بسم الله الرحمن الرحيم

Sudan University of Sciences & Technology

College of Petroleum Engineering & technology

Petroleum engineering department

Project Title:

Hole Cleaning Modelling & Simulation In Horizontal Wells

(Case Study Heglig Field)

نمذجة ومحاكاة نظافة البئر في الأبار الأفقية

(دراسة حالة في حقل هجليج)

Graduation project submitted to college of petroleum engineering & technology in Sudan University of Science & technology partial fulfilment for one of requirements to take the degree of B.Tech in petroleum engineering

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الإستهلال

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قال تعـــــالى:

(إقْرَأْ بِاسْمِ رَبِّكَ الَّذِي

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مِنْ عَلَقٍ (٢) اقْرَأْ وَرَبُّكَ

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صدق الله العظيم

"سورة العلق"

DEDICATION

This work is dedicated

To the people who helped, strived to get us where we are now and supported us in all aspects of life,our deepest heart gratitude to;

"Our parents"

To those who stand by our side during the whole journey;

"Our brothers & sisters"

To those who gave us a lot of lessons to learn, and inspired us to get involved in a beautiful world of science,

"Our teachers"

To those who have a hand in this success

"Our friends"

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All the thanks due to Allah, for the continuous endless blessings and guidance throughout our life .

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Abstract

Field experience shows that the accumulation of cutting in a wellbore causes several drilling problems. These include an increase in torque and drag, which may limit drilling from reaching to a desired target of Formation In addition, it may cause drill string sticking and poor hydraulics as well. Therefore, an efficient hole cleaning is the most important aspect of drilling operation. Efficient cuttings transport and hole cleaning are very important factors for obtaining an effective drilling operation. In horizontal drilling, hole cleaning issue is a common and complex problem.

In this project, hole cleaning modeling process have been performed on a horizontal well (ABMG-77) located in Sudanese field (Heglig), block 2b using Landmark software. The modeling & simulation processes have been performed in three steps.A analysis of first build section, tangent and second build section and horizontal section to determine the effect of poor hole cleaning.

The modeling & simulation results show that the ABMG-77 horizontal has poor hole cleaning effect in the first build section (ANA-2952) due to rising of rate of penetration (ROP) from 100ft/min to 250ft/min against very low 300 GPM as a result cutting (bed) accumulated behind the BHA, and therefore, tight hole, back off, and pipe sticking occurred.

While modeling results show that the ABMG-77 horizontal well has a good hole cleaning in the next tangent &second build (ANA-6222), and horizontal displacement sections (ANA-6974) due to acceptable rate of penetration (ROP) against GPM.

Key words: hole cleaning, rate of penetration, horizontal well and cuttings bed

التجريد

التجارب الحقلية تبين أن تراكم القطع الصخر ية في البئر يسبب العديد من المشاكل اثناعمليات الحفر. وتشمل هذه المشاكل مثل زيادة في عزم الدوران والسحب، مما قد يحد من الحفر من الوصول إلى الهدف المنشود في الطبقات وبالإضافة إلى ذلك، فإنه يسبب التصاق خيط الحفر ونقصان في هيدروليكية الحفر أيضا. ولذلك، فان التنظيف الامثل لجدار البئر هو الجانب الأكثر أهمية في عملية الحفر.

ان كفاءة نقل القطع الصخرية وعملية تنظيف تجويف البئر تعتبر من العوامل المهمة في زيادة فعالية عمليات حفر الابار النفطية، ويعتبر تنظيف تجويف البئر من المشاكل المألوفة والمعقدة وخاصة في الابار المحفورة افقياً .

في هذا البحث تم إجراءعملية التحاليل والمحاكاة لبئرأفقية (ABMG-77) horizontal well في حقل هجليج السوداني باستخدامبرنامجLandmark. وتم إجراءعملية التحليل والمحاكاة في ثلاثة خطوات:

أولا، تم تحليل جزء البناء الاول من البئر((ANA-2952) first build sections) ونتائج التحاليل توضح ان هنالك مشكلة نسبتا لزيادة معدل التثقيب (الاختراق) العالي من ١٠٠قدم لكلدقيقة الي ٢٥٠ قدم لكل دقيقة مما ادئ الي تراكم الفتات الصخري علي جدار البئر وتماسك خيط الحفر(BHA).بينما نتائج التحاليك البئرية اثبتت ان ليس هنالك مشكلة في جزء البناء المائل الثاني second build sections (ANA-6222)) وجزء البناء الثالث والذي يمثل الازاحة الافقية للبئر((ANA-6974)(horizontal section)) نسبتا لإستخدام معدل التثقيب(الاختراق) المناسب وايضا معدل السريان المناسب.

الكلمات الرئيسية: تنظيف البئر، معدل التثقيب ،البئر الافقي

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Nomenclature:

MD …….Measured Depth
TVD……True Vertical Depth
HD……..Horizontal displacement
TD………Total Depth
CCI……..carrying capacity index.
T&D…….Torque and Drag
BHA Bottom Hole Assembly
DLS……..Dog Leg Severity
WOB ……Weight on Bit
WBM……Water Based Mud
OBM ……Oil Based Mud
ECD ……equivalent circulation density [sg]
ROP…….rate of penetration [f/hr]
PV……...plastic viscosity, cP
YP………yield stress / Yield point, [lbf/100sqft]
MWD…..Measurements While Drilling
ft/hr……..foot per hour
pcf………pound per cubic foot
deg……...degree
gpm……..gallon per minute
ppg……...pound per gallon

Chapter 1

INTRODUCTION

1.1. INTRODUCTION:

During drilling the well, the material produced by the bit when it is drilling the formation, must be removed as much as possible and taken to the surface. This process is called hole cleaning, a very important operation that requires careful procedures. Despite recent improvements in hole cleaning procedures, debris continues to remain in the wells, which makes operations difficult to perform during drilling when cuttings are not removed from the bore hole, they accumulate in the well and form a cuttings bed around the Bottom Hole Assembly (BHA). This result in pack off which are responsible for a not productive time (NPT). such as stuck pipes, hole instability, etc. Even though having several parameters that influence hole cleaning, due to the complex mechanisms involved, this phenomenon is not yet fully understood. (Chukwu, 2009).

Transport of cuttings from the bottom hole up to the surface through the annulus is one of the primary objectives of a drilling mud. Failure to accomplish this function will lead to cuttings accumulation in the lower part of the annulus. (Alfredo Sanchez, 1999).

Hole cleaningis the process of moving solids, produced from the drilling process, from the bit to the surface, and out of the drilling environment.

Transport of cuttings from the bottom hole up to the surface through the annulus is one of the primary objectives of a drilling mud. Failure to accomplish this function will lead to cuttings accumulation in the lower part of the annulus.

Hole cleaning is one of the biggest challenges in high deviated drilling wells. Despite all recent improvements in technologies and procedure we cannot know what is really happening in the downhole yet, even though efforts have been made to understand what is happening relative to cuttings and borehole condition when drilling, tripping and running the casing.

Hence during planning phase, proper design and implementation of cutting transport is very important for the success of the overall drilling operation. Poor hole-cleaning leads to several negative effects

Transportation of cuttings in the annulus is a very complex process. It is affected by many parameters.(Alexandre, P., 2008).)

The most relevant factors that affect the carrying capacity of drilling fluids. As shown in Table 1.1, the parameters can be categorized into three groups: Fluid parameters, cutting parameters and operational parameters:

Fluid parameters	**Cutting parameters**	**Wellbore configuration**
Mud density	Cutting density	Angle of inclination
Rheology	Cutting size	Pipe rotation
	Cutting shape	Rate of penetration
	Cutting concentration	Eccentricity of the hole
		Flow rate
		Depth
		Hole size/Casing well inside diameter

1.2 Problem Statement:

Inadequate hole cleaning can lead to a number of problems, including pipe sticking, Annular pack off , loss of circulation , formation damage , excessive torque and drag , trouble in logging and cementing ,slow drilling rate and excessive hydrostatic pressure. Drill cuttings in the hole cause wear and tear of the drill string and also reduce the rate of penetration, thereby increasing the cost and time for drilling; hence, there is need to know the main reasons and solutions.

1.3 Objectives:

The objectives of this project are:

1.3.1 General Objectives:

- To explain in details the concept of drilling fluids and hole cleaning.
- To explain the concept of operational analysis model.
- To explain the concept of parametric analysis model.

1.3.2 Specific objective:

To perform hole cleaning model process on a horizontal well, by using Landmark's WellPlan™ software.

1.4 Methodology:

The project work is broken into the following parts:

- Lesson to learn model on ABGM-77 horizontal well is cause study for this project
- An 5406ft True vertical depth (TVD), 8020ft measured depth (MD), horizontal displacement 1046.2ft (HD) horizontal well located in Heglig field block 2b is chosen as lesson to learn model and a case study for this project to determine the effect of study hole cleaning problems in horizontal wells.
- Analysis of cutting transport in horizontal wells using WELLPLAN Landmark software by.
    - ✓ Hole Cleaning Operational analysis model.
    - ✓ Hole cleaning parametric analysis model.
    - ✓ Compare the results with well data
- The data required for this model include:
  Well proposal, Well plan plot, Well program ,Well survey ,Daily drilling report (DDR) and Daily Mud Report (DMR)

1.5 Scope of Study

The scope of this project is to model the drilling parameters which affect hole cleaning in one of Sudanese horizontal wells by using WellPlan™ software modeling data to determine the mean reason and other factors affecting hole cleaning.

CHAPTER 2

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Literature Review:

Ayad A. Al-Haleem, Abd Al-Razzaq (2016), efficient cuttings transport and hole cleaning are very important factors for obtaining an effective drilling operation. In an inclined and horizontal drilling, hole cleaning issue is a common and complex problem.The results show that parameters for optimum hole cleaning were flow rate, yield point, mud weight, plastic viscosity and rotation of the drill string.

Ali Piroozian et al (2012), have experimentally investigated the influence of the drilling fluid viscosity, velocity and hole inclination on cuttings transport in horizontal and highly deviated wells.

Mengjiao et al (2011), have written a new approach to improve cutting transport in horizontal wells. By using chemical surfactants. During the lab-scale test, their test result in horizontal section shows that: Without chemical additives, no cuttings were transported, with the addition of straight chained chemical surfactants, 30% of the cuttings were carried out by air and many others were carried partially across the tube, Use of branched chemical surfactants, 58% of the cutting was transported.

Baker Hughes(2009), The factors which affect the carrying capacity of the fluid includes: fluid density and rheology, annular velocity and flow regime, pipe rotation, cuttings density, size and shape of the cutting, and annulus size and eccentricity. An optimum drilling fluid is expected to lift cuttings from the wellbore and suspend them when circulation is stopped.

Bilgesu,et al., (2002), Another study was investigated the effect of fluid rheology and cuttings sizes on the circulation rate required to ensure that the drilling cuttings in horizontal wells are efficiently transported to the surface. The results of this study observed that much higher annular velocities are required for effective hole cleaning in horizontal wells. It was also observed that higher viscosity drilling fluid yield better transport than lower viscosity drilling fluid within the same flow regime

Adari, et al., (2000), Insufficient hole cleaning is responsible for a large portion of all stuck pipe. Some would argue that it is the number one cause of stuck pipe around the world, especially in high - angle holes. Previous study in the North Sea attributed 33% of the stuck pipe incidents to poor hole

Larsen et al. (1997), A new simulations show drill pipe rotation can improve the cuttings transport but the effect ismore renounced for smaller particle size. Cutting transport efficiency has a decreasing trendwith increase in annular velocity. In addition, inclination and ROP also have major impacts on cuttings concentration**,**

Annis and Smith, (1996), Hole cleaning is a more severe problem in high-angle holes than in vertical holes. It is not only more difficult to carry the cuttings out of the hole, but they need to settle only to the low side of the hole and causes problems like stuck pipe. Consequently more attention should be paid to hole cleaning requirements in directional holes

Bassal,(1995), A new mathematical method for estimating the minimum fluid transport velocity for system with the inclination between 55° to 90° was developed. It was found that the model worked fairly well within inclination angle 55° to 90° and there were no correction factors yet for inclination less than 55°. From Larsen method it was known that there are three parameters which affect determination of minimum fluid annular velocity for inclined hole: inclination, ROP, and mud

Vinod, (1994), The study of hole cleaning in deviated holes requires an understanding of the flow behavior of drilling fluids not only in a concentric annular geometry but also in an eccentric annular geometry as well as the phenomena of transport of solids by fluids. Cuttings are mobilized and suspended when the driving fluid forces acting on the solids are greater than the opposing gravitational and frictional force.

Clark and Bickham (1994), developed a mechanistic model is based on the momentum-forces acting on a particle. The model predicts the minimum pump rate to transport a particle. They define three modes for cuttings transport: settling, lifting, and rolling each dominant within a certain range of wellbore angles. The authors came up with solutions for the minimum velocities to transport particle on the bed. However, the model takes into account the annular (axial) velocity only without consideration of drill string rotational speed. The model predicts quite well the given experimental data.

Sifferman, et al. (1990), A study showed that drill string rotation has a moderate to significant effect on hole cleaning, and that this effect also depends on the hole angle and other cuttings properties. Also the drill string rotation enhances hole cleaning more when the used mud has a higher viscosity with smaller cuttings sizes. It was found that for hole angle at 65 degrees, and at horizontal, the effect drill string rotation caused an improvement in cuttings transport,

Paden et al. (1990), have developed minimum transport velocity prediction models for: a) cuttings suspension and b) cuttings rolling. The predictions were compared with laboratory data. The effectiveness of hole-cleaning is dependent on the rheology of the fluid and fluid flow regimes (i.e laminar or turbulent flow).

Ford et al (1990), have experimentally investigated the cutting transport phenomenon in an included wellbore. The main investigation obtained from the experiments is that the velocity that initiates cuttings transport is sensitive to hole-inclination. The effectiveness of a circulating fluid in removing drilled cuttings dependent on the rheology of the fluid and the fluid flow pattern.

Hussain et al (1983), have conducted an experimental study of cutting transport. Their investigation shows that annular velocity and yield strength of drilling fluid increases are favorable conditions for efficient hole-cleaning.

2.2 Theoretical Background:

2.2.1DRILLING FLUIDS (DF):

Drilling fluid or drilling mud is one of the most important elements of drilling. The DF helps us avoid many hazards associated with drilling. Therefore, the properties of the DF must be analyzed very carefully to fulfill all the necessary requirements to have a good drilling performance. (HERIOT WATT UNIVERSITY, 2005).

2.2.2 Functions of drilling fluid.

1- To remove and suspend cuttings
2- To prevent formation fluids flowing into the wellbore
3- Maintain wellbore stability

4- Cooling and lubricate the bit

5- Transmit hydraulic horse power to bit

6- Transport drilling cuttings to surface

7- Gathering information about the formations

8- Provide Buoyancy to the drillingstring

2.2.3 Drilling fluid properties

1- Density: is a measure of mud weight, density which is very important to maintaining well control. (Tomas, 2011)

2- Rheology: There are three important criteria when discussing drilling fluid rheology which include:(Mims, Krepp, 2007)

A- **Gel Strength:** can be assumed as the strength of any internal structures formed in the mud when is static. This characteristic can keep cuttings suspended. Provide the ability of drilling fluid to keep the cuttings in suspension when mud has been static due to the connections or other reason. Provide the indication of the pressure necessary to restart the flow after stationary condition.

B- Plastic Viscosity (PV): The plastic viscosity is a measure of resistance of liquids to flow. Despite the fact that increased viscosity has smaller effect on pressure loss and improving the transport of debris, it has a negative effect on ROP, caused by particles in the DF becoming heavier and leading to an increase in rotation per mints (RPM) to maintain the rate of penetration (ROP).

3- Yield Point (YP): The yield point is a measure of electro–chemical attractive forces in the mud.

4- Filtration: occurs when the mud pressure is higher than the pore pressure and mud penetrates the pores of the formation.this infiltration should be controlled to avoid damage to the formation. It can be allowed to invade the formation up to a certain distance (a few meters) to build a cake protection. Once the mud cake reaches the correct thickness, invasion slows down and stops. The filter cake building properties of mud can be measured by means of a filter press which reflects both the efficiency with which the solids in the mud are creating an impermeable filter cake and the efficiency thickness of the filter cake that will be created in the wellbore.

5- **Sand Content:** is the proportion of sand in the mud. This proportion should not be high in order to avoid mud pump damage.

Table 2.1 bellow describes the physical and chemical properties of the mud function. (HERIOT WATT UNIVERSITY, 2005):

The Table 2.1show the Function and Physical Properties of Drilling Fluid

Function	**Physical/Chemical property**
Transport cuttings from wellbore	YP, apparent viscosity, velocity, gel strength
Prevent formation fluid flowing into the wellbore	Density
Maintain wellbore stability	Density, reactive with clay
Cool and lubricate the bit	Density, velocity
Transmit hydraulic horsepower to bit	Velocity, density and viscosity

2.3. Main types of drilling fluid (DF)

2.3.1 Water Based Mud (WBM):

is a type of drilling fluid used when the continuous phase of the system is water (salt water or fresh). It consists of a mixture of solids, liquids and chemicals. (Adari, Miska,2000).

Advantages

- In offshore applications, there is an abundance of seawater supply.
- It is economical and environmental friendly.
- Easier to detect a kicks in high pressure and high temperature wells (HPHT)

Disadvantage

The water can create instability to the wellbore.

- Clay swelling
- Less lubricant
- Thicker mudcake
- Easier to get differential stuck

2.3.2 Oil Base Mud (OBM): consists of a composite of WBM, but the continuous phase is oil instead of water. In an invert oil emulsion (a mix of water with the oil in the continuous phase), mud water may increase to a large percentage of the volume, but oil is still in continuous phase. OBM does not contain free water which can react with clays in shale.

Advantages

- Provides excellent wellbore stability.
- Less formation risk damage than WBM.

Disadvantages

- More expensive and require more careful handling than WBM.
- Drilled cuttings contaminated by OBM can have lasting environment impact.

2.4 WELLBORE STABILITY ISSUE:

Wellbore stability is critical when drilling the horizontal phase, and is critical to all assumptions of feasibility and performance on an extended reach well. Hole cleaning is significantly affected by intervals of hole enlargement or swelling (Mims, Krepp, 2007)

2.4.1 Hole angle:

hole angle is one of the main reasons for wellbore stability. Generally, as the inclination increases, drilling fluid weight does not need to vary greatly because in many cases we are crossing the same formation. Otherwise, high angles result in longer intervals of troublesome formations being open, which can lead to an increase of problems related to hole stability

2.4.2 Annular Velocity.

Annular velocity (AV) is probably one of the most important factors in achieving good hole cleaning in low angle and vertical situations. It is defined, as the speed that the fluid moves in the annulus region of the borehole. (Barker et al., 2007)

2.4.3 Pipe Eccentricity

It is the term used to describe how off- centered a pipe is within another pipe or the open hole. It is usually expressed as a percentage. A pipe would be considered to be fully (100%) eccentric if it were lying against the inside diameter of the enclosing pipe or hole and concentric (0% eccentric) if it were perfectly centered in the outer pipe or hole.(Hemphill, T.; and Ravi, K.: 2006).

2.4.4 Cutting Size and shape:

The size and shape of the cuttings combined is one of the most important factors that effects wellbore stability.(Walker and Li, 2000)

2.4.5 Flow rate:

Using the maximum flow rate for every section is recommended, but this is conditioned by equivalent circulating density (ECD). Consideration may lead to reduction of the flow rate.

2.4.5 Drill pipe Rotation:

Rotation can improve hole cleaning even more effectively working together with other parameters. This level of enhancement due to pipe rotation is a function of the simultaneous combination of mud rheology, cuttings size, and mud flow rate. Also it was observed that the dynamic behavior of the drill pipe (steady state vibration, unsteady sate vibration, whirling rotation, true axial rotation parallel to hole axis, etc.) plays a major role on the improvement of hole cleaning. With rotation, the cuttings resting on the lower side of the hole will stir up into the upper side, where the flow is effective (Sanchez et al, 1999)

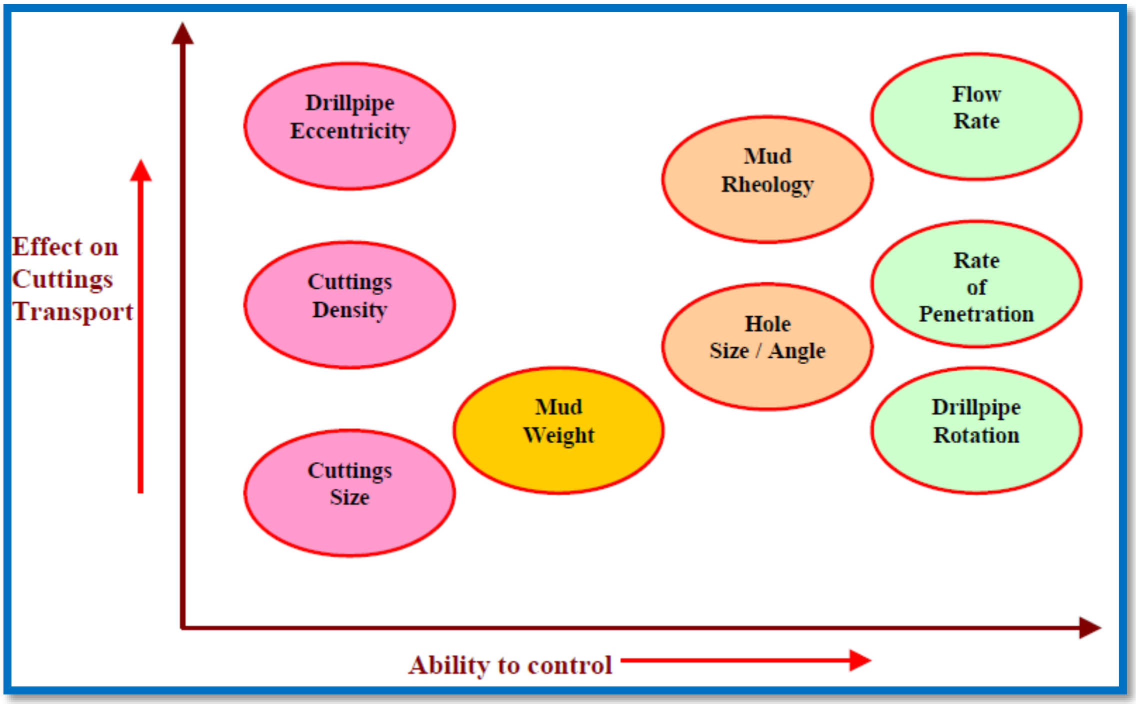

Fig.2.1 show the factors that affect the hole cleaning and wellbore instability

2.5 Hole Cleaning Indicators (HCI)

2.5.1 Transport Ratio:

Transport ratio is defined as the transport velocity (difference between the mean annular velocity and the particle slip velocity) divided by the mean annular velocity. A positive value indicates that some of the cuttings will be transported, and 100% indicates no cuttings remain in the hole to optimize drill-cutting transport, the transport ratio should be maintained as high as possible, though 100% in practice is not possible. (Vinod, 1994)

2.5.2 Carrying Capacity Index (CCI).

The three hole cleaning variables that can be controlled at the rig (mud weight, drilling fluid viscosity, and annular velocity) improve hole cleaning when increased. Good hole cleaning is indicated when the cuttings arrive at the surface with sharp edges.

2.6 Fundamentals Of Hole Cleaning

Hole cleaning is one of the biggest challenges in high deviated drilling wells. Despite all recent improvements in technologies and procedure we cannot know what is really happening in the downhole yet, even though efforts have been made to understand what is happening relative to cuttings and borehole condition when drilling, tripping and running the casing. (Mims, Krepp 2007)

2.6.1 Cuttings Behavior In Downhole:

As inclination increase the difficult to bring the cuttings to surface increase as well. Hole cleaning in the vertical phase depends on the Annular Velocity (AV). In vertical wells the cuttings move around the drill pipe through flow path. On the other hand, in the high inclinations the fluid path is essential moving above drill pipe, the problem is that cuttings fall quickly to the low side of the hole, where the flow path is very slow. Figure bellow shows how cuttings move in low and high inclination and annulus.

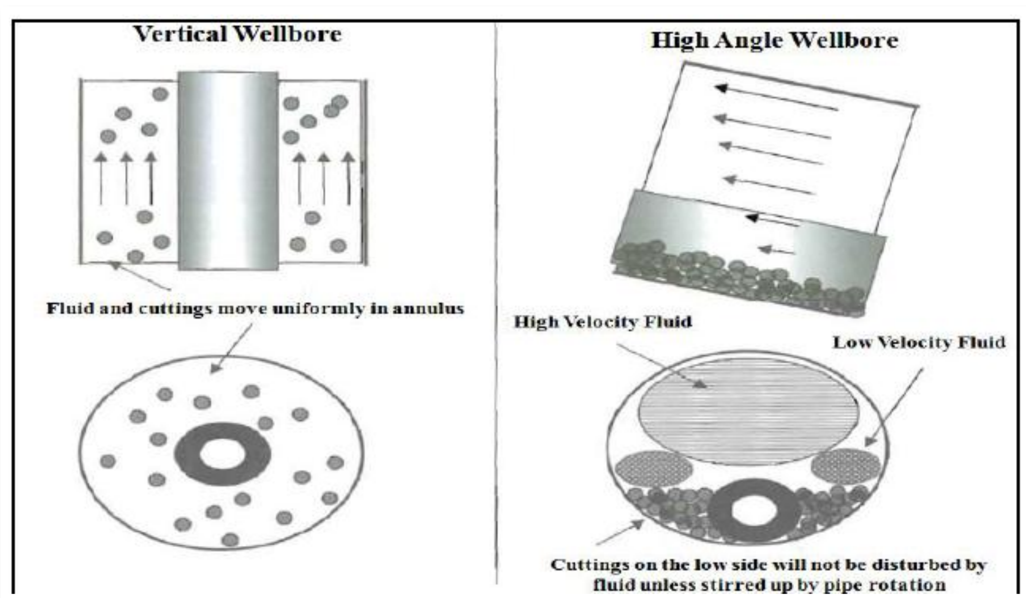

Fig2.2: Fluid Movement in the Annulus (Drilling Design and Implementation For Extended Reach and Complex Wells).

