Directionall well design using Paradigm Sysdrill simulator

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Master's Thesis

DIRECTIONAL WELL DESIGN USING PARADIGM SYSDRILL SIMULATOR

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Abstract

The aim of this thesis was to present a general overview of Paradigm Sysdrill 10 well planning software, with a comparison of torque and drag results calculated by the Sysdrill 10 Torque and Drag module for different BHA at the same depth. The data regarding a geothermal well drilling were given by the drilling company Cougar that operates in Turkey. Geothermal well drilling was presented in the thesis to show the complexity of such operations, particularly in directional drilling, and the benefits that such software has on it, in terms of planning and monitoring directional wells.

Keywords: Sydrill 10, geothermal well, directional drilling, torque, drag.

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PROJEKTIRANJE USMJERENE BUŠOTINE KORIŠTENJEM PARADIGM SYSDRILL SIMULATORA

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Diplomski rad izrađen: Sveučilište u Zagrebu

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Sažetak

Cilj ovog rada bio je prikazati opće značajke Paradigm Sysdrill 10 sustava za projektiranje bušotina, uz konkretnu usporedbu vrijednosti torzije i natega za različite BHA na istoj dubini duž kanala bušotine. Podaci vezani za geotermalnu bušotinu dobiveni su na korištenje od strane kompanije za usmjereno bušenje Cougar, čije se djelatnosti odvijaju u Turskoj. Objašnjena je izrada geotermalnih bušotina u cilju prikaza složenosti tih postupaka, s naglaskom na usmjereno bušenje i kako sustav poput Sysdrill 10 može pomoći u projektiranju i praćenju usmjerenih bušotina.

Ključne riječi: Sysdrill 10, geotermalna bušotina, usmjereno bušenje, torzija, nateg.

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Content

LIST OF ABREVATIONS

API - American Petroleum Institute

BHA - Bottom Hole Assembly

BHHP - Bit Hydraulic Horse Power

CMC - Carboxymethyl Cellulose

DEG - Degree

DLS - Dog Leg Severity

ECD - Equivalent Circulating Density

ESD - Equivalent Static density

HPHT - High Pressure High Temperature

HWDP - Heavy Weight Drill Pipe

ID - Inside Diameter

INC - Inclination

JIF - Jet Impact Force

KOP - Kick Off Point

LCM - Lost Circulation Materials

LWD - Logging While Drilling

MD - Measured Depth

MMS - Magnetic Multy Shot

MSS - Magnetic Single Shot

MWD - Measuring While Drilling

OD - Outside Diameter

PDM - Positive displacement motor

TVD - True Vertical Depth

TFA - Total Flow Area

WOB - Weight on Bit

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1. INTRODUCTION

Sysdrill 10 was developed by the company Paradigm, and it is one of the industry most advanced software for directional drilling, well planning and survey management system. It is used both by operating and drilling service companies, to plan, drill and monitor directional wells.

In geothermal drilling, the high temperature and hardness of the rock cause some major drilling problems such as: abrasion of the down hole components (mostly bit and drill collars), reduction of the steel strength, uses of special down hole motors.

Geothermal wells directional drilling is a complex technology and there is a number of ways to drill a deviate hole, the most usual is to use a down hole motor to drive the bit without rotating the drill string, hydraulically powered by drilling fluid flowing throw it.

Directional drilling in geothermal wells is more difficult because both the electronic tool used to control and survey the well trajectory and elastomer elements in the motor are affected by high temperatures. Progress has been made in this area, but it is still a technical challenge.

High values of drill string torque and drag is a common problem in directional drilling while increasing the inclination of the well. That is why a good modeling program, such as Sysdrill 10 Torque and Drag can be a reliable tool to effectively calculate values for torque and drag analyses. During the planning phase of a well the models are used to optimize the trajectory design, to minimize torque and drag and contact forces between the drill string and borehole.

The models are also used to monitor the hole conditions while drilling, detecting potential hole cleaning problems, watching out for differential sticking materials, monitoring for high torque in planned highly tortuous trajectories.

Accurate torque and drag modeling gives the opportunity to build reliable well trajectories, wıth consideration of the rig capabilities and geological complexity of the structures where the drilling will be achieved.

In this case torque and drag analysis were made using an actual geothermal directional drilling data, which was given by the drilling company Cougar that operates in Turkey.

2 DIRECTIONAL DRILLING

Controlled directional drilling is the process of deviating a wellbore along a predetermined course to a target whose location is given as a lateral distance from the vertical (Adams 1985).

The need for directional drilling is dictated by geological targets, in order to intersect as many fractures as possible or lease boundaries, which are included in the well design. Quite often a target zone lies beneath a surface location that is impractical as a rig site. Common examples include: mountains, riverbeds, residential locations, roads, etc…

Rotary systems

In directional drilling the bit is turned with the rotary system or a down hole motor device, the conventional rotary system has the bit connected directly to the drill string, and is rotated from the surface. Down hole motors/turbines are receiving a significant amount of use because they can be used in connection with bents subs and steering tools. Motors and turbines are provided in a wide range of sizes, torque characteristics and operating speeds (Adams, 1985).

MWD (Measurement While Drilling) is also a common method of measuring parameters down hole and sending results to the surface without interrupting routine drilling operations. A special tool containing sensors, transmitters and power supply is installed as a part of the BHA. The information is transmitted to the surface by a telemetry system using mud pulses.

High - temperature turbines have been demonstrated, and service companies have recently begun to offer positive displacement motors (PDM). This technology is relatively new, but could be a significant asset for geothermal drilling.

Neither PDM or MWD operate reliably at high temperatures, so corrections are mostly done at depths are still cooler than 175°C (Blankenship and Finger, 2010).

Drilling parameters

There are three drilling parameters which guarantee, in the right combination, an optimum rate of penetration. One of the most important parameter is the flow rate of the drilling mud, which serves as a transportation mean for cuttings, and cleaning the bit. The efficiency of the flow rate depends on the borehole diameter, mud and rocks parameters (Bracke et al, 2013).

The next parameter is WOB (weight on bit) and it has the purpose to overcome the compressive strength of the formations to produce the cuttings, which is mostly created by 3/4rd of the drill collars weight.

The rotation additionally reduces the drag and torque of the drilling equipment (Bracke et al, 2013).

