bit longer time to complete the design drawing because the author needs to learn on how to use the software himself.
2. The author also a first-time user and needs to learn the basic steps in using the ANSYS software. It take a few weeks to learn and able to use it.

After doing some researches and discussions with supervisor, the parameters for the model's design is decided. It must be noted that in this design process, some assumptions were made to simplify the design.

- Wellbore will be assume as Pipe A, where the size of Pipe A same as the wellbore size.
- The drillpipe will be assume as Pipe B, where the size of Pipe B same as the drillpipe size.
- For each model, the particles are all in same size and placed in organized and compacted position.
- Only the horizontal section will be design since the simulation later only focusing in horizontal well section.

Comparison between Drilled Hole And Model Design

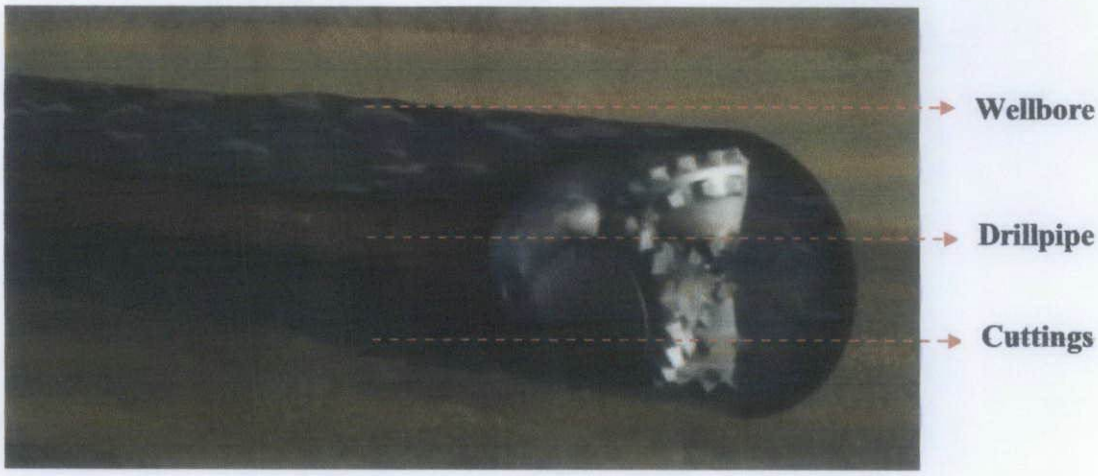

Figure 8: Drilled Hole Diagram

The wellbore will be described in the design drawing as Pipe A,

The drillpipe will be described in the design drawing as Pipe B,

Cuttings will be described as small particle in the design drawing.

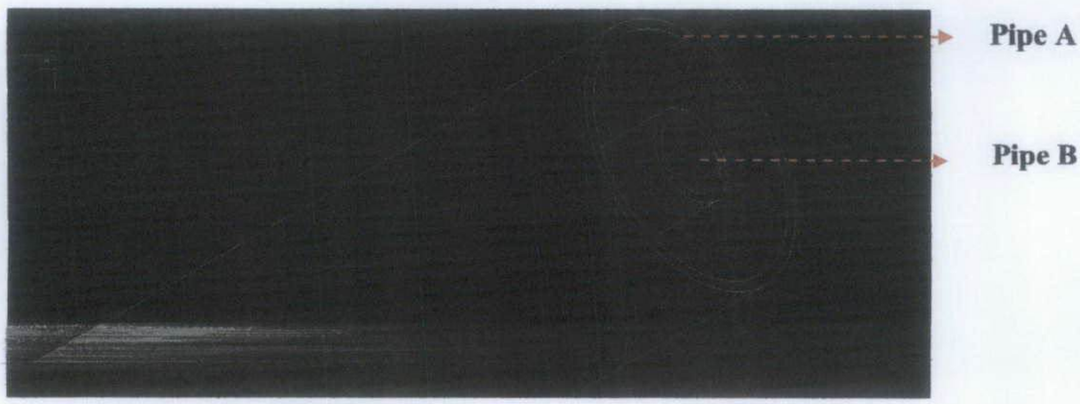

Figure 9: Basic Pipe A and B Design Drawing

3.4 Project Milestone / Gantt chart

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Briefing & update on student progress																						
2	Project work commences																						
3	Submission of Progress Report																						
4	PRE-EDX, Poster Presentation, Submission of Final Report (CD Softcopy & Softbound)								Mid Semester Break														
5	EDX																						
6	Final Oral Presentation																						
7	Delivery of Final Report to External Examiner / Marking by External Examiner																						
8	Submission of Hardbound Copies																						

3.5 Tools

3.5.1 ANSYS Version 11.0

The ANSYS 11.0 version software will be used in this project to develop a model on cuttings transport mechanism in horizontal well. The software is available in the university lab. Using this software, it is possible to develop a model and using some parameters, the comparison between each model can be made. With this, the result can be better and the objective can be achieved.

