Effect of Drillpipe Rotation on Cuttings Transport in Horizontal Wellbore Section

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Final Report submitted in partial fulfilment of
the requirement for the
Bachelor of Engineering (Hons)
Degree in Petroleum Engineering

September 2012

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(PETROLEUM ENGINEERING)

Approved by,

____

(Dr. Sonny Irawan)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2012

CERTIFICATE OF ORIGINALITY

I hereby declare that all information presented in this report are my own work, study materials and literatures used in this project are cited and listed in reference. I am responsible for the content and accuracy of the project in accordance with Universiti Teknologi PETRONAS academic rules and work ethics.

SAYIDOLIMKHON MIRZAEV

Signature:___________________

ABSTRACT

In this project interaction between drill pipe rotation and drilling fluid to remove the cuttings from horizontal concentric annuli were simulated using ANSYS CFX 14 Computational Fluid Dynamics (CFD). CFD software has proven to be successful tool in studying fluid flow in bit hydraulic and gas liquid flow in pipeline and separator. Investigation of drill pipe rotation effect on cuttings volume fraction and annular pressure losses has been validated against flow loop tests conducted by Ozbayoglu and Saasaen (2008).

Cuttings transport has been one of the major concerns during drilling horizontal and directional wells cleaning. Inadequate hole cleaning significantly affect cost, time and quality of horizontal wells. Improper hole cleaning may lead to number of problems such as pipe sticking, causing higher drag and toque, slower rate of penetration, formation of fractures and wellbore steering problems, especially in eccentric horizontal annulus. Our aim is to simulate the pipe rotation to achieve better transport of cuttings from horizontal annuli during conventional drilling. The process includes using ANSYS CFX 14 software to simulate the flow of water–flow medium through two concentric cylinders annuli containing initial stationary cuttings bed. The inner cylinder rotates while the outer is fixed. The parameters of focus Newtonian fluid (water) and cuttings concentration and rotary speed, would be varied accordingly and the effects on cuttings concentration and friction pressure losses would be observed. Data obtained has been validated against experimental data by Ozbayoglu and Saasaen (2008) which showed a good agreement.

AKNOWLEDGEMENT

I would like to express the deepest appreciation to the Petroleum Engineering Department Expertise of Universiti Teknologi PETRONAS. Whose teachings and valuable lessons served as a strong foundation in completing this project.

I wish to thank to Dr. Sonny Irawan, who has the attitude and the substance of a genius. I very much appreciate his persistent support and guidance in conducting my Final Year Project under his supervision. Without his guidance and persistent help this dissertation would not have been possible.

I am also thankful to Dr. Reza Ettehadi for providing such an interesting topic for the Final Year Project and his study materials. In addition thank you GA students Titus and Javit for their help in understanding the subject of project and their help in conducting simulation work.

I wish to offer regards and blessings to all technicians of Univerisiti Teknologi PETRONAS and my fellow classmates for their assistance and I am grateful to have them around me, when I needed their help.

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ABBREVIATIONS AND NOMENCLATURES

ε	=	Eccentricity
e	=	Distance between the centre of inner and outer pipe
R_o	=	Outer pipe radius
R_i	=	Inner pipe radius
u	=	mass averaged mixture velocity (m/s)
P	=	pressure (Pa)
G	=	gravity vector (m/s^2)
c_s	=	dimensionless particle mass fraction
u_{slip}	=	relative velocity between the solid and the liquid phases (m/s)
ρ_f	=	liquid pure-phase densities (kg/m^3)
ρ_s	=	solid pure-phase densities (kg/m^3)
φ_s	=	the solid-phase volume fraction (m^3/m^3)

CHAPTER 1
INTRODUCTION

1.1 Background

Proper hole cleaning during horizontal well drilling can be challenging compared to vertical wells. Drilling generated cuttings tend to fall down and accumulate at the bottom of horizontal wellbore. In conventional drilling we circulate drilling fluid in order to remove the cuttings from the wellbore. However, in horizontal wells circulating drilling fluid is not as effective as in vertical wells to remove the cuttings. It is a complex mechanism affected by several parameters.

According to Azar and Samuel (2007) [1], cuttings transport mechanism can be classified into cuttings slip velocity, annular mud velocity, flow regime of fluid and cuttings slippage, annular velocity profile, cuttings-bed formation, drill pipe rotary speed, drilling rate, fluid rheological properties and hole inclination.

Numerous studies have been conducted to investigate cuttings transport mechanism and very few of them considered drillpipe rotation effects on cuttings transport. One of these studies has been conducted by Ford et al and Peden et al (1990) [2] to investigate the effect of the pipe rotation on minimum fluid velocity preventing cuttings bed development in inclined wellbores.

Computational Fluid Dynamics (CFD) has been used by Mishra and Amri (2007) [3] to study the effect of drilling parameters on hole cleaning.

1.2 Problem Statement

Followings are potential problems that might occur if the hole is not properly cleaned out of cuttings:

- Increase of pipe sticking potential due to the sedimentation of the cuttings below the drill pipe.
- Higher drag which requires additional force to rotate the drill pipe and higher torque to drive the drill bit into the formations.
- Slower rate of penetration due to premature bit wear and higher torque
- Formation of fractures due to the increment in the frictional pressure losses
- Wellbore steering problems as a result of pipe sticking

Aforementioned problems create complications in drilling operations causing a delay in project completion. The negative effects of inadequate hole cleaning are more observed in deviated wells, especially horizontal wells. Better understanding of cuttings transport phenomenon would help to overcome above mentioned problems.

1.3 Objective and Scope of Study

The primary objective of this project is:

- To investigate effect of pipe rotation by using CFD method

The scope of study:

a) Solid particles tracking in Newtonian fluid (Water) in horizontal concentric annulus using Eulerian phase.

b) Sensitivity analysis of annular pressure drop due to pipe rotation.

CHAPTER 2
LITERATURE REVIEW

2.1 Forces acting on Cuttings Particle

Fluid flow run through the borehole will create some forces on cuttings particle which in result cause the particles migrate along with the fluid. If the cuttings particles are treated individually we find that there are five major forces that act in different directions: drag force (f_d), buoyancy force (f_b), lift force (f_l), friction force (f_f), gravitational force (f_g) and Van de Waals Force (f_{van}). Figure 2.1 shows free body diagram of the particle and forces acting in different directions.

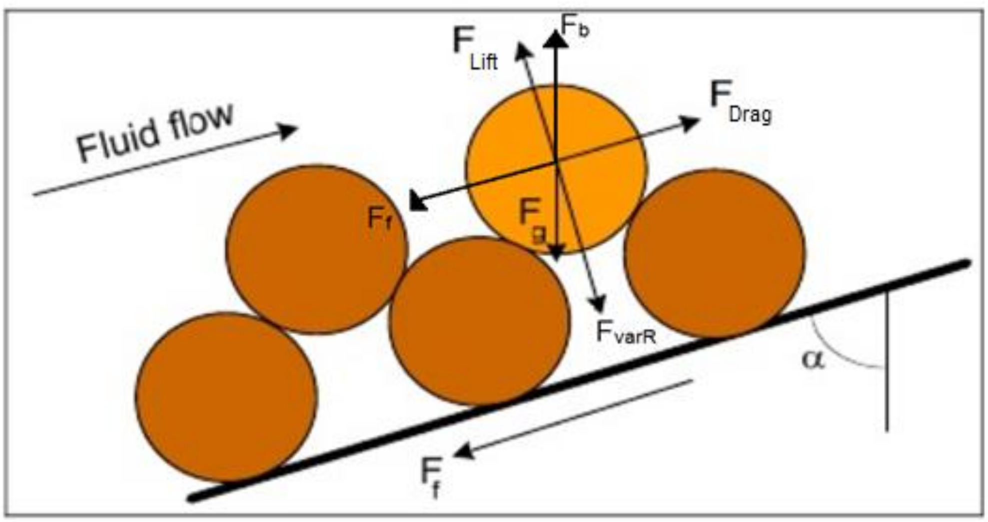


Figure 2.1:Forces acting on solid particle in drilling fluid

Generally, Figure 2.1 describes that if the cuttings are very small it becomes more difficult to transport the cuttings. However, using high viscous mud effectively removes the smaller cuttings, the smaller cuttings seem to become easier to transport.

2.2 Drilling Fluid Effect

One of the important functions of the drilling fluid is to carry out the drill cuttings to the surface. Its ability to do so depends on cuttings size, shape, density and also annular velocity. These considerations are analogous to the ability of a stream to carry sediment. Large sand grains at lower annular velocity settle to the bottom, while small sand grains at high annular velocity are carried with the water. The mud viscosity is another important property, as cuttings will settle to the bottom of the well if the viscosity is too low.

Sufficient annular velocity is required to transport stationary beds formed inside annulus. Increasing the fluid velocity in vertical wells would generally work for cuttings transport. However, as the well starts to deviate from horizontal axis, increasing fluid velocity becomes difficult due to physical and hydraulic limitations.

To prevent the cuttings depositing downward fluid velocity must exceed the minimum transport velocity (MTV). According to Ford et al (1990) [2] findings the lower MTV produce higher the drilling fluid carrying capacity and vice versa.

2.3 Annular Eccentricity

Due to the gravity force, the drillpipe always tends to lie on the low side of the hole which is known as an eccentric condition of a drillpipe. The drillpipe eccentricity measured in percentage of inclination from the center of the outer pipe or open hole. It is defined from equation (2.1):

$$\varepsilon = \frac{e}{Ro - Ri} \qquad (2.1)$$

In horizontal wells eccentricity results in velocity increase in larger areas, while reducing the velocity in the constricted area. Consequently, the latter area is less fitted for cuttings transport. Thus, for horizontal well with positive eccentricity cuttings-transport problems are accentuated.

Figure 2.2 depicts concentric and eccentric annular geometries.