3. DIRECTIONAL SURVEY

Directional survey is the method used to obtain the needed measurement to calculate and plot the 3D well path. There are three parameters measured at multiple locations along the well:

- measured depth (MD);
- inclination;
- hole direction

MD is the actual depth of the hole drilled to any point along the wellbore, inclination is the angle measured in degrees and hole direction is the angle, measured in degrees, of the horizontal component of the borehole or survey-instrument axis from a known north reference. The measurements are used together to calculate the 3D coordinates, which can then be presented as a table of numbers called a survey report.

The purposes of directional survey are to (Lake, 2006):

- determine the exact bottomhole location;
- monitor the actual well path to ensure the target will be reached;
- orient deflection tools for navigating well paths;
- ensure that the drilled well does not intersect nearby wells (avoid collision);
- calculate the TVD of the various formations to get a proper geological mapping;
- evaluate the dog leg severity (DLS), which is the total angular inclination and azimuth in the wellbore, calculated;
- to fulfill requirements by the regulatory authorities.

3.1. Inclination

Inclination angle is normally measured by a mechanical pendulum positioned in a special barrel.

The instrument measures the hole inclination in degrees and records this measurement on a paper disc when punched by the pendulum stylus. The paper disc is divided into concentric circles, each circle representing one degree of deviation. The device is also equipped with a timing device to control the movement of the paper when the survey depth is reached. The instrument is usually called, Totco, after the company who firstly produced it. (Rabia, 2002)

Another way of measuring hole inclination is by using the Teledrift Inclination only with MWD tool.

It measures deviation angles up to 10 ½ °. The tool generates signals in the form of pressure surges in the mud stream. Those signals are then detected on the surface by a chart recorder.

3.2. Magnetic survey tools

Magnetic Survey Tools are designed for measure both hole inclination and azimuth.

The common magnetic survey tools used in the industry (Rabia, 2002):

- magnetic single shot (MSS): either photomechanical or electronic;
- magnetic multishot (MMS): either photomechanical or electronic;
- measurement while drilling (MWD).

3.2.1. *Magnetic single shot*

The instrument measures hole inclination and magnetic north direction. The instrument consists of:

- compass card;
- pendulum: (gives hole inclination);
- camera: to capture the image of direction and inclination on film;

- timing device: to turn the light on;
- battery.

Magnetic single shot are often run if MWD fails (Rabia, 2002). Figure 3-1.shows a typical magnetic single shot device.

Figure 3-1. Magnetic single shot device (www.china-ogpe.com)

3.2.2. *Magnetic multishot*

The electronic magnetic multishot use the same components as the electronic single-shot; the only difference is that electronic multishots record multiple survey records. The instruments measures both hole inclination and directions, and records data on a photographic film or digitally.

3.2.3. *Measurement While Drilling (MWD)*

MWD measures hole inclination and azimuth in real time. The magnetic survey information is obtained with an electronic compass, but, unlike previous systems that stored the information, the MWD relays the data through the mud. The real-time survey information enables the drillers to make directional-drilling decisions while drilling. The tool contains a plunger which send signals through the mud inside the drill string. The tool is called positive pulse MWD.

MWD tools which sends signals through the annulus are called negative pulse MWD. It sends signals through an aperture inside the casing of the MWD tool through mud in the annulus to be detected at the surface. When the plunger is operated it partially restricts the flow of mud through the tool, this is observed in the surface as an increase in the standpipe pressure. When the tool is operated a series of mud pulses are observed at the surfaces and decoded into directional data.

MWD can also have other sensors to measure a variety of down hole data including: temperature, direction, drill string dynamic and formation evaluation data (gamma ray, resistivity and density). When other than directional data, namely also formation evaluation data are measured, the combined tool is called LWD (Logging While Drilling).

3.3. Gyroscopic sensors

Gyroscopic survey instruments are mostly used when the results of other magnetic survey systems may be influenced by extraneous parameters, such as cased holes, production tubing, and geographic location or nearby existing wells. A rotor gyroscope is composed by a spinning wheel positioned on shaft, also called gimbal , it is powered by an electric motor, and it can reach speeds up to 40, 000 rev/min. The rotor can be orientated or pointed in a known direction (Lake, 2006).

The direction in which the Gyro rotates is maintained by its own inertia, and it can be used as a reference for measuring the azimuth.

There are three types of Gyros:

- conventional or free Gyro;
- rate or north seeking Gyro;
- inertial navigation systems.

Conventional or free Gyro

The main parts of conventional or free Gyro is a rapidly spinning rotor mounted on a frame or gimbals. The spinning top of the Gyro should maintain a vertical direction as long as the top spins fast enough and no other external forces act on it. The rotation is maintained by a electrical motor. Although, it is almost impossible to maintain a perfectly vertical direction because of the external forces. A typical Gyro used in the oil and gas industry has two frames (gimbals) which remain perpendicular to each other and they allow free rotation of the rotor. There are outer and inner gimbals. The gimbal is the one holding the rotor.

The rotor has two other basic components: a compass and a plumb bob assembly over the compass for measuring hole inclination.

North seeking Gyros

The north seeking Gyros use electronics to calculate the rate of rotation of the earth, and then determine the direction of true north. These use the horizontal component of the Earths rotational rate to determine north. The Earth rotates 360° in 24 hours, or 15° in 1 hour.

North seeking Gyros can be run inside drillpipe or casing, they provide surface readout of the wellbore survey through a conducting wireline. They are often used for orientation purpose and can provide a section or complete wellbore survey (Rabia, 2002).

Inertial navigation system

Inertial navigation system uses group of gyros to establish the true north, and accelerometers to measure movements in the x, y and z axes of the wellbore. It is more expensive than the previous two.

3.4. Survey quality control

The problem of a directional surveying is that it can never be precisely verified. It is very difficult to go down the well and get sure that the calculations is right and the bottom is located where the calculations claim. The most efficient way of verifying survey results is to have surveys obtained from two different sensor types such as a combination of MWD and gyroscopic systems.

4. DRILL RIG

To ensure maximum operating efficiency, the rig must be properly sized for the well. Usually, the rig is specified on the depth range and the hoisting horse power. Less rig power means a lower price, but if the lower powered rig does not meet the specifications, it will increase the costs for the contractor. On the other hand an oversized rig well insures higher costs as necessary (Bracke et al, 2013). Figure 4-1 shows a typical drilling rig.