The annular space increases after the BHA, which leads to a decrease in AV. With this decreases, the cuttings quickly fall to the low side of the well and will accumulate to form dunes. If the dunes reach a critical height it is possible to pack off the hole with cuttings once rotation starts. It is essential toprevent the dunes from reaching a critical height, and is important to take this phenomenon into account before start the rotation (Mims, Krepp, 2007)

2.6.2 Cuttings Transportation:

The main purpose of hole cleaning is to carry as much debris as possible from downhole to the surface. To understand clearly what is happening in the entire hole, hole can be divided in three categories based on the wellbore inclination. (Mims, Krepp, 2007),

2.6.2.1 Cuttings behavior with inclination range from (0°- 45°):

in this inclination, cuttings are brought to surface by fighting gravity and slip velocity. Rheology properties and flow rate in annular play as an important role in cuttings transportation. Viscous and gel strength are in charge and keep cuttings suspended when the pumps are turned off. But luckily, the cuttings are not alone. The fluid is crowded with solids, therefore, in a crowded solids environment a mechanism called hindered settling occurs. For each cutting that drops, another is forced upwards. (Mims, Krepp, 2007),

2.6.2.2 Cuttings behavior with inclination range from (45° - 65°):

Here the cuttings move up the hole mostly on low side and begin to form dunes, with rotation is easily to stirred up the cuttings into the effective flow regime. The main issue in this range is that when pumps are stopped, the cuttings will fall in low side and begin to slide as an avalanche to downhole. Alteration in hole cleaning strategy must be done with respect to the vertical well section . (Mims, Krepp, 2007),

2.6.2.3 Cuttings behavior with inclination range from (65° - 90°):

At ranges, the cuttings fall to low side and form a long continuous cutting bed. As we already know the great issue is that the drilling fluid will flow above the drill pipe, mechanical agitation is necessary to stir up cuttings through the effective flow area. Hole cleaning in this section is actually less critical than in inclination range 45° - 65°, but takes a lot of time: The figure bellow shows how cuttings behavior in different inclinations. (Mims, Krepp, 2007).

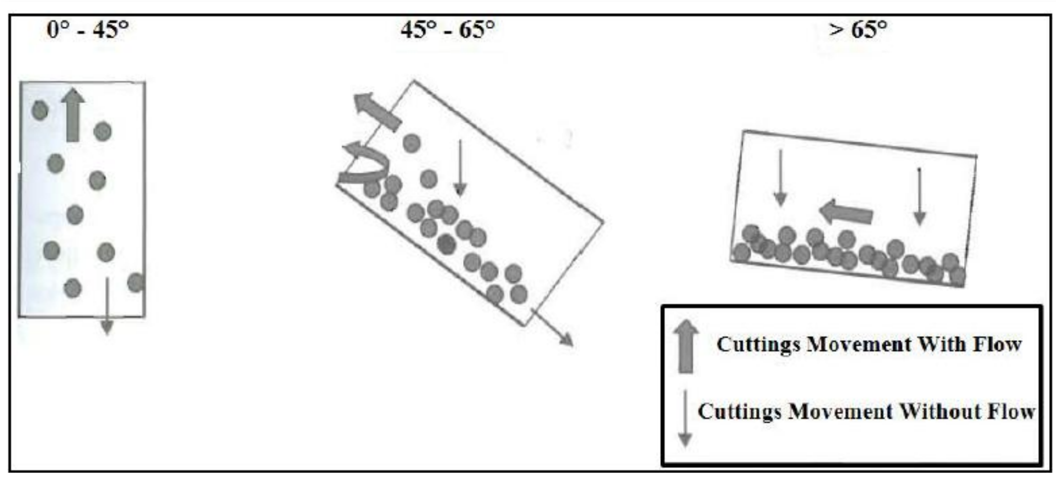

Fig.2.3 Cuttings behavior at different ranges of inclination.

2.6.3 Bed height of cutting:

Bed height is calculated based on the fundamental trigonometric relations. The model back the Wellplan^{TM} simulator.(Hareland et al (2012)

2.7 Landmark:

Landmark is a software program consist of two components Compass and Wellplan.

2.7.1 Compass:

Compass is directional well planning software developed by Halliburton. It is used for path planning, survey data management, and anti-collision analysis. The software is deployed on Landmark's Engineer's Data Model (EDM) enabling data consistency and reduced planning cycle times by sharing common data compass has three core functions planning to design the shape of proposed well paths, survey to calculate as drilled wellpath position, and anti-collision to calculate distance between wellpaths (Landmark Compass user manual,1998.).

2.7.2 WELLPLAN:

Wellplan is a component of Landmark software developed by Halliburton. Wellplan software is able to solve number of technical challenges such as Torque Drag, Well Control, Surge And hole cleaning (Hydraulics). (Landmark wellplan user manual,1998.).

CHAPTER 3
Methodology

3 Hole cleaning modelling:

3.1Theory of cutting transport back to the WellPlan simulator

This model is based on the analysis of forces acting on the cuttings. It can be used to predict the critical (minimum) flow rate required to remove or prevent the formation of stationary cuttings beds during a horizontal drilling operation. The WellPalan software model includes more operation, which could capture hole cleaning phenomenon.

3.2 Description of modeling and Simulation arrangement

3.2.1 ABGM-77 Horizontal Well Description:

3.2.1.1 ABGM-77 Horizontal Well trajectory:

The well ABGM-77 selected for case study is a horizontal well located in Heglig field block 2b. The well start vertically with a kick off point of approximately 2952ft MD and a first build section from kick off point to 5890ft MD (EOC#1). From this depth the tangent section starts to hold the angle of 71.67º along the wellbore path with lock-up BHA until depth of 6222 MD with the same lock-up angle, then from this depth the second build-up section start to kick off point (KOP#2) with angle of 73.51ºalong wellbore path to depth of 6974ft with angle of 90.05 º, the horizontal extended section starts from 6974ft MD to TD i.e. 8020ft with approximately lock-up angle of 90.05 º .Fig.4.1shows the geometry of ABGM-77 well and Fig.4.2 shows the vertical section. Hole cleaning analysis results can be seen in Fg.4.1 through Fig.4.25 in chapter four.

3.2.1.2 Analysis sequence:

We divided this well into three sections as the well trajectory; we named each section as the following, and will be the same through whole next chapter:

3.2.1.3 ANA-2952 (First build-up section):

As we illustrate in the mention discussion, the well Kick off from vertical with approximately depth of 2952ft MD with angle of 2.4 º, and continue to build through wellbore path until reach the depth of 5890ft MD with end of curve angle 77.2º, this will be the first analysis section, and will be named by ANA-2952.

3.2.1.4 ANA-6222 (Second build-up section)

This section start with short tangent section from end of curve depth of 5890ft with hold angle of 71.67 º along wellbore bath until reach depth of 6479ft MD, from this depth the well start to kick off point with angle 73.51 º continue to build-up until reach depth of 6974ft MD with end of curve angle of 90.05 º.

3.2.1.5 ANA-6974 (Horizontal displacement section)

This section represent the horizontal extended section start from depth of 6974ft MD withhold angle approximately of 90.05º till reach the TD of 8020ft MD. Then hole cleaning analysis will be performed on ABGM-77 well through three section (ANA-2952, ANA-6222 and ANA-6974) to analyze the effect of various well parameter on well hole cleaning, and give the optimum parameter to unable well cutting transfer to surface without accumulate behind BHA and cause stack. as can be seen in the geometry of this well in Fig.4.1. Fig.4.2 and Fig.4.3 shows the vertical section versus TVD, inclination versus MD, and DLS versus MD respectively through next chapter.

3.3 Hole cleaning Modeling Methodology:

3.3.1 Analysis of existing Data:

The analysis process involves reviewing of the available well and field data to understand and collect the data needed for the modelling process such as:

1- Field and wells surface and subsurface data. In addition to the target location data.
2- BHA and drill string data for the well.
3- Well trajectory
4- Mud properties
5- DDR data

In this research we used two Hole cleaning model (Operational & Parametric), which Landmark software provided as a part of Hydraulic model.

3.3.2 Hole cleaning Model (Operational & Parametric)

This model is based on a mathematical model that predicts the critical (minimum) annular velocities/flow rates required to remove or prevent a formation of cuttings beds during the horizontal drilling operation. This is based on the analysis of forces acting on the cuttings and its associated dimensional groups. The model can be used to predict the critical (minimum) flow rater required to remove or prevent the formation of stationary cuttings. This model has been validated with extensive experimental data and field data, by using this mode, the effects of all the major drilling variables on cuttings transport have been evaluated and the results show excellent agreement between the model predictions and all experimental and field results.

The variables considered for hole cleaning analysis include

1- Cuttings density
2- Cuttings load (ROP)
3- Cuttings shape
4- Cuttings size
5- Deviation
6- Drill pipe rotation rate
7- Drill pipe size
8- Flow regime
9- Hole size
10- Mud density
11- Mud rheology
12- Mud velocity (flow rate)

3.3.3 Types of hole cleaning model.

1- Hole cleaning Operational model
2- Hole cleaning parametric model

3.3.4 The different between Hole cleaning operational & parametric model:

Hole Cleaning Operational model is used to analyze the current well situation. while the hole cleaning parametric analysis mode, is used to determine the effect of varying parameters, including hole/string geometry and varied flow rate using the varied hole geometry. The operational model is first used, and after analysis is performed, then flowed by the parametric model. However the both modeling based on the transport analysis data dialogue, so in the following discussion we show brief details

3.3.5 Transport analysis data dialogue:

Use this dialog to specify the analysis parameters that will be used in the Hole Cleaning Parametric analysis. It is used to analyze the cuttings transport flow rate suspended volume, and bed height for a particular wellbore and pipe configuration at a desired depth for various hole angles. Although this analysis uses the fluid entered in the Fluid Editor dialog**,** this dialog has the following items:

Cuttings Diameter:

Specify the diameter of the cuttings. A normal range is 0.1 to .25 inches.

Cutting Density:

Specify the specific gravity of the formation being drilled. Typically shale is 2.65sg.

Bed Porosity:

Specify the porosity of the cuttings bed on the low side of the hole. A typical estimate is 36%.

Rate of Penetration:

Specify the rate at which the formation is being drilled. This value is used to determine the amount of cuttings produced per time increment in effect a cuttings flow rate.

Annulus Diameter:

Specify the diameter of the annulus. This value is used to determine the annulus cross-sectional area.

Pipe Diameter:

Specify the diameter of the work string. This value is used to determine the stand-off of the pipe from the wellbore wall.

Minimum Pump Rate:

Specify the minimum pump rate to evaluate. Cuttings build-up will be evaluated for the pump rates specified.

3.3.6 Hole Cleaning Operational Model (Hydraulics):

This operational analysis is used to determine the percentage of cuttings in the annulus of the current active case. The cuttings concentration percentage, bed height, and critical transport velocity flow rate is determined from the current inclination and annular diameters.

3.3.6.1 Input Data require:

1- General Data
2- Wellbore Editor
3- String Editor
4- Survey Data
5- Fluid Data
6- Transport analysis data

3.3.6.2 Operational analysis results can be displayed on the:

1- Operational plot
2- Minimum Flow Rate vs Rate Of penetration (ROP) plot
3- Operational report

3.3.7 Hole Cleaning Parametric Analysis Mode (Hydraulics)

This analysis mode can be used to evaluate a proposed mud scheme (PV, YP Fann data, and density) for a range of flow rates and hole angles. This mode can be used to illustrate the relationship of mud-carrying capacity with hole angle and flow rate. The parametric mode assumes that, the well has constant wellbore and string geometry (constant annulus diameter, pipe diameter, and joint diameter), and that it performs the cuttings transport analysis for the range of flow rates specified over the inclination range from 0 to 90 º degrees.

3.3.7.1 Input Data Require:

1- General Data
2- Fluid Data
3- Transport analysis data

3.3.7.2 Parametric analysis results can be displayed on the:

1. Bed Height plot
2. Minimum Flow Rate plot
3. Suspended Volume % plot
4- Total Volume % plot

3.4 Input Data into Compass :

The need for Compass in this project is to generate the well trajectory or profile for the ABGM-77 horizontal well through three section (ANA-2952, ANA-6222 and ANA-6974). Before inputting the survey data, to get the well geometry, there is some basic data need to be inputted such as: new company, new field, new site, new well, and new wellpath. The Fig.3.3, Fig.3.4, Fig.3.5, Fig.3.6, illustrates the data inputted to each section respectively. Then, the survey data will be entered from the well plan report. It should be noted that the survey data in this project can be found in appendix A.

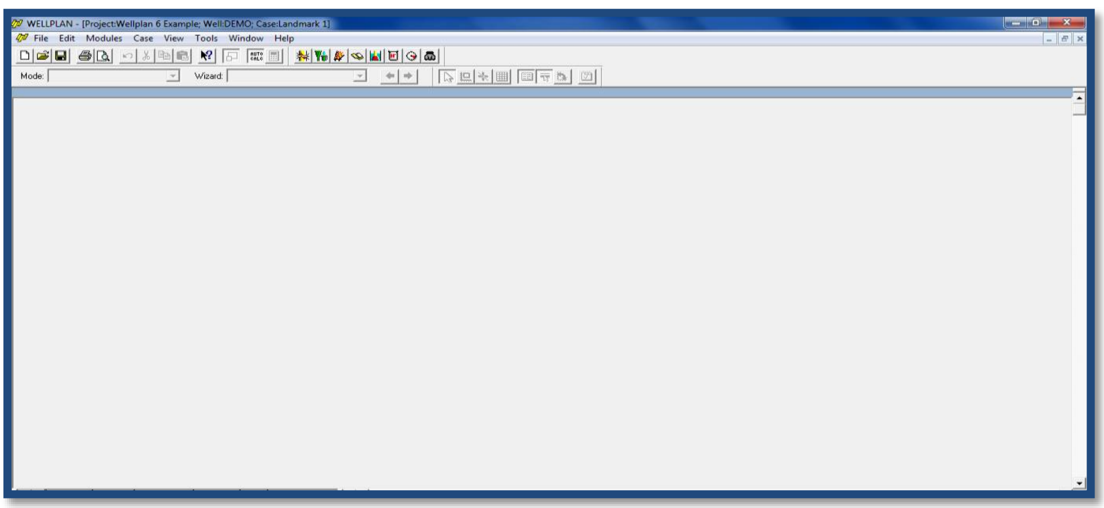

Fig.3.1: Compass User Interface (Compass).

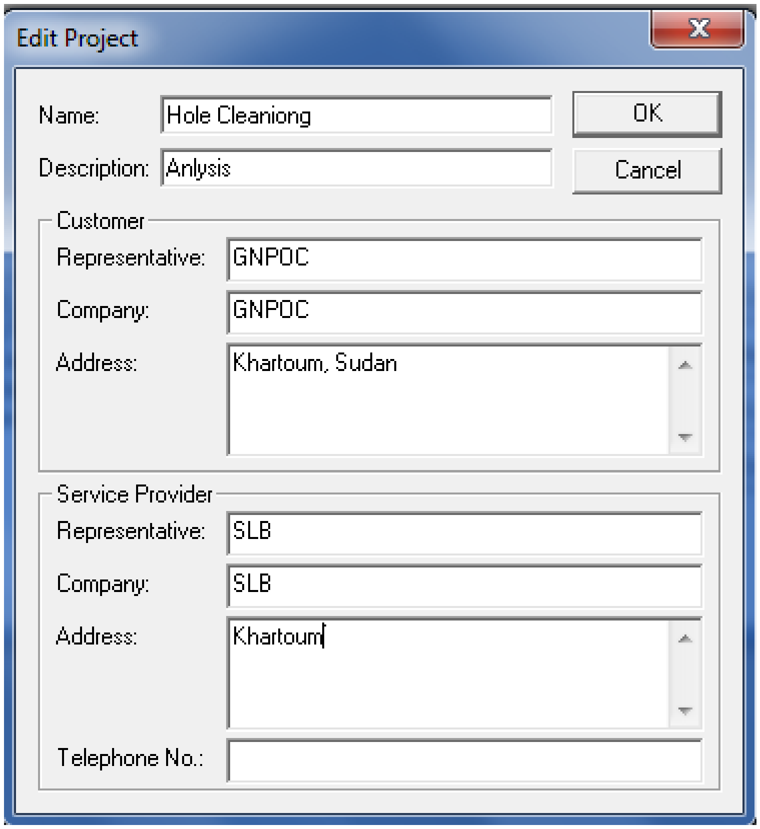

Figure 3.2: Company Setup (Compass).

3.5 Input Data into Wellplan:

As mentioned before, Hole cleaning modeling in this project will be done using Wellplan. There are cases and parameters that need to be inputted. Here is a brief explanation of what data has been inputted and what data is assumed.

3.5.1 General:

In this section inputting the general data from the well such as Origin N, E Azimuth, welldepth MD and reference point is inputted.

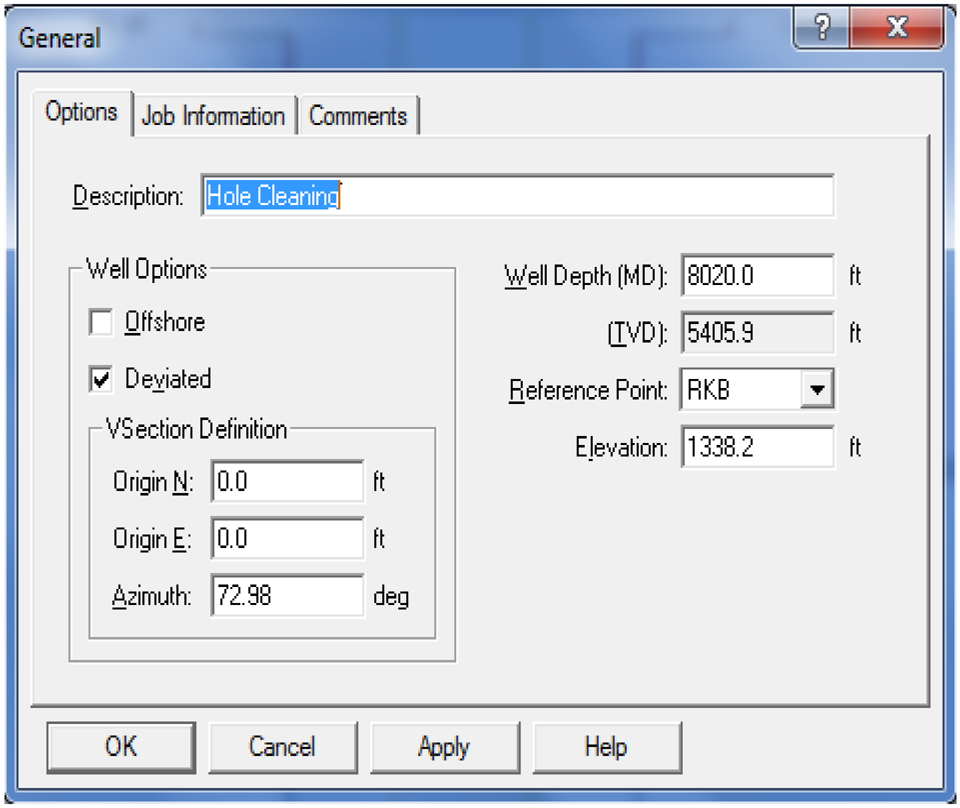

Fig.3.3: ABGM-77 Horizontal Well General Data (Wellplan).

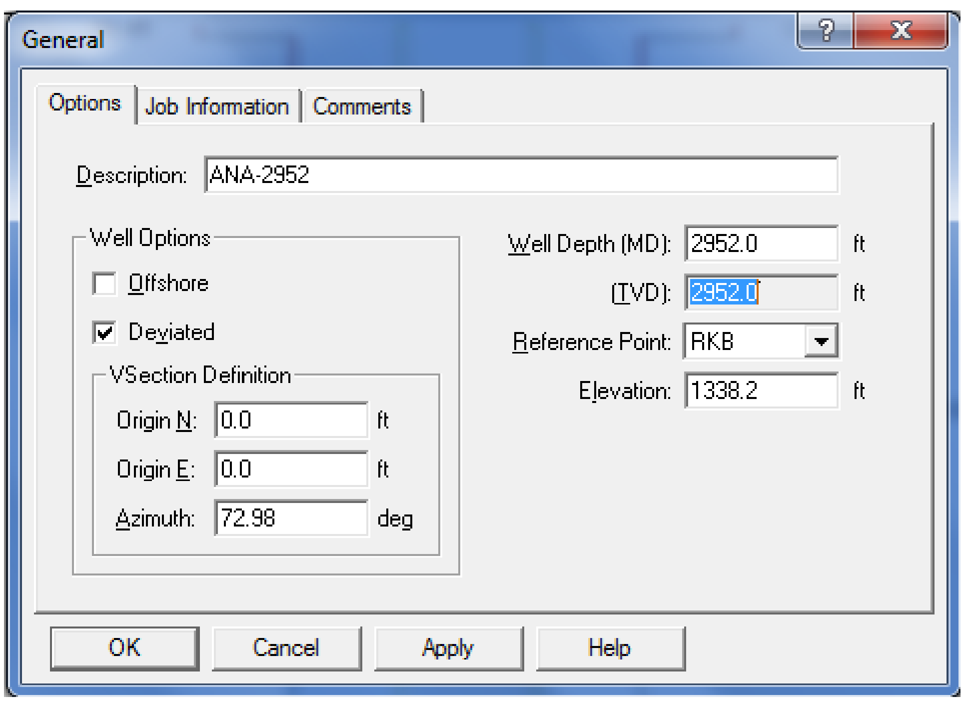

Fig.3.4: ANA-2952 Horizontal Well General Data (Wellplan).

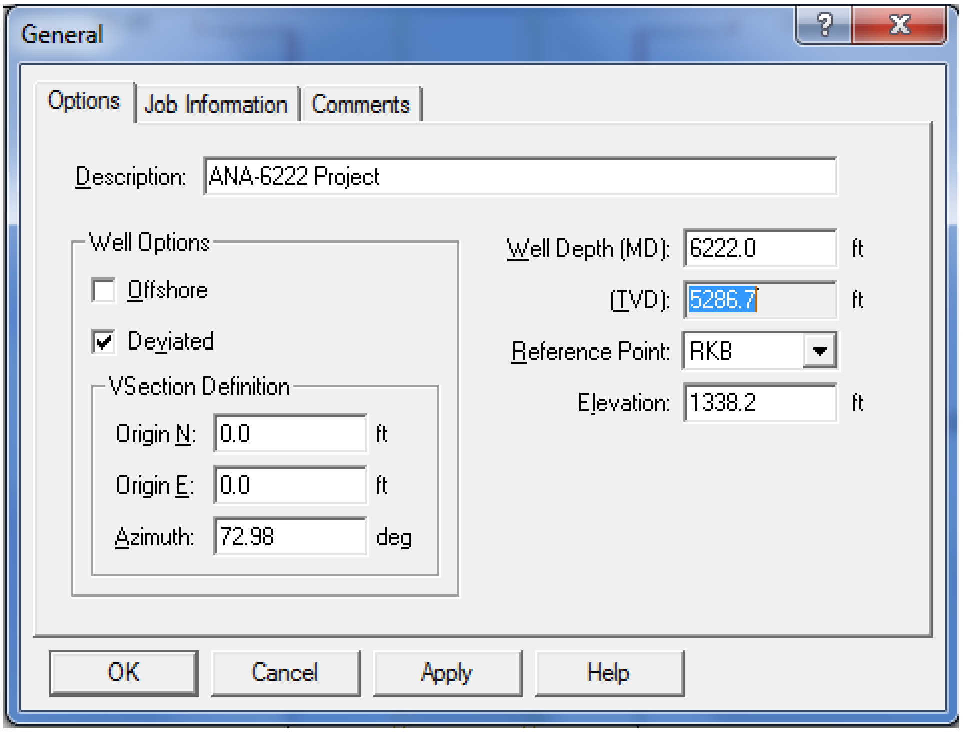

Fig.3.5: ANA-6222 Horizontal Well General Data (Wellplan).