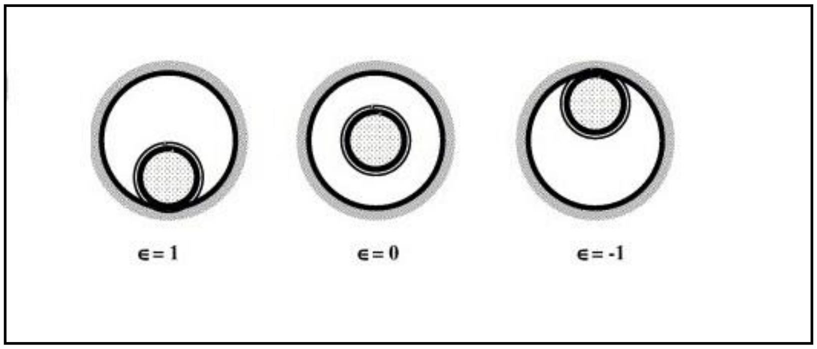


Figure 2.2: Concentric and eccentric annular geometries

According to Ogugbue et al (2010) [4], the frictional pressure losses depend significantly on eccentricity. Experimental results showed that pressure losses declined with the increased of eccentricity.

2.4 Rate of Penetration

The drilling rate shows a direct relationship with cuttings concentration. As the rate increases, more cuttings solid particles are generated. The existing drilling fluid velocity is unable to transport all the cuttings to the surface in time. Hence, it can be observed that the increment of drilling rate causes the decrease in cuttings transport efficiency. Nazariet al (2010) [5] summarizes as the increase in rate of penetration (ROP), the hydraulic requirement for effective hole cleaning is increased.

2.5 Drillpipe Rotation Effect

The experimental study conducted by R. Avila and E. Pereira (2008) [6] on the low-pressure/low-temperature flow loop showed two types of drillpipe motion:

1. Rotary motion (rotation around its own axis)
2. Orbital motion.

Based on the experiment conducted, orbital motion of a drillpipe found to be more effective in hole cleaning. The position of the drillpipe in the inclined section of the hole has an important effect on drilling fluid efficiency in the removal of drilled cuttings in the annular space. Radial component of gravity results the drillpipe to be on the low side of the hole (Figure 2.3). This position of the drillpipe makes hole cleaning complicated. It causes low fluid velocities near the drillpipe where most of the cuttings are located, and higher velocities in the gap greater than the drillpipe.

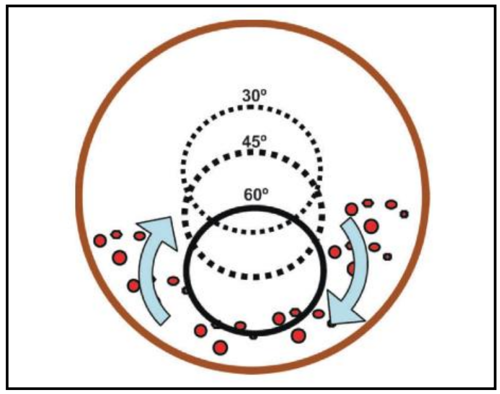


Figure 2.3: Position of the drillpipe from 80 to 110 rpm: (a) at 30° and 45° and (b) at 60°.

The magnitude of the drillpipe's orbital motion depends on its eccentricity and rotary speed. Based on the experiments conducted in University of Tulsa [7] it is stated that higher rotary speed causes a higher orbital motion.

Orbital motion of the pipe improves the transport of the cuttings in two ways:
First, mechanical agitation of the cuttings in an inclined hole sweeps the cuttings resting on the lower side of the hole into the upper side, where the annular velocity is higher (Figure 2.4).

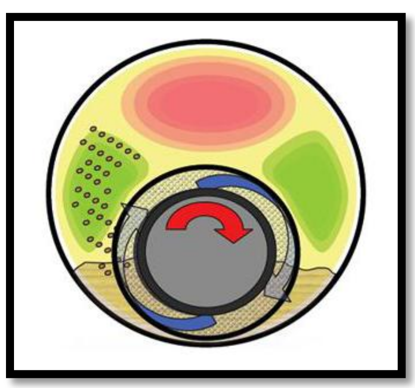


Figure 2.4: Drillpipe orbital motion effect

Above Figure 2.4 shows the orbital motion effects inside horizontal wellbore. Red area represents highest drilling fluid velocity while the green areas show lower velocity. Cuttings resting at the bottom of the hole are moved to high velocity area where the cuttings can be transported to the surface.

Second, the orbital motion exposes the cuttings under the drillstring cyclically to the moving fluid particles.

2.6 Governing Equations in Computational Fluid Dynamics

For this project Comsol Multiphysics 3.5a software can be used to simulate the cuttings transport in horizontal well under the influence of drillpipe rotation using Newtonian fluid (water). The model simulates the flow of a dense suspension consisting of light, solid particles in a liquid placed between two concentric cylinders. The inner cylinder rotates while the outer is fixed.

For this purpose we have chosen two-phase flow model in Comsol Multiphysics using the Mixture Model Application mode, which uses the following equation (2.2) to model the momentum transport:

$$\rho\frac{\partial u}{\partial t} + \rho(u \cdot \nabla)u = -\nabla\rho - \nabla\cdot(\rho c_s(1-c_s)\cdot u_{slip}\cdot u_{slip}) + \nabla\cdot[\eta(\nabla u \not+ \nabla u^T)] + \rho g \qquad (2.2)$$

Mixture density is given by equation (2.3):

$$\boldsymbol{\rho} = (1-\varphi_s)^* \rho_f + \varphi_s\rho_s \qquad (2.3)$$

The mixture model uses the following form of the continuity equation (2.4)

$$(\rho_f - \rho s)\ [\nabla\cdot (\varphi_s(1-c_s)u_{\,slip)]} + \rho_f(\nabla \cdot u) = 0 \qquad (2.4)$$

The transport equation (2.5) for the solid-phase volume fraction is

$$\frac{\partial \varphi s}{\partial t}+ \nabla\cdot(\varphi_s u +\varphi_s(1-c_s)-u_{slip})=0 \qquad (2.5)$$

Dynamics of a suspension can be modelled using above three equations.

CHAPTER 3
METHODOLOGY

In this chapter the methodology of achieving the objective of this project is presented by using commercial software ANSYS-CFX 14 to simulate the two phase flow modeling of dense suspension in the horizontal section of wellbore.

3.1 Simulation Parameters

The simulation model is build based on the horizontal test parameters published in Ozbayoglu and Saasaen (2008) [9].

Geometry used for the simulation has 3ft length with an internal diameter (I.D) of 2.91 inch and inner drill pipe of outer diameter (O.D) of 1.85 inch. Simulation is conducted at zero eccentricity.

Table 3.1: Parameters used in Simulation

Parameters	Value
Wellbore Length	3 ft
Wellbore Diameter	2.91 in.
Drillpipe Diameter	1.85 in.
Eccentricity	0
Cuttings Material	Gravel
Cuttings Diameter	0.079 in.
Cuttings Density	23 ppg
Cuttings Volume Fraction	0.3
Annular Water Flow Rate	3 ft/s
Rotary Speed	0-120 rpm
Pressure	14.7 psi

The cuttings material is gravel with diameter of 0.079 inch and its density is 23.050 ppg. 30% cuttings concentration is originally inside annulus, fluid flow velocity of 3 ft/s and constant, the only varying parameter is rotary speed changing from 0-120rpm. Reference pressure 1 atm has been used for analysis.

3.2 Simulation Model Setup

First step in ANSYS CFX 14 is to setup the geometry based on parameters selected. To do this we select horizontal plane and build model with the length of 3 ft long, 2.91 in. outer diameter and 1.85 in. inner diameter. As there is no eccentricity being studied in this project we set two concentric cylinders. Figure 3.1 shows the model geometry created using design Modeler.

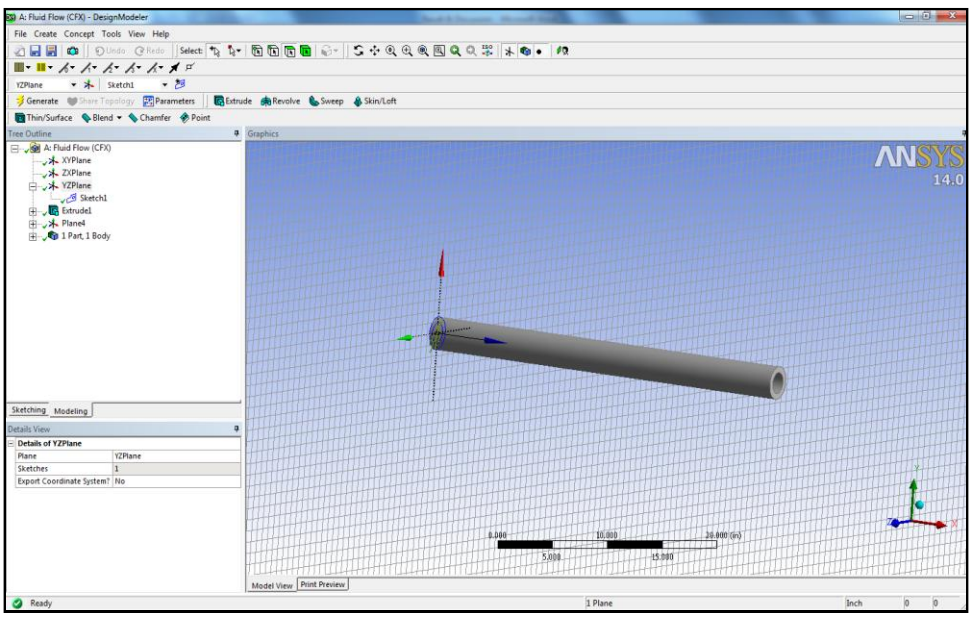


Figure 3.1: Design Modeler

After the geometry is built elements are generated discretely on the mesh geometry in form of mesh to define the region of the interest. Fluid flow regions and surface boundary is created (Figure 3.2).