Figure 4-1. A typical drilling rig (Aydin, 2015)

The rig requirements also change with well diameter and depth. When the drilling rates are decreasing the wellbore size becomes smaller or bit runs decrease ass less rotary torque and pump power is needed (Bracke et al, 2013).

The weight of the drill string is much greater than the desirable force on the bit, so the rig should have a hoisting capability to hold back some of the string weight to control force on the bit. The outside diameter of the drill collars is defined by the necessary annulus between the collars and the wellbore. The inside diameter of the drill collar is determined by hydraulic considerations (large enough to prevent excessive pressure drop, the necessity to pass logging tools, etc..) Although very large diameters holes for geothermal wells, the outer diameter of the drill collars is limited by the practicalities of handling large diameter tools with the current equipment. Because most of the BHA is in compression, the increase loading susceptible for H_2S, requiring special attention to material specifications. Therefore, there are usually used, special designed stress relief connections to minimize the cyclic stresses. Other components of the BHA assembly usually include:

- stabilizers;
- reamers;
- shock subs;
- jars.

4.1. Stabilizers

Because the drill collars and other components must be smaller than the wellbore diameter to provide a space for circulation, they can have major lateral deflections. Stabilizers that have full wellbore diameters and ribs along the outside surface, but leave a flow path between the ribs, are usually used at multiple points in and above the bottom – hole assembly. A minimum number of stabilizers should be run to reduce the risk of getting stuck in cuttings (Blanckenship and Finger, 2010). Figure 4-2.shows a standardly used stabilizer.

Figure 4-2. Stabilizers (Aydin, 2015)

4.2. Reamers

Because of the possibility of the bit getting stuck, additional cutting elements are implemented, either as fixed cutters or as toothead, cylindrical rollers to the BHA just above the bit, to help maintain the full hole diameter. This type of solution is more common in abrasive geothermal formations than in oil and gas. The figure shows a typically used reamer.

Figure 4-3. Reamers (www.nodiequipment.com.au)

4.3. Shock subs

The purpose of shocks subs is to dampen the vibrations produced by the drill bit and the drill string. It is reasonable to suppose that shock subs prolong the life of a drill bits and drill strings and in some cases the rig. They have limited applications in straight hole drilling where large drill collars may be more effective in reducing bottom hole vibrations (Mitchell, 1995).

An example of a shock sub is shown in the Figure 4-4.

Figure 4-4. Shock Sub (www.tubetechnologiesinc.com)

4.4. Jars

If the drill string is stuck in the hole, it can be released by the impact force produced by jars. When getting stuck while going down, the pipe need to be jarred up. When getting stuck while going up, the pipe needs to be jarred down. The jar’s function is to release energy stored in the drill string by pulling up on it and stretching, or setting down and compressed it (Blanckenship and Finger, 2010).

There are two principle types of jars: mechanical and hydraulic jars. They both operate at the same principle. Correct placement of the jars in the BHA is critical to maximize their effectiveness and avoid causing failure. Figure 4-5. shows a jar pulled on the rig.

Figure 4-5. Jars (Aydin, 2015)

4.5. Pump capacity

The pumps should have enough volumetric capacity to give sufficient velocity in the annulus to lift the cuttings. Their pressure capacity must provide the desire pressure drop through the bit, compensate all pipe pressure losses and possible drive a down hole motor (Bracke et al, 2013).

Because of the generally larger hole sizes (and volumes) in geothermal wells, pumps will be bigger than for oil wells of comparable depth. The pumps should also be able to handle lost circulation materials (LCM). As a primary part of geothermal well control is the ability to pump cooling water into the well (reinjection), it is desirable to have a standby diesel driven mud pump on diesel electric rigs. Figure 4-6. shows a typically used mud pump.

Figure 4-6. 3 cylinder mud pump (Aydin, 2015)

4.6. Mud program (drilling fluids)

The drilling fluid flows down through the inside of the drill pipe, through the nozzles in the bit and back up in the annulus between the borehole wall and drill pipe, carrying the cuttings produced by the bit action on the rock. However, the mud has to be adjusted to the formation rock and fluid chemistry in order to reduce interaction between the two (Bracke et al, 2013).

The main objective for the mud is to control formation pressure, stabilize the well, to transport produced cuttings and to help them stay in suspension while there is no circulation.

Other functions of the mud is to: cool and clean the bit, lubricate the drill string, allow collection of geological information, form a semi – permeable filter cake to seal the pore spaces in the formations, transmit hydraulic horse power for down hole motors.

İn order to control the formation pressure and stabilize the well, the mud pressure must be controlled in a small window between the pore pressure and the formation pressure/fracture gradient of the rock. The mud pressure is dictated by the density of the cutting loaded mud with consideration of additional friction losses and the true vertical depth. Figure 4-7. shows a graphical view of mud window and casing shoes.

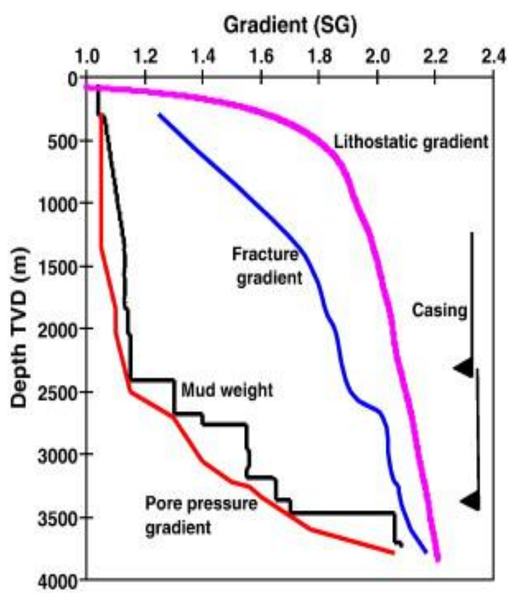


Figure 4-7. Mud window with casing shoe depth (Bracke et al, 2013)

Viscosity is another important parameter of the mud that increases the efficiency of the cuttings transport. Increasing viscosity means hıgh pressure loss due to friction effects. This affect the ECD (Equivalent Circulating Density).