3.5.2 CATIA Version 5.0

In this modeling project, the main part that must be done before doing the simulation process is designing the model itself. As required to design the model, it is decided to use CATIA Version 5.0 software as a tool to design the model.

CATIA (Computer Aided Three-Dimensional Interactive Application) is mechanical drawing software used to design any mechanical object in any area of work. The important criteria in CATIA is it can design a solid Three-Dimensional (3D) drawing better than any other mechanical drawing software. Since this project's model related to high pressure and extreme wellbore condition, the solid 3D model is needed to obtain the better result in the simulation part later.

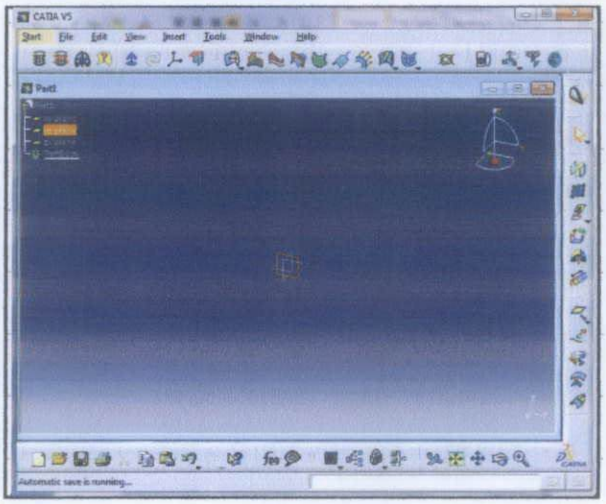

Figure 10: CATIA Version 5.0

CHAPTER 4

RESULT AND DISCUSSION

The result is presented in two parts, which are the first parts is result from the model design process, and the second part is result from model simulation process.

4.1 Model Design

Design Specifications

1. Pipe A and Pipe B

Table 2: Pipe Design Specification

Specifications	Pipe A	Pipe B
Length	8.0 ft	7.0 ft
Outer Diameter	12.00 inch	3.5 inch
Inner Diameter	11.25 inch	2.764 inch

- The position of Pipe B is 1.0 ft behind the Pipe A from starting point and it end in same point with Pipe A.
- The position of Pipe B is in center of Pipe A.

Design Drawing

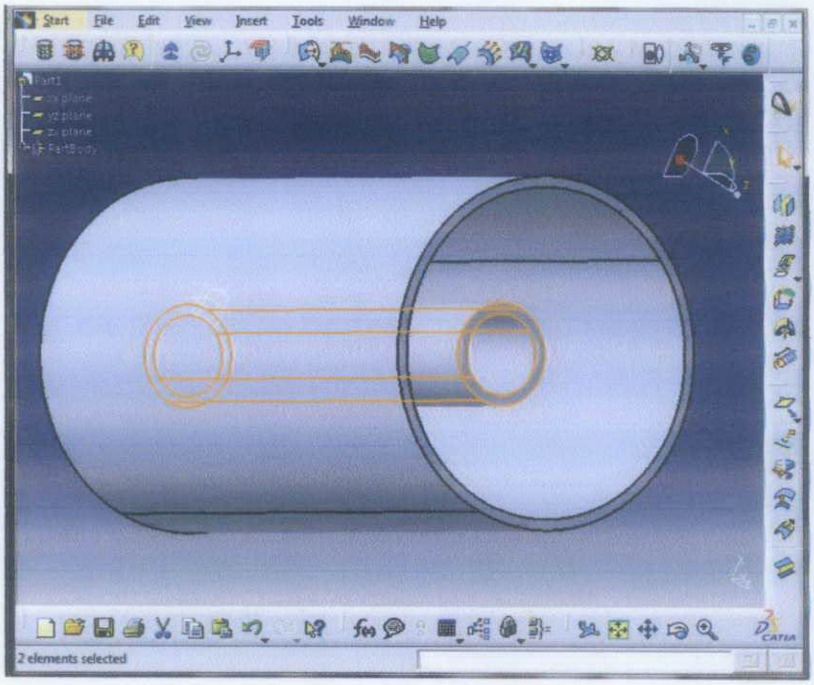

Figure 11: Horizontal View Drawing (Pipe A and Pipe B)