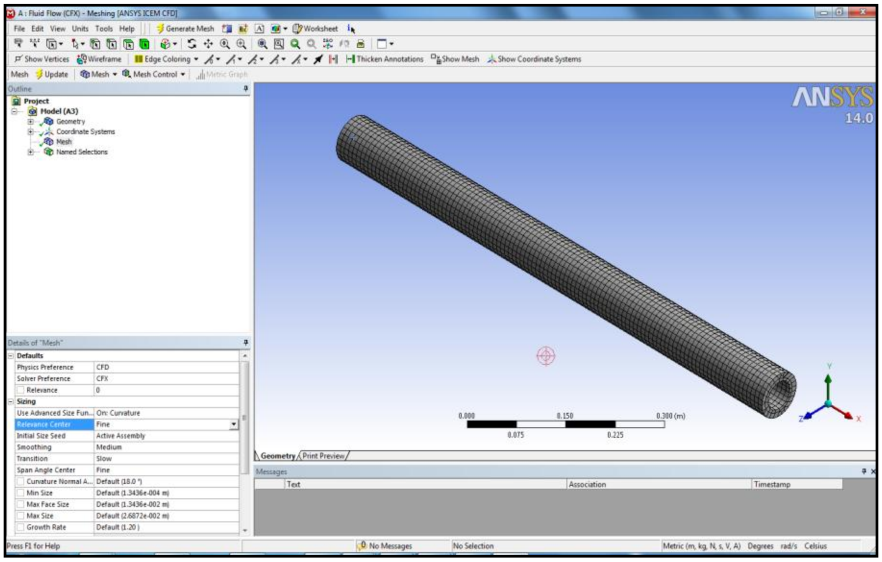


Figure 3.2: Isometric Meshing

Configuring set up module. Cuttings added to the material list and properties of the cuttings are defined. Next, domain has to be defined with water flow and cuttings volume fraction 0.3. Inlet and outlet boundary conditions are defined (Figure 3.3).

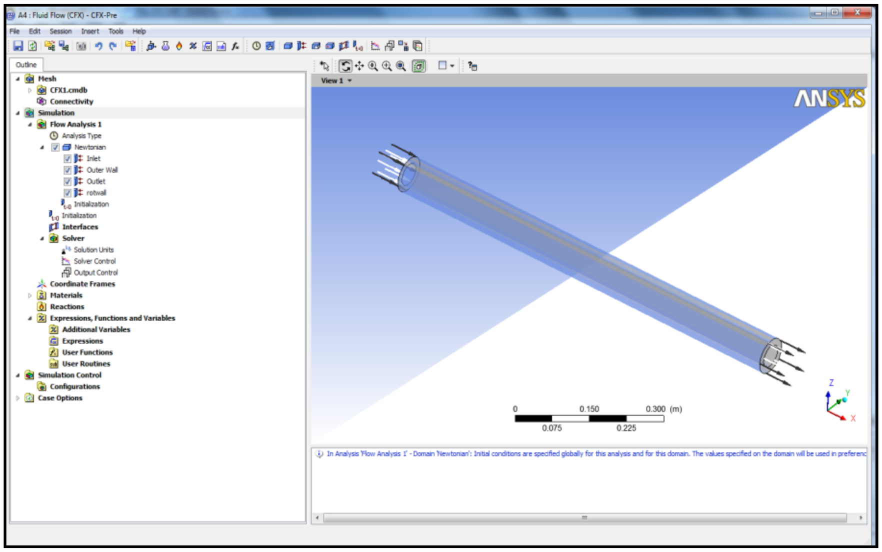


Figure 3.3: CFX Pre

After the set up is complete, the simulation is ready for run. From ANSYS Workbench, the CFX Solver is selected and simulation is started (Figure 3.4).

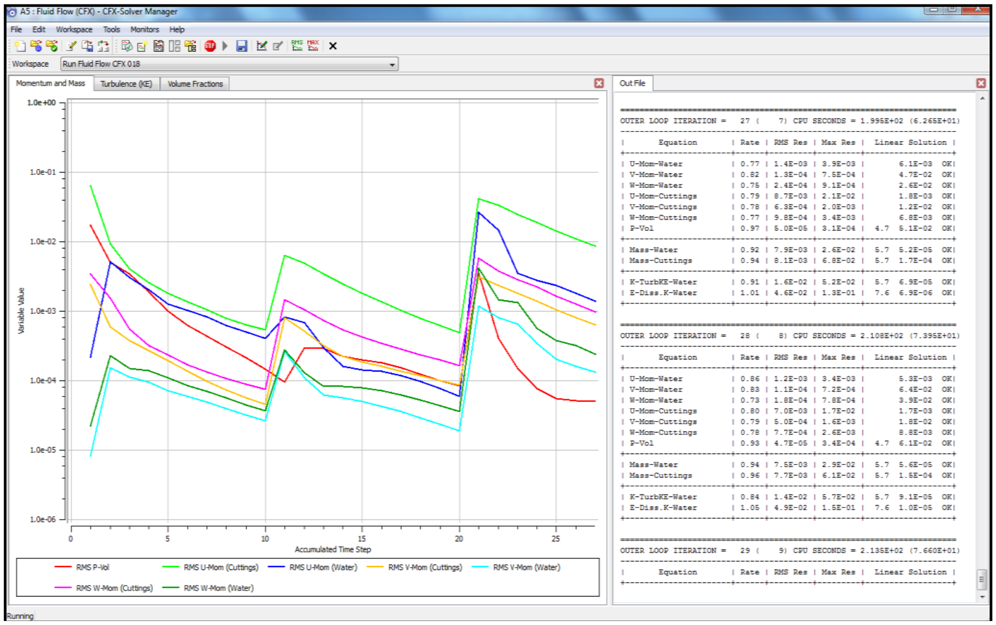


Figure 3.4: CFX Solver

After simulation is completed results are produced from CFX Post (Figure 3.5).

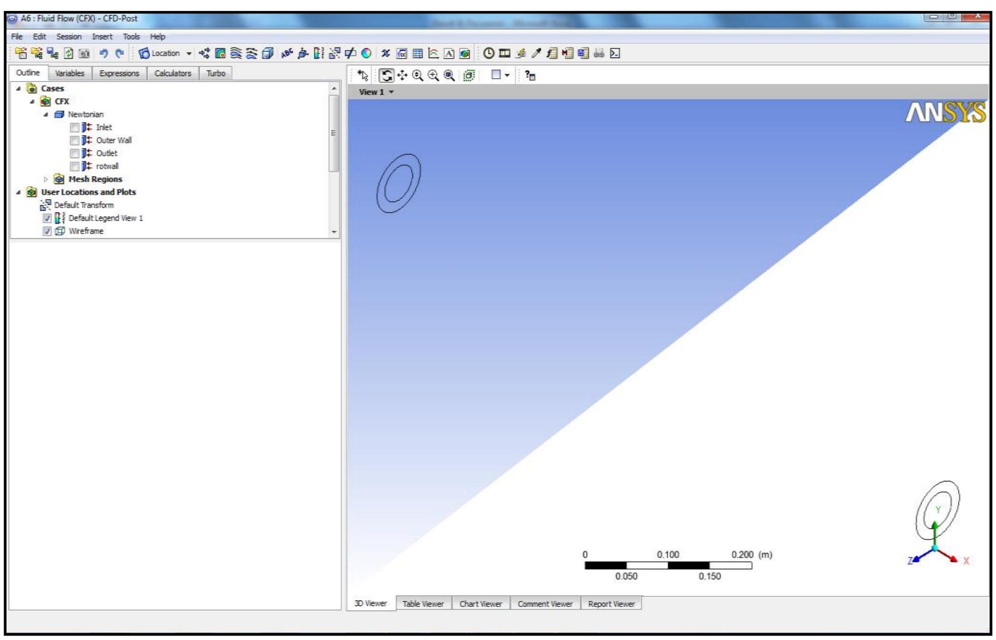


Figure 3.5: CFX Post

Figure 3.6 summarizes the methodologies involved in setting up the model for simulations.

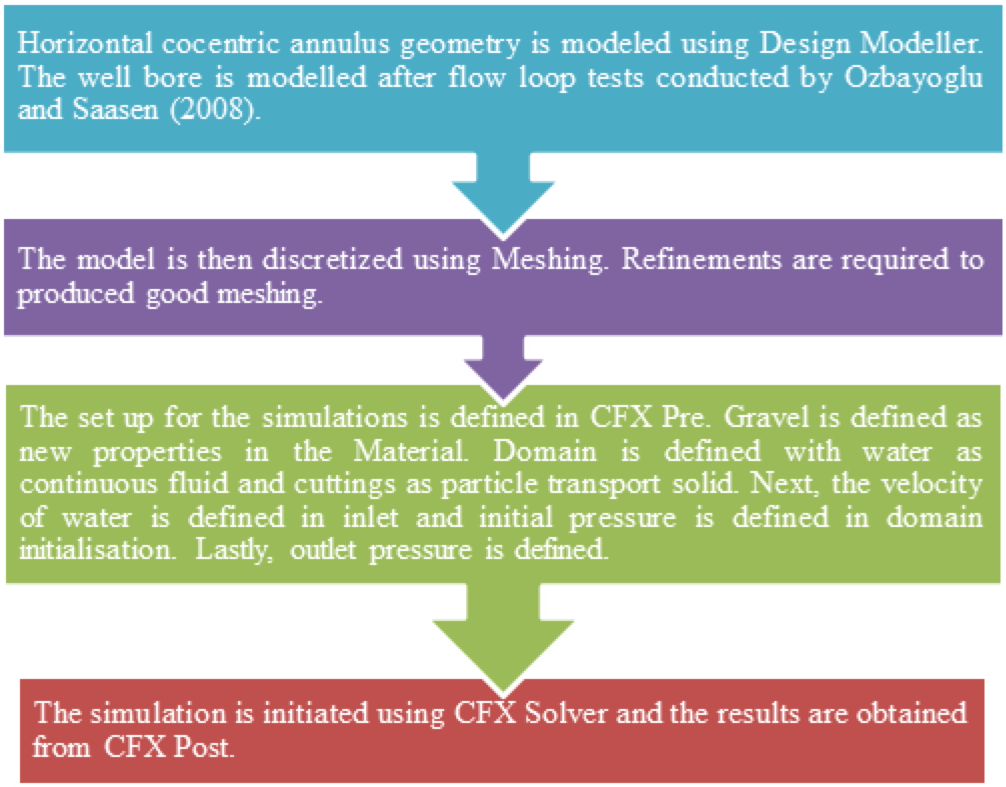


Figure 3.6: Summary of ANSYS SCX 14 Setup

3.3 Key Milestones

The key milestones of the project are given below in the Table 3.2

Table 3.2: Project Milestones

Final Year Project 2		
1	Progress Report Submission	7 Nov. 2012
2	Poster Submission	28 Nov. 2012
3	Final Report Submission	30 Nov. 2012
4	Oral Presentation	19 Dec. 2012
5	Project Dissertation Submission (hard bound)	2 Jan. 2012

CHAPTER 4
RESULT AND DISCUSSION

This chapter presents the results obtained from series of simulations run using ANSYS 14 software. The simulation results are verified with experimental data, “Effect of Pipe Rotation on Hole Cleaning for Water-Based Drilling Fluid in Horizontal and Deviated Wells” from M.E. Ozbayoglu and A. Saasan 2008 [9]. The effect of varying rotary speeds on hole cleaning are investigated. During the analysis major focus is emphasized on stationary cuttings bed thickness, cuttings volume fraction and frictional pressure drop.