Drilling fluid can be either liquid or gas, and liquid based fluid is universally called “mud” because the first fluids where just a mixture of water and clay. Large hole volumes and frequent loss mean that expensive mud has a significant impact on drilling cost.

Drilling record from a number of geothermal wells in several reservoirs showed the typical property range bellow (Blanckenship and Finger, 2010).

- Density 1.03 – 1.15 g/cm3
- Funnel Viscosity 35 – 55 sec
- pH 9.5 – 11.5
- Plastic vıscosity 0.01 – 0.02 Pas
- Yield point 25 – 125 Pa.

5. BOTTOM HOLE ASSEMBLY (BHA)

The BHA is a portion of the drill string that affects the trajectory of the bit and, consequently, of the wellbore. The BHA design objective for directional control is to provide the directional tendency that will match the planned trajectory of the well. The bit side force is the most important factor affecting the drilling tendency. The direction and magnitude of the bit side force determine the build, drop, and turn tendencies.

The bottom hole assembly refers to the drill collars, heavy wall drill pipes (HWDP), stabilizers and other accessories used in the drill string. All wells whether vertical or directional require careful design of the bottom hole assembly (BHA) to control the direction of the well in order to achieve the targets objectives. Stabilizers and drill collars are the main components used to control hole inclination (Rabia, 2002).Figure 5-1. shows a schematic view of drillstring as well as BHA.

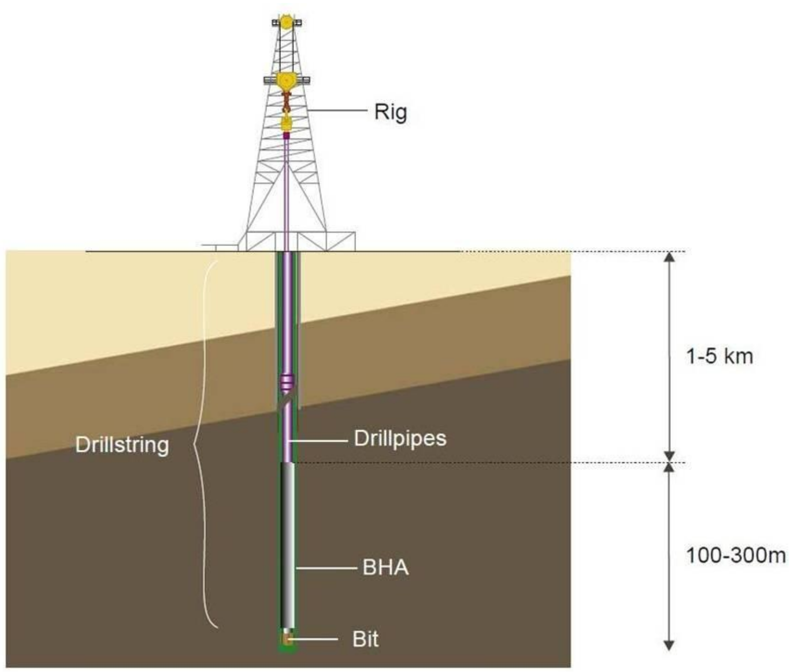


Figure 5-1. Schematic view of the drillstring with BHA (www.abdn.ac.uk)

There are three ways in which BHA may be used for directional control (Rabia, 2002):

- pendulum principle;
- packed hole stabilization principle fulcrum principle;
- fulcrum principle.

5.1. Pendulum principle

Pendulum principle is used to drop angle especially on high angle wells where it is usually very easy to drop angle. The pendulum technique relies on the principle that the force of gravity can be used to deflect the hole back to vertical. The force of gravity is related to the length of the drill collars between the drill bit and the first point of tangency between the drill collars and hole (Rabia, 2002).

Increasing the length of the drill collars causes the side force to increase more rapidly than the along hole component. High WOB's used with a pendulum assembly may bend the BHA and cause the hole angle to build instead of drop.

5.2. Packed hole stabilization principle

This is used to hold or maintain the hole inclination and direction, and are typically used to drill a tangent section of a well. The packed BHA relies on the principle that two points will contact and follow a sharp curve, while three points will follow a straight line. Packed BHA have several full gauge stabilizers in the lowest portions of the BHA, typically three or four stabilizers (Rabia, 2002).

Figure 5-2. shows the difference between pendulum and packed hole assemblies.

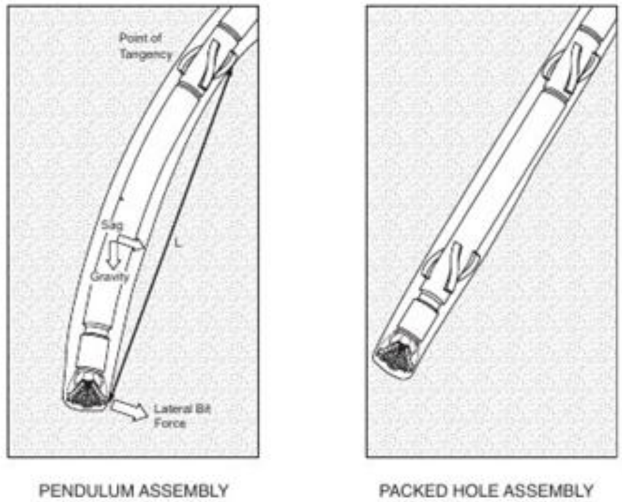


Figure 5-2. Pendulum and Packed Hole assemblies (www.oilngasdrilling.com)

5.3. Fulcrum principle

This principle is used to build angle (or increase hole inclination) by using a near bit stabilizer to act as a pivot or fulcrum of a lever. The lever is a length of the drill collars from the point of contact with the low side of the hole and top of the stabilizers. The drill bit is pressed to the high side of the hole causing angle to be built as drilling ahead.. Since the drill collars bend more as more WOB is applied, the rate of angle build will also increase with WOB (Rabia, 2002).

5.4. Standard BHA components

Using the three principles of BHA, there are five basic types of BHA's which may be used to control the direction of the well (Rabia, 2002):

1. Pendulum assembly

2. Packed bottom hole assembly

3. Rotary build assembly

4. Rotary bottom assembly

5. Steerable assembly

6. Mud motor and bent sub assembly.

5.5. Non – magnetic Drill Collars

The primary purpose of non –magnetic drill collars is to reduce the interference of the magnetic field associated with those sections of the BHA which are both above the magnetic compass contained in the survey tool with the earth's magnetic field. The non – magnetic collars reduce this type of interference by moving the BHA section away from the survey compass.