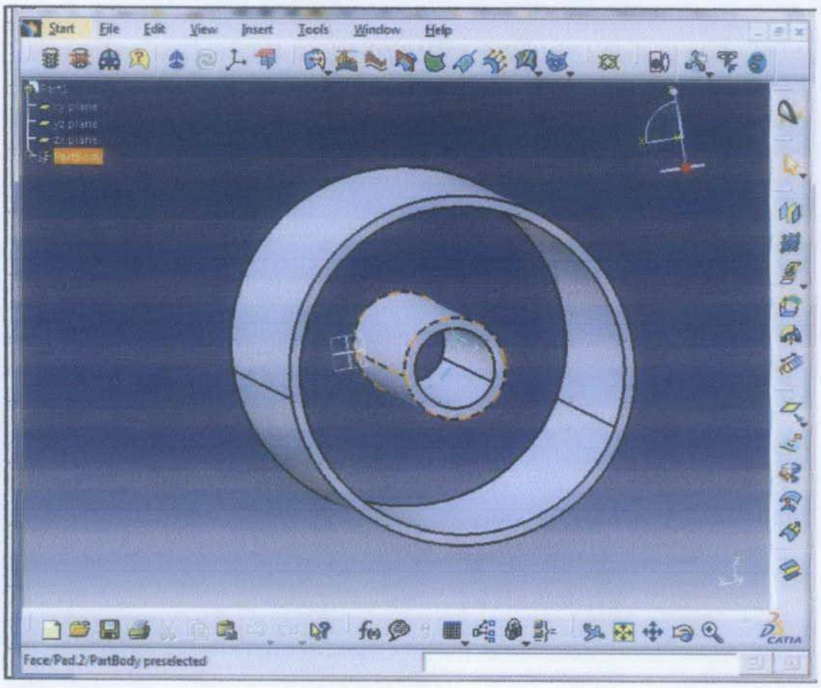

Figure 12: Front View Drawing (Pipe A and Pipe B)

2. Particles

Table 3: Particles Design Specification

Specifications	Design 1	Design 2
Diameter	0.185 inch	0.275 inch

- The particles will be placed at the bottom of along Pipe A.
- There will be 7 layers of particles and it is organized and compacted.
- There will be two designs, which are design with particles size 0.185 inch and design with particles size 0.275 inch.

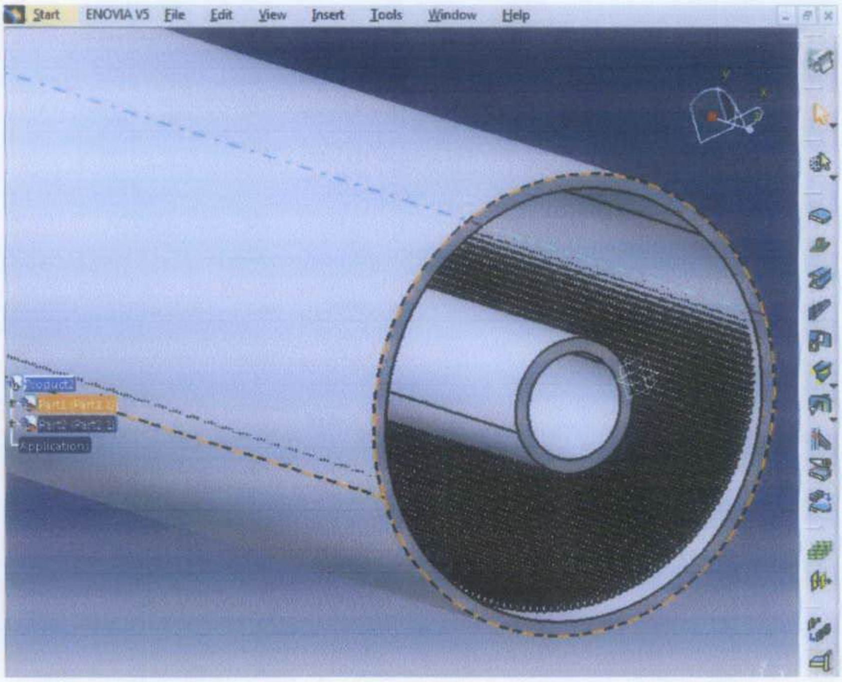

Figure 13: Particles Drawing

4.2 Model Simulation

The simulation process was started by determined the value of parameters that will be used in the project's simulation. The parameters values used are as below:

- For Particles Size: 0.185 inch

Table 4: Tests Specification (Particle Size 0.185 inch)

Simulation Test	**Annular Velocity (m/s)**	**Fluid Density (kg/m^3)**
Test 1	20, 40, 60	998.2
Test 2	20, 40, 60	1198
Test 3	20, 40, 60	1497

- For Particles Size: 0.275 inch

Table 5: Tests Specification (Particle Size 0.275 inch)

Simulation Test	**Annular Velocity (m/s)**	**Fluid Density (kg/m^3)**
Test 1	20, 40, 60	998.2
Test 2	20, 40, 60	1198
Test 3	20, 40, 60	1497