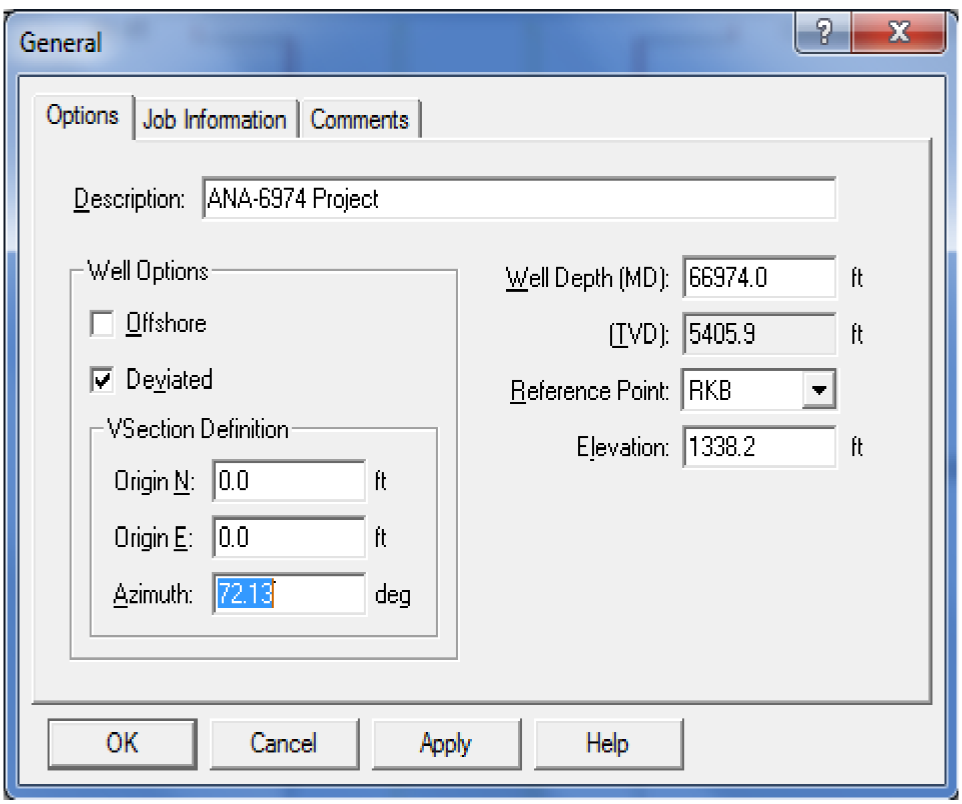

Fig.3.6: ANA-6974 Horizontal Well General Data (Wellplan).

3.6 Hole cleaning operation model data input:

3.6.1 Wellbore Editor:

Wellbore Editor Spreadsheets or the Fluid Editor dialog is used to calculate annular volumes and hole inclination. These editors are available through most modules and are shared by all modules. We use this spreadsheet to define the wellbore profile and inner configuration of the well. Since the project have multiple cases (ANA-2952, ANA-6222 and ANA-6974), and we enter data in this spreadsheet to define the well profile and well depth of a particular case for analysis. On Fig.3.7, Fig.3.8 and Fig.3.9 we define the components of the wellbore and the material properties of the components as the real data on the depth interest. Later on we will focused in first case (ANA-2952) which faces issue due to hole cleaning problem

Wellbore Editor

Well Depth (MD): 6000.2 ft

	Section Type	Depth (ft)	Length (ft)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Friction Factor	Volume Excess (%)	Catalog Summary
1	Casing	98.4	98.43	19.000	18.813		0.00		CAS 20 in, 106.50 ppf, K55, BTC
2	Casing	2805.2	2706.82	12.415	12.259		0.00		CAS 13 3/8 in, 68.00 ppf, K55, BTC
3	Open Hole	6000.2	3194.95	12.415			0.00	0.00	
4									

Fig.3.7: ANA-2952 Horizontal Wellbore Editor (Wellplan).

Wellbore Editor

Well Depth (MD): 6973.8 ft

	Section Type	Depth (ft)	Length (ft)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Friction Factor	Volume Excess (%)	Catalog Summary
1	Casing	98.4	98.40	19.000	18.813		0.00		CAS 20 in, 106.50 ppf, K55, BTC
2	Casing	2902.8	2804.40	12.415	12.259		0.00		CAS 13 3/8 in, 68.00 ppf, K55, BTC
3	Open Hole	6973.8	4070.97	12.415			0.00	0.00	
4									

Fig.3.8: ANA-6222 Horizontal Wellbore Editor (Wellplan).

Wellbore Editor

Well Depth (MD): 8019.6 ft

	Section Type	Depth (ft)	Length (ft)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Friction Factor	Volume Excess (%)	Catalog Summary
1	Casing	98.4	98.40	19.000	18.813		0.00		CAS 20 in, 106.50 ppf, K55, BTC
2	Casing	2804.4	2706.00	12.415	12.259		0.00		CAS 13 3/8 in, 68.00 ppf, K55, BTC
3	Casing	6953.6	4149.20	8.835	8.750		0.00		CAS 9 5/8 in, 40.00 ppf, K55, BTC
4	Open Hole	8019.6	1066.00	8.835			0.00	0.00	
5									

Fig.3.9: ANA-6974 Horizontal Wellbore Editor (Wellplan).

3.6.2 String Editor:

String Editor Account as centralized editors for most model which used on this software, however in Fig.3.10, Fig.3.11 and Fig.3.12 as spreadsheet to define a work string that is to be analyzed in WELLPLAN for ANA-2952, ANA-6222 and ANA-6974 respectively. In this spreadsheet we specify section types, describe each section type. For example, length specify of the section, and several geometrical properties of that section. Each section consists of one row of information. Specify the work string is entered from the top to bottom.

String Editor

String Initialization

String Type: Drill String   String Depth: 5892.2 ft   Specify: Top to Bottom

	Section Type	Length (ft)	Depth (ft)	OD (in)	ID (in)	Weight (ppf)	Catalog Description
1	Drill Pipe	5660.23	5660.2	5.000	4.276	22.08	DP 5 in, 19.50 ppf, X, H90, P
2	Heavy Weight	30.44	5690.7	5.000	3.000	49.70	HW Grant Prideco, 5 in, 49.70 ppf
3	Jar	33.00	5723.7	6.500	2.750	91.79	JRH Dailey Hyd., 6 1/2 in
4	Heavy Weight	29.52	5753.2	5.000	3.000	49.70	HW Grant Prideco, 5 in, 49.70 ppf
5	Drill Collar	29.52	5782.7	6.500	2.813	90.83	DC 6 1/2 in, 2 13/16 in,
6	Stabilizer	5.00	5787.7	8.750	3.000	180.59	NBS 12 1/4" FG, 8 3/4 x3 in
7	Drill Collar	43.44	5831.1	8.500	2.813	170.18	DC 8 1/2 in, 2 13/16 in,
8	MWD	30.00	5861.1	8.000	2.813	149.92	MWD 8 , 8 x2 13/16 in
9	Mud Motor	30.00	5891.1	8.000	2.813	149.92	BHM 8 , 8 x2 13/16 in
10	Bit	1.02	5892.2	12.200		35.00	
11							

Fig.3.10: ANA-2952 Horizontal Well String Editor (Wellplan).

String Editor

String Initialization

String Type: Drill String String Depth: 6973.8 ft Specify: Top to Bottom

	Section Type	Length (ft)	Depth (ft)	OD (in)	ID (in)	Weight (ppf)	Catalog Description
1	Drill Pipe	6105.12	6105.1	5.000	4.276	22.08	DP 5 in, 19.50 ppf, X, H90, P
2	Heavy Weight	650.36	6755.5	5.000	3.000	49.70	HW Grant Prideco, 5 in, 49.70 ppf
3	Jar	33.00	6788.5	6.250	2.250	90.88	JRM Dailey Mech., 6 1/4 in
4	Heavy Weight	60.20	6848.7	5.000	3.000	49.70	HW Grant Prideco, 5 in, 49.70 ppf
5	Drill Collar	29.52	6878.2	6.500	2.813	90.83	DC 6 1/2 in, 2 13/16 in,
6	Stabilizer	5.00	6883.2	6.000	2.500	79.52	NBS 8 1/2" FG, 6 x2 1/2 in
7	Drill Collar	29.52	6912.7	6.500	2.813	90.83	DC 6 1/2 in, 2 13/16 in,
8	MWD	30.00	6942.7	8.000	2.813	149.92	MWD 8 , 8 x2 13/16 in
9	Mud Motor	30.00	6972.7	8.000	2.813	149.92	BHM 8 , 8 x2 13/16 in
10	Bit	1.05	6973.8	12.250		50.00	
11							

Fig.3.11: ANA-6222 Horizontal Well String Editor (Wellplan).

String Editor

String Initialization

String Type: Drill String String Depth: 8019.6 ft Specify: Top to Bottom

	Section Type	Length (ft)	Depth (ft)	OD (in)	ID (in)	Weight (ppf)	Catalog Description
1	Drill Pipe	7137.04	7137.0	5.000	4.276	22.08	DP 5 in, 19.50 ppf, X, H90, P
2	Heavy Weight	650.36	7787.4	5.000	3.000	49.70	HW Grant Prideco, 5 in, 49.70 ppf
3	Jar	33.00	7820.4	6.250	2.250	90.88	JRM Dailey Mech., 6 1/4 in
4	Heavy Weight	60.20	7880.6	5.000	3.000	49.70	HW Grant Prideco, 5 in, 49.70 ppf
5	Drill Collar	43.43	7924.0	6.500	2.813	90.83	DC 6 1/2 in, 2 13/16 in,
6	Stabilizer	5.00	7929.0	6.000	2.500	79.52	NBS 8 1/2" FG, 6 x2 1/2 in
7	Drill Collar	29.52	7958.5	6.500	2.813	90.83	DC 6 1/2 in, 2 13/16 in,
8	MWD	30.00	7988.5	8.000	2.813	149.92	MWD 8 , 8 x2 13/16 in
9	Mud Motor	30.00	8018.5	8.000	2.813	149.92	BHM 8 , 8 x2 13/16 in
10	Bit	1.05	8019.6	8.500		5.00	
11							

Fig.3.12: ANA-6974 Horizontal Well String Editor (Wellplan).

3.6.3 Survey Editor:

In Survey editor, MD, Inclination and Azimuth are inserted from the survey file in well Daily Drilling Report (DDR). The TVD, dogleg, Vertical section is calculated automatically as the MD given, Inclination and Azimuth data inserted. As stated, the survey editor data can be found in appendix A in form of standard survey report,

3.7 Hole Cleaning Parametric Analysis Mode data input

3.7.1 Fluid Editor:

String Editor and wellbore Editor account as centralized editors for most model which used on this software, however, in this well geometry two types of mud was used to drill the three well section, the first type of mud was KCL Polymer, mud density was between 10–11.2ppg, the plastic viscosity was between 29-30cp, the yield point between 61-62Ibf/100ft2, mud type one used to drill ANA-2952 and ANA-6222, the second mud have density between 8.7-8.8ppg, the plastic viscosity between 11-12cp, and the yield point between 59-60Ibf/100ft2, the type of mud was FLOPRO mud used to drill the horizontal section as we named ANA-6974, this two types of mud was used to evaluate the cutting transport phenomenon. The adding procedure defining as the Fig.3.13 and Fig.3.14 for three section respectively ANA-2952, ANA-6222 and ANA-6974.

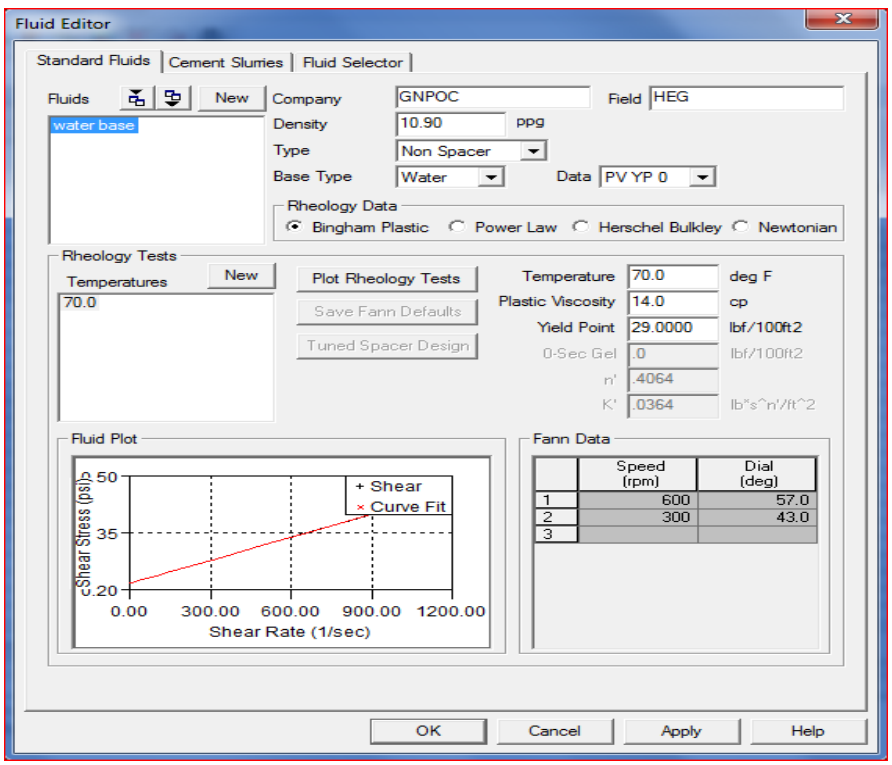

Fig.3.13: ANA-2952 & ANA-6222 Well Fluid Editor (wellplan).

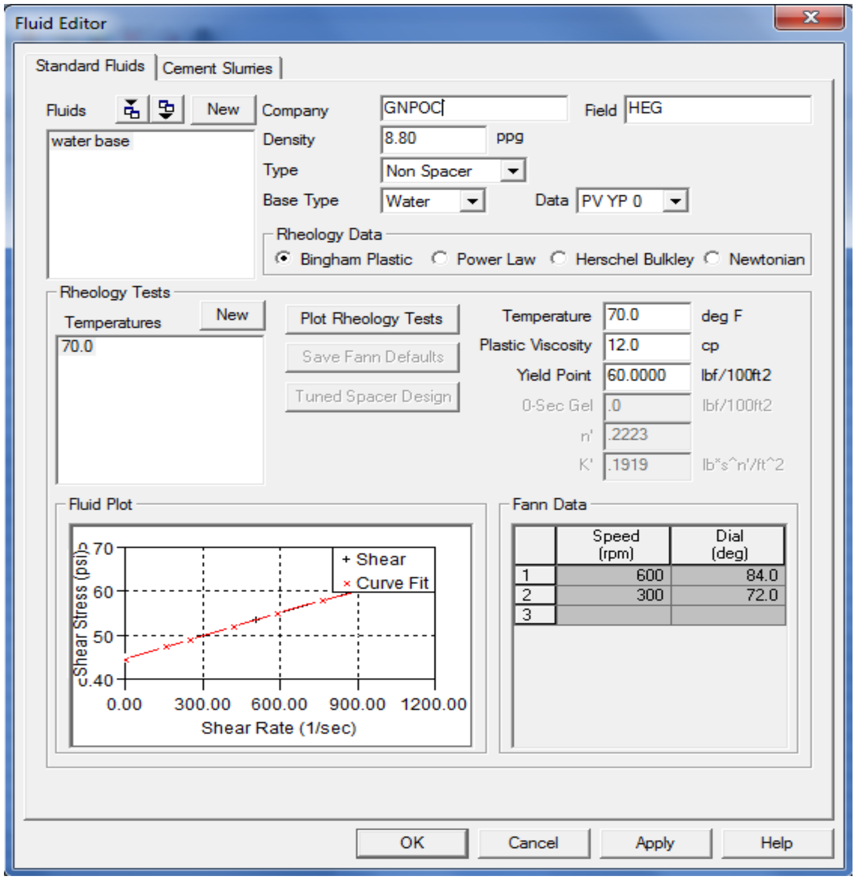

Fig.3.14: ANA-6974Well Fluid Editor (wellplan).

3.7.2 Transport analysis data input:

Use this dialog to estimate the minimum flow rate required for hole cleaning for various desired ROPs (rates of penetration), the data input type was performed for three section of the well trajectory as we named earlier; ANA-2952, ANA-6222 and ANA-6974 as defined in the Fig.3.15, Fig.3.16, through Fig.3.18.

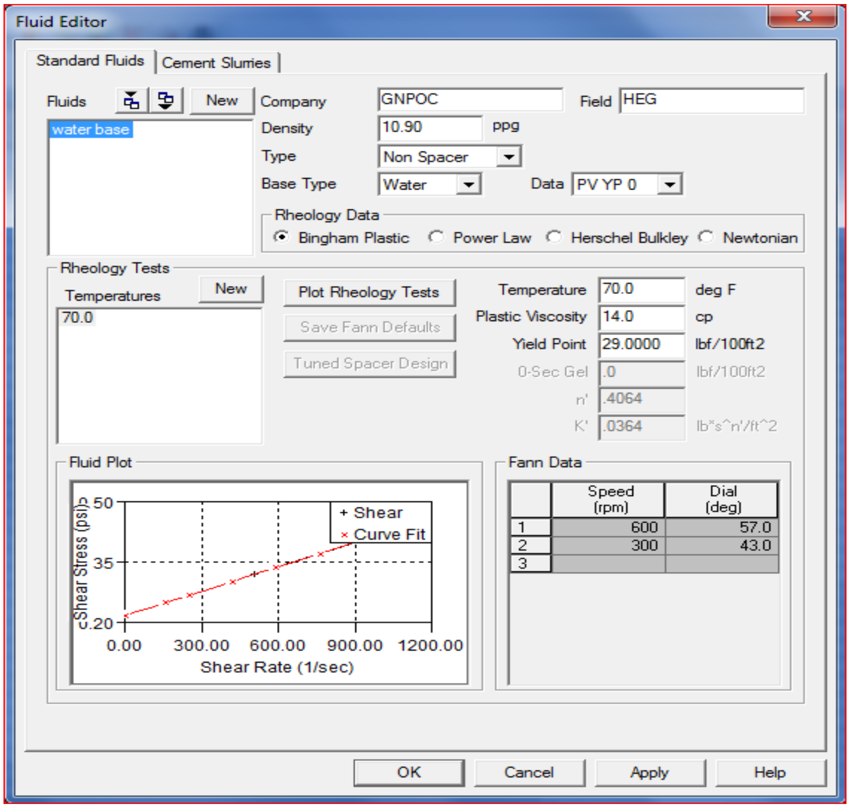

Fig.3.15: ANA-2952 Transport Analysis Editor (wellplan).

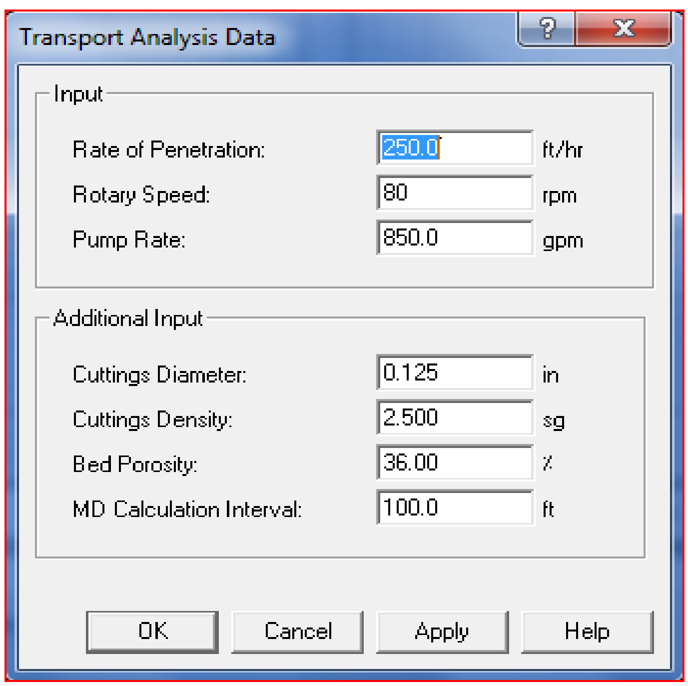

Fig.3.16: ANA-2952 Transport Analysis Editor (wellplan).

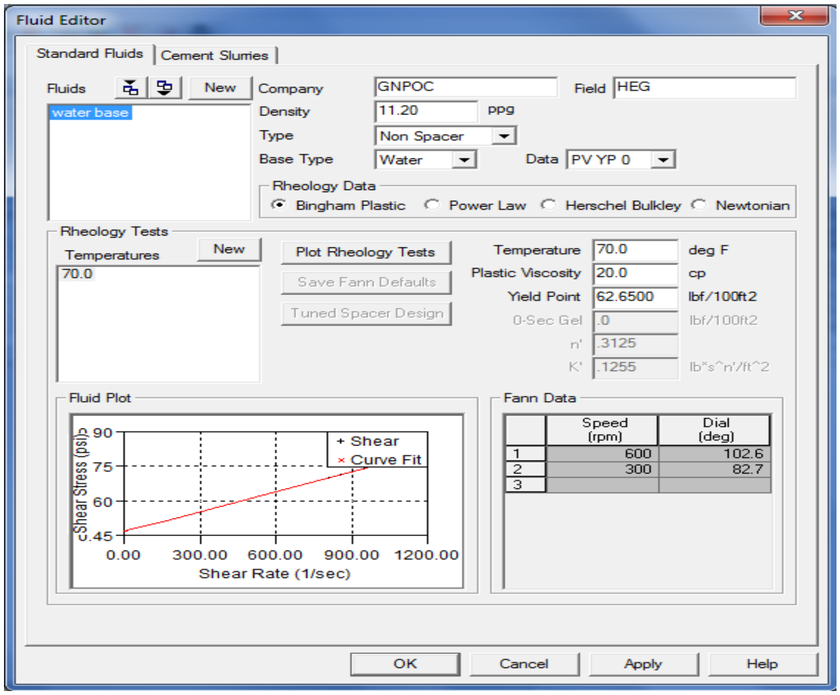

Fig.3.17: ANA-6222 Transport Analysis Editor (wellplan).

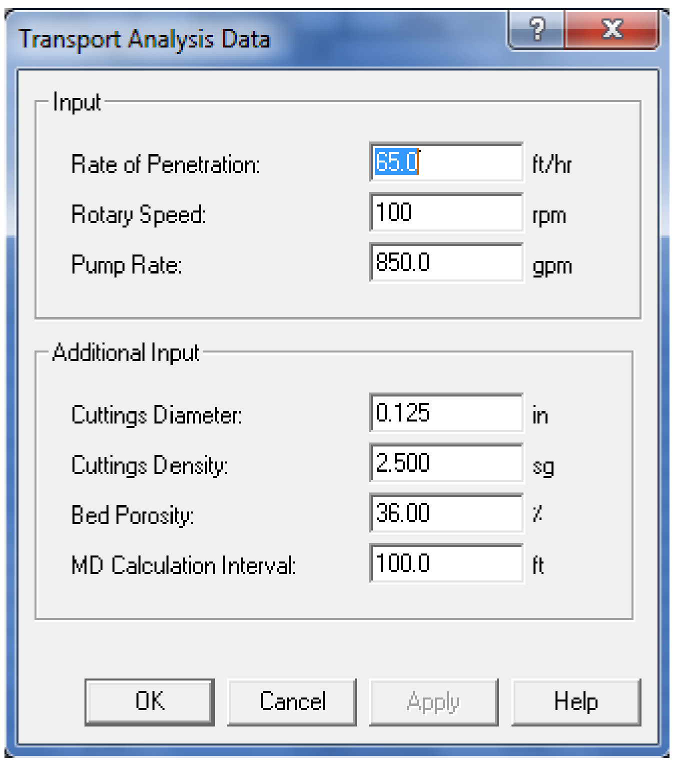

Fig.3.18: ANA-6222 Transport Analysis Editor (wellplan).

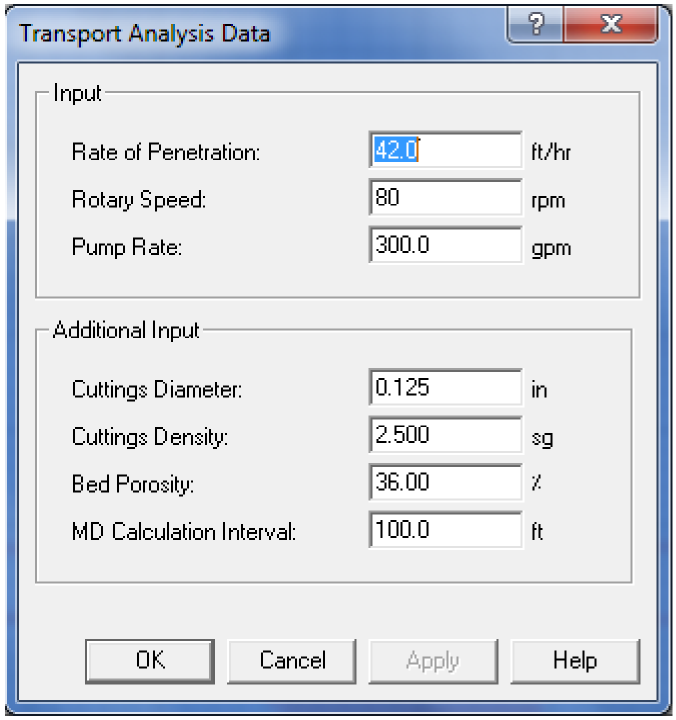

Fig.3.19: ANA-6974 Transport Analysis Editor (wellplan).