Magnetic surveys suffer from the following sources of errors (Rabia, 2002):

- drill string magnetization;
- magnetic effects from casing strings or BHA;
- geological structures containing magnetic materials;
- magnetic storm effects;
- wireline magnetization;
- magnetic declination;
- tool misalignment;
- depth measurement.

There are four critical factors in selecting nonmagnetic collars:

a) the total length;

b) the location of the survey compass;

c) the type of materials of which the compass is made;

d) distinguished “hot spots “.

“Hot spots” are zones of high magnetic field strengths within the material of the collars. Hot spots can affect compasses by a much of 4 degrees (Rabia, 2002).

Non – magnetic collars may be manufactured by many type of materials. The selection is based primarily on the corrosion resistance of the material. The most common non – magnetic material is stainless steel, while monel, which is 60% nickel and 30% cooper, is seldom used.

A practical method of ascertaining the best location for the survey compass and the requisite non – magnetic collar length is to run a BHA into the drill hole and pull a compass through the nonmagnetic collars. The portion of the non - magnetic collars which do not show the effects of the fields of the BHA may be removed from the BHA. The figure bellow (figure 5-3.) shows a non – magnetic drill collar.

Figure 5-3. Non – magnetic drill collar (Aydin, 2015)

6. POSITIVE DISPLACEMENT MOTOR

The first commercial positive displacement motor (PDM) was introduced to the petroleum industry in the late 1960s. Since then, PDM use has been accelerated greatly for directional-drilling applications.

A positive displacement motor is a hydraulically driven downhole motor that uses the Moineau principle to rotate the bit, independent of drill string rotation.

Figure 6-1. Schematic figure of a PDM (www.laser-ndt.com)

The PDM is made of several sections:

- by – pass valve or dumps sub;
- motor section;
- universal joint or connecting rod section;
- bearing section with drive sub.

Figure 6-2.shows the components of a PDM.

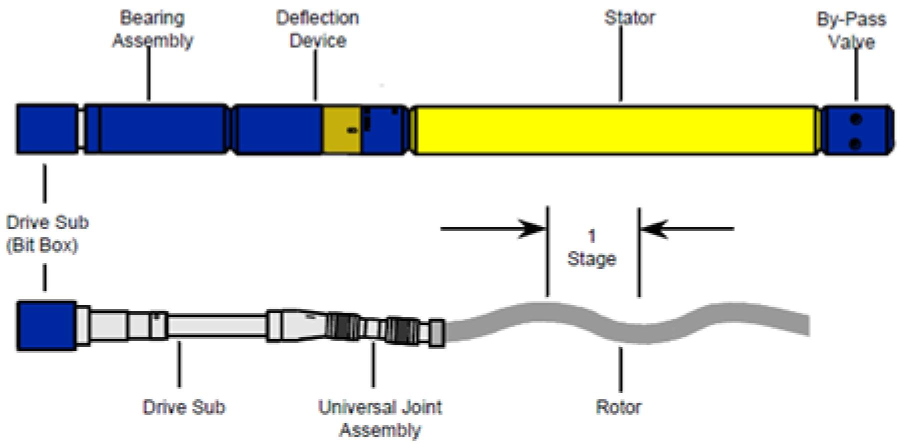


Figure 6-2. Components of a PDM (www.BakerHughes.com)

By – pass valve

The by pass valve allows fluid to fill the drill string while tripping in the hole and to drain while tripping out. When mud is pumped, the valve closes causing fluid to move through the tool. Most valves are of a spring piston which closes under pressure to seal off ports to the annulus. When there is no downward pressure, the spring forces the piston up so fluid can channel through the ports of the annulus. Figure 6-3. Shows the operation that allows a By pass valve.

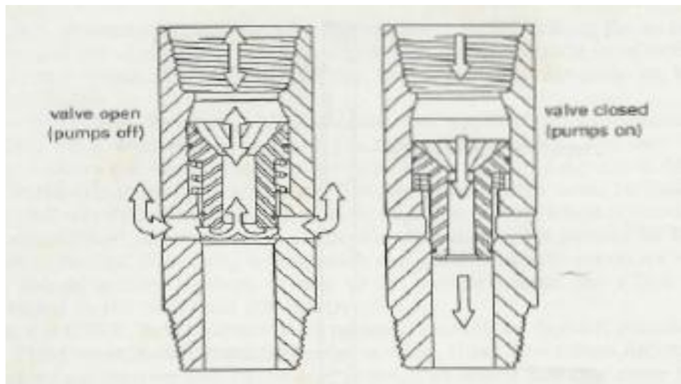


Figure 6-3. Operation of a By pass valve (Inglis, 1987)

Motor section

The PDM consist of a helical steel motor fitted inside a spirally – shaped elastomer modeled stator. A rotor/stator pair converts the hydraulic energy of the pressurized circulating fluid to mechanical energy for that allows rotate the rotor.

The magnitude of rotation produced is proportional to the volume of mud pumped through the motor. The torque generated in the PDM is proportional to WOB and to the pressure drop in the motor. The highest the value of WOB, the highest is the differential pressure in the power section. Which means that an increase in WOB will cause an increase in pumping pressure due to increased differential pressure across the power section. This must be a concern in drilling operations when only a limited pumping pressure is available.

The rotor and stator are of lobed design. Both rotor and stator lobe profiles are similar, with the steel rotor having one less lobe than the elastomeric stator. The rotor / stator configuration (or lobe ratio) currently in use are: 1/2, 3/4, 5/6, 7/8, 9/10. The speed and torque of a power section is linked directly to the number of lobes on the rotor and stator. The greater the number of lobes, the greater the torque and the lower the rotary speed. Figure 6-4. shows a typical rotor / stator configuration from a PDM.