Simulation Result

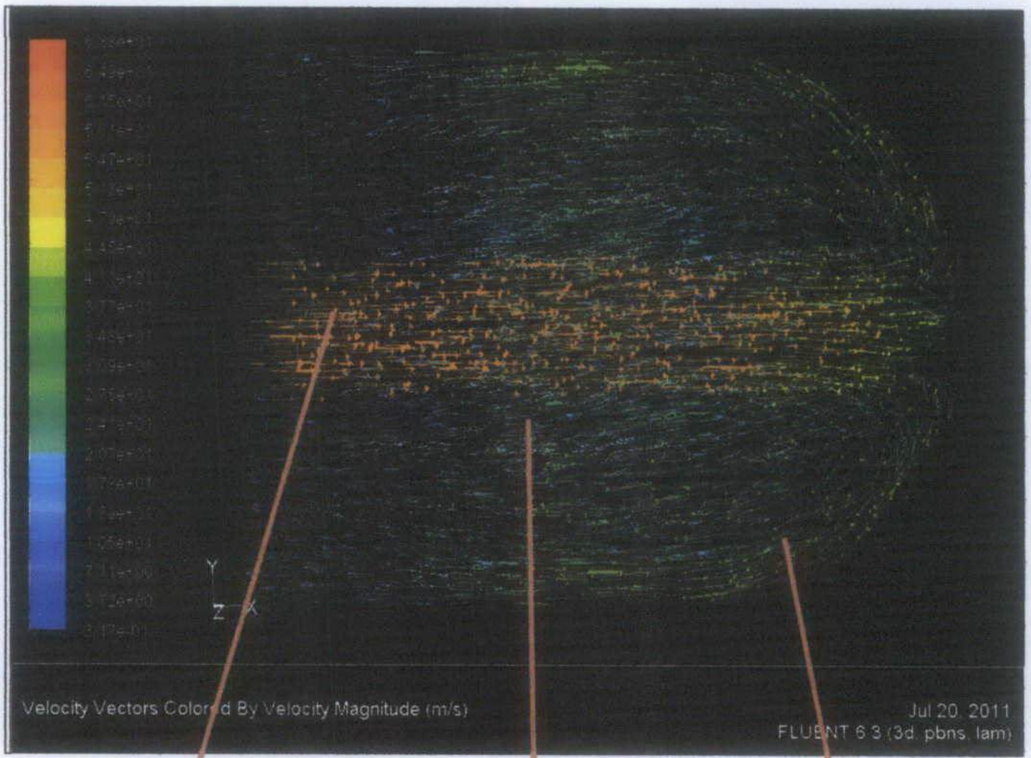

Figure 14: ANSYS Fluid Flow Simulation

The fluid flow direction was designed to flow from inside Pipe B (Red dot) out to the inside Pipe A (Blue and Green dot). At the bottom of the pipe, there are particle assembled.

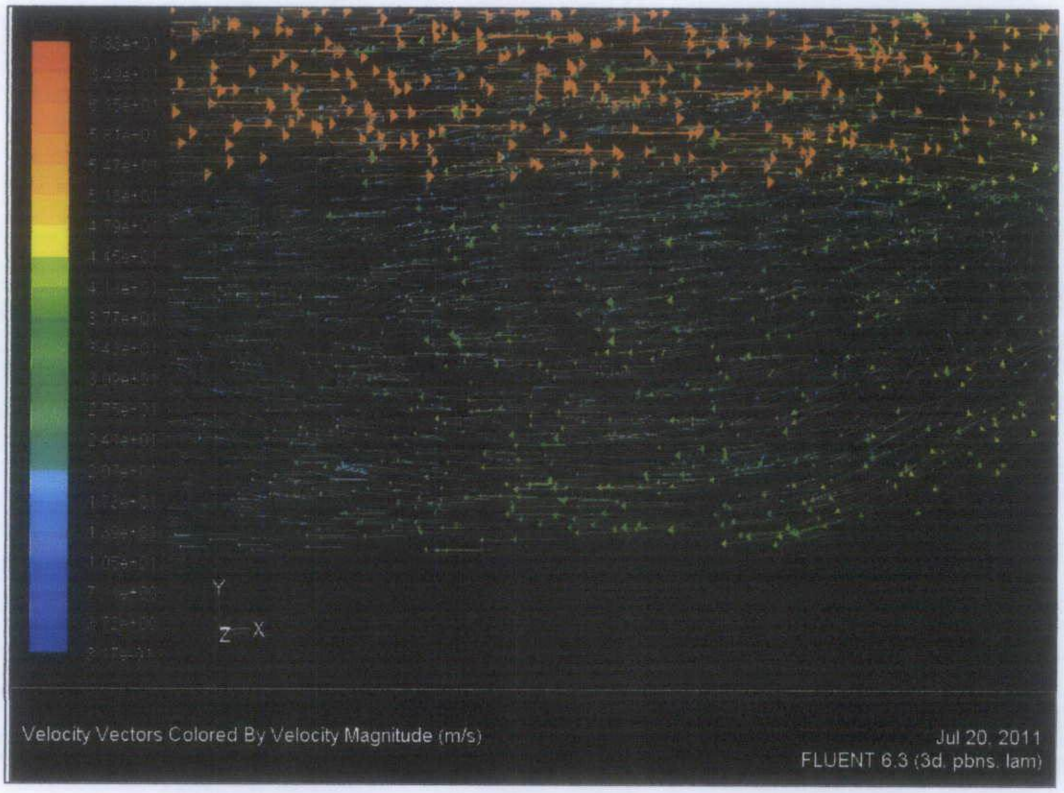

Figure 15: Fluid Flow at the Bottom of Pipe

The fluid flow diagram above show that when the fluid is flow from inside the Pipe B (Red dot) out to the Pipe A (Blue and Green dot), the velocity of the fluid will determined how many particles will be transported. The particle is designed with Specific Gravity 2.4. The various annular velocities used mean that the amount of particles movement in every velocity is different. The result of particle movement is shown in table below.