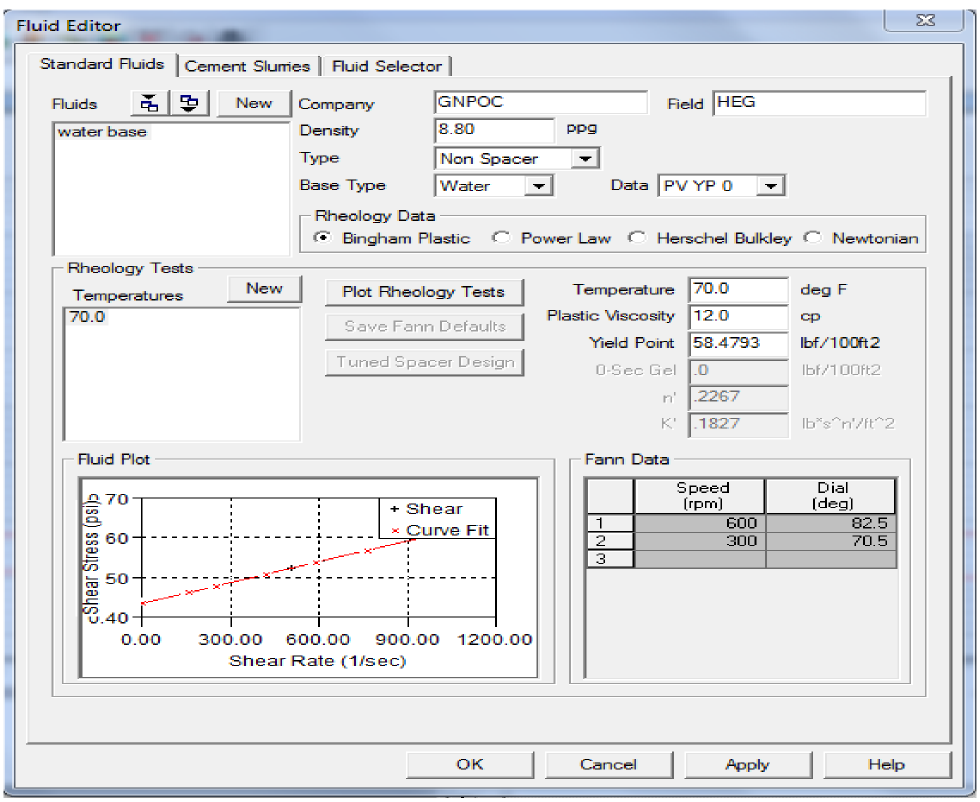

Fig.3.20: ANA-6974 Transport Analysis Editor (wellplan).

CHAPTER 4:

4.1 Results and discussion:

The well selected for the case study is a horizontal well drilled in the Hegilg field, block 2b. It was drilled from the drilling rig Y to TD at 8020ft MD. A 20 inch conductor casing was set to 98.4ft MD. And a 13-3/8 inch surface casing was set to 2903ft MD. A 9-5/8inch intermediate casing was set to 6954ft MD. The 7inch Screen Liner was set from 6954ft MD to 8020ft MD. as can be seen in the geometry of this well on each section (ANA-2952ft, ANA-6222ft and ANA-6974ft) as we illustrated in previous chapter Fig.4.1. Fig.4.2 through Fig.4.5 shows the vertical section versus TVD inclination versus MD, and DLS versus MD respectively.

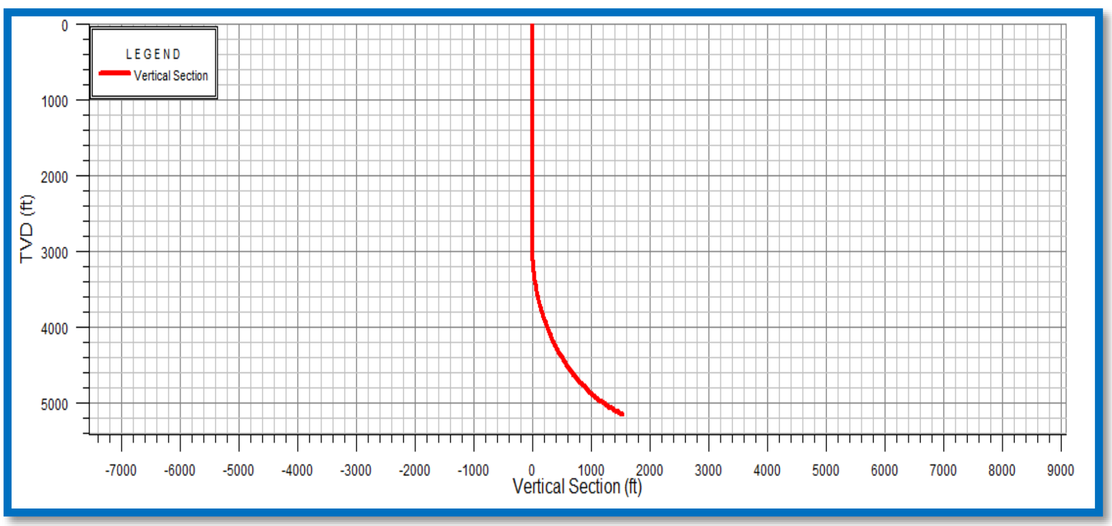

Fig. 4.1, ANA-2952 Horizontal Well Survey Vertical Section (Wellplan)

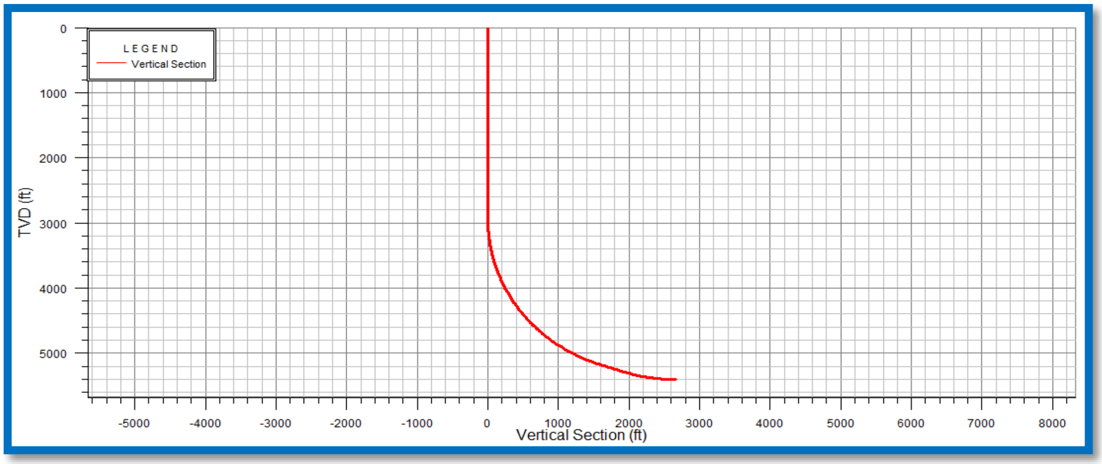

Fig. 4.2, ANA-6222ft Horizontal Well Survey Vertical Section (Wellplan)

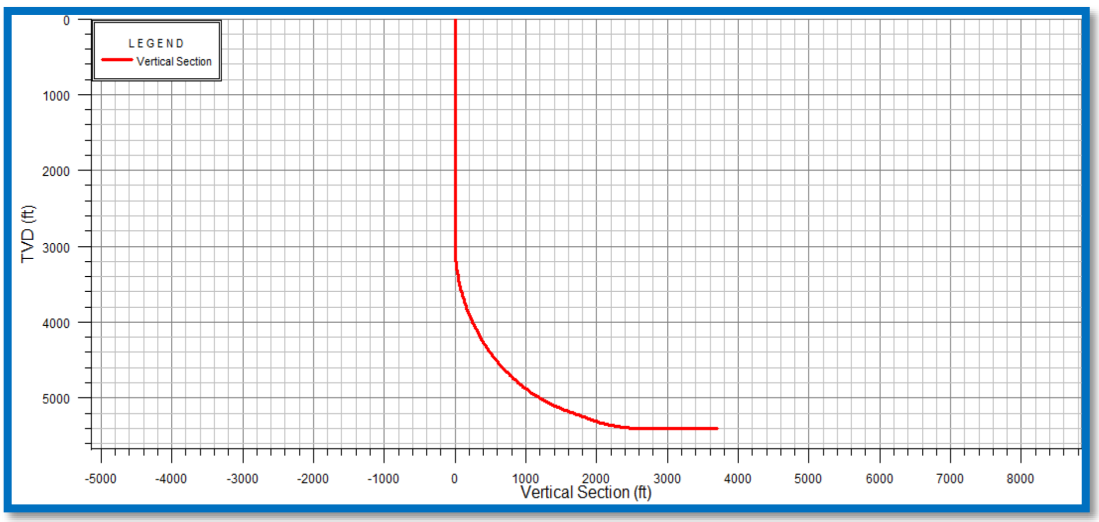

Fig. 4.3, ANA-6974ft Horizontal Well Survey Vertical Section (Wellplan)

4.1.1 Inclination Plot

Use this plot to determine the inclination at any depth in the wellbore. This plot is based on the survey data specified in the Survey Editor spreadsheet. In Fig.4.4 defining ANA-2952ft section show that the straight line start with point coordinate (0,0) and continue dropped down vertically with increase with Y axes value (MD) and holding approximately Zero^{o} value in X axes (Inclination) till reach the kick off point one (KOP#1) the point coordinate for KOP#1 is (2952,2.4), from this point the value of X axes increased gradually with increasing in Y access (MD) with approximately BUR of

3/100ft. the lines slightly goes down from KOP#1 till reach the End of curve one (EOC#1) at 5890ft MD with EOC angle of 71.67º (5890,71.67)

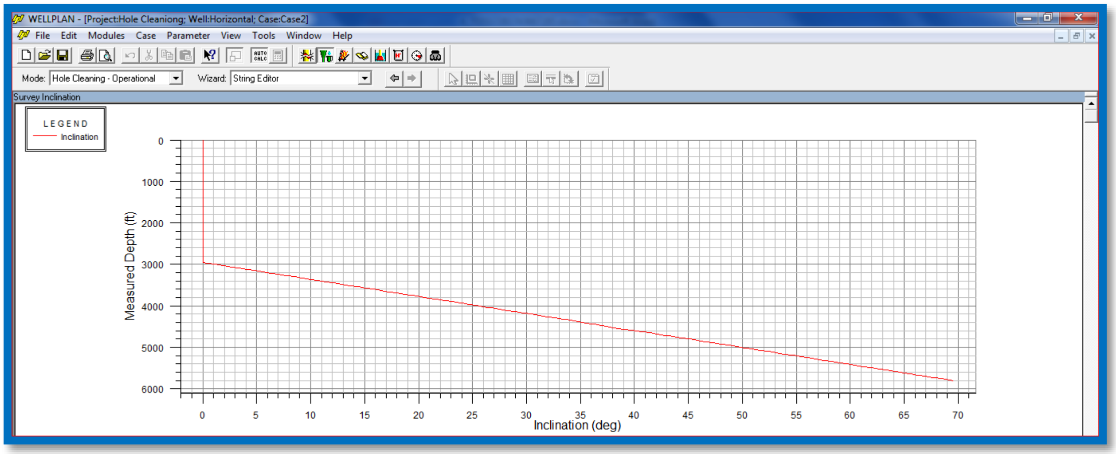

Fig.4.4, ANA-2952ft Survey Inclination Horizontal well (Wellplan)

4.1.2 ANA-6222 Survey inclination plot:

From End of curve at 5890ft MD with EOC#1 angle of 71.67º the corresponding coordinate point in the graph is (5890,71.67), the line goes down vertically result of increasing in measure depth of 5890ft MD in Y axes with lock-up angle of 71.67º till reach the depth of 6222ft MD with same angle 71.67º, this indicate that this is the tangent section, from this point the value of X aces increased gradually with increasing in Y access (MD) with approximately BUR of 3/100ft. the lines slightly goes down from end on tangent section and start to build kick of point two (KOP#2) with depth of 6222ft MD and an angle of 71.67º till reach the End of curve at 6974ft MD with End of curve two (EOC#2) angle of 90.05º the corresponding coordinate point in the graph is (6974,90.05). Fig.4.5 represents the typically ANA-6222ft survey inclination plot.

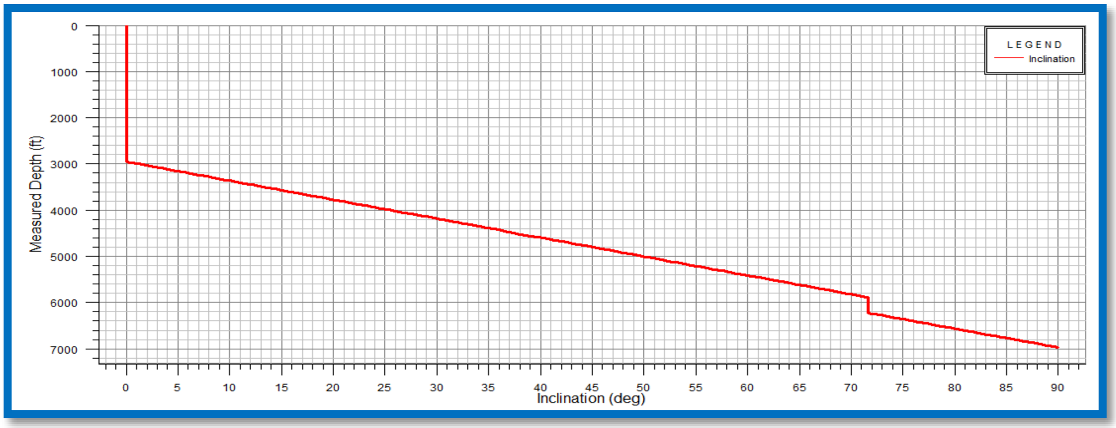

Fig.4.5, ANA-6222 Survey Inclination Horizontal well (Wellplan)

4.1.3 ANA-6974 Survey inclination plot:

From End of curve at 6974ft MD with EOC#2 angle of 90.05º the corresponding coordinate point in the graph is (6974,90.05), the line goes down vertically result of increasing in measure depth of 8019ft MD in Y axes with lock-up angle of 90.05º till reach the TD depth of 8019ft MD with same angle of 90.05º, this indicate that this is the horizontal displacement section, the corresponding coordinate point in the graph is (8019,90.05). Fig.4.6 represents the typically ANA-6974 survey inclination plot.

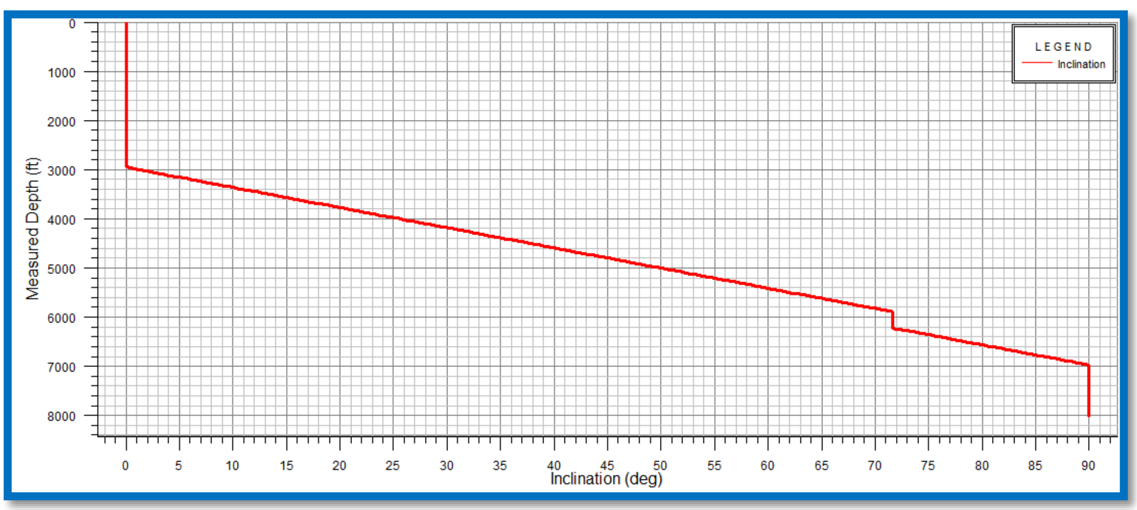

Fig.4.6, ANA-6974 Survey Inclination Horizontal well (Wellplan)

4.1.4 Dogleg Severity Plot (DLS)

Use this plot to display the wellbore curvature or DLS as a function of MD or TVD. This plot can be used to determine DLS at any depth in the wellbore. Fig.4.7 through Fig.4.9 represents the DLS plot of ANA-2952, ANA-6222 and ANA-6974 section respectively.

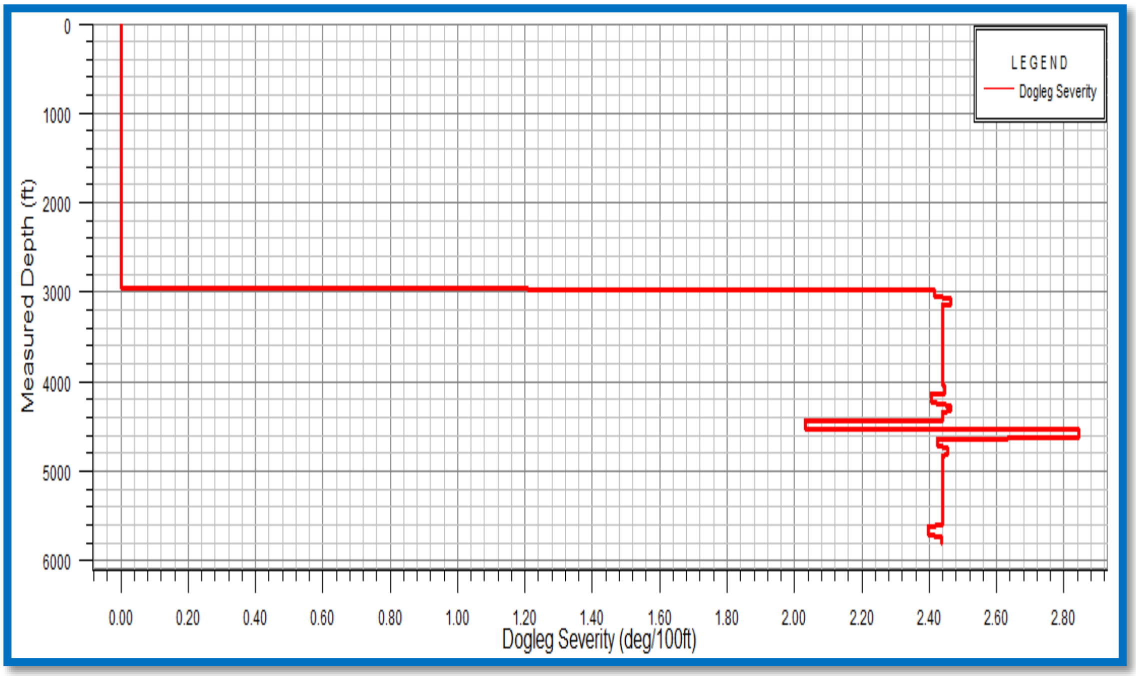

Fig.4.7, ANA-2952 Horizontal Well measured depth (ft) vs Dogleg severity (deg/100ft), (Wellplane)

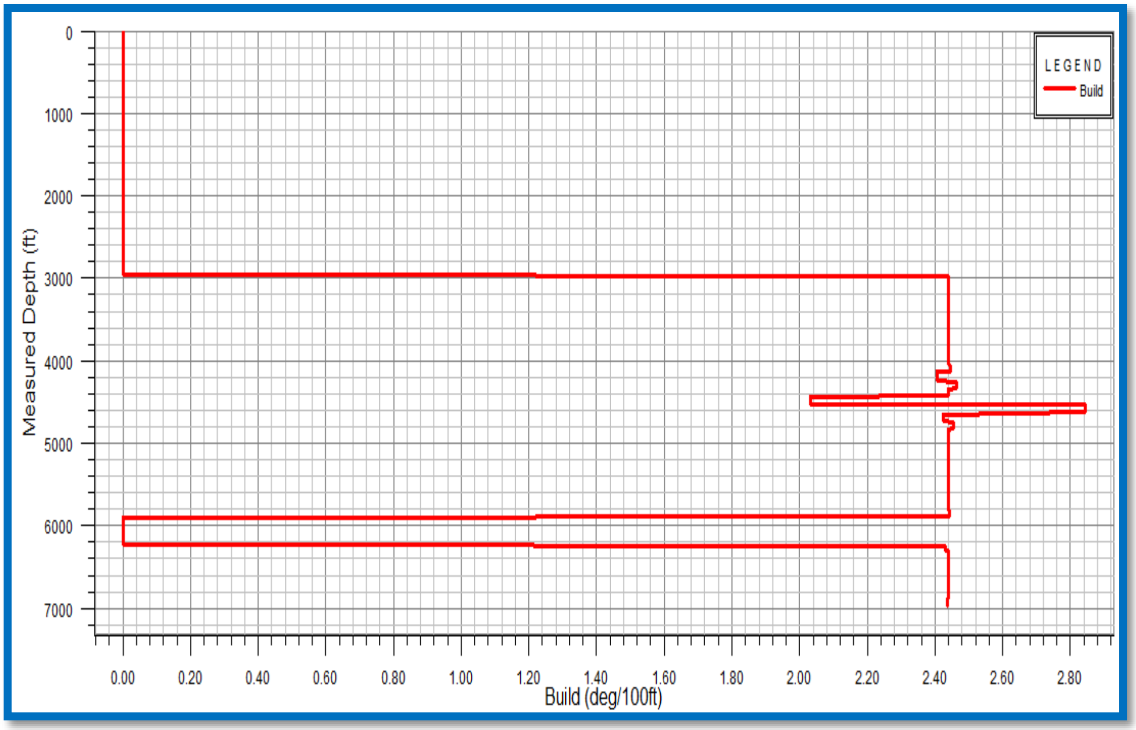

Fig.4.8, ANA-6222 Horizontal Well measured depth (ft) vs Dogleg severity (deg/100ft), (Wellplane)

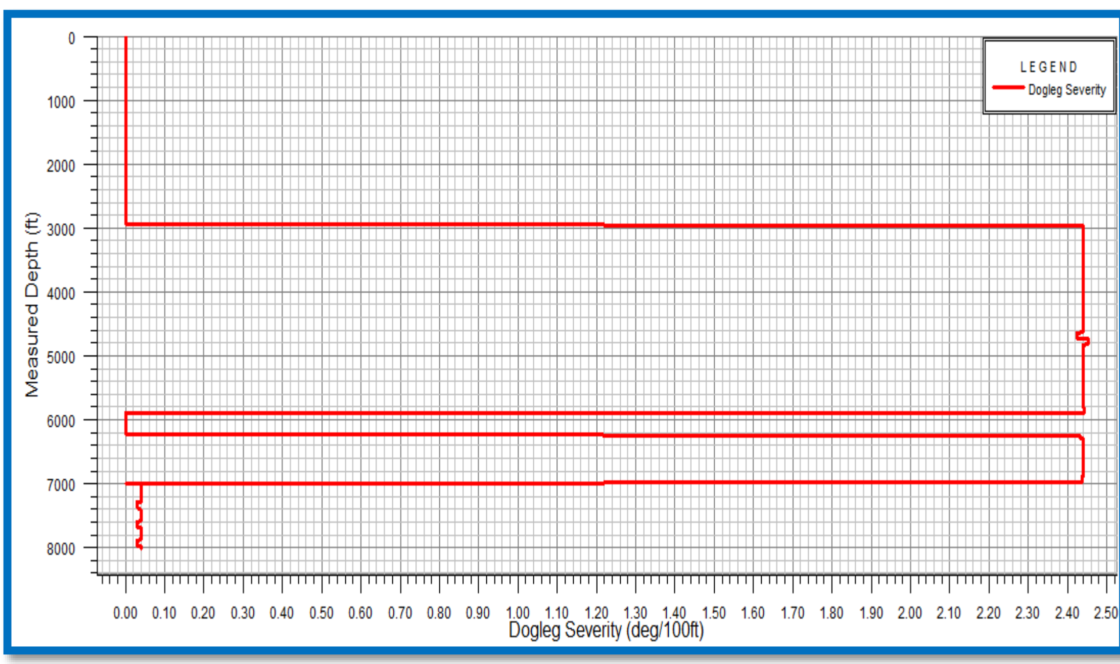

Fig.4.9, ANA-6974ft Horizontal Well measured depth (ft) vs Dogleg severity (deg/100ft), (Wellplane)

4.2 Result analysis

4.2.1 From Hole cleaning operation analysis:

4.2.1.1 Operational plote:

This plot represents the following variables for the entire length of the wellbore:

- Inclination versus measured depth
- Flow rate at minimum flow rate (critical transport fluid velocity) versus measured depth
- Suspended cuttings volume versus measured depth
- Bed height versus measured depth

1- **Operational plot for ANA-2952 section:**

Fig.4.10 is the simulation result carried out on the real well geometry. As can be seen on the Fig.4.10 below, at around 33º depth of 4370ft MD . The analysis result shows that cutting volume increases from 0% to 95 % and bed height increases from 0 inch to 1.9inch as well inclination increases from vertical/near vertical to 33º. The result in general shows that the hole-cleaning problem increases as well inclination increases. In other words, a higher flow rate is required for highly inclined well.