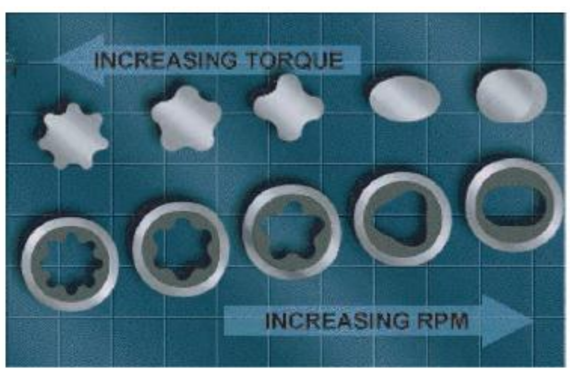


Figure 6-4. Typical rotor / stator configurations (www.BakerHughes.com)

Universal joint

It is connected to the lower end of the rotor. It transmits the torque and rotational speed to the drive shaft and bit.

Bearing section

It transmits drilling thrust and rotational power to the drill bit.

Steerable positive displacement motor

A steerable motor can be used in oriented mode (sliding) or rotary mode. In rotary mode the steerable motor becomes "locked" with respect to the trajectory and the hole direction and inclination are maintained while drilling. In the sliding mode, the drill string remains stationary (the rotary table or top drive is locked) while the drill bit is rotated by the motor.

The use of steerable motors with the correct bit and BHA reduces the time needed to get the desired inclination / azimuth.

7. GENERAL ABOUT PARADIGM SYSDRILL 10

Paradigm Sysdrill 10 as a well planning program allows drilling engineers to perform advanced engineering analysis in integrated software with minimal effort in order to enhance well planning accuracy.

Sysdrill modules

The software allows the use of different modules, such as: well design, engineering analyses, torque and drag analyses, hydraulics analyses, cementing and casing analyses.

Benefits of Sysdrill 10

- minimize training time using flexible spreadsheet's, given by Paradigm that allow the drilling engineer to quickly plan wells;
- plan the most precise and cost effective directional survey programs to ensure the wellbore placement wıthin the driller target;
- reduce drilling risk by minimizing the possibility of collision wellbore using wellbore positional uncertainty incorporated into the anti-collisions analysis;
- save time by using directional survey data that can be entered manually or imported from a file.

Well planning

The software allows the drilling engineer to visualize the target including shape, dimension, rotations, thickness, position, dip and offsets. It is also possible to import surfaces created from both Paradigm and 3rd party geological packages into Sysdrill to create a 3D model, for visualization and computing intersection for casing placement. Sysdrill can be used to plan sidetrack, multilateral and reentry wells by tying to existing wellbores stored in the Sysdrill database. Casings, hole sections, comments, and survey errors tools can also be defined.

Field & data management

Sysdrill has been designed a corporate data base for wellbore data. The global position of field, rigs and slots can be specified in geographic, UTM or Lambert coordinates from over 1000 coordinate system included as standard formats. In Sysdrill targets can be created at either Fields or Wellbore levels, they can be associated wıth field, well and wellbore objects in the data hierarchy so as to enable easier target management. Targets entered at field level are available to all wells and wellbore that are defined beneath the field. As well as manually entered targets the software allows to import targets from other software applications. Lease lines and local boundaries can also be entered and visualized. Unit definitions, clearance rules, and other defaults settings can be specified on an individual operator basis.

Slots and rig datum

A slot defines the surface position from which a wellbore is drilled. A rig datum is a depth reference point against which subsequent depth measurement should be taken. This is commonly the rotary table of the drilling rig and similar and may be subject to change over time, for example if different drilling rigs are used to drill the original hole and subsequent sidetrack.

Individually rig kelly bushing (RKB) elevations and slot permanent datum are stored for each wellbore, allowing wells to be entered wıthout having to modify the original data. This ensures the integrity of the database and provides a definitive wellbore history, including RKB elevations, overlapping surveys, and errors models. A sophisticated security function using a set of access controls allows permissions and a history log that permits to restrict and to monitor access to individual users and group.

Creating a planned wellpath

A planned wellpath is a description of the shape and orientation of a proposed wellbore. Wellpaths can be relatively simple for vertical wellbores but can become very complicated for directional and horizontal wellbores.

Sysdrill uses values entered by the user to calculate a minimum curvature wellpath between the stations, certain combinations of values have to be entered to allow the calculations to be calculated.. To help wıth this calculation Sysdrill supports a series of predefined profiles that can be solved by entering constraints at the stations.

These profiles correspond to commonly used sequences of curving, (build/drop/turn) and straight (hold) sections used in wellpath design. Both 2D (constant azimuth) and 3D (changing azimuth) profiles are supported. There are often many different ways to solve a planned wellpath.

The wellpath spreadsheet uses dıfferent colors to indicate dıfferences within the data. Values which constrain the design (targets positions, manually entered values etc.) are displayed as white text on a green background while values calculated by the system (based on the entered values) appear as black text on a white background.

Survey error models

As with any form of measurement there is a positional uncertainty associated with the exact location of all wells drilled. This positional uncertainty will vary in size depending upon which survey tools are run and which Survey Error Models are therefore applied to the Planned Wellbore. It is possible to apply one or more Survey Error Models to the Planned Wellpath to determine the overall extent of the position uncertainty. The definitive wellbore is created by specifying to/from depths for each survey section resulting in the definitive wellbore position and its positional uncertainty. Once the final survey has been loaded, it can be locked as definitive, thus ensuring the integrity of the database for anti-collision analysis or future re-entry.

Anti-collision analysis

Anti – collisions analysis can be performed against an unlimited number of offset wells stored in the Paradigm Sysdrill Database.If positional uncertainty has been specified at surface, than it can also be included in the anti – collision analysis.

Pressure & temperature data

Pressure and temperature data is used in the sysdrill for engineering calculatıons. Data such as pore pressure, fracture gradient, hole collapse gradient and temperature profiles can be defined in Sysdrill in SI Metric, API Oilfield, API Metric units. Pressure and temperature data can be entered as values or gradients and as MD or TVD.

Casing design

Sysdrill allows the user to design the minimal number of casing string required in order to safely complete a well, reducing the well costs as much as possible. The design of the load cases can be specıfied according to company policy and stored in catalogs. It is also possible to get a graphical view of the casing positioned in the well.

Casing seat calculations

Casing setting depths can be automatically calculated based upon the pressure data, swab and surge margin and maximal open hole distance. It is possible to get than a graphical display of the proposed casing depths.

Kick tolerance calculator

Sysdrill 10 offers two calculation methods in the Well Control Analysis module.