4.1 Cuttings Volume Fraction

Snapshot of simulated particle concentration at similar time are shown in Figure 4.1. Based on what was observed experimentally, the assumptions of initially “uniform” solution is not applied to this problem. This simulation assumes fixed temperature of 25°C and ambient pressure of 1 atm. Model generated shows the cutting particles distribution. After a time, drilling fluid (Newtonian fluid-water) is injected at a constant rate of 36.9 gpm which is estimated to achieve 3 ft/s velocity. Flowing water when the inner pipe initially in stationary condition carries the certain amount of cuttings particle from the annulus, process illustrated in below image from ANSYS 14 CFX.

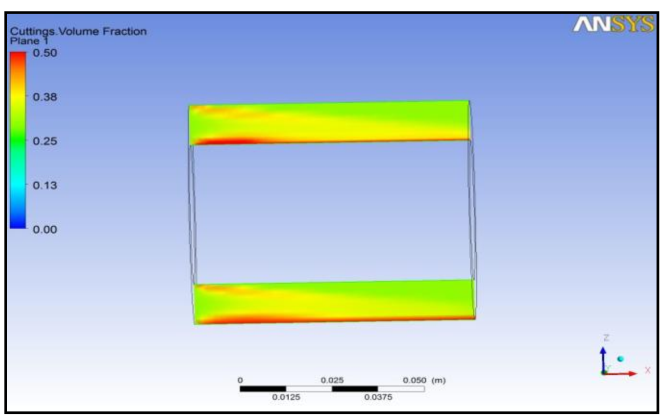


Figure 4.1: Cuttings Volume Fraction at 0 rpm

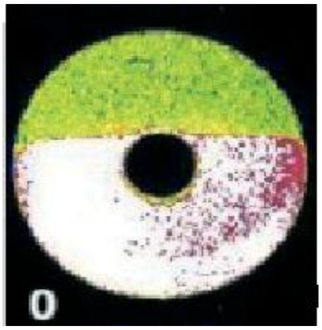
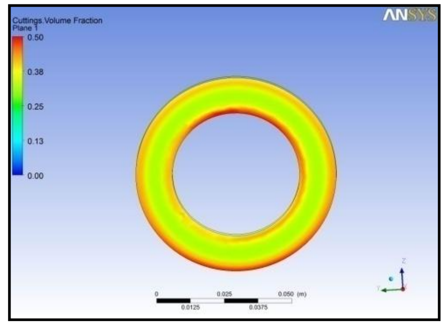
NMR imaging for 0 rotation	Simulation result for 0 rpm
	

Figure 4.2: Comparison of NMR image and simulation result at 0 rpm

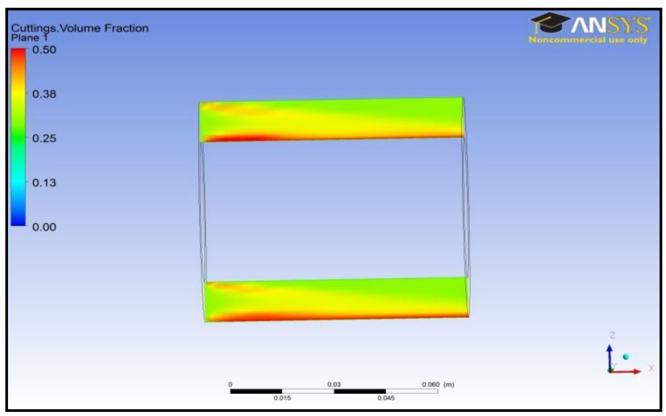


Figure 4.3: Cuttings Volume Fraction at 20 rpm

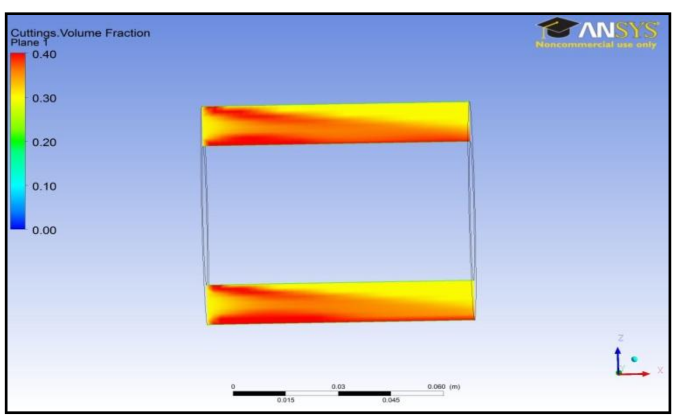


Figure 4.4: Cuttings Volume Fraction at 40 rpm

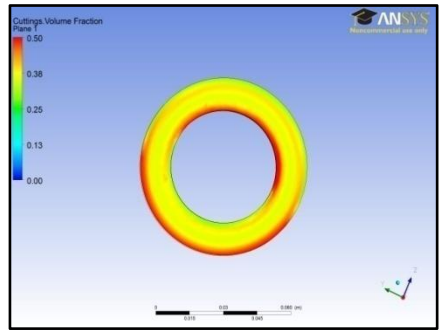
NMR imaging for 40 rotation	Simulation result for 40 rpm
	

Figure 4.5: Comparison of NMR image and simulation result at 40 rpm

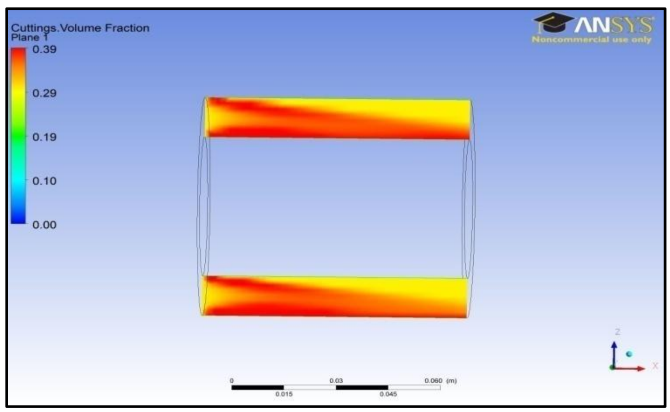


Figure 4.6: Cuttings Volume Fraction at 60 rpm

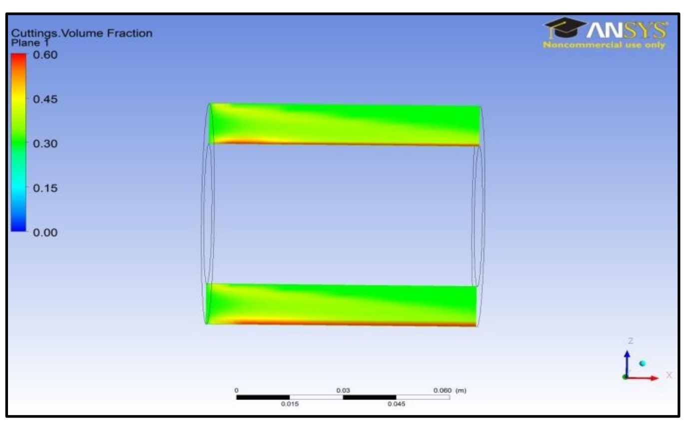


Figure 4.7: Cuttings Volume Fraction at 80 rpm

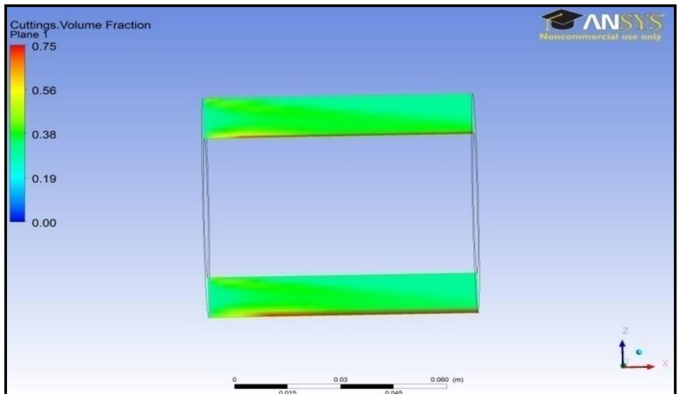


Figure 4.8: Cuttings Volume Fraction at 100 rpm

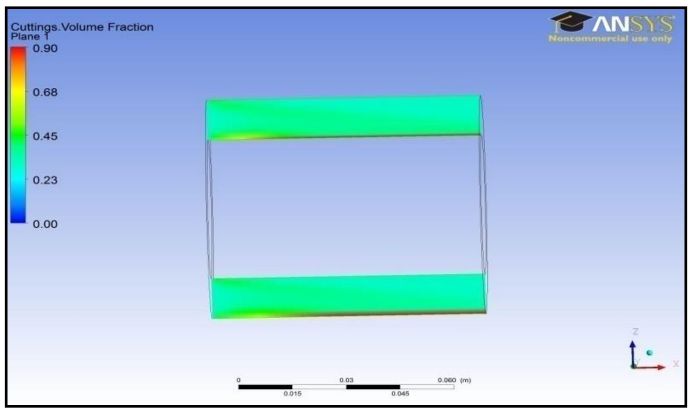


Figure 4.9: Cuttings Volume Fraction at 120 rpm

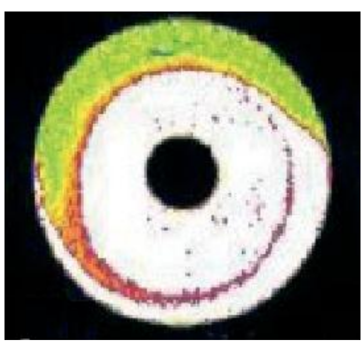
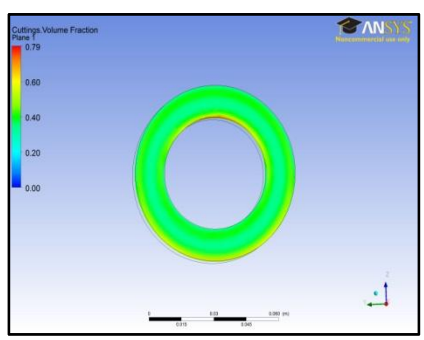
NMR imaging for 120 rotation	Simulation result for 120 rpm
	