However, at depth around 4320ft MD to 5220ft MD (course of 900ft) the drilling operation in 12-1/2inch hole tend to increase the ROP from 100ft/min to 250ft/min, inclination angle around 33º to 55.2º as mentioned in daily drilling report (DDR), from this point as analysis result that the total volume of cutting in annular increase from Zero% to 95%, and bed height increase from Zero inch to 1.9inch, the question is what this mean, this means; the total volume of cutting in annular become more than suspend volume of cutting in the same region, this typically increase the bed height in the well which will reflect later on in many issues in drilling process such as excusive drag, over pull and high torque while drilling, this typically which happened in actually drilling sequence, also on other hand the corresponding minimum flow rate will increase and reach value around 1000gpm, this indeed will increase the stand pipe pressure and put more pressure in surface equipment, also this typically which happened in actual drilling sequence as reported in daily drilling report that the operation stopped many time due to leakage in standby hummer union several time while drilling.

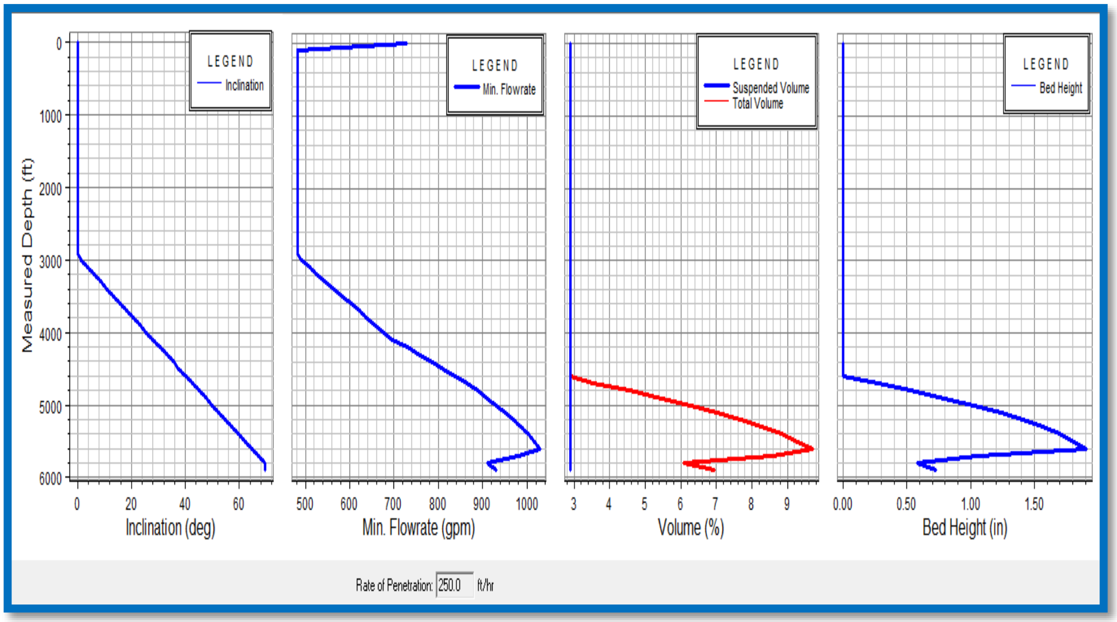

Fig.4.10, ANA-2952 MD vs Inclination &Min.Flowrate (gpm) & Volume (%) Bed height (In)

Evidence confirmed the mention analysis:

- After drill the section from 4320ft MD to 5215ft MD, the angle changed from 33º to 55.2º respectively, and preformed short wiper tripped, Rig supervisor reported in DDR that, observed normal over pull about 15Ton, and dragged at depth of 4372ft MD
- Second, after the progress on the drilling a head this section, and while preformed log wiper trip, again observed the same value of over pull and dragged as the same depth, and the Rig side supervisor stated in DDR that suspected the cutting accumulate behind BHA string
- Also recorded that in the DDR, many time recorded Nun productive time (NPT) due to stand pipe hummer union leakage many time, this indicate that the drilling string pressure increased due to bed height generate in the low side of well bore.

- Finally, they recorded that, the string got differential stuck, but after many process, the string free and they solved this issue.

2- **Operational plot for ANA-6222 section:**

As we illustrate earlier in previous chapter this section consist of 12-1/2inch BUC#2 and tangent section, this section start from EOC#1 continue with tangent till reach inclination angle of 73.51^{o} at depth 6222ft MD, Fig.4.11 is the analysis result which carried out on the real well geometry. As can be seen on the Fig.4.11 below, as the data collected from DDR and slide sheet of surface company, at around 5890ft the inclination began to lock-up angle of 71.67^{o}. The analysis result shows that suspend volume equal to the total volume, that mean no bed height will generate at the low side of the wellbore, also the tangent section play a significant role to reduce the minimum corresponding flow rate versus ROP, that will guaranty to restricted the bed height generation.

However, as reported in (DDR), the average ROP was 66ft/min, after simulation and analysis as discussed above shows that this ROP it’s so enough to eliminate the total volume to become greater than suspend volume result in no bed height will generate in the low side of wellbore, but the drilling operation time increase due to bed height which generate from the previous section (ANA-2952), this problem force drilling operation time to increase due to reduce the ROP as less as possible, and of course this which Landmark analysis tell, because they can increase ROP up to 150ft/min with the same flow rate range from 500-600gpm without generating bed height while drilling a head this suction, and for instant the logger operation take, the more dollar will be flow to surface company bucket this well lead to increase the overall operation cost. Fig.4.11 below show and illustrate the typically inclination versus measure depth for ANA-6222 section

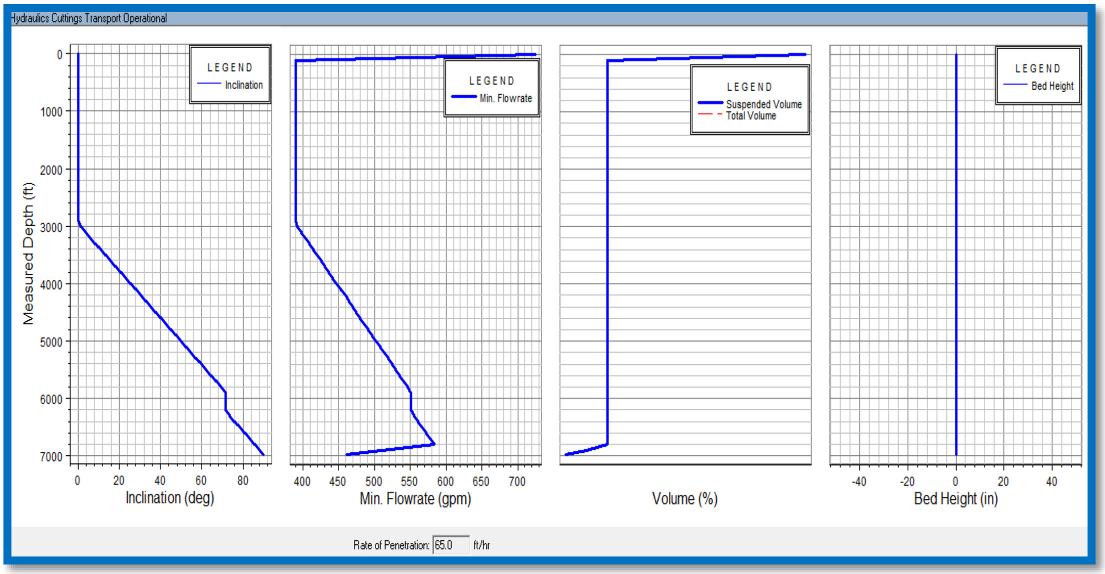

Fig.4.11 ANA-6222 MD vs Inclination & Min.Flowrate (gpm) &Volume(%) &Bed height (In)

3- **Operational plot for ANA-6974 section:**

As we illustrate earlier in previous chapter this section represent the horizontal displacement section start from the EOC#2 at depth of 6974ft MD continue to hold approximately angle of 90.05º till reach the TD at 8020ft MD**.** For recorded, the problematic section of the well bore already isolated and cased by 9-5/8inch intermediate casing set at 6957ft MD inclination angle of 87.91º, this off course will isolate the active zone, and play a key demonstrated to get better hole cleaning will drilling, anyway, this exactly what below graph reflex, that no problem will face at all when continue to drill a head this section, because we got a good result from the equality ratio between suspended cutting volume in annular and total cutting volume in the same region, this result seems to be ideal.

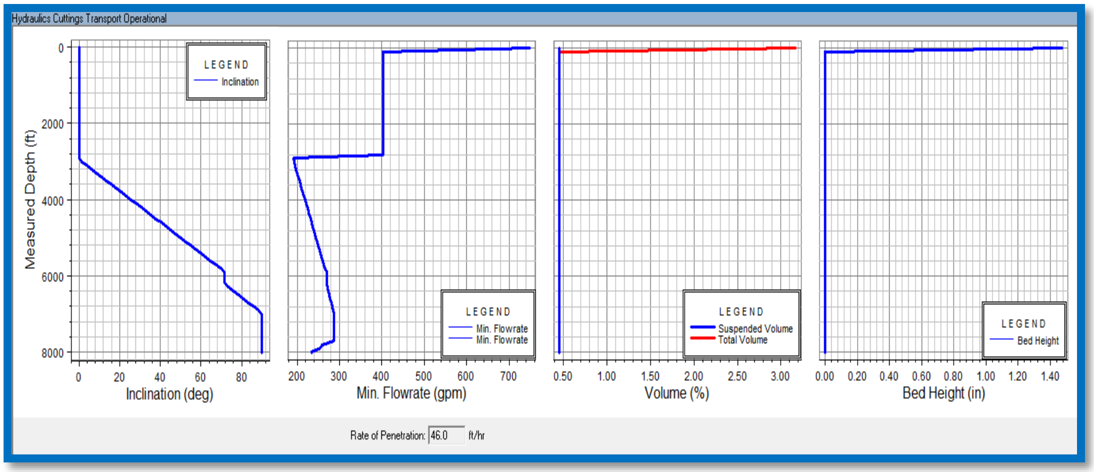

Fig.4.12, ANA-6974, MD vs Inclination &Min.Flow rate (gpm) &Volume(%) &Bed height (In)

4.2.1.2 Flow rate at minimum flow rate (critical transport fluid velocity) versus measured depth plot:

This plot represents the minimum flow rate for various ROPs (rates of penetration) in the different geometry sections of the well. This plot is based on engineering code for the following hole cleaning analysis variables:

· Mud rheology
· Mud density
· Cuttings size
· Cuttings density
· Cuttings shape

1- **Flow rate at minimum flow rate (critical transport fluid velocity) versus measured depth plot for ANA-2952 section:**

As investigation of well drilling stage, we focus on depth between 4370ft MD inclination angle of 33º to 5220ft MD angle of 55.2º, which observed a wide increasing in rate of penetration; anyway in late stage of drilling operation this increase of ROP cause differential stuck as mention before, stack mainly occurs by cutting accumulate behind BHA.

From Fig.4.13 below, show that the save zone for ROP range from 0 to 100 ft/hr the corresponding flow rate from 650gpm to 850gpm, which suitable for minimum & maximum (300 gpm to 850 gpm) Rig pump rate can provide, and shaded zone (Red color zone) for both ROP & Flow rate which range of ROP from 100ft/hr to 250ft/hr the corresponding flow rate must be range from 850gpm to 1050gpm

From field data as mentioned in report (DDR) and Slide sheet report that, during build section from depth 4370ft MD to 5220ft MD the ROP increase from 101ft/hr to 250ft/hr, after they performed wiper trip to casing shoe they observed 15 ton drag @ 4700ft MD, this typically the begging of bed height to generate in the side of the wellbore as the operational plot show in previous Fig.4.10, also Fig.4.13 show the typical Flow rate vs ROP plot in the shaded red zone which illustrate on the plot represent the Flow rate vs ROP..

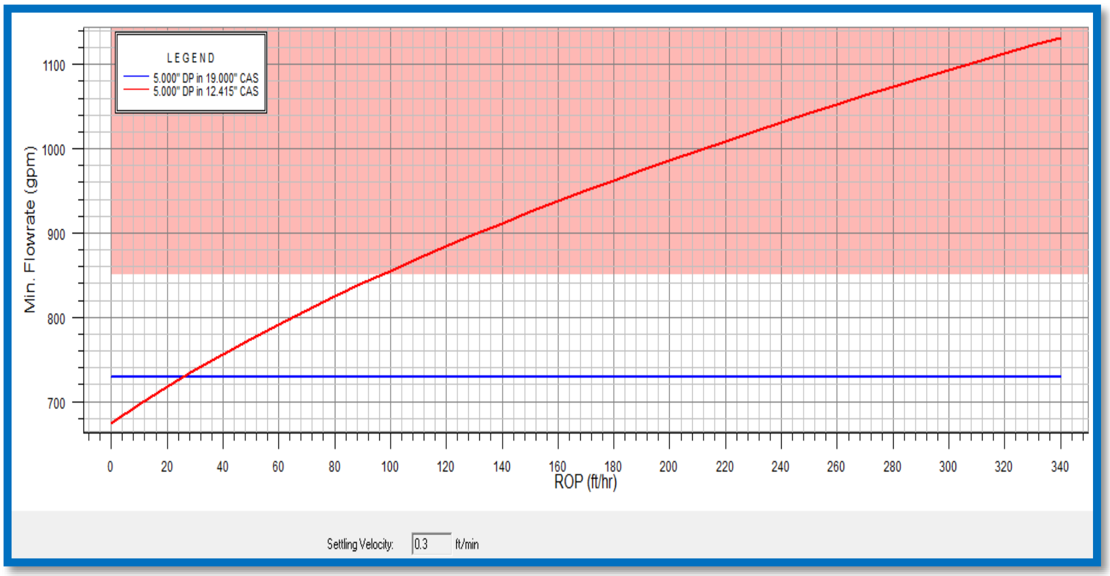

Fig.4.13, ANA-2952 Horizontal Well Minimum flow rate(GPM) vs ROP(ft/hr)

2- **Flow rate at minimum flow rate (critical transport fluid velocity) versus measured depth for ANA-6222 section:**

For this section, as the Fig.14 below show that, the wide range of ROP start from Zero to 110ft/min the corresponding minimum flow rate is 590gpm, and this range of volume typically used in actual drilling operation parameter, which they use average ROP of 66ft/min with minimum flow rate of 700gpm. Here also confirm which operation plot analysis that, there was no bed height will generate due to total cutting volume equal to the suspended cutting volume, and also with tangent section the cutting transfer ability higher compared with just one curve along wellbore bath.

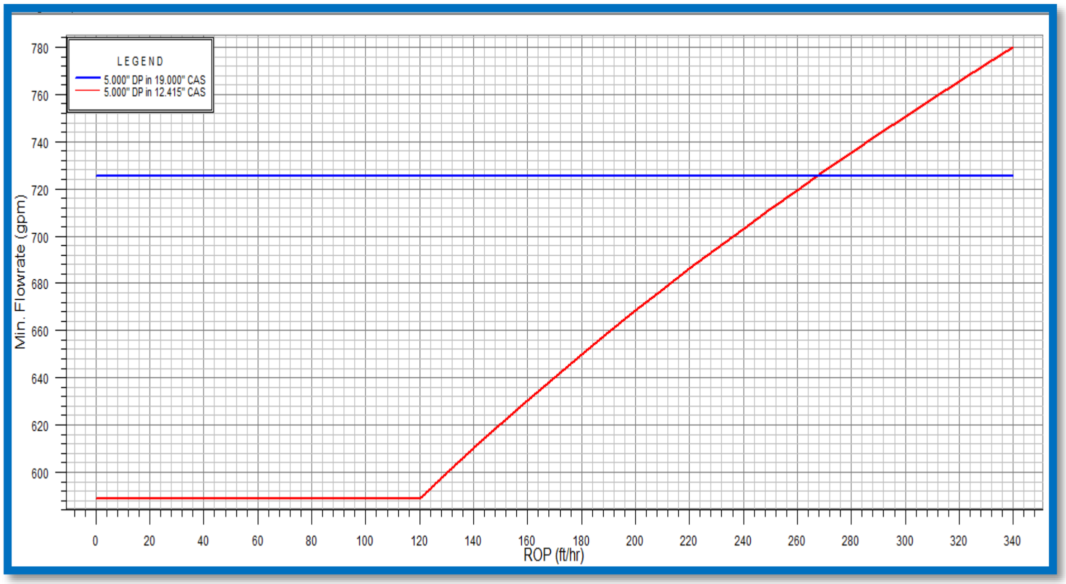

Fig.4.14, ANA-2952 Horizontal Well Minimum flow rate (GPM) vs ROP (ft/hr)

3- **Flow rate at minimum flow rate (critical transport fluid velocity) versus measured depth for ANA-6974ft section:**

In this section (horizontal displacement section), the minimum corresponding flow rare is 500gpm versus the actual average ROP of 43ft/min will be very enough to deliver cutting to surface without causing bed height to generate in the side of the wellbore, if we compared this analysis with operation analysis we will see equal analysis outcome conclusion of no bed height will generate at all, but if we reduce the actual flow rate to 400gpm the result will be different as we can see in Fig.4.15 bellow that the red shaded zone will increase and the some value of ROP start from 260ft/min will be inside the shaded zone, however this value of ROP consider to be higher but just in case the drilling operation sequence force to use such as this value to keep in mind to use minimum value of 500gpm to be in safe side.

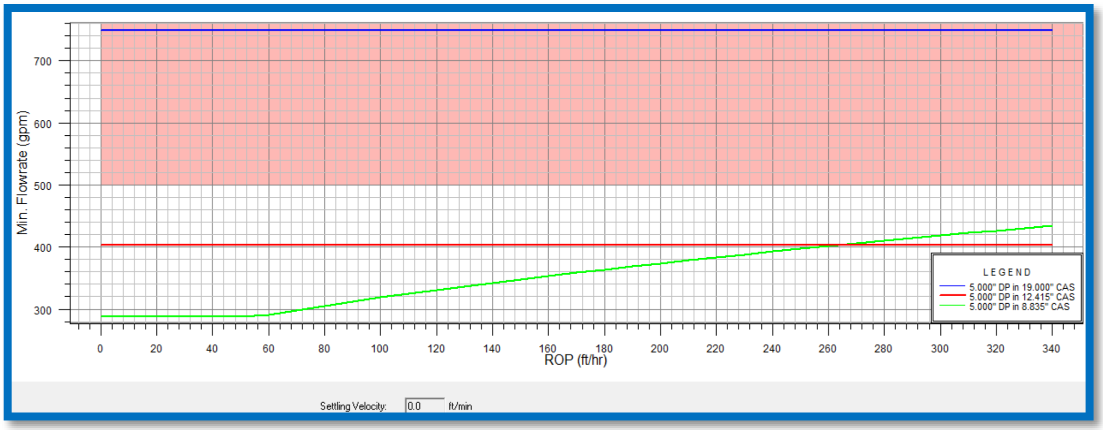

Fig.4.15, ANA-6974 Horizontal Well Minimum flow rate (GPM) vs ROP (ft/hr)

4.2.2 Hole Cleaning Parametric Analysis Mode output:

4.2.2.1 Bed Height Plot:

Use this plot to determine the bed height of the cuttings that will be in the annulus for any wellbore inclination ranging from 0 to 90 º, for a particular depth.

1- **Bed height plot analysis for ANA-2695 section:**

The Fig.4.16 show the ratio between hole angle and total cutting volume percentage depend on pumping flow rate, the graph give brief analysis between minimum and maximum flow rate the Rig side pump can provide, as mentioned in report (DDR) that the minimum and maximum flow rate that the rig side pump can provide between 300-850gpm, as mention value the graph gave us typical value of the ratio between total cutting volume percentage and hole angle, let start with pump rate of 1100 & 900gpm which seems to be perfect enough to prevent bed height to generate until versus whole hole inclination up to 71.67º, which from begging the rig side cannot provide it atoll as the data collected from DDR, let's take the other quantity of flow rate of 700gpm as the plot show that with this value of gpm there will be no bed height generate until angle of 40º, from this angle the total volume of cutting will generate until reach the value of 1.9in bed height with angle of 55 º, and that exactly which happened if we compare with operational plot when they increase the ROP up to 250ft/min in the previous discussion, lets continue to take other quantity of flow rate of 600gpm, the cutting total volume will generate earlier from angle 25º continue increasing until reach the value of 3.3inch, so outcome of this plot is to increase the flow rate as much as possible to unable mud system to transfer the cutting to surface to prevent cutting accumulate in wellbore and thus generate bed height in the low side of the wellbore, and for 300gpm is totally not acceptable.

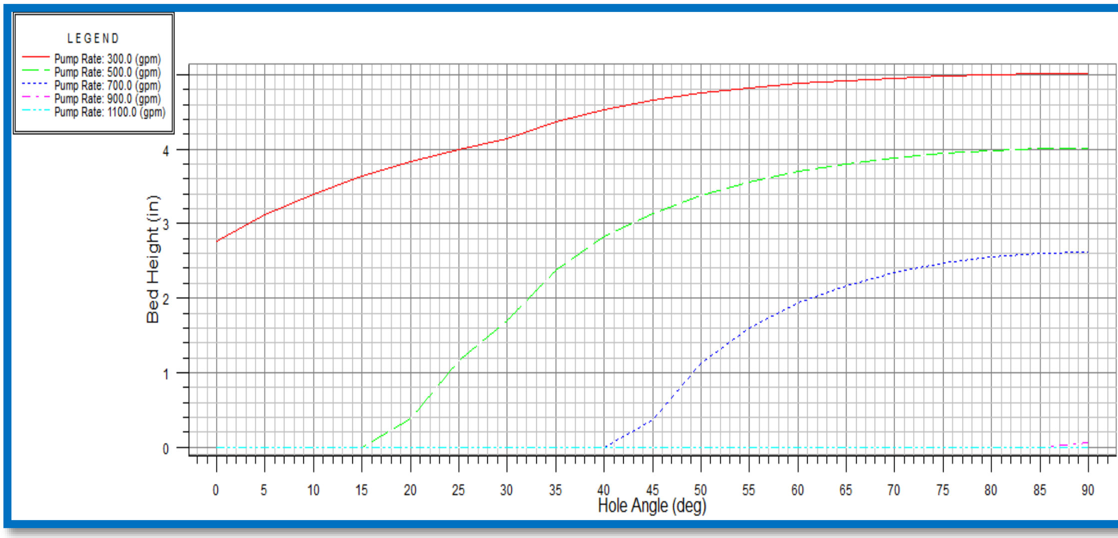

Fig.4.16, show the ratio between bed height and hole angle depended on minimum flow rate of 300gpm for ANA-2952

WELLPLAN - [Project:Hole Cleaniong; Well:Horizontal; Case:Case2]

File Edit Modules Case Parameter View Tools Window Help

Mode: Hole Cleaning - Parametric Wizard: Transport Analysis Data

Hydraulics Cuttings Transport Parametric - Bed Height

	Pump Rate: 300.0 (gpm)		Pump Rate: 500.0 (gpm)		Pump Rate: 700.0 (gpm)		Pump Rate: 900.0 (gpm)		Pump Rate: 1100.0 (gpm)	
	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)
1	0.00	2.765	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
2	5.00	3.119	5.00	0.000	5.00	0.000	5.00	0.000	5.00	0.000
3	10.00	3.403	10.00	0.000	10.00	0.000	10.00	0.000	10.00	0.000
4	15.00	3.635	15.00	0.000	15.00	0.000	15.00	0.000	15.00	0.000
5	20.00	3.833	20.00	0.391	20.00	0.000	20.00	0.000	20.00	0.000
6	25.00	4.001	25.00	1.160	25.00	0.000	25.00	0.000	25.00	0.000
7	30.00	4.147	30.00	1.691	30.00	0.000	30.00	0.000	30.00	0.000
8	35.00	4.370	35.00	2.374	35.00	0.000	35.00	0.000	35.00	0.000
9	40.00	4.532	40.00	2.826	40.00	0.000	40.00	0.000	40.00	0.000
10	45.00	4.654	45.00	3.143	45.00	0.366	45.00	0.000	45.00	0.000
11	50.00	4.749	50.00	3.381	50.00	1.135	50.00	0.000	50.00	0.000
12	55.00	4.822	55.00	3.561	55.00	1.605	55.00	0.000	55.00	0.000
13	60.00	4.878	60.00	3.699	60.00	1.935	60.00	0.000	60.00	0.000
14	65.00	4.922	65.00	3.806	65.00	2.170	65.00	0.000	65.00	0.000
15	70.00	4.956	70.00	3.885	70.00	2.344	70.00	0.000	70.00	0.000
16	75.00	4.980	75.00	3.946	75.00	2.466	75.00	0.000	75.00	0.000
17	80.00	4.997	80.00	3.986	80.00	2.551	80.00	0.000	80.00	0.000
18	85.00	5.006	85.00	4.010	85.00	2.597	85.00	0.000	85.00	0.000
19	90.00	5.009	90.00	4.016	90.00	2.612	90.00	0.061	90.00	0.000

Fig.4.16.1, show the ratio between bed height and hole angle depended on minimum flow rate of 300gpm spreadsheet for ANA-2952

2- **Bed height plot analysis for ANA-6222 section:**

As we explain earlier, this plot give the ratio between bed height in inch and hole angle for various flow rate, Fig.4.17 typically explain this ratio, so for flow rate of 900, 750 and 600gpm there will be no bed height in the low side of the wellbore, and this vary enough compare with data collected while drilling, but for flow rate of 450gpm the total volume generate in wellbore while drilling will start earlier and will increase continually until reach the value of 2inch thick around wellbore, let's take the flow rate of 300gpm, this quantity of flow rate account as the worst gpm and must be preventing to use such as this value while drilling sequence.