Data Obtained

1. For particles size: 0.185 inch

- Fluid Density = 998.2 kg/m^3

Table 6: Test #1 Result Particles Movement (0.185 inch)

Annular Velocity (m/s)	20	40	60
Particle Movement (%)	9	29	51

- Fluid Density = 1198 kg/m^3

Table 7: Test #2 Result Particles Movement (0.185 inch)

Annular Velocity (m/s)	20	40	60
Particle Movement (%)	18	37	64

- Fluid Density = 1497 kg/m^3

Table 8: Test #3 Result Particles Movement (0.185 inch)

Annular Velocity (m/s)	20	40	60
Particle Movement (%)	30	50	83

2. Particle Size = 0.275 inch

- Fluid Density = 998.2 kg/m^3

Table 9: Test #1 Result Particles Movement (0.275 inch)

Annular Velocity (m/s)	20	40	60
Particle Movement (%)	5	19	41

- Fluid Density = 1198 kg/m^3

Table 10: Test #2 Result Particles Movement (0.275 inch)

Annular Velocity (m/s)	20	40	60
Particle Movement (%)	10	24	47

- Fluid Density = 1497 kg/m^3

Table 11: Test #3 Result Particles Movement (0.275 inch)

Annular Velocity (m/s)	20	40	60
Particle Movement (%)	19	44	71

4.3 Result Analysis

4.3.1 Analysis Result Simulation for Particles Size 0.185 inch

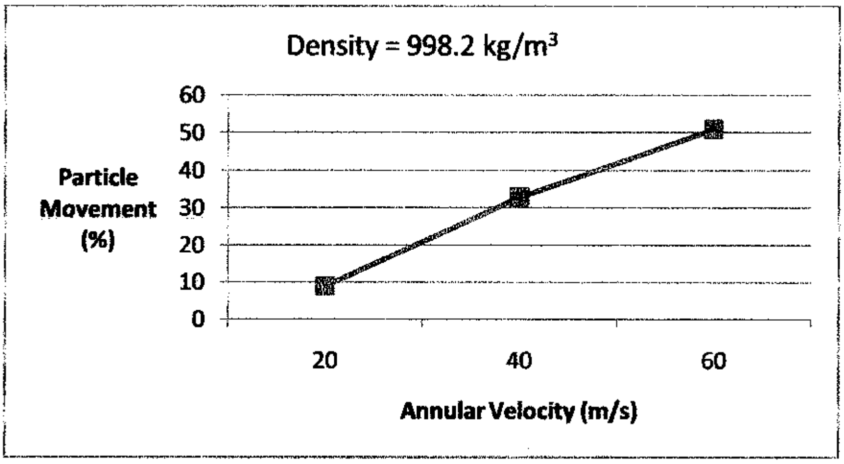

Figure 16: Particles Movement Test #1 (Particles Size 0.185 inch)

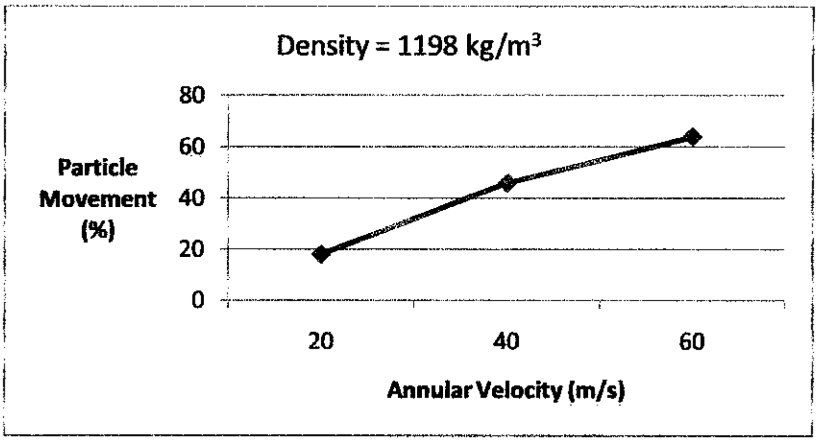

Figure 17: Particles Movement Test #2 (Particles Size 0.185 inch)