Figure 4.10: Comparison of NMR image and simulation result at 120 rpm

Above figures compare NMR image and simulation results for initially sedimented suspension. From NMR images we can observe that initially packed zone thins out when rotation is apllied , and increasing the speed of ratation will gradually reduce the solid packing between Couette gap. Any mixing at higher turns occurs near to outer wall while the region around the inner wall remains void of particles because of the shaer-induced migration.

The simulated concentration profiles agree qualitively with the NMR imaging results. An initial two-phase mixture moves in almost rotating cylinder of maximum packing zone. Starting from 80 rpm to 120 rpm effect of shear-induced migration can be seen. This migration hinders the mixing of outer layers and the simulation begins to lag the experemental results. However, qualitative features, such as the asymmetry created by buyoncy effects interacting with the turn directions, are preserved.

4.2 Annular Pressure Drop

From the simulation results we can analyze the influence of pipe rotation on frictional pressure drop. Figure 4.11 shows the annular pressure drop profile obtained from simulation for Water flow 3 ft/s and cuttings concentration of 30%. Comparing simulation result to a flow loop data for fluid velocity of 3.2 ft/s we can see that simulation result is overall in good trend with experimental result.

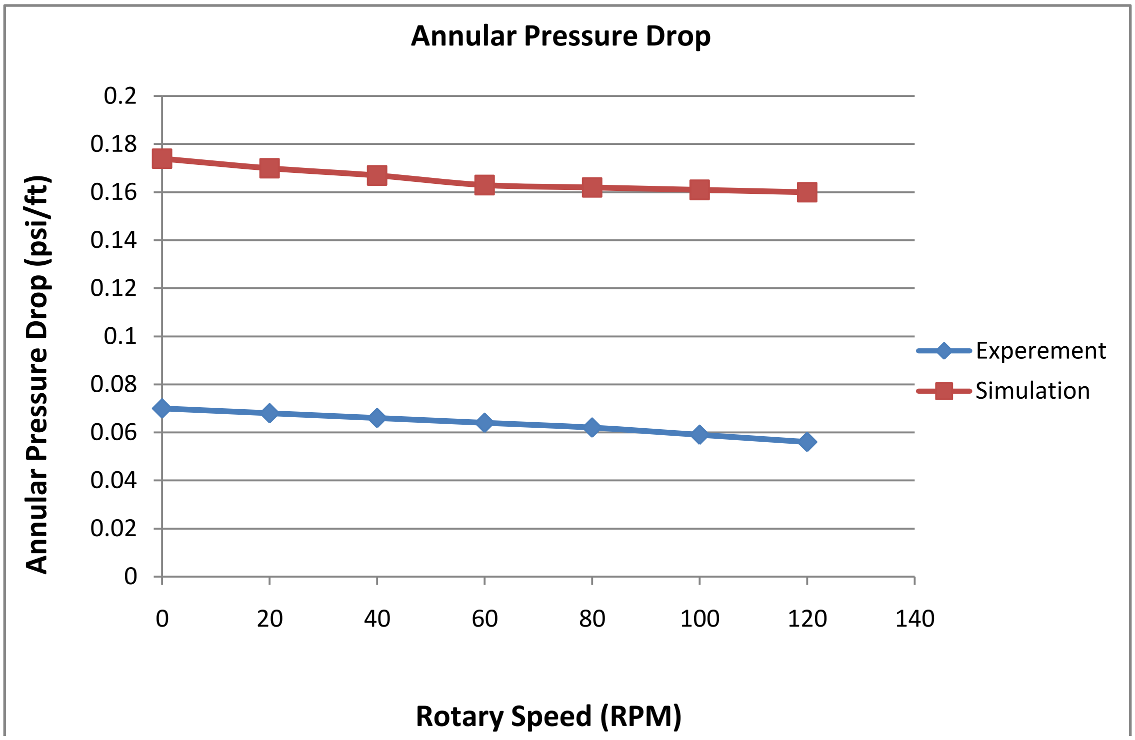


Figure 4.11: Comparison of Annular Pressure Drop between Simulation and Experiment for Water flow 3ft/s and 30% concentration

Increasing the pipe rotation when there are cuttings are present in the wellbore, we can observe decrease in frictional pressure drop compared to no-rotation case. This is due to the reduction of significant stationary bed by drillstring rotation. As a result fluid flow area is increased. This leads to a reduction on the average flow velocity of the fluid, which causes a decrease in pressure drop.

If we analyze the Figure 4.11 closer we can see that simulation result is in good accuracy with experimental result from 0-60 rpm, starting from 60 rpm to 120 rpm simulation results starts to lag the experimental data by decreasing at very small amount in annular pressure drop. This difference might be the result of using two different geometries for simulation and experimental data.

4.3Cuttings Concentration

In Figure 4.12 comparison was made for cuttings volume fraction between ANSYS CFX 14 simulation results and flow loop data.

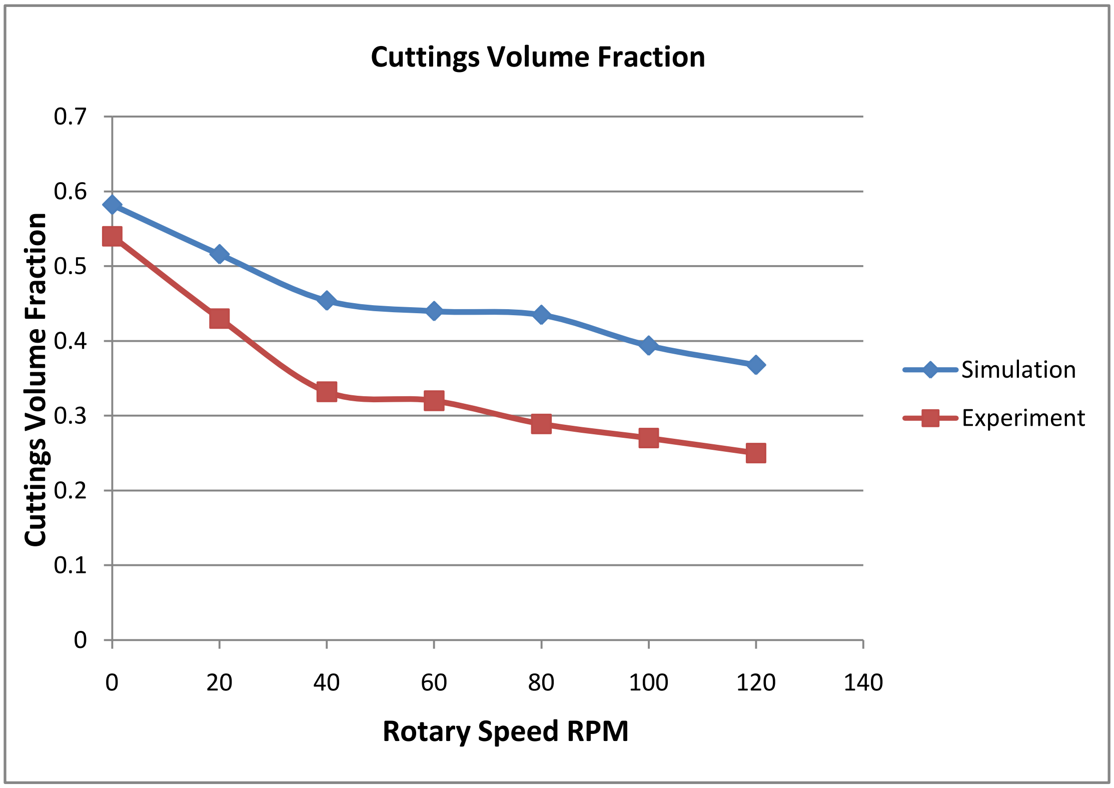


Figure 4.12: Comparison of Cuttings Volume Fraction between Simulation and Experiment for fluid velocity 2.67 ft/s

ANSYS CFX 14 shows good agreement with experimental data. From 0-40 rpm the most effective improvement in cuttings removal can be seen. However, from 60-120 rpm cuttings bed will slightly decrease as the speed of rotation increased. We can conclude from simulation results that after some point in speed of rotation the cuttings transport t effectiveness of pipe rotation becomes minor.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In this project, effect of drillpipe rotation on hole cleaning in horizontal concentric annulus is investigated using Newtonian fluid. An 2.91 in. diameter wellbore, 3 ft long, with a 1.85 in. drillpipe geometry was used for the analysis. Other parameters used in this study are water, as a drilling fluid with 3 ft/s flow velocity and 30 % cuttings concentration. Observations based on simulation work are as follows:

a) ANSYS CFX 14 has successfully modelled drillpipe rotation effects on cuttings transport, with good accuracy. A small percentage of errors in results found when compared with experimental data. Which could be the result of using different geometry for simulation and experiment

b) Orbital motion of drillpipe has significant influence in cuttings bed removal

c) As drillpipe rotation increases, the cuttings transport increases

d) Increasing drillpipe rotation decreases the annular pressure drop

e) Pipe rotation has a significant influence on cuttings transport ability of the fluid. As the pipe is rotated, an improvement in hole cleaning can be observed.