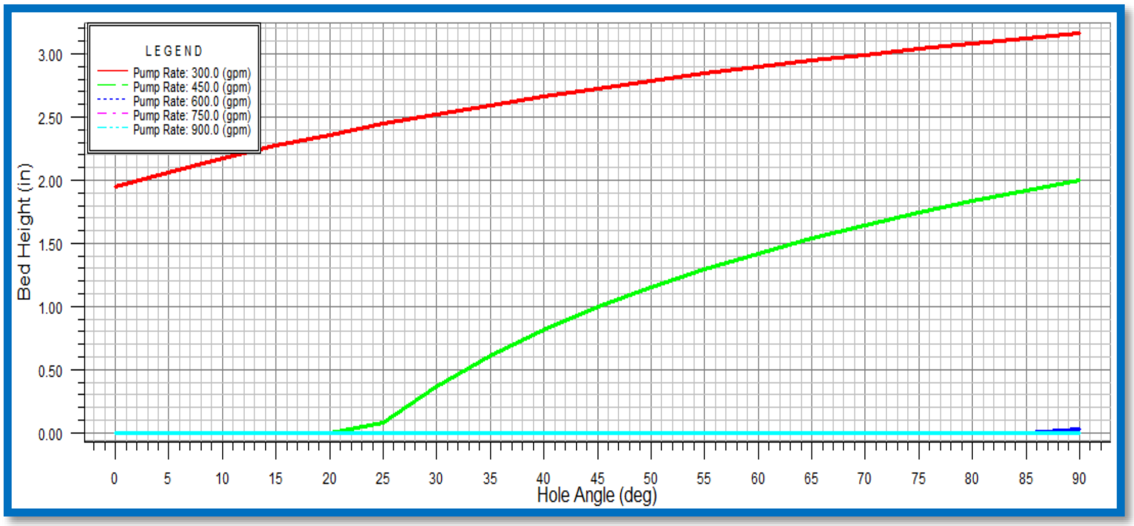

Fig.4.17, show the ratio between bed height and hole angle depended on minimum flow rate of 300gpm for ANA-6222

Hydraulics Cuttings Transport Parametric - Bed Height

	Pump Rate: 300.0 (gpm)		Pump Rate: 450.0 (gpm)		Pump Rate: 600.0 (gpm)		Pump Rate: 750.0 (gpm)		Pump Rate: 900.0 (gpm)	
	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)
1	0.00	1.947	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
2	5.00	2.063	5.00	0.000	5.00	0.000	5.00	0.000	5.00	0.000
3	10.00	2.173	10.00	0.000	10.00	0.000	10.00	0.000	10.00	0.000
4	15.00	2.271	15.00	0.000	15.00	0.000	15.00	0.000	15.00	0.000
5	20.00	2.362	20.00	0.000	20.00	0.000	20.00	0.000	20.00	0.000
6	25.00	2.444	25.00	0.079	25.00	0.000	25.00	0.000	25.00	0.000
7	30.00	2.521	30.00	0.366	30.00	0.000	30.00	0.000	30.00	0.000
8	35.00	2.594	35.00	0.610	35.00	0.000	35.00	0.000	35.00	0.000
9	40.00	2.661	40.00	0.818	40.00	0.000	40.00	0.000	40.00	0.000
10	45.00	2.728	45.00	0.995	45.00	0.000	45.00	0.000	45.00	0.000
11	50.00	2.786	50.00	1.154	50.00	0.000	50.00	0.000	50.00	0.000
12	55.00	2.844	55.00	1.294	55.00	0.000	55.00	0.000	55.00	0.000
13	60.00	2.896	60.00	1.416	60.00	0.000	60.00	0.000	60.00	0.000
14	65.00	2.945	65.00	1.538	65.00	0.000	65.00	0.000	65.00	0.000
15	70.00	2.994	70.00	1.642	70.00	0.000	70.00	0.000	70.00	0.000
16	75.00	3.040	75.00	1.740	75.00	0.000	75.00	0.000	75.00	0.000
17	80.00	3.082	80.00	1.834	80.00	0.000	80.00	0.000	80.00	0.000
18	85.00	3.122	85.00	1.923	85.00	0.000	85.00	0.000	85.00	0.000
19	90.00	3.162	90.00	2.002	90.00	0.024	90.00	0.000	90.00	0.000

Fig.4.17.1, show the ratio between bed height and hole angle depended on minimum flow rate of 300gpm spreadsheet for ANA-6222

3- **Bed height plot analysis for ANA-6974 section:**

For flow rate of 900, 750, 600, 450 and 300gpm there will be no bed height at value of total cutting volume percentage in the wellbore seems to be negligible value, and this vary enough compare with data collected while drilling, if we compare this result with hole cleaning operational analysis we will get the same outcome that means there will be no bed height generate around wellbore while drilling a head this section.

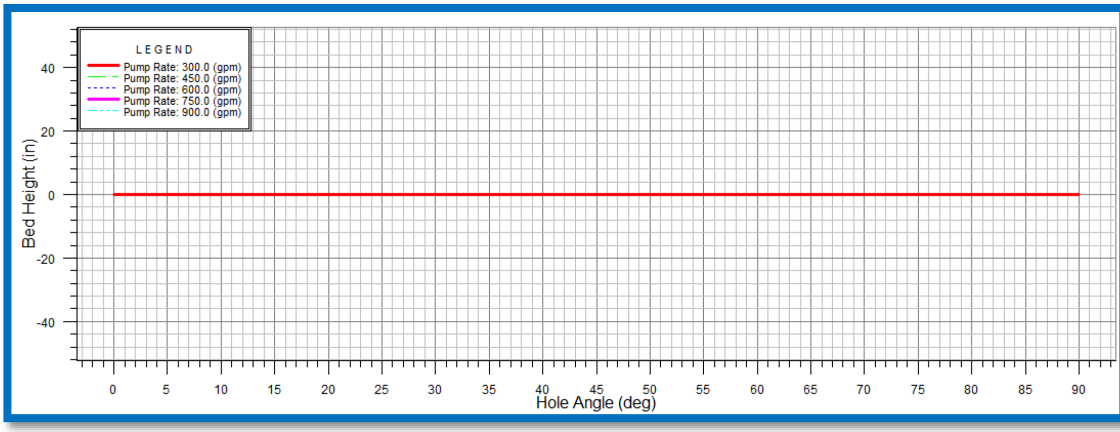

Fig.4.18, show the ratio between bed height and hole angle depended on minimum flow rate of 300gpm for ANA-2952

Hydraulics Cuttings Transport Parametric - Bed Height

	Pump Rate: 300.0 (gpm)		Pump Rate: 450.0 (gpm)		Pump Rate: 600.0 (gpm)		Pump Rate: 750.0 (gpm)		Pump Rate: 900.0 (gpm)	
	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)	Hole Angle(deg)	Bed Height(in)
1	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
2	5.00	0.000	5.00	0.000	5.00	0.000	5.00	0.000	5.00	0.000
3	10.00	0.000	10.00	0.000	10.00	0.000	10.00	0.000	10.00	0.000
4	15.00	0.000	15.00	0.000	15.00	0.000	15.00	0.000	15.00	0.000
5	20.00	0.000	20.00	0.000	20.00	0.000	20.00	0.000	20.00	0.000
6	25.00	0.000	25.00	0.000	25.00	0.000	25.00	0.000	25.00	0.000
7	30.00	0.000	30.00	0.000	30.00	0.000	30.00	0.000	30.00	0.000
8	35.00	0.000	35.00	0.000	35.00	0.000	35.00	0.000	35.00	0.000
9	40.00	0.000	40.00	0.000	40.00	0.000	40.00	0.000	40.00	0.000
10	45.00	0.000	45.00	0.000	45.00	0.000	45.00	0.000	45.00	0.000
11	50.00	0.000	50.00	0.000	50.00	0.000	50.00	0.000	50.00	0.000
12	55.00	0.000	55.00	0.000	55.00	0.000	55.00	0.000	55.00	0.000
13	60.00	0.000	60.00	0.000	60.00	0.000	60.00	0.000	60.00	0.000
14	65.00	0.000	65.00	0.000	65.00	0.000	65.00	0.000	65.00	0.000
15	70.00	0.000	70.00	0.000	70.00	0.000	70.00	0.000	70.00	0.000
16	75.00	0.000	75.00	0.000	75.00	0.000	75.00	0.000	75.00	0.000
17	80.00	0.000	80.00	0.000	80.00	0.000	80.00	0.000	80.00	0.000
18	85.00	0.000	85.00	0.000	85.00	0.000	85.00	0.000	85.00	0.000
19	90.00	0.000	90.00	0.000	90.00	0.000	90.00	0.000	90.00	0.000

Fig.4.18.1, show the ratio between bed height and hole angle depended on minimum flow rate of 300gpm spreadsheet for ANA-2952

4.2.2.2 Minimum Flow Rate Plot (Hole Cleaning Parametric)

Use this plot to determine the minimum (critical) flow rate at which a cuttings bed will begin to form. In order to prevent cuttings from forming a bed height at the low side of the wellbore, so must maintain a flow rate for a particular depth greater than the critical flow rate. The analysis results presented in the previous sections deals with the determination of minimum flow rate to completely clean cuttings out of the hole without bed formation. In this section an attempt is made to study the sensitivity of flow rate on cutting bed deposition when the flow rate is lower than the minimum flow rate. The study will look into the situations at various angles.

1- **Minimum flow rate plot for ANA-2952 section**

The operational parameters used for this simulation were ROP 250ft/hr and rotations speed of 90RPM.The cutting density and cutting size were 2.5sg & 0.125inch respectively. The 10.9ppg density of the mud was used as transport media. Fig.4.19 shows the simulation result. As can be seen on the Fig.4.19, the 300gpm flow rate is the minimum flow rate vs ROP of 250ft/hrthat not capable of completely cleaning the cutting out of the hole throughout the drilling depth. However, when the flow rate reduces from the minimum flow rate, the cutting beds begin forming in highly to lower well inclination, as the reported in (DDR) that the ROP was increased from 101ft/hr to 250 ft/hr, with the same minimum pump output of 300gpm, from the Landmark software determine that no data can be show or display (which means unacceptable well parameter atoll) as the illustrate in the Fig.4.19 below:

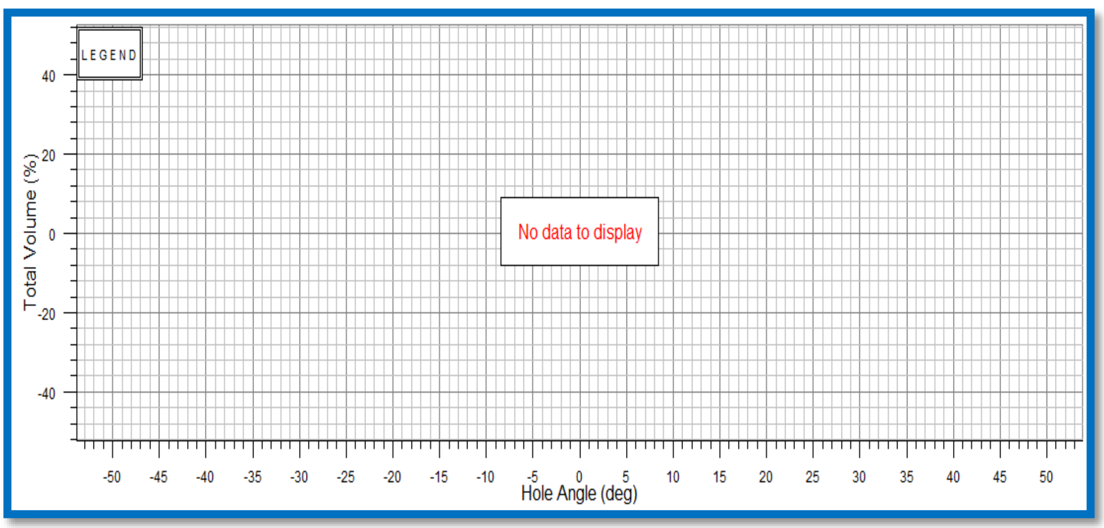

Fig.4.19. Show the output when the Minimum flow rate vs ROP

Note:

From this result as illustrate in Fig.4.19 as output show that, the minimum flow rate of 300 gpm vs ROP of 250 ft/hr it's not acceptable to lifting the cutting which can lead the cutting bed deposition in the wellbore and totally blind the annular space.

2- **Minimum acceptable flow rate according to Landmark software:**

As can be seen on the Fig.4.20, the either to use 600gpm flow rate is the minimum acceptable flow rate against ROP of 250ft/hr or 300gpm flow rate against ROP of 150ft/hr is with the same mud type#1, was consider to be capable of completely cleaning the cutting out of the hole throughout the drilling depth. However, when the flow rate reduces from the minimum flow rate the cutting beds begin forming in highly to lower well inclination.

Hydraulics Cuttings Transport Parametric - Critical Flow Rate

	Min. Flowrate	
	Hole Angle(deg)	Min. Flowrate(gpm)
1	0.00	486.6
2	5.00	527.5
3	10.00	568.3
4	15.00	609.2
5	20.00	650.1
6	25.00	691.0
7	30.00	732.9
8	35.00	794.5
9	40.00	850.2
10	45.00	900.3
11	50.00	945.1
12	55.00	984.5
13	60.00	1018.7
14	65.00	1047.6
15	70.00	1071.3
16	75.00	1089.7
17	80.00	1102.9
18	85.00	1110.9
19	90.00	1113.5

Fig.4.20.1, Show the acceptable minimum flow rate vs ROP of 250 ft/hr spreadsheet

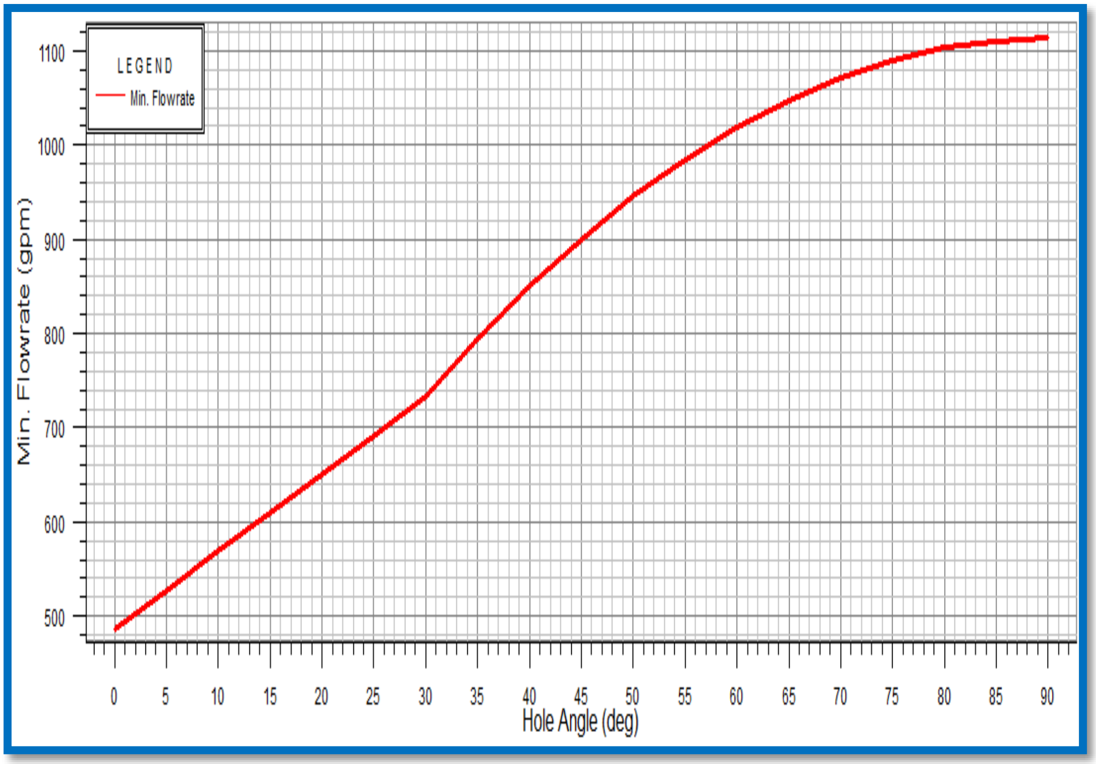

Fig.4.20.2, Show the acceptable minimum flow rate vs ROP of 250 ft/hr

Hydraulics Cuttings Transport Parametric - Critical Flow Rate

	Min. Flowrate	
	Hole Angle(deg)	Min. Flowrate(gpm)
1	0.00	396.6
2	5.00	436.4
3	10.00	476.2
4	15.00	516.0
5	20.00	555.8
6	25.00	595.6
7	30.00	636.3
8	35.00	693.1
9	40.00	744.8
10	45.00	791.4
11	50.00	833.2
12	55.00	870.1
13	60.00	902.2
14	65.00	929.4
15	70.00	951.8
16	75.00	969.2
17	80.00	981.7
18	85.00	989.2
19	90.00	991.7

Figure 4.20.3, Show the acceptable minimum flow rate300gpm vs ROP of 150 ft/hr

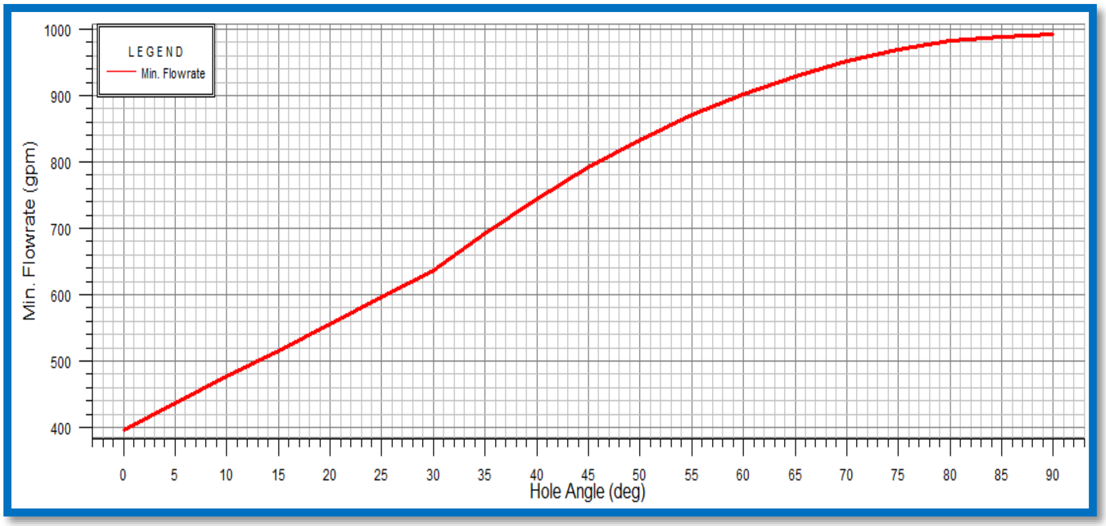

Figure 4.20.4, Show the acceptable minimum flow rate300gpm vs ROP of 150 ft/hr

Note:

The Fig.4.20.2 & Fig.4.20.4 show that either if we increasing the minimum flow rate or reducing the ROP will enhance the ability of cutting transfer to surface with the same mud properties.

3- Minimum flow rate plot for ANA-6222 section

The operational parameters used for this analysis were ROP 65ft/hr and rotations speed of 100RPM.The cutting density and cutting size were 2.5sg & 0.125inch respectively. The 10.9ppg density of the mud was used as transport media. Fig.4.21 shows the analysis result. As can be seen on the Fig4.21, the 300gpm flow rate is the minimum flow rate vs ROP of 65ft/hr that considered to be capable of completely cleaning the cutting out of the hole throughout the drilling a head this section, as the collecting data from the actual drilling operation as reported in (DDR) and the slide sheet of surface company that stat the average ROP was 65ft/min and minimum flow rate is 300gpm, this analysis data can be show as the illustrate in the Fig.4.21 below:

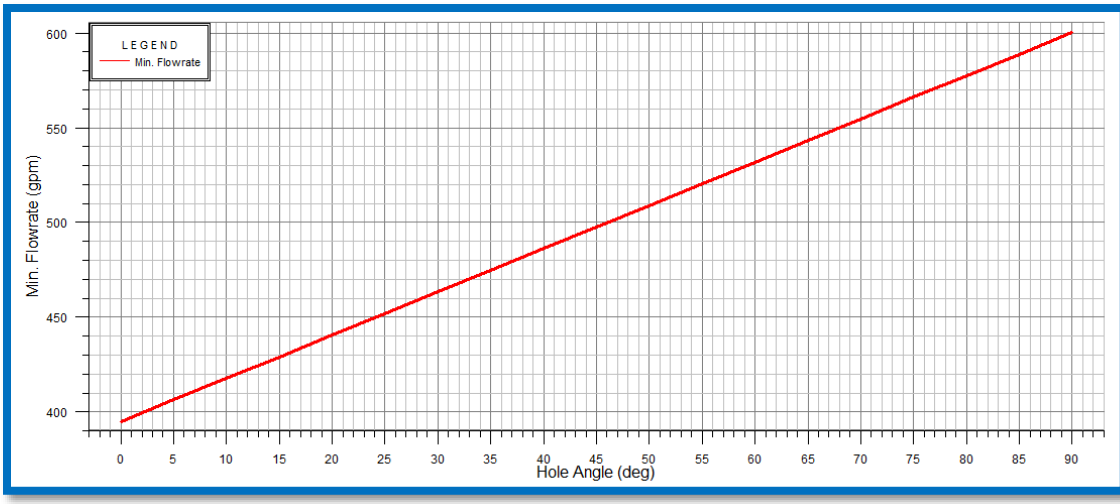

Fig.4.21, Show the output for 300gpm Minimum flow rate vs hole angle for ANA-6222

4- Minimum flow rate plot for ANA-6974 section

The operational parameters used for this simulation were ROP 42ft/hr and rotations speed of 90RPM.The cutting density and cutting diameter were 2.5sg& 0.125inch respectively. The 8.8ppg density of the mud was used as transport media. Fig.4.22 shows the analysis result. As can be seen on the 300gpm flow rate is the minimum flow rate vs ROP of 65ft/hr that considered to be capable of completely cleaning the cutting out of the hole throughout the drilling a head this section, as the collecting data from the actual drilling operation as reported in DDR and the slide sheet of surface company that stat the average ROP was 42ft/min and minimum flow rate is 300gpm, this analysis data can be show as the illustrate in the Fig.4.22 below:

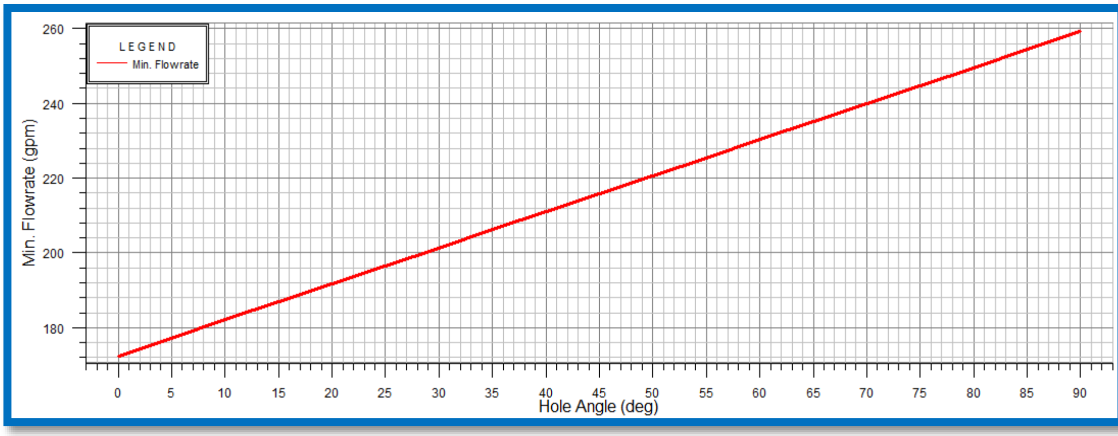

Fig.4.22, Show the output for 300gpm Minimum flow rate vs hole angle for ANA-6974

4.2.2.3 Suspended cuttings volume versus measured depth:

1- ANA-2952 analysis result

Use this plot to determine the percentage of the annular volume filled with cuttings suspended in the drilling fluid. The suspended volume does not include cuttings lying in the hole for a particular depth and forming a bed. The operational parameters used for this simulation were ROP 250ft/hr and rotations speed of 80RPM.The cutting density and cutting size were 2.5sg& 0.125inch respectively. The 10.9ppg density of the mud was used as transport media. Fig.4.23 shows the simulation result. As can be seen on the 300gpm flow rate is the minimum flow rate vs ROP of 250ft/hr that not capable of completely cleaning the cutting out of the hole throughout the drilling depth. However, when the flow rate reduces from the minimum flow rate the suspended volume percentage begin forming in highly to lower well inclination, as reported in (DDR) that the ROP was increased from 101ft/hr to 250 ft/hr, with the same minimum pump output of 300gpm, from the Landmark software determine that no data can be show which means unacceptable well parameters to use as the illustrate in the Fig.4.23.1 below:

Note:

From this result as illustrate in Fig.4.23.1 as output show that, the minimum flow rate of 300 gpmvs 250 ft/hr it's not acceptable to lifting the cutting which can lead to excessive the suspend volume percentage generate in annular of the wellbore.