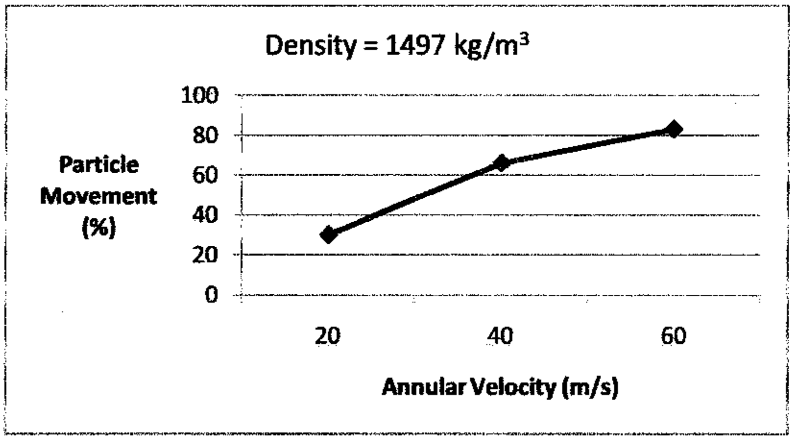

Figure 18: Particles Movement Test #3 (Particles Size 0.185 inch)

4.3.2 Analysis Result Simulation for Particles Size 0.275 inch

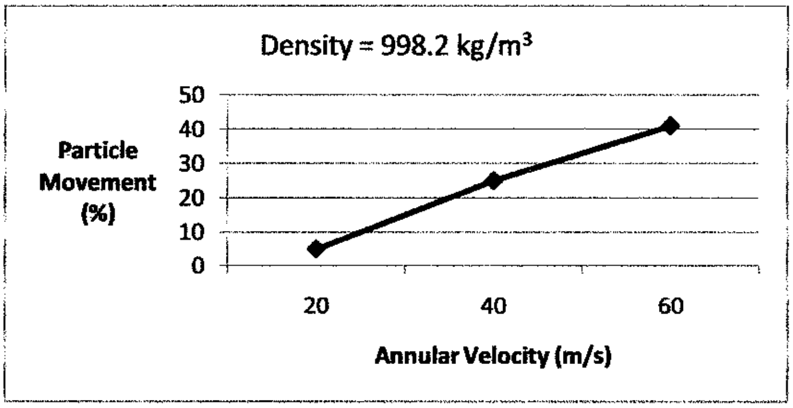

Figure 19: Particles Movement Test #1 (Particles Size 0.275 inch)

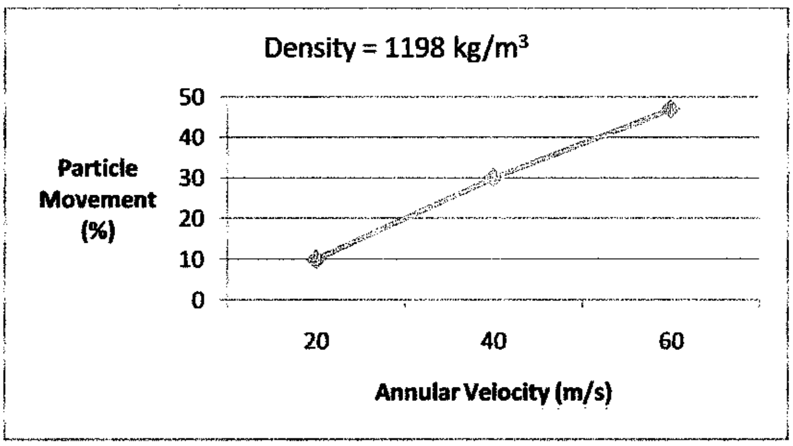

Figure 20: Particles Movement Test #2 (Particles Size 0.275 inch)

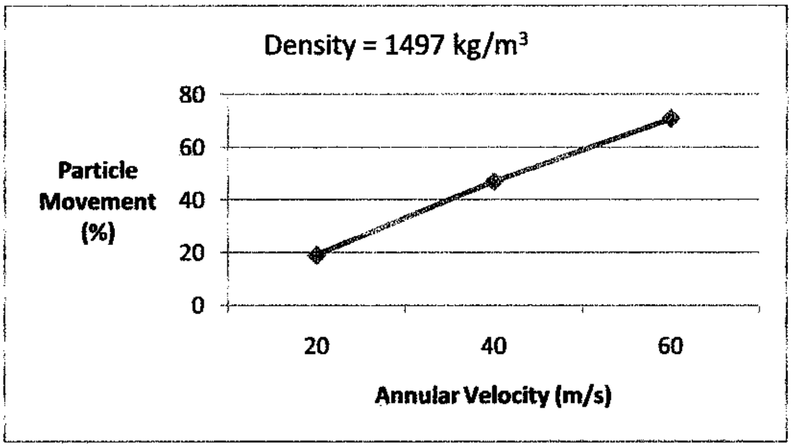

Figure 21: Particles Movement Test #3 (Particles Size 0.275 inch)