Firstly the Kick Pressure Test calculates the safe casing shoe depth or point at which a fixed volume of gas would cause fracture whilst circulating out the kick. Secondly the Maximum Influx Calculation calculate the maximum possible influx of gas at TD before fracture would occur while circulating out the kick.

The kick tolerance uses a Single Bubble Method to determine the volume and the density of a bubble as it is circulated out of the wellbore.

Creating a rig

A rig is defined by the physical operating parameters of the surface equipment. The defined items are:

- rig name;
- rig type;
- block weight;
- max torque;
- max hook load;
- surface equipment.

Sysdrill also allows to choose a required mud pump from the catalogue, the Sysdrill catalogue has a various number of mud pumps, every pump is defined by their specifications (name, type, rod diameter, stroke length, max SPM, mechanical power, pop off pressure, volumetric efficiency, maximal operating pressure, volume per stroke).Figure 7-1. shows the proprieties of a mud pump from Sysdrill database.

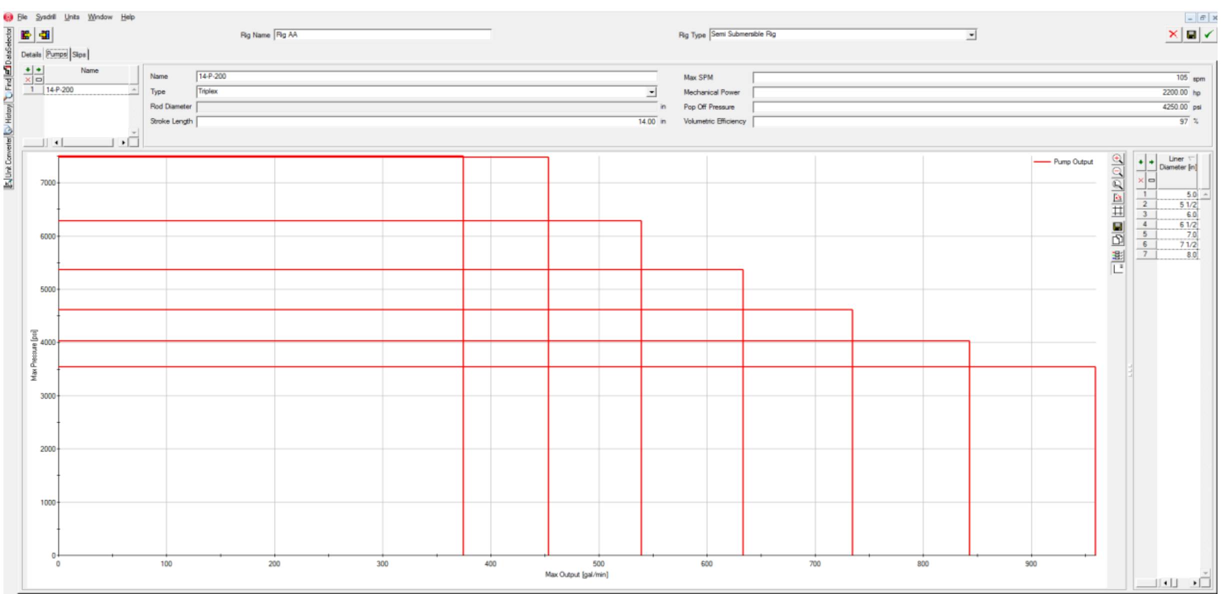


Figure 7-1. Mud pump taken from the Sysdrill 10 catalogue (Sysdrill 10)

Plotting & reporting

Sysdrill offers an extensive set of predefined plots and reports templates for calculations. Users can set up their favorite (most used) plots and reports for planned and actual wellbore.

3D Visualization

The actual wellbore can be viewed interactively in the 3D viewer and compared against the planned wellbore, and other wells in the field. Geological surfaces, casings, uncertainty, and drillers targets may also be displayed. Figure 7-2. shows a 3D visualization of the wellpath with casing strings.