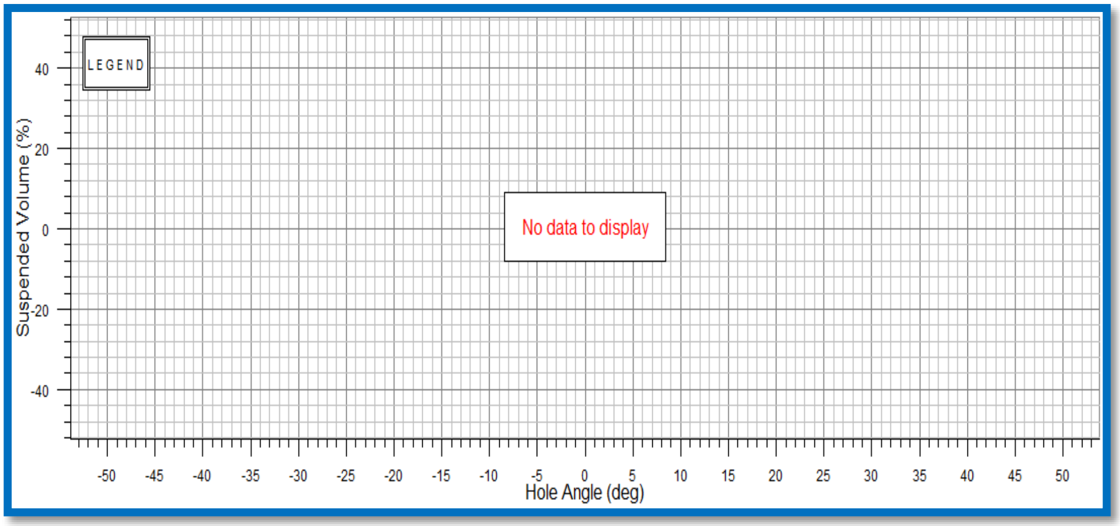

Fig.4.23.1, ANA-2952 the ratio between suspended volume % and hole angle depending on 300gpm Minimum Pump rate

Hydraulics Cuttings Transport Parametric - Suspended Volume

	Pump Rate: 300.0 (gpm)		Pump Rate: 450.0 (gpm)		Pump Rate: 600.0 (gpm)		Pump Rate: 750.0 (gpm)		Pump Rate: 900.0 (gpm)	
	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)
1	0.00	4.88	0.00	3.30	0.00	2.49	0.00	2.00	0.00	1.68
2	5.00	4.88	5.00	3.30	5.00	2.49	5.00	2.00	5.00	1.68
3	10.00	4.88	10.00	3.30	10.00	2.49	10.00	2.00	10.00	1.68
4	15.00	4.88	15.00	3.30	15.00	2.49	15.00	2.00	15.00	1.68
5	20.00	4.88	20.00	3.30	20.00	2.49	20.00	2.00	20.00	1.68
6	25.00	4.88	25.00	3.30	25.00	2.49	25.00	2.00	25.00	1.68
7	30.00	4.88	30.00	3.30	30.00	2.49	30.00	2.00	30.00	1.68
8	35.00	4.88	35.00	3.30	35.00	2.49	35.00	2.00	35.00	1.68
9	40.00	4.88	40.00	3.30	40.00	2.49	40.00	2.00	40.00	1.68
10	45.00	4.88	45.00	3.30	45.00	2.49	45.00	2.00	45.00	1.68
11	50.00	4.88	50.00	3.30	50.00	2.49	50.00	2.00	50.00	1.68
12	55.00	4.88	55.00	3.30	55.00	2.49	55.00	2.00	55.00	1.68
13	60.00	4.87	60.00	3.30	60.00	2.49	60.00	2.00	60.00	1.68
14	65.00	4.87	65.00	3.30	65.00	2.49	65.00	2.00	65.00	1.68
15	70.00	4.87	70.00	3.30	70.00	2.49	70.00	2.00	70.00	1.68
16	75.00	4.87	75.00	3.30	75.00	2.49	75.00	2.00	75.00	1.68
17	80.00	4.87	80.00	3.30	80.00	2.49	80.00	2.00	80.00	1.68
18	85.00	4.87	85.00	3.30	85.00	2.49	85.00	2.00	85.00	1.68
19	90.00	4.87	90.00	3.30	90.00	2.49	90.00	2.00	90.00	1.68

Fig.4.23.2, ANA-2952 the ratio between suspended volume % and hole angle depending on 300gpm Minimum Pump rate spreadsheet

2- Minimum acceptable flow rate according to Landmark software:

As can be seen on the Fig.4.24, either to use 600gpm flow rate is the minimum acceptable flow rate against ROP of 250ft/hr or 300gpm flow rate against ROP of 150ft/hr using the same mud properties is consider as capable of completely cleaning the cutting out of the hole throughout the drilling a head this section. However, when the flow rate reduces from the minimum flow rate the suspended volume will be excusive and will loaded to wellbore causes stack in a short time.

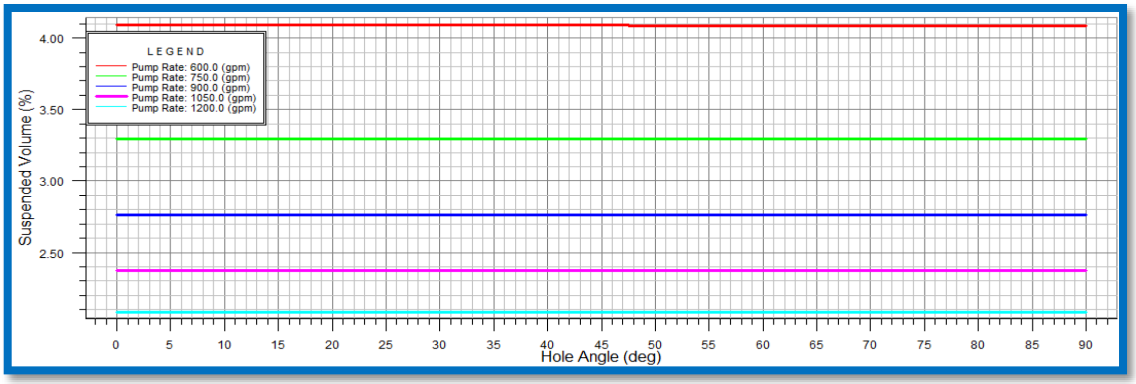

Fig.4.24.1 show the ratio between suspend volume % and hole angle depended on 600gmp flow rate and 250ft/min ROP

Hydraulics Cuttings Transport Parametric - Suspended Volume

	Pump Rate: 600.0 (gpm)		Pump Rate: 750.0 (gpm)		Pump Rate: 900.0 (gpm)		Pump Rate: 1050.0 (gpm)		Pump Rate: 1200.0 (gpm)	
	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)
1	0.00	4.88	0.00	3.30	0.00	2.49	0.00	2.00	0.00	1.68
2	5.00	4.88	5.00	3.30	5.00	2.49	5.00	2.00	5.00	1.68
3	10.00	4.88	10.00	3.30	10.00	2.49	10.00	2.00	10.00	1.68
4	15.00	4.88	15.00	3.30	15.00	2.49	15.00	2.00	15.00	1.68
5	20.00	4.88	20.00	3.30	20.00	2.49	20.00	2.00	20.00	1.68
6	25.00	4.88	25.00	3.30	25.00	2.49	25.00	2.00	25.00	1.68
7	30.00	4.88	30.00	3.30	30.00	2.49	30.00	2.00	30.00	1.68
8	35.00	4.88	35.00	3.30	35.00	2.49	35.00	2.00	35.00	1.68
9	40.00	4.88	40.00	3.30	40.00	2.49	40.00	2.00	40.00	1.68
10	45.00	4.88	45.00	3.30	45.00	2.49	45.00	2.00	45.00	1.68
11	50.00	4.88	50.00	3.30	50.00	2.49	50.00	2.00	50.00	1.68
12	55.00	4.88	55.00	3.30	55.00	2.49	55.00	2.00	55.00	1.68
13	60.00	4.87	60.00	3.30	60.00	2.49	60.00	2.00	60.00	1.68
14	65.00	4.87	65.00	3.30	65.00	2.49	65.00	2.00	65.00	1.68
15	70.00	4.87	70.00	3.30	70.00	2.49	70.00	2.00	70.00	1.68
16	75.00	4.87	75.00	3.30	75.00	2.49	75.00	2.00	75.00	1.68
17	80.00	4.87	80.00	3.30	80.00	2.49	80.00	2.00	80.00	1.68
18	85.00	4.87	85.00	3.30	85.00	2.49	85.00	2.00	85.00	1.68
19	90.00	4.87	90.00	3.30	90.00	2.49	90.00	2.00	90.00	1.68

Fig.4.24.2 show the ratio between suspend volume % and hole angle depended on 600gmp flow rate and 250ft/min ROP spreadsheet

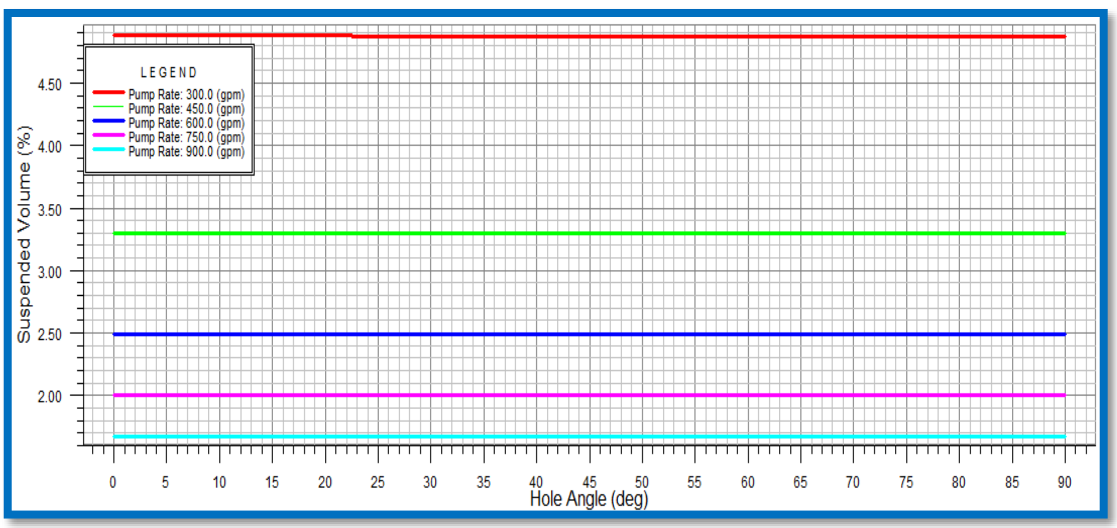

Fig.4.24.3 show the ratio between suspend volume % and hole angle depended on 300gmp flow rate and 150ft/min ROP actual data input

Hydraulics Cuttings Transport Parametric - Suspended Volume

	Pump Rate: 600.0 (gpm)		Pump Rate: 750.0 (gpm)		Pump Rate: 900.0 (gpm)		Pump Rate: 1050.0 (gpm)		Pump Rate: 1200.0 (gpm)	
	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)	Hole Angle(deg)	Suspended Volume(%)
1	0.00	4.88	0.00	3.30	0.00	2.49	0.00	2.00	0.00	1.68
2	5.00	4.88	5.00	3.30	5.00	2.49	5.00	2.00	5.00	1.68
3	10.00	4.88	10.00	3.30	10.00	2.49	10.00	2.00	10.00	1.68
4	15.00	4.88	15.00	3.30	15.00	2.49	15.00	2.00	15.00	1.68
5	20.00	4.88	20.00	3.30	20.00	2.49	20.00	2.00	20.00	1.68
6	25.00	4.88	25.00	3.30	25.00	2.49	25.00	2.00	25.00	1.68
7	30.00	4.88	30.00	3.30	30.00	2.49	30.00	2.00	30.00	1.68
8	35.00	4.88	35.00	3.30	35.00	2.49	35.00	2.00	35.00	1.68
9	40.00	4.88	40.00	3.30	40.00	2.49	40.00	2.00	40.00	1.68
10	45.00	4.88	45.00	3.30	45.00	2.49	45.00	2.00	45.00	1.68
11	50.00	4.88	50.00	3.30	50.00	2.49	50.00	2.00	50.00	1.68
12	55.00	4.88	55.00	3.30	55.00	2.49	55.00	2.00	55.00	1.68
13	60.00	4.87	60.00	3.30	60.00	2.49	60.00	2.00	60.00	1.68
14	65.00	4.87	65.00	3.30	65.00	2.49	65.00	2.00	65.00	1.68
15	70.00	4.87	70.00	3.30	70.00	2.49	70.00	2.00	70.00	1.68
16	75.00	4.87	75.00	3.30	75.00	2.49	75.00	2.00	75.00	1.68
17	80.00	4.87	80.00	3.30	80.00	2.49	80.00	2.00	80.00	1.68
18	85.00	4.87	85.00	3.30	85.00	2.49	85.00	2.00	85.00	1.68
19	90.00	4.87	90.00	3.30	90.00	2.49	90.00	2.00	90.00	1.68

Fig.4.24.4 show the ratio between suspend volume % and hole angle depended on 300gmp flow rate and 150ft/min ROP actual data input

3- Suspended volume plot analysis for ANA-6222 section:

The 10.9ppg density of the mud was used as transport media. Fig.4.25 shows the simulation result that, the 300gpm flow rate is the minimum flow rate vs ROP of 66ft/hr will be capable of completely cleaning the cutting out of the hole throughout the drilling a head this section, as mentioned in report (DDR) that the 66ft/hr ROP 750gpm flow rate, RMP of 100 and the mud as the same properties of mud type one, refer to Fig.4.33 below show that from high flow rate of 900gpm to lower gpm of 300gpm the suspended volume percentage of annular filled with cutting was range from 0.74 to 2.4%, typically for 750gpm the suspended volume of cutting in annular equal to 0.98%, this value consider to be very enough to prevent cutting accumulate behind the BHA while drilling a head this section.

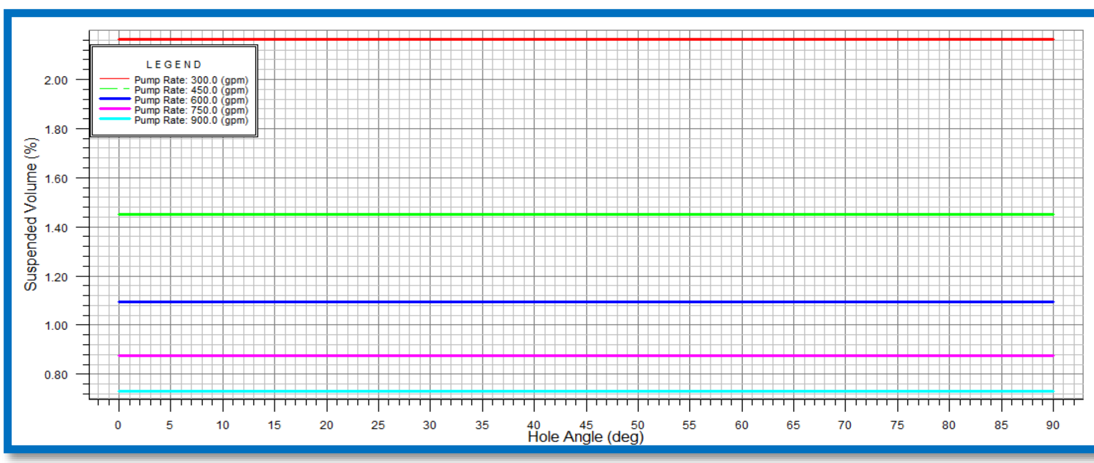

Fig.4.25. show the ratio between suspended volume % vs hole angle depended on 300gpm minimum flow rate and 66ft/hr for ANA-6222

4- Suspended volume plot analysis for ANA-6974 section:

The 8.8ppg density of the mud was used as transport media. Fig.4.26 shows the simulation result that, the 300gpm flow rate is the minimum flow rate vs ROP of 42ft/hr will be capable of completely cleaning the cutting out of the hole throughout the drilling a head this section, so as mentioned in report (DDR) that the 42ft/hr ROP 500gpm flow rate, RMP of 80 and the mud as the same properties of mud type two, refer to Fig.4.26 below show that from maximum flow rate of 900gpm to lower gpm of 300gpm the suspended volume percentage of annular filled with cutting was range from 0.23 to 0.68%, typically for 750gpm the suspended volume of cutting in annular equal to 0.27%, this value consider to be very enough to prevent cutting accumulate behind the BHA while drilling a head this section.

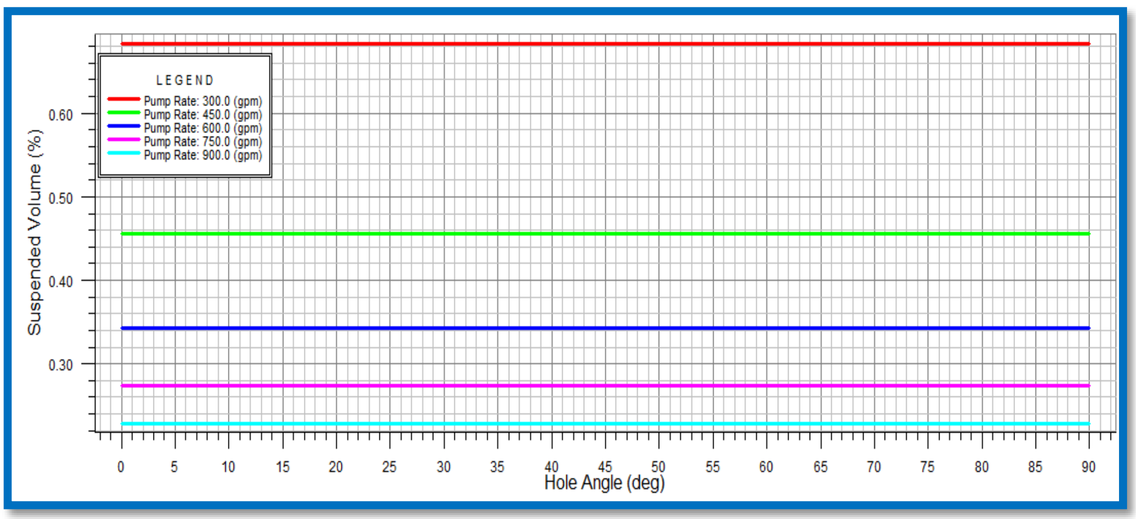

Fig.4.26 show the ratio between suspended volume % vs hole angle depended on 300gpm minimum flow rate and 42ft/hr data input for ANA-6974

Table 4.1 represents the comparison between the outcome of the previous analysis with actual parameters for each individual section:

No	Analysis section	Parameter	Actual	Recommending	Remark
1	ANA-2952	ROP	250ft/min	32-100ft/min	ROP recorded to high
		GPM	850gpm	1000gpm	To low
		RPM	80-100rpm	80-100rpm	Good enough
		MW	10.9	9.2-11	Good enough
		Lubricant	4%	3%	Increased due to HC issue
2	ANA-6222	ROP	65	30-100	Good enough
		GPM	850gpm		Good enough
		RPM	80-100rpm	80-100rpm	Good enough
		MW	10.9	9.2-11	Good enough
		Lubricant	4%	3%	Increased due to HC issue
3	ANA-6974	ROP	42	40-60	Good enough
		GPM	500gpm	400-500gpm	Good enough
		RPM	80rpm	70-80rpm	Good enough
		MW	8.8ppg	8.7-8.8ppg	Good enough
		Lubricant	3%	3%	Good enough

CHAPTER 5:

Conclusions & Recommendations

Conclusions:

- ✓ Good hole-cleaning operation is one of the major factors for the successful drilling operation. On the other hand, poor hole-cleaning causes several drilling related problems such as high torque and drag, drill string sticking and poor hydraulics. As a result, this leads to higher operational costs for the industry.
- ✓ The results show that the impact of poor hole clearing depends on various combinations parameters.
- ✓ Slightly change can make a huge different in hole cleaning phenomena. Because it's complex process.
- ✓ by comparing between three suction (ANA-2695, ANA-6222 and ANA-6974) as we analysis in previous chapter4, the flow require for mud type#1 more than the flow rate in mud type#2 .
- ✓ The analysis and simulation result shows that cutting transport phenomenon is more sensitive to other parameters in deviated well than in vertical well.
- ✓ Instantaneous ROP of the bit found to be very high against recommended ROP compared with the rig pumping capacity.

Problems result from rising ROP from 1ooft/min to 250/min in sand formation

1- Tight hole while tripping due to poor hole cleaning.
2- Hole pack-off while reaming/back reaming.
3- Finally differential stuck occur
4- Down time due to repairing
5- Cost due to delay in operation sequence.

Observations:

1- ROP was higher compared to flow rate.
2- GPM is too low, however the recommended GPM was not suitable for pump capacity.

3- Continue drilling a head without making sure that all bed height which generated from excusive ROP was totally removed from the wellbore
4- No numerical or experimental analysis done to evaluate rising ROP
5- No algorithmic question is done, such as what shall happened if the ROP, raised faster than drilling operation or not? What the consequences?

From the extensive research and reviews done in chapters, 2, 3 and 4, the following conclusions have been drawn:

1- ROP, GPM and MW are the key factors to drill successful horizontal wells.
2- Drill pipe rotation improves hole cleaning by keeping cuttings in suspension. This effects also a function of the hole angle and cuttings properties.
3- Annular cuttings concentration decreases as the flow rate increases, resulting in decrease in bed height as rate increases.
4- Increasing in ROP over design value can cause poor hole cleaning, my lead to totalloss of wellbore path
5- Increasing mud weight reduces the flow rate required

Recommendations:

The following are addressed recommendations for improved hole cleaning process in the future:

1- Monitoring and reporting the cuttings quantity at the surface in short intervals (every 30 or 15 minutes) will provide valuable information about the clean condition of the well and the possibility of taking preventive actions earlier.
2- To maintain a minimum of 900 GPM pumping rate while drilling the 12-1/4in section. (200-300 ft/min annular velocities). Upgrading the current drilling rigs is essential. (Not followed and still pumping capacity is main reason for all hole problems in all drilled wells maximum GPM was reached 850), For recorded this point really as has been obtained from client company.
3- Make extensive research in hole cleaning problem, how to improve and avoid hole cleaning problem? Especially in Sudanese oil field, cost analysis.

Recommended from practices while drilling:

1- For hole angle from (40° - 60°) turbulent flow is recommended.
2- The practice of wiper tripping every 300m drilled or every 24 hrs should be optimized.
3- 5.5 inch Drill pipe should be used instead of 5inch to minimize the open section between hole and the BHA.
4- Try to minimize the length of the 40° - 60°deviation if possible.
5- In case of reaming or back reaming, rig supervisor should make sure that the hole is clean enough before resume drilling.
6- backreaming must be done slowly
7- Maintain smooth well trajectory and avoid any sharp/high Doglegs.
8- Any sign of caving while drilling should be taken seriously and immediately we have to control drilling parameters by lowering ROP and give chance to clean the hole first.
9- Lubrication: advise to start with 1% at kick off point and increase it gradually to 3% at 30 deg and in case of Torque increase it should be increased to 5 %.