4.3.3 Comparison of Particles Movement for Three Fluid Types

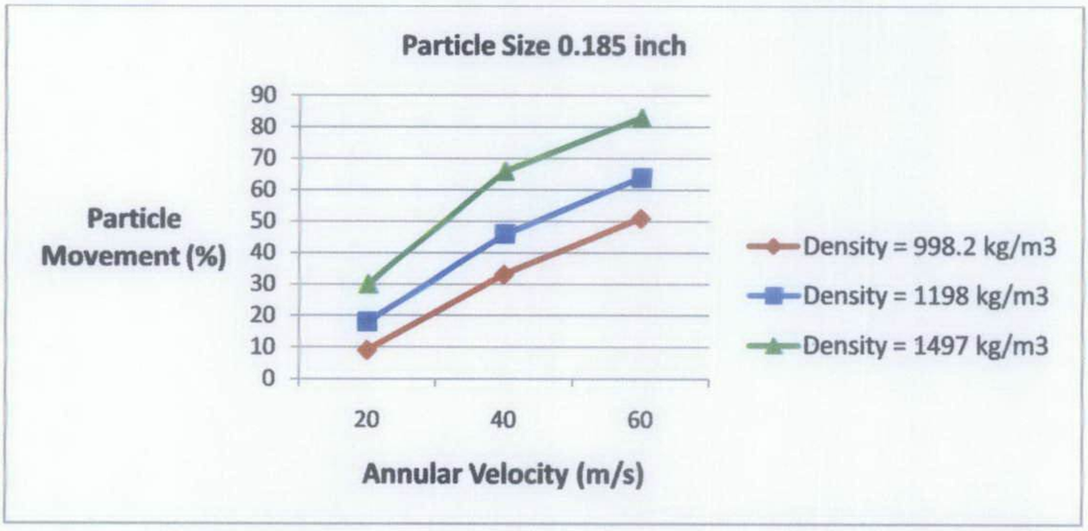

Figure 22: Comparison Test #1, Test #2, and Test #3 (Particles Size 0.185 inch)

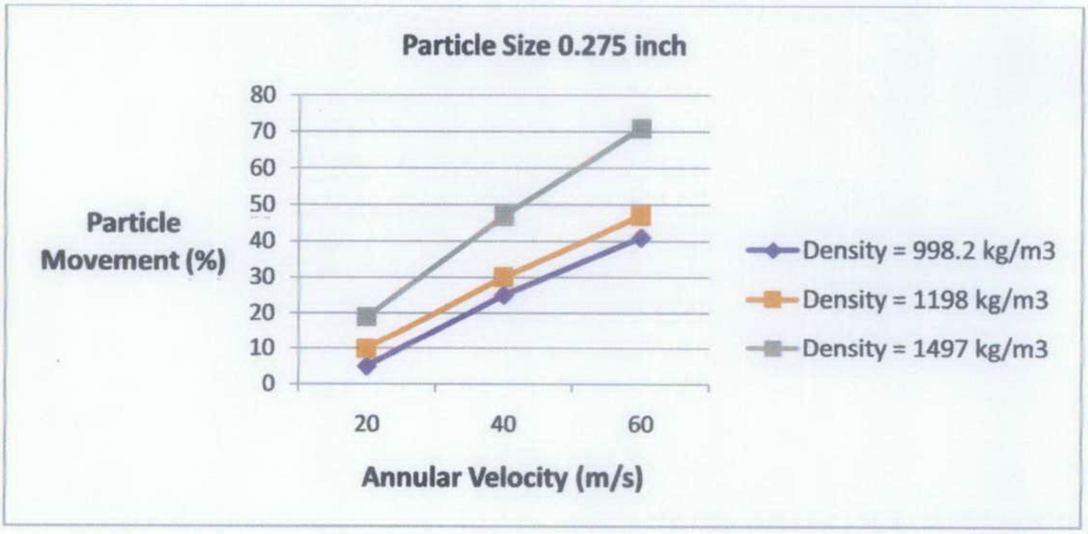

Figure 23: Comparison Test #1, Test #2, and Test #3 (Particles Size 0.275 inch)

The final result for tests conducted using ANSYS model was shown in Figure 22 and Figure 23 above. Both figures represent the relationship between annular velocities for three different fluids and percentage of particles movement. The graph basically shows the amount of particles that will be move when certain value of annular velocity was applied in the pipe. For all types of fluid, the slope show a decreasing pattern when the annular velocity applied was increased.

For both particles size, the fluid with higher density characteristics showed a better cleaning result where it causes higher particle movement in the pipe. As example, for particles size 0.185 inches, when 60m/s velocity was applied, the particle movements were 51%, 64%, and 83% for fluid density 998.2 kg/m^3, 1198 kg/m^3, and 1497 kg/m^3.

Particle size also contributes to a percentage of its movement. From the result, it is shown that it needs a higher annular velocity to transport the larger particles size. For particle size 0.185 inches and using fluid with density 998.2 kg/m^3, it need 40 m/s annular velocity to transport 29% of particles. But for particle size 0.275 inches and using same fluid density 998.2 kg/m^3, annular velocity 40 m/s can only transport 19% of particles. This proves that for the same fluid density and using same annular velocity, smaller particles size will be transported higher than larger particles size.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The method to investigate the parameters affecting cuttings transport in horizontal well has been demonstrated in this report. The parameters are annular velocity of fluid, density of fluid, and cuttings size. The comparisons between the parameters are simulated using ANSYS and conclusion can be made that:

1. Annular velocity is the most important parameter in transporting cuttings in horizontal well. It is demonstrated that higher annular velocity will lead to higher percentage of cuttings transport.
2. Applications of higher fluid density as a drilling fluid lead to higher particle transportation in horizontal well.
3. Objective of the project is to model and simulate the cuttings transport mechanism using various parameters that affect the cuttings transport. From the result obtained in this project, the objective is achieved.