Throughout working processes in this project author has found several areas that can improve the accuracy and perform effective study of drillpipe rotation effects in cuttings transport. Author would recommend:

a) This study only focused on Newtonian fluid. Hence, further studies can be conducted on Non-Newtonian.

b) Further studies can be conducted on the effect of different well inclination from vertical axis.

c) For future studies different fluid velocity can be considered.

d) For future studies eccentricity can be applied.

e) Develop Graphical User Interface (GUI) of the model that simplifies the commands, inputs required and made user friendly for suitability of the operation purposes.

f) For more accurate results the mesh geometry should be finer and velocity profile should be introduced into the model.

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APPENDIX 1

Annular Pressure Drop

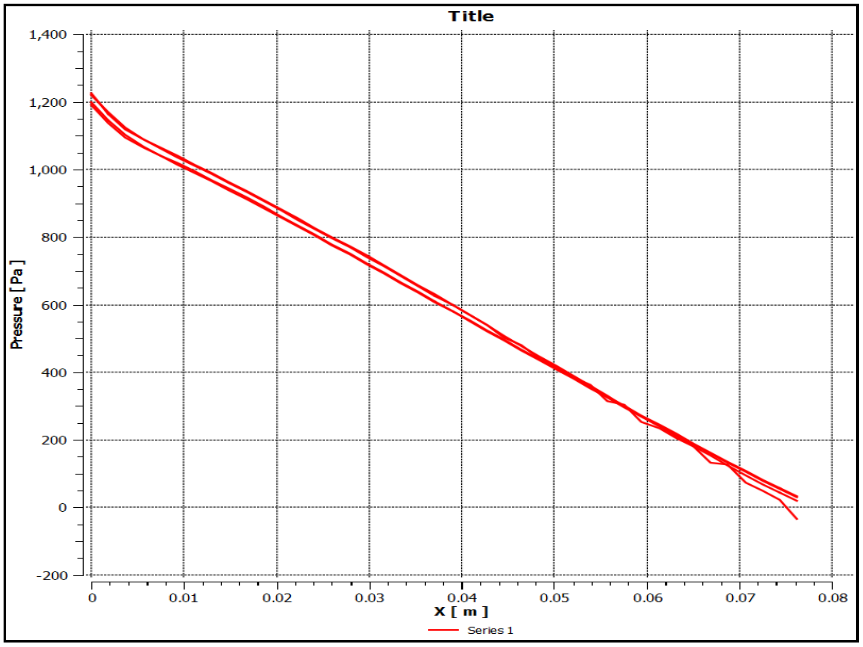

Figure 5.1: Annular Pressure Drop for Water Velocity 3 ft/s at 0-rpm

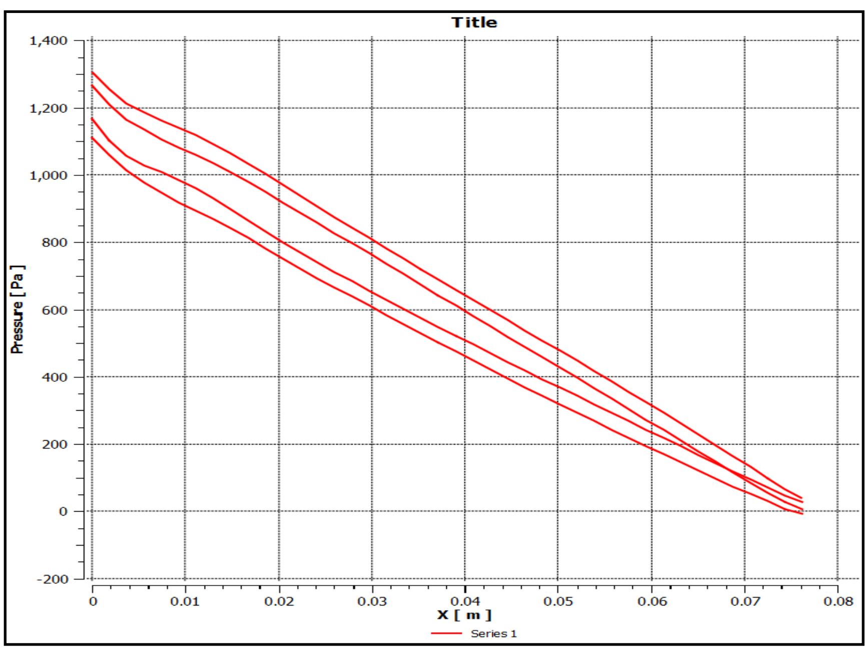

Figure 5.2: Annular Pressure Drop for Water Velocity 3 ft/s at 20-rpm

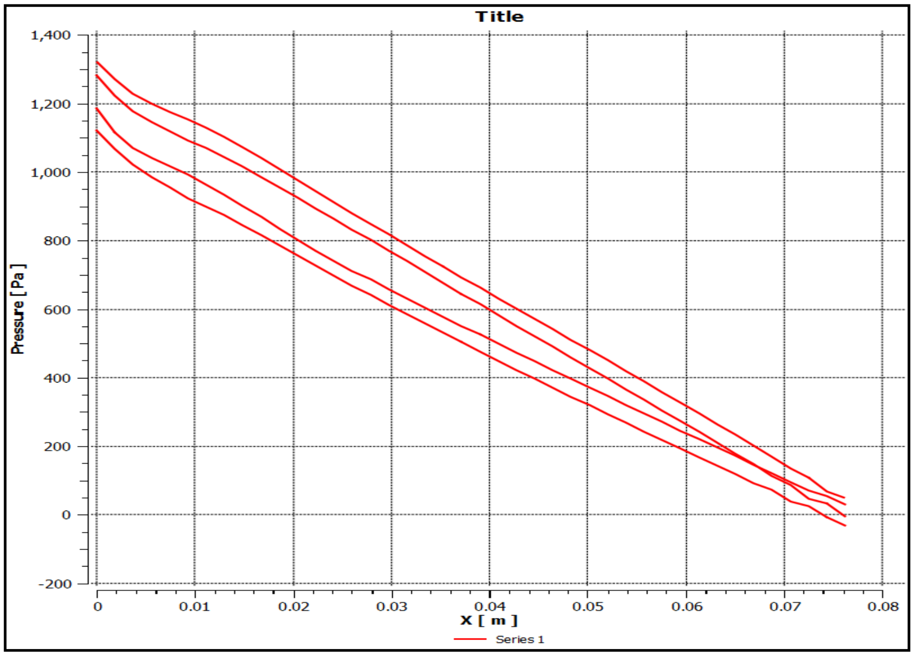

Figure 5.3: Annular Pressure Drop for Water Velocity 3 ft/s at 40-rpm

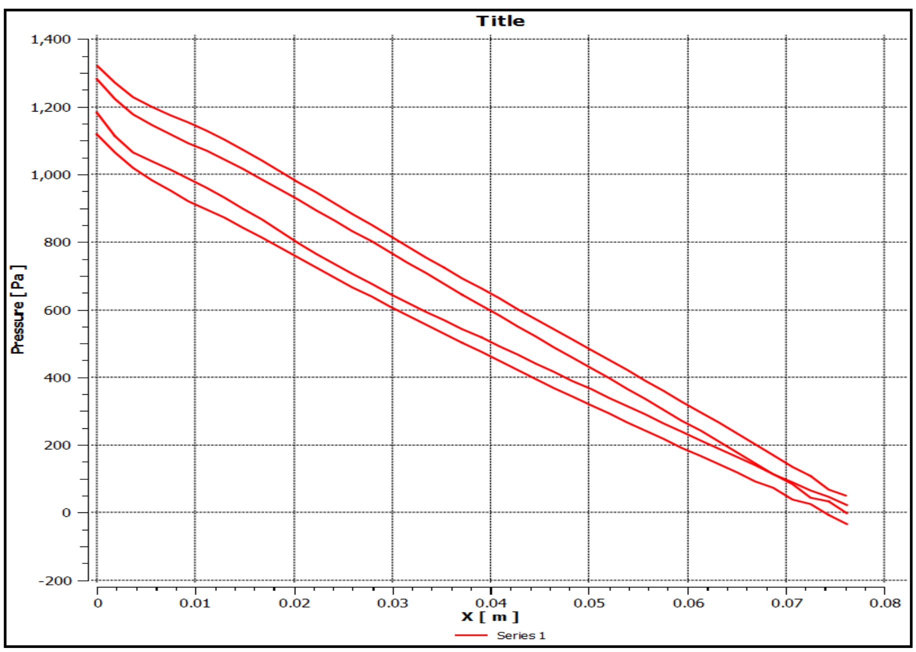

Figure 5.4: Annular Pressure Drop for Water Velocity 3 ft/s at 60-rpm

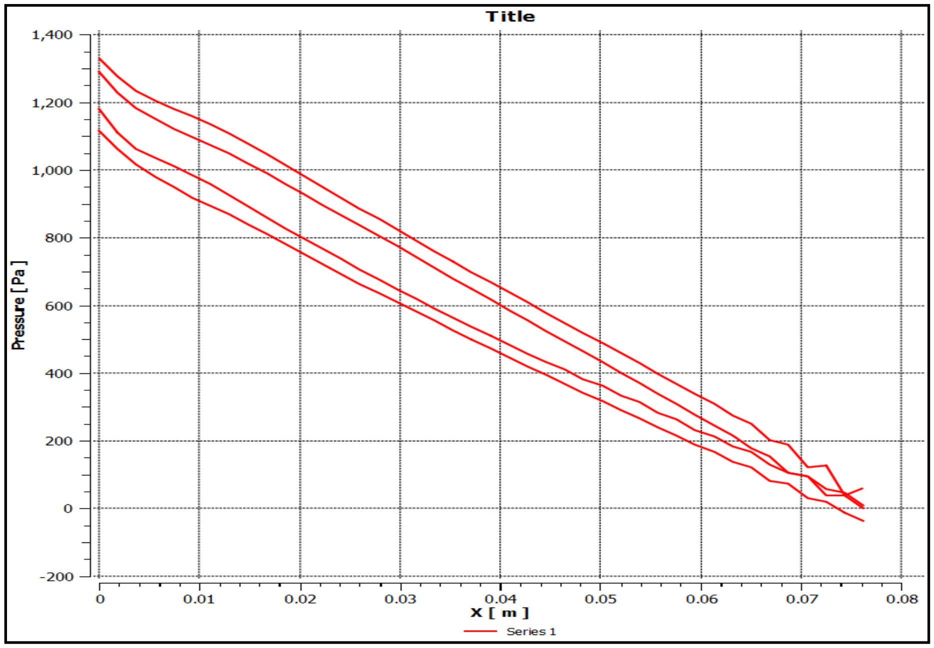

Figure 5.5: Annular Pressure Drop for Water Velocity 3 ft/s at 80-rpm

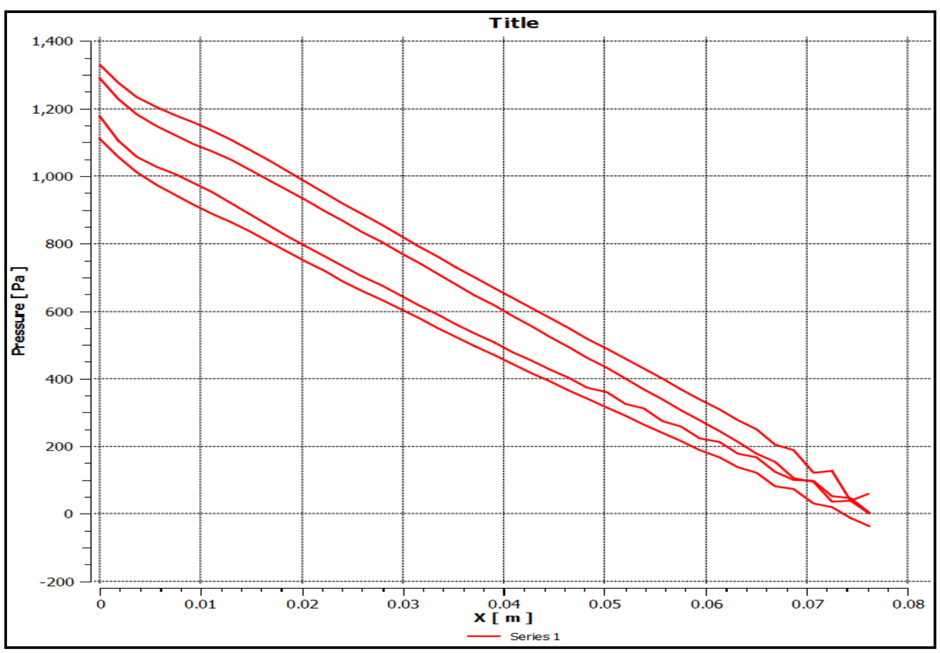

Figure 5.6: Annular Pressure Drop for Water Velocity 3 ft/s at 100-rpm

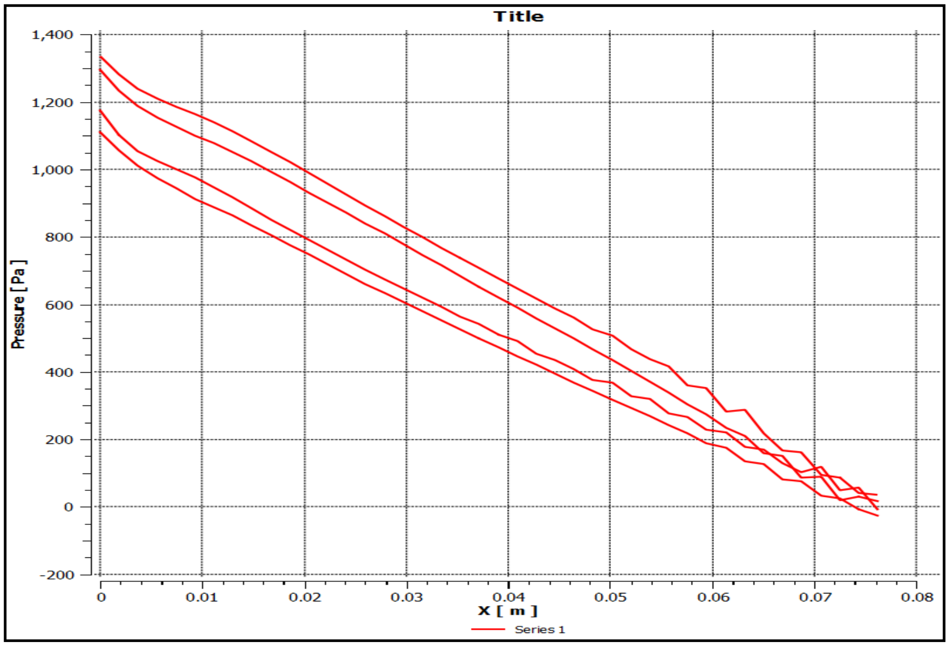