References:

- Alfredo Sanchez, R., Azar, J.J., Bassal, A.A., Martins, A.L.(1999). *Effect of Drillpipe Rotation on Hole Cleaning During Direction-Well Drilling - Society of Petroleum Engineers.*
- Alexandre, P.(2008). *Hole Cleaning - Petroleum Specialization Program. TOTAL E&P Angola. Luanda.*
- Adari, R., Miska, S., Kuru, E., Bern, P., Saasen, A. (2000). *Selecting Drilling Fluid Properties and Flow rates For Effective Hole Cleaningin High Angle and Horizontal Wells - Society of Petroleum Engineers Inc.*
- Barker, C. et al.: Petroleum Technology, Volume I-II, (2007), JOHN WILEY & SONS Inc.
- Chukwu, G.A.; and Belavadi, M.N., (2009), Experimental study of the parameters affecting cuttings transportation in a vertical wellbore annulus.
- Tomás, D., (2011). *Drilling Pazflor Oligocene Wells - Petroleum Specialization Program. TOTAL E&P Angola. Luanda.*
- Mims M &Krepp T. (2007). *Drilling Design and Implementation For Extended Reach and Complex Wells – Third Edition, K&M Technologies Group, LLC.USA.*
- HERIOT WATT UNIVERSITY, (2005). *Drilling Engineering, - Heriot Watt University.*
- Hemphill, T.; and Ravi, K. (2006), Pipe rotation and hole cleaning in an eccentric annulus," In proceedings of the IADC/SPE Drilling Conference.
- Halliburton, (1998), Compass . [Computer Program] Landmark Graphics Corporation
- Vinod, S.P. (1994) Effect of fluid rheology on hole cleaning in highly-deviated wells," Ph.D. Dissertation, Rice University.
- Walker, S.; and Li, J.(2000), The effects of particle size, fluid rheology, and pipe eccentricity on cuttings transport," paper SPE presented at the SPE/ICoTA Coiled Tubing Roundtable held in Houston,

Appendix A: Standard Survey

Hole Cleaning

Case Name:	Case1	**Date:** 31/10/2016	**Time:** 12:42:00 **Page:** 1
Description:	Hole Cleaning		
Well Name:	Horizontal	**Project Name:**	Hole Cleaning
Well Description:	Hole Cleaning	**Project Description:**	Anlysis

GENERAL INFORMATION

PUMP RATE	400.0	gpm
CUTTINGS DIAMETER	0.125	in
CUTTINGS DENISITY	2.600	sg
BED POROSITY	36.00	%
ROP	42.0	ft/hr
WELL MD	8019.6	ft
SURFACE RPM	80	rpm

MUD PROPERTIES: Bingham Plastic

MUD WEIGHT	8.80	ppg
MUD YIELD POINT	58.5	lbf/100ft2
MUD PLASTIC VISCOSITY	12.0	cp
MUD POWER INDEX (n)	0.000	
MUD CONSISTENCY INDEX (k)	0.000	lbf·sec^n/ft

BOOSTER PUMPS (not in operation)

INJECTION DEPTH (MD)	0.0	ft	INJECTION TEMPERATURE	0.0	deg F	INJECTION RATE	0.0	gpm

BACK REAMING

MAX. BACK REAMING RATE	0.0	ft/hr

CUTTINGS

SETTLING VELOCITY	0.0	ft/min

MINIMUM FLOW RATE

MINIMUM FLOW RATE FOR CUTTINGS TRANSPORT IS	749.4	gpm	AT	0.0	ft

DRILLSTRING

TYPE	LENGTH COMPONENT ft	LENGTH TOTAL ft	BODY OD in	BODY ID in	STABILIZER / TOOL JOINT LENGTH ft	STABILIZER / TOOL JOINT OD in	STABILIZER / TOOL JOINT ID in	FISHNECK ft	WEIGHT ppf	MTL GRADE	CLASS*
DP	7137.04	7137.04	5.000	4.276		5.844	3.250		22.08	CS_API 5D/7 X	P
HW	650.36	7787.40	5.000	3.000		6.500	3.063		49.70	CS_1340 MOD 1340 MOD	
JAR	33.00	7820.40	6.250	2.250					90.98	CS_API 5D/7 4145H MOD (1)	
HW	60.20	7880.60	5.000	3.000		6.500	3.063		49.70	CS_1340 MOD 1340 MOD	
DC	43.43	7924.03	6.500	2.813					90.83	SS_15-15LC 15-15LC MOD (1)	
IBS	5.00	7929.03	6.000	2.500	1.00	8.450		3.00	79.52	CS_API 5D/7 4145H MOD (1)	
DC	29.52	7958.55	6.500	2.813					90.83	SS_15-15LC 15-15LC MOD (1)	
MWD	30.00	7988.55	8.000	2.813					149.92	SS_15-15LC 15-15LC MOD (1)	
BHM	30.00	8018.55	8.000	2.813					149.92	CS_API 5D/7 4145H MOD (1)	1
BIT	1.05	8019.60	8.500						5.00		

COUPLING

TYPE	LENGTH COMPONENT ft	LENGTH TOTAL ft	BODY OD in	BODY ID in	AVG. JOINT LEN. ft	COUPLINGS OUTSIDE LENGTH ft	COUPLINGS ID in
DP	7137.04	7137.04	5.000	4.276			
HW	650.36	7787.40	5.000	3.000			
JAR	33.00	7820.40	6.250	2.250			
HW	60.20	7880.60	5.000	3.000			
DC	43.43	7924.03	6.500	2.813			
IBS	5.00	7929.03	6.000	2.500			
DC	29.52	7958.55	6.500	2.813			
MWD	30.00	7988.55	8.000	2.813			
BHM	30.00	8018.55	8.000	2.813			
BIT	1.05	8019.60	8.500				

WELLBORE

TYPE	SECTION DEPTH ft	SECTION LENGTH ft	EFFECTIVE INSIDE DIAMETER in	COEFFICIENT OF FRICTION	VOLUME EXCESS %
CAS	98.4	98.40	19.000	0.00	
CAS	2804.4	2706.00	12.415	0.00	
CAS	6953.6	4149.20	8.835	0.00	
OH	8019.6	1066.00	8.835	0.00	0.00

Survey **Tortuosity: None** **Calculation Method: Minimum Curvature**

Md ft	Incl deg	Direc deg	Tvd ft	Build deg/100ft	Walk deg/100ft	Dls deg/100ft
0.0	0.00	72.98	0.0	0.00	0.00	0.00
98.4	0.00	72.98	98.4	0.00	0.00	0.00
196.8	0.00	72.98	196.8	0.00	0.00	0.00
295.2	0.00	72.98	295.2	0.00	0.00	0.00
393.6	0.00	72.98	393.6	0.00	0.00	0.00

Hole Cleaning

Case Name:	Case1		**Date:** 31/10/2016	**Time:** 13:42:00	**Page:**	2
Description:	Hole Cleaning					
Well Name:	Horizontal		**Project Name:**	Hole Cleaning		
Well Description:	Hole Cleaning		**Project Description:**	Anlysis		

Survey **Tortuosity: None** **Calculation Method: Minimum Curvature**

Md ft	Incl deg	Direc deg	Tvd ft	Build deg/100ft	Walk deg/100ft	Dls deg/100ft
492.0	0.00	72.98	492.0	0.00	0.00	0.00
590.4	0.00	72.98	590.4	0.00	0.00	0.00
688.8	0.00	72.98	688.8	0.00	0.00	0.00
787.2	0.00	72.98	787.2	0.00	0.00	0.00
885.6	0.00	72.98	885.6	0.00	0.00	0.00
984.0	0.00	72.98	984.0	0.00	0.00	0.00
1082.4	0.00	72.98	1082.4	0.00	0.00	0.00
1180.8	0.00	72.98	1180.8	0.00	0.00	0.00
1279.2	0.00	72.98	1279.2	0.00	0.00	0.00
1377.6	0.00	72.98	1377.6	0.00	0.00	0.00
1476.0	0.00	72.98	1476.0	0.00	0.00	0.00
1574.4	0.00	72.98	1574.4	0.00	0.00	0.00
1672.8	0.00	72.98	1672.8	0.00	0.00	0.00
1771.2	0.00	72.98	1771.2	0.00	0.00	0.00
1869.6	0.00	72.98	1869.6	0.00	0.00	0.00
1968.0	0.00	72.98	1968.0	0.00	0.00	0.00
2066.4	0.00	72.98	2066.4	0.00	0.00	0.00
2164.8	0.00	72.98	2164.8	0.00	0.00	0.00
2263.2	0.00	72.98	2263.2	0.00	0.00	0.00
2361.6	0.00	72.98	2361.6	0.00	0.00	0.00
2460.0	0.00	72.98	2460.0	0.00	0.00	0.00
2558.4	0.00	72.98	2558.4	0.00	0.00	0.00
2656.8	0.00	72.98	2656.8	0.00	0.00	0.00
2755.2	0.00	72.98	2755.2	0.00	0.00	0.00
2853.6	0.00	72.98	2853.6	0.00	0.00	0.00
2952.0	0.00	72.98	2952.0	0.00	0.00	0.00
3050.4	2.40	72.98	3050.4	2.44	0.00	2.44
3148.8	4.80	72.98	3148.6	2.44	0.00	2.44
3247.2	7.20	72.98	3246.4	2.44	0.00	2.44
3345.6	9.60	72.98	3343.8	2.44	0.00	2.44
3444.0	12.00	72.98	3440.4	2.44	0.00	2.44
3542.4	14.40	72.98	3536.2	2.44	0.00	2.44
3640.8	16.80	72.98	3631.0	2.44	0.00	2.44
3739.2	19.20	72.98	3724.5	2.44	0.00	2.44
3837.6	21.60	72.98	3816.8	2.44	0.00	2.44
3936.0	24.00	72.98	3907.5	2.44	0.00	2.44
4034.4	26.40	72.98	3996.5	2.44	0.00	2.44
4132.8	28.80	72.98	4083.7	2.44	0.00	2.44
4231.2	31.20	72.98	4168.9	2.44	0.00	2.44
4329.6	33.60	72.98	4252.0	2.44	0.00	2.44
4428.0	36.00	72.98	4332.8	2.44	0.00	2.44
4526.4	38.40	72.98	4411.2	2.44	0.00	2.44
4624.8	40.80	72.98	4487.0	2.44	0.00	2.44
4723.8	43.20	72.98	4560.5	2.42	0.00	2.42
4821.6	45.60	72.98	4630.4	2.45	0.00	2.45
4920.0	48.00	72.98	4697.8	2.44	0.00	2.44
5018.4	50.40	72.98	4762.1	2.44	0.00	2.44
5116.8	52.80	72.98	4823.2	2.44	0.00	2.44
5215.2	55.20	72.98	4881.0	2.44	0.00	2.44
5313.6	57.60	72.98	4935.5	2.44	0.00	2.44
5412.0	60.00	72.98	4986.4	2.44	0.00	2.44
5510.4	62.40	72.98	5033.8	2.44	0.00	2.44
5608.8	64.80	72.98	5077.6	2.44	0.00	2.44
5707.2	67.20	72.98	5117.6	2.44	0.00	2.44
5805.6	69.60	72.98	5153.8	2.44	0.00	2.44
5890.4	71.67	72.98	5181.9	2.44	0.00	2.44
5904.0	71.67	72.98	5186.2	0.00	0.00	0.00
6002.4	71.67	72.98	5217.2	0.00	0.00	0.00
6100.8	71.67	72.98	5248.1	0.00	0.00	0.00
6199.2	71.67	72.98	5279.0	0.00	0.00	0.00
6221.9	71.67	72.98	5286.2	0.00	0.00	0.00
6297.6	73.51	72.93	5308.8	2.43	-0.07	2.43
6396.0	75.91	72.86	5334.8	2.44	-0.07	2.44
6494.4	78.31	72.80	5356.7	2.44	-0.06	2.44
6592.8	80.71	72.74	5374.6	2.44	-0.06	2.44
6691.2	83.11	72.67	5388.5	2.44	-0.07	2.44
6789.6	85.51	72.61	5398.2	2.44	-0.06	2.44
6888.0	87.91	72.55	5403.9	2.44	-0.06	2.44
6973.8	90.00	72.50	5405.5	2.44	-0.06	2.44
6986.4	90.00	72.50	5405.5	0.00	0.00	0.00
7084.8	90.00	72.46	5405.5	0.00	-0.04	0.04

Hole Cleaning

Case Name:	Case1		**Date:**	21/10/2016	**Time:**	13:42:00	**Page:** 3
Description:	Hole Cleaning						
Well Name:	Horizontal		**Project Name:**	Hole Cleaning			
Well Description:	Hole Cleaning		**Project Description:**	Anlysis			

Survey **Tortuosity: None** **Calculation Method: Minimum Curvature**

Md ft	Incl deg	Direc deg	Tvd ft	Build deg/100ft	Walk deg/100ft	Dls deg/100ft
7183.2	90.00	72.42	5405.5	0.00	-0.04	0.04
7281.6	90.00	72.38	5405.5	0.00	-0.04	0.04
7380.0	90.00	72.35	5405.5	0.00	-0.03	0.03
7478.4	90.00	72.31	5405.5	0.00	-0.04	0.04
7576.8	90.00	72.27	5405.5	0.00	-0.04	0.04
7675.2	90.00	72.24	5405.5	0.00	-0.03	0.03
7773.6	90.00	72.20	5405.5	0.00	-0.04	0.04
7872.0	90.00	72.16	5405.5	0.00	-0.04	0.04
7970.4	90.00	72.13	5405.5	0.00	-0.03	0.03
8019.9	90.00	72.11	5405.5	0.00	-0.04	0.04

CUTTINGS TRANSPORT TABLE

MEASURED DEPTH ft	INC deg	ANN OD in	PIPE OD in	JOINT OD in	MINIMUM FLOW RATE gpm	CUTTINGS TOTAL %	CUTTINGS SUSPENDED %	BED HEIGHT in	EQUIVALENT MUD WEIGHT ppg
0.0	0.0	19.000	5.000	5.844	749.4	4.25	0.51	1.890	8.86
100.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
200.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
300.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
400.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
500.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
600.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
700.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
800.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
900.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1000.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1100.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1200.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1300.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1400.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1500.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1600.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1700.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1800.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
1900.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2000.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2100.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2200.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2300.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2400.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2500.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2600.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2700.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2800.0	0.0	12.415	5.000	5.844	403.0	0.70	0.51	0.121	8.86
2900.0	0.0	8.835	5.000	5.844	191.2	0.51	0.51	0.000	8.86
3000.0	1.2	8.835	5.000	5.844	192.5	0.51	0.51	0.000	8.86
3100.0	3.6	8.835	5.000	5.844	195.1	0.51	0.51	0.000	8.86
3200.0	6.0	8.835	5.000	5.844	197.7	0.51	0.51	0.000	8.86
3300.0	8.5	8.835	5.000	5.844	200.3	0.51	0.51	0.000	8.86
3400.0	10.9	8.835	5.000	5.844	202.9	0.51	0.51	0.000	8.86
3500.0	13.4	8.835	5.000	5.844	205.5	0.51	0.51	0.000	8.86
3600.0	15.8	8.835	5.000	5.844	208.1	0.51	0.51	0.000	8.86
3700.0	18.2	8.835	5.000	5.844	210.7	0.51	0.51	0.000	8.86
3800.0	20.7	8.835	5.000	5.844	213.4	0.51	0.51	0.000	8.86
3900.0	23.1	8.835	5.000	5.844	216.0	0.51	0.51	0.000	8.86
4000.0	25.6	8.835	5.000	5.844	218.6	0.51	0.51	0.000	8.86
4100.0	28.0	8.835	5.000	5.844	221.2	0.51	0.51	0.000	8.86
4200.0	30.4	8.835	5.000	5.844	224.3	0.51	0.51	0.000	8.86
4300.0	32.9	8.835	5.000	5.844	226.4	0.51	0.51	0.000	8.86
4400.0	35.3	8.835	5.000	5.844	229.0	0.51	0.51	0.000	8.86
4500.0	37.8	8.835	5.000	5.844	231.6	0.51	0.51	0.000	8.86
4600.0	40.2	8.835	5.000	5.844	234.2	0.51	0.51	0.000	8.86
4700.0	42.6	8.835	5.000	5.844	236.8	0.51	0.51	0.000	8.86
4800.0	45.1	8.835	5.000	5.844	239.4	0.51	0.51	0.000	8.86
4900.0	47.5	8.835	5.000	5.844	242.0	0.51	0.51	0.000	8.86
5000.0	50.0	8.835	5.000	5.844	244.8	0.51	0.51	0.000	8.86
5100.0	52.4	8.835	5.000	5.844	247.2	0.51	0.51	0.000	8.86
5200.0	54.8	8.835	5.000	5.844	249.9	0.51	0.51	0.000	8.86
5300.0	57.3	8.835	5.000	5.844	252.5	0.51	0.51	0.000	8.86
5400.0	59.7	8.835	5.000	5.844	255.1	0.51	0.51	0.000	8.86

Hole Cleaning

Case Name:	Case1			**Date:** 31/10/2016	**Time:** 13:42:00	**Page:**	4
Description:	Hole Cleaning						
Well Name:	Horizontal			**Project Name:**	Hole Cleaning		
Well Description:	Hole Cleaning			**Project Description:**	Anlysis		

CUTTINGS TRANSPORT TABLE

MEASURED DEPTH ft	INC deg	ANN OD in	PIPE OD in	JOINT OD in	MINIMUM FLOW RATE gpm	CUTTINGS TOTAL %	CUTTINGS SUSPENDED %	BED HEIGHT in	EQUIVALENT MUD WEIGHT ppg
5500.0	62.1	8.835	5.000	5.844	257.7	0.51	0.51	0.000	8.86
5600.0	64.6	8.835	5.000	5.844	260.3	0.51	0.51	0.000	8.86
5700.0	67.0	8.835	5.000	5.844	262.9	0.51	0.51	0.000	8.86
5800.0	69.5	8.835	5.000	5.844	265.5	0.51	0.51	0.000	8.86
5900.0	71.7	8.835	5.000	5.844	267.9	0.51	0.51	0.000	8.86
6000.0	71.7	8.835	5.000	5.844	267.9	0.51	0.51	0.000	8.86
6100.0	71.7	8.835	5.000	5.844	267.9	0.51	0.51	0.000	8.86
6200.0	71.7	8.835	5.000	5.844	267.9	0.51	0.51	0.000	8.86
6300.0	73.6	8.835	5.000	5.844	269.9	0.51	0.51	0.000	8.86
6400.0	76.0	8.835	5.000	5.844	272.5	0.51	0.51	0.000	8.86
6500.0	78.4	8.835	5.000	5.844	275.1	0.51	0.51	0.000	8.86
6600.0	80.9	8.835	5.000	5.844	277.7	0.51	0.51	0.000	8.86
6700.0	83.3	8.835	5.000	5.844	280.3	0.51	0.51	0.000	8.86
6800.0	85.8	8.835	5.000	5.844	282.9	0.51	0.51	0.000	8.86
6900.0	88.2	8.835	5.000	5.844	285.5	0.51	0.51	0.000	8.86
7000.0	90.0	8.835	5.000	5.844	287.4	0.51	0.51	0.000	8.86
7100.0	90.0	8.835	5.000	5.844	287.4	0.51	0.51	0.000	8.86
7200.0	90.0	8.835	5.000	6.500	287.4	0.51	0.51	0.000	8.86
7300.0	90.0	8.835	5.000	6.500	287.4	0.51	0.51	0.000	8.86
7400.0	90.0	8.835	5.000	6.500	287.4	0.51	0.51	0.000	8.86
7500.0	90.0	8.835	5.000	6.500	287.4	0.51	0.51	0.000	8.86
7600.0	90.0	8.835	5.000	6.500	287.4	0.51	0.51	0.000	8.86
7700.0	90.0	8.835	5.000	6.500	287.4	0.51	0.51	0.000	8.86
7800.0	90.0	8.835	6.250	0.000	256.5	0.51	0.51	0.000	8.86
7900.0	90.0	8.835	6.500	0.000	252.5	0.51	0.51	0.000	8.86
8000.0	90.0	8.835	8.000	0.000	231.1	0.51	0.51	0.000	8.86
8019.6	90.0	8.835	8.000	0.000	231.1	0.51	0.51	0.000	8.86

MINIMUM FLOW RATE vs. ROP

ROP ft/hr	5.000" DP in 19.000" CAS gpm	5.000" DP in 12.415" CAS gpm	5.000" DP in 8.835" CAS gpm
0.0	749.4	403.0	287.4
10.0	749.4	403.0	287.4
20.0	749.4	403.0	287.4
30.0	749.4	403.0	287.4
40.0	749.4	403.0	287.4
50.0	749.4	403.0	287.4
60.0	749.4	403.0	291.3
70.0	749.4	403.0	298.6
80.0	749.4	403.0	305.6
90.0	749.4	403.0	312.2
100.0	749.4	403.0	318.7
110.0	749.4	403.0	324.9
120.0	749.4	403.0	331.0
130.0	749.4	403.0	336.8
140.0	749.4	403.0	342.5
150.0	749.4	403.0	348.1
160.0	749.4	403.0	353.5
170.0	749.4	403.0	358.8
180.0	749.4	403.0	363.9
190.0	749.4	403.0	369.0
200.0	749.4	403.0	373.9
210.0	749.4	403.0	378.7
220.0	749.4	403.0	383.5
230.0	749.4	403.0	388.1
240.0	749.4	403.0	392.7
250.0	749.4	403.0	397.1
260.0	749.4	403.0	401.5
270.0	749.4	403.0	405.9
280.0	749.4	403.0	410.1
290.0	749.4	403.0	414.3
300.0	749.4	403.0	418.5
310.0	749.4	403.0	422.5
320.0	749.4	403.0	426.5
330.0	749.4	403.0	430.5
340.0	749.4	403.0	434.4

Appendix B: Hole Cleaning Calculations

Hole Cleaning Calculations

Calculate n, K, τ_y, and Reynold's Number

$$n = \frac{(3.32)(\log 10)(YP + 2PV)}{(YP + PV)}$$

$$K = \frac{(PV + YP)}{511}$$

$$\tau_y = (5.11K)^n$$

$$R_A = \frac{\rho V_a^{(2-n)}(D_H - D_P)^n}{(2/3)G_{fa}K}$$

Concentration Based on ROP in Flow Channel

$$C_o = \frac{(V_r D_B^2/1471)}{(V_r D_B^2/1471) + Q_m}$$

Fluid Velocity Based on Open Flow Channel

$$V_a = \frac{24.5Q_m}{D_H^2 - D_P^2}$$

Coefficient of Drag around Sphere

If $R_e < 225$ then,

$$C_D = \frac{22}{\sqrt{R_a}}$$

else,

$$C_D = 1.5$$

Mud carrying capacity

$$C_M = \frac{4g\left(\frac{D_c}{12}\right)(\rho_c - \rho)}{3\rho C_D}$$

Settling Velocity in the Plug in a Mud with a Yield Stress

$$U_{sp} = \left[\frac{4}{3}\frac{gD_c^{1+bn}(\rho_c - \rho}{aK_b\rho_c^{1-b}}\right]^{\frac{1}{2-b(2-n)}}$$

Where:

$$a = 42.9 - 23.9n$$

$$b = 1 - 0.33n$$

Angle of Inclination Correction Factor

$$C_a = (\sin(1.33\alpha))^{1.33}\left(\frac{5}{D_H}\right)^{0.66}$$

Cuttings Size Correction Factor

$$C_s = 1.286 - 1.04D_c$$

Mud Weight Correction Factor

If $(\rho < 7.7)$ then

$$C_m = 1.0$$

else

$$C_m = 1.0 - 0.0333(\rho - 7.7)$$

Critical Wall Shear Stress

$$\tau wc = [ag\sin(\propto)(\rho_c - \rho)D_c^{1+b}\rho^{b/2}]\frac{2n}{2n - 2b + bn}$$

Where:

$a = 1.732$

$b = -0.744$

Critical Pressure Gradient

$$Pgc = \frac{2\tau wc}{r_h[1-(\frac{rp}{r_h})^2]}$$

Total Cross Sectional Area of the Annulus without Cuttings Bed

$$A_A = \frac{\pi}{4}\frac{\left(D_H{}^2 - D_P{}^2\right)}{144}$$

Dimensionless Flow Rate

$$\Pi g_c = \Pi[8 \times \frac{\frac{n}{2(1+2n)}}{(a)\frac{1}{b}}]^{\frac{1}{2-(2-n)b}} \times (1-(\frac{r_p}{r_h})^2)(1-(\frac{r_p}{r_h})^{\frac{b}{2-(2-n)b}}]$$

Where:

$a = 16$

$b = 1$

Critical Flow Rate (CFR)

$$Q_{crit} = r_h{}^2[\frac{\rho gc^{1/c} r_h{}^{(\frac{1}{c+n})}}{K\rho^{(\frac{1}{c-1})}}]^{\frac{c}{2-c(2-n)}} \Pi_{gc}$$

Correction Factor for Cuttings Concentration

$$C_{BED} = 0.97 - \left(0.00231\mu_a\right)$$

Cuttings Concentration for a Stationary Bed by Volume

$$C_{bonc} = C_{BED}\left(1.0 - \frac{Q_m}{Q_{crit}}\right)(1.0 - \phi_B)(100)$$

Where:

D_B = Bit diameter

D_H = Annulus diameter

D_P = Pipe diameter

D_{TJ} = Tool joint diameter

D_C = Cuttings diameter

τ_y = Mud yield stress

G_{fa} = Power law geometry factor

R_A = Reynolds number

ρ = Fluid density

ρ_c = Cuttings density

V_a = Average fluid velocity for annulus

V_R = Rate of penetration, ROP

V_{CTV} = Cuttings travel velocity

V_{so} = Original slip velocity

$_{SV}$ elocity

V_{CTFV} = Critical transport fluid velocity

V_{TC} = Total cuttings velocity

K = Consistency factor

n = Flow behavior index

a, b, c = Coefficients

YP = Yield point

PV = Plastic viscosity

Q_C = Volumetric cuttings flow rate

Q_m = Volumetric mud flow rate

Q_{crit} = Critical flow rate for bed to develop

C_o = Cuttings feed concentration

C_D = Drag coefficient

C_m = Mud carrying capacity

C_A = Angle of inclination correction factor

C_S = Cuttings size correction factor

C_{mud} = Mud weight correction factor

C_{BED} = Correction factor for cuttings concentration

C_{bonc} = Cuttings concentration for a stationary bed by volume

U_{sp} = Settling velocity

U_s = Average settling velocity in axial direction

U_{mix} = Average mixture velocity in the area open to flow

α = Wellbore angle

ϕ_B = Bed porosity

μ_a = Apparent viscosity

λ_p = Plug diameter ratio

g = Gravitational coefficient

r_0 = Radius of which shear stress is zero

r_p = Radius of drill pipe

r_h = Radius of wellbore or casing

P_{gc} = Critical frictional pressure gradient

τ_{wc} = Critical wall shear stress