5.2 Recommendation

From the result obtained, it is found that the result can be improved if the simulation process can animate the movement of the cuttings movement. Hence, the proposed analysis simulation method has demonstrated a workable alternative to study the cuttings transport mechanism in horizontal well. However, further investigation are recommended in order to improved the quality of the data obtained and accuracy of its data, exactly equal with the real world situation. Also the model can be improved if there is a numerical model been developed to represent the fluid characteristics such as turbulent and laminar flow. These characteristics need a lot of calculation to prove and if the numerical solution can be model, the data and result accuracy will be better. Besides that, I recommend further study to be conducted in future on the affect of viscosity of fluid in cuttings transport mechanism in horizontal well. Since this project only investigate affect of density, future study about viscosity of fluid will strengthen the data and analysis gained. In addition, more critical and detail explanations can be made to explain the mechanism of cuttings transportation.

REFERENCE

1) M.E. Ozbayoglu et al., 2005, "Using foam in horizontal well drilling: A cutting transport modeling approach," *Journal of Petroleum Science and Engineering* 46: 267 – 282

2) CHENG Rong-chao and WANG Rui-he, 2008, "A Three-Segment Hydraulic Model For Annular Cuttings Transport With Foam In Horizontal Well," *Journal of Hydrodynamics* 20(1): 67-73

3) A.M. Kamp, M. Rivero. 1999, "Layer Modeling for Cuttings Transport in Highly Inclined Wellbores," paper SPE 53942 presented at 1999 SPE Latin American and Caribbean Petroleum Engineering Conference, Caracas, Venezuela, 21-23 April.

4) Ali A. Pilehvari, J.J. Azar, and Siamack A. Shirazi. 1995, "State-Of-The-Art Cuttings Transport in Horizontal Wellbores," paper SPE 37079 presented at 1996 SPE International Conference on Horizontal Well Technology, Calgary, Canada, 18-20 November.

5) AZAR, J.J. and SANCHERZ, R.A., Important Issues in Cuttings Transport for Drilling Directional Wells; paper SPE 39020 presented at the 5th Latin America and Caribbean Petroleum Engineering Conference, Rio de Jeneiro, Brazil, August 30-September 3, 1997.

6) H. CHO, S.N. SHAH, and S.O. OSISANYA, "A Three-Segment Hydraulic Model for Cuttings Transport in Coiled Tubing Horizontal and Deviated Drilling," Journal of Canadian Petroleum Technology: 32 – 39

7) Jeff Li, SPE, and Scott Walker, SPE, BJ Services & Co., "Sensitivity Analysis of Hole Cleaning Parameters in Directional Wells," paper SPE 74710 presented at the 1999 SPE/ICoTA Coiled Tubing Roundtable, Houston, Texas, 25-26 May.

8) Y. LI, N. BJORNDALEN, E. KURU, "Numerical Modeling of Cuttings Transport in Horizontal Well Using Conventional Drilling Fluids," paper 2004-227 presented at Petroleum Society 5th Canadian International Petroleum Conference. Calgary, Alberta, Canada, June 8-10, 2004.

9) Xiao-le Guo, Zhi-ming Wang, Zhi-hui Long, "Study on Three Layer Unsteady Model of Cuttings Transport for Extended Reach Well," Journal of Petroleum Science and Engineering 73 (2010): 171-180

10) O. Osunde and E. Kuru, "Numerical Modeling of Cuttings Transport with Foam in Inclined Wells," The Open Fuels & Energy Science Journal, 2008: 19-33

11) NGUYEN D., RATHMAN S. S. "A three-layer hydraulic program for effective cuttings transport and hole cleaning in highly deviated and horizontal wells", SPE Drilling and Completion, 1998, 13(3): 182-189

12) H.I. Bilgesu, M.W. Ali, K. Aminian, S. Ameri, "Computational Fluid Dynamic (CFD) as a Tool to Study Cutting Transport in Wellbores", paper SPE 78716 presented at SPE Eastern Regional Meeting held in Lexington, Kentucky, U.S.A., 23-25 October 2002.

13) http://www.energyindustryphotos.com/how_oil_and_gas_wells_are_drille.htm

14) http://oilgasinformation.com/drilling-rig-diagram

15) http://www.ansys.com/Products/Simulation+Technology/Fluid+Dynamics/ANSYS+FLUENT

16) http://oilgasglossary.com

17) http://www.glossary.oilfield.slb.com