Figure 5.7: Annular Pressure Drop for Water Velocity 3 ft/s at 120-rpm

APPENDIX 2

Cuttings Volume Fraction

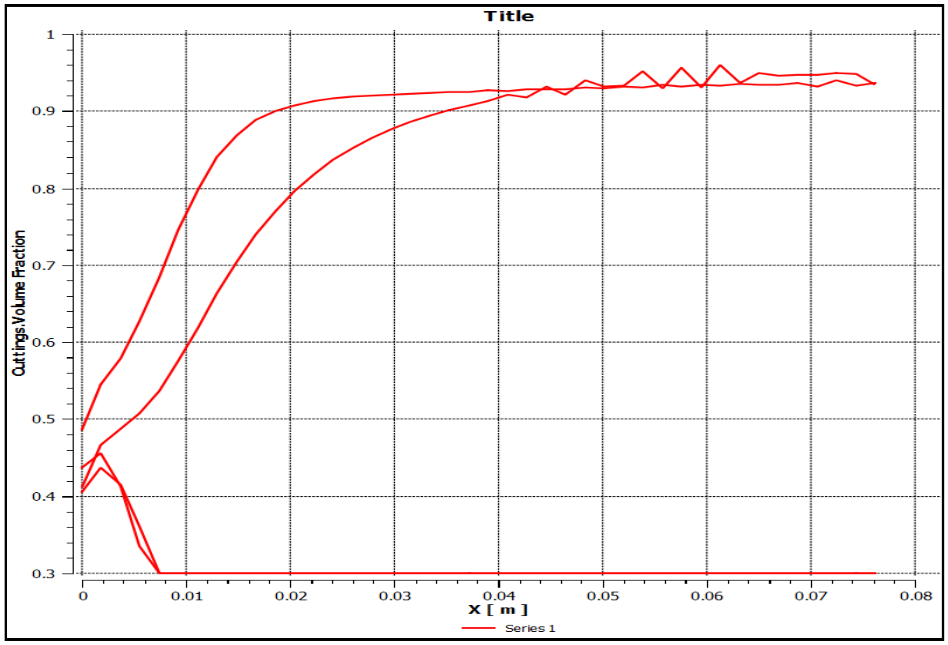

Figure 6.1: Cuttings Volume Fraction for 3 ft/s at 0-rpm

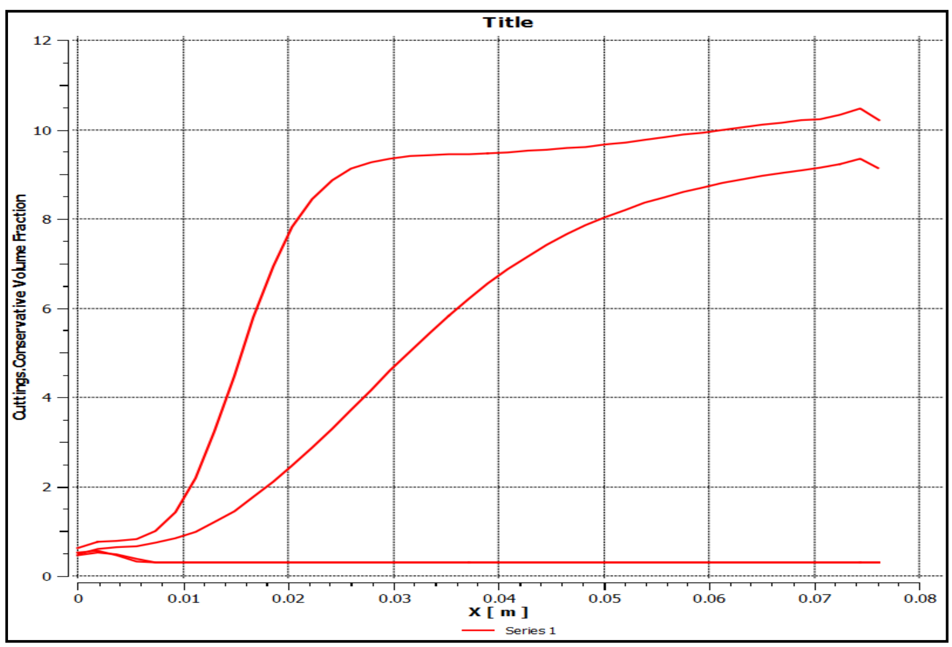

Figure 6.2: Cuttings Volume Fraction for 3 ft/s at 20-rpm

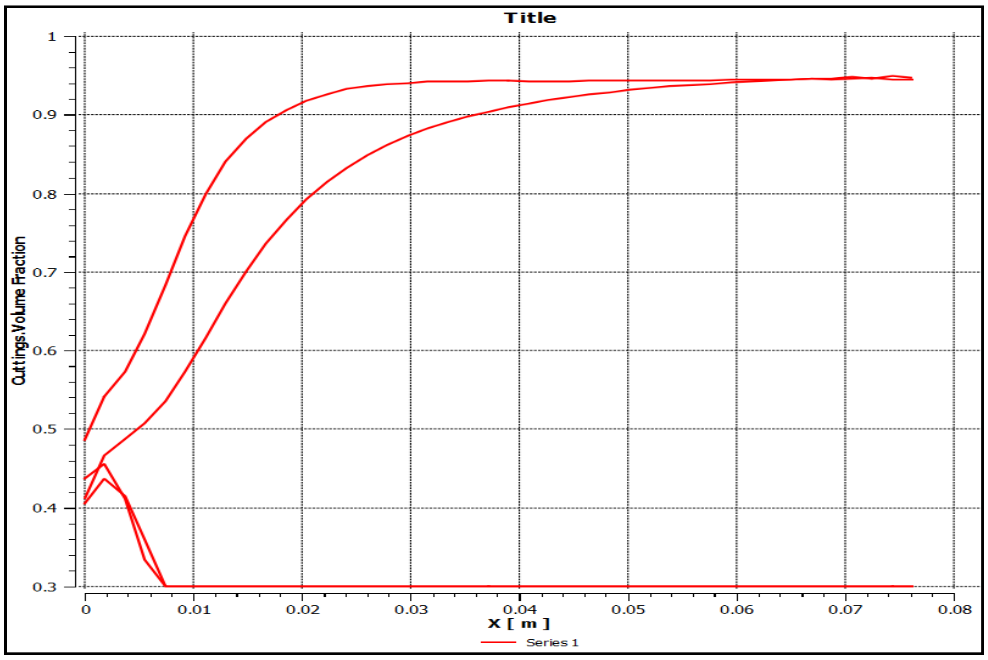

Figure 6.3: Cuttings Volume Fraction for 3 ft/s at 40-rpm

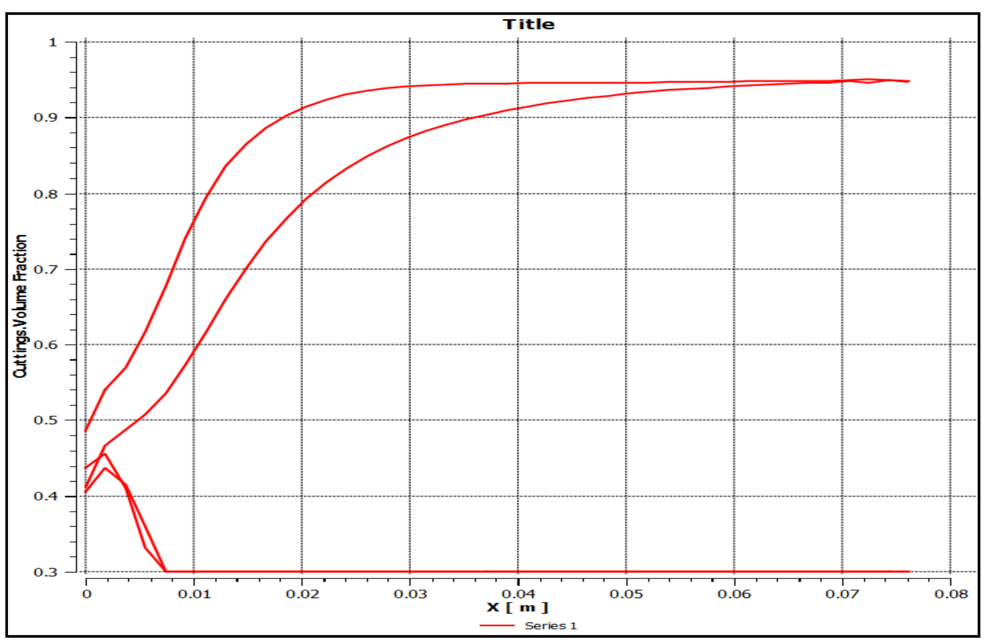

Figure 6.4: Cuttings Volume Fraction for 3 ft/s at 60-rpm

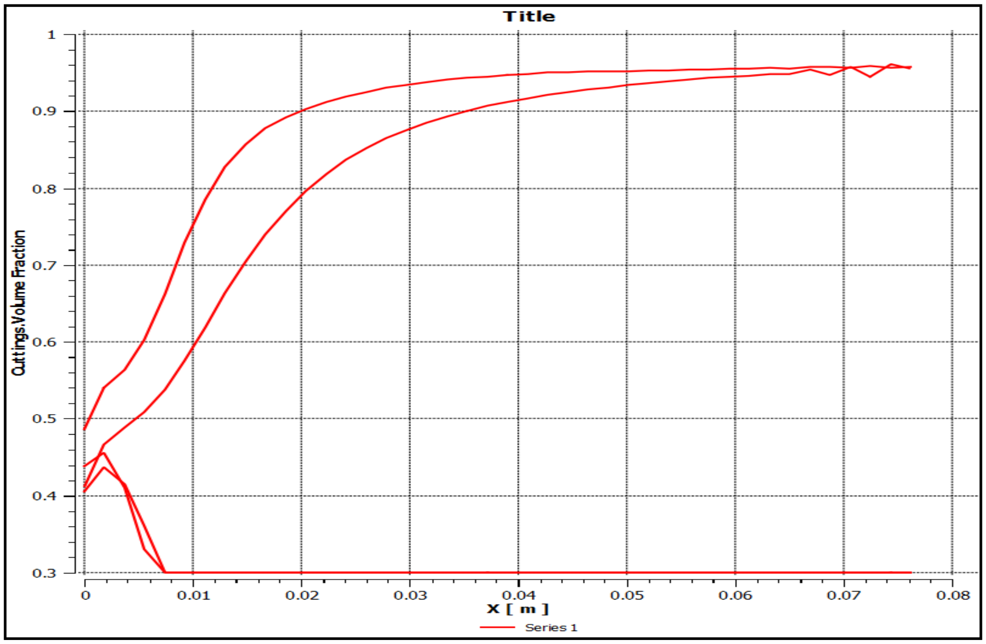

Figure 6.5: Cuttings Volume Fraction for 3 ft/s at 80-rpm

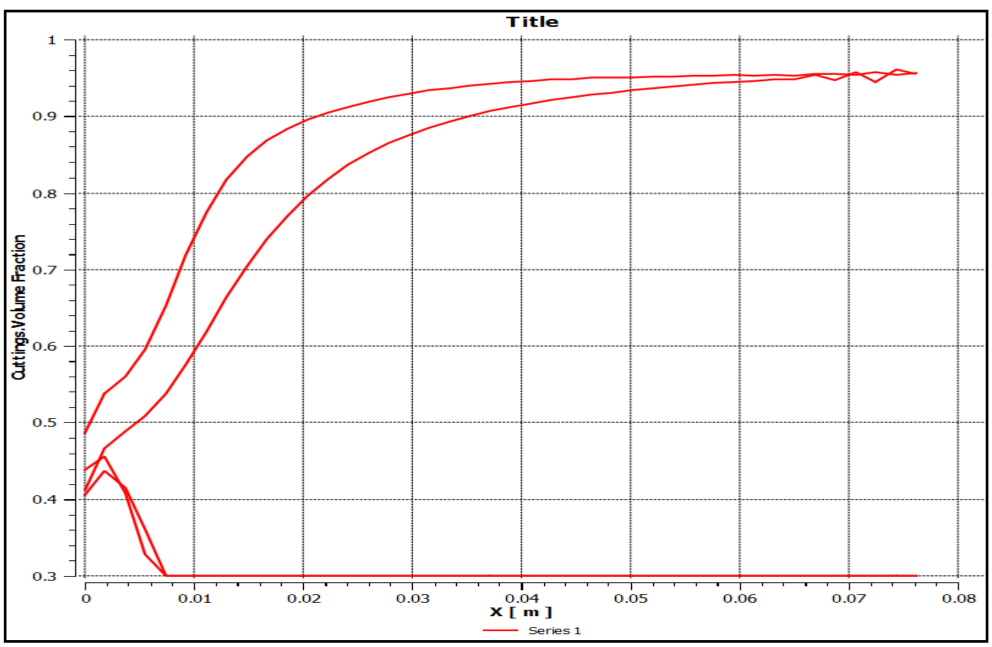

Figure 6.6: Cuttings Volume Fraction for 3 ft/s at 100-rpm

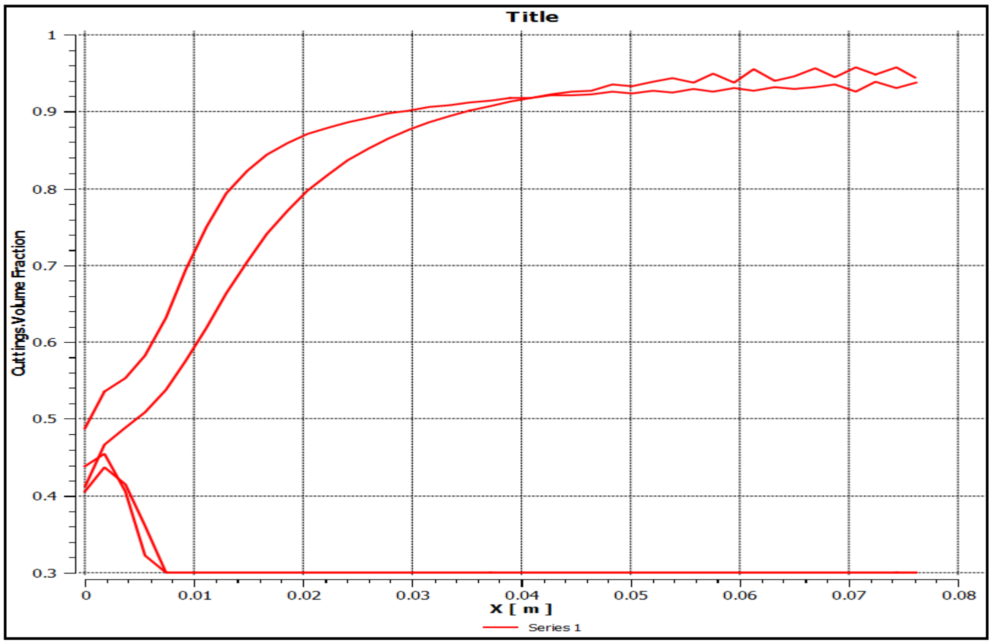

Figure 6.7: Cuttings Volume Fraction for 3 ft/s at 120-rpm