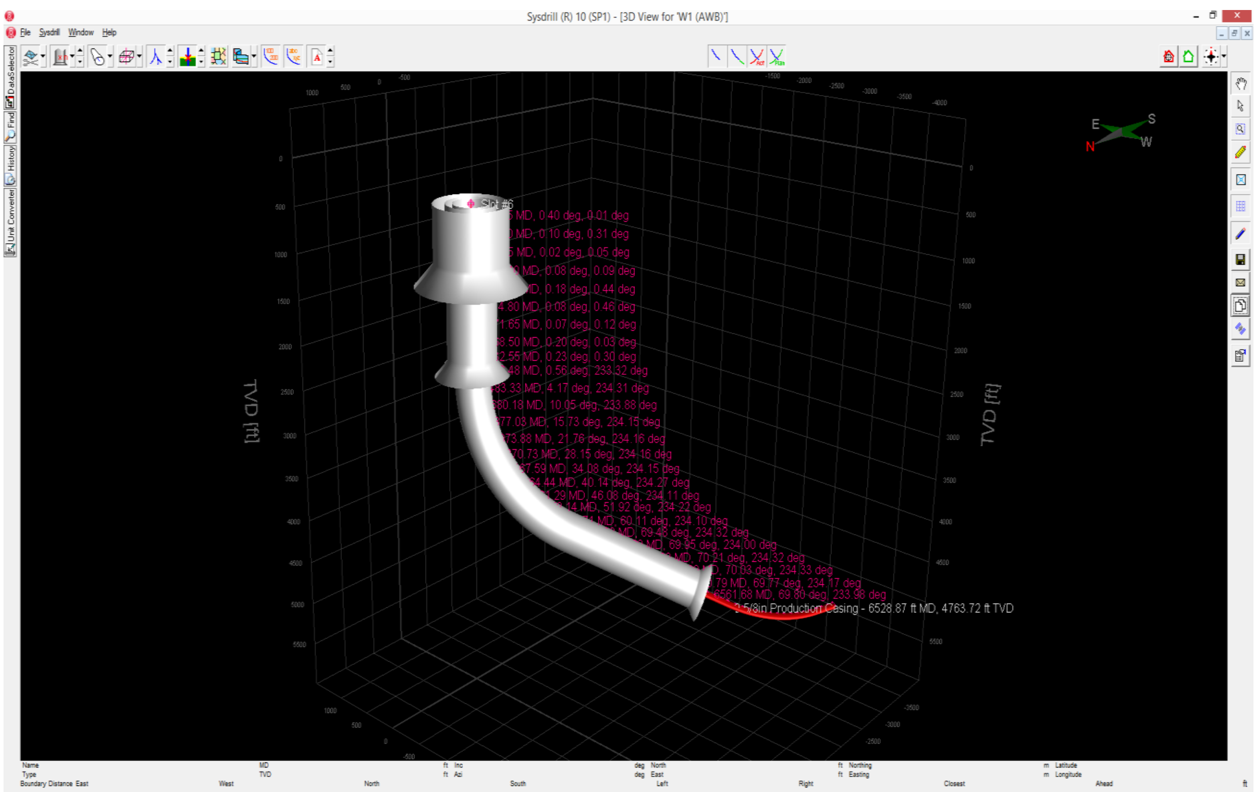


Figure 7-2. 3D view of a well (Sysdrill 10)

Assemblies

Sysdrill allows complex BHA's by rapid filtering of extensive catalogs of drilling equipment including bits, collars, pressure loss devices, centralizers, stabilizers, torque reduction subs, and accessories. BHA's that are created can be stored in catalogs for future usage and new catalogs can be added. A customizable graphical view combines mechanical properties and physical dimensions. The Assembly Builder includes tools to allow definition of complex assemblies. Accessory components are those that can be inserted between or clamped on a tubular item. Common accessories are stand – off devices, torque reducers, pipe protectors, centralizers etc. Casing couplings and connections are also defined in this manner.

Sysdrill also provides a few simple mechanisms that allow defined assemblies to be copied between different projects between different projects in the database.

The Assembly Wizard allows the user to specify the assembly type and the creation method.

Table 7-1. shows the different assembly's options.

Table 7-1. Choosing assembly option (Sysdrill 10)

Option	Description
Type	Indicates that the assembly is to be manually defined.
Existing	The new assembly is to be crated as copy of an existing assembly within a the database .A filter – based search mechanism allows rapid identification of a particular assembly in the database
Catalogue	The new assembly is to be crated as a copy that exist within en equipment catalogue. A filter based search mechanism allows rapid identification of particular assembly or group of potential assemblies within available catalogues.
File	The new assembly is to be created from an external file.

Figure 7-3. shows a graphical view of a chosen BHA assembly.

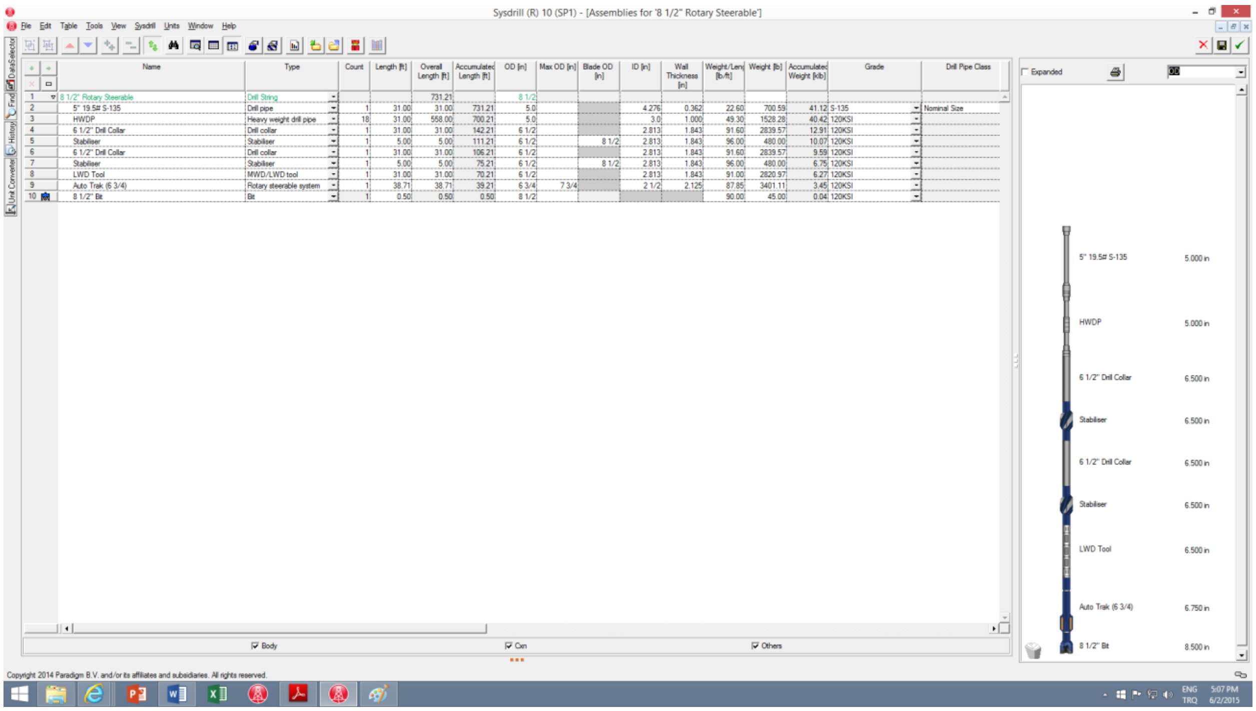


Figure 7-3. Graphical view of a BHA assembly (Sysdrill 10)

Torque & drag analysis

The torque & drag calculation involves mechanical analysis of a string within a particular hole section. It is used to validate well design and to prevent loss of rig time by eliminating drill string failure. The torque & drag calculation editor allows efficient definitions of inputs, execution of calculations and analysis of results, plus access to other related calculations and functions.

Functional feature

Sysdrill functional features include:

- any number and combination of operating modes may be defined and used in a calculation;
- calculation may be run as a static depth analysis or over a depth interval range;
- calculation can be run using ‘Soft String’ or ‘Stiff String’ models;
- visualize effective tension, true tension, torque, slide force, twist/stretch, drag, pressure and stress loads against operating limits;
- import and display of surface torque and hook load values for comparison with calculated results;
- vibration, stuck point, friction and packer calculations are also available within the Torque & Drag calculation.

Figure 7-4. shows Sysdrill torque and drag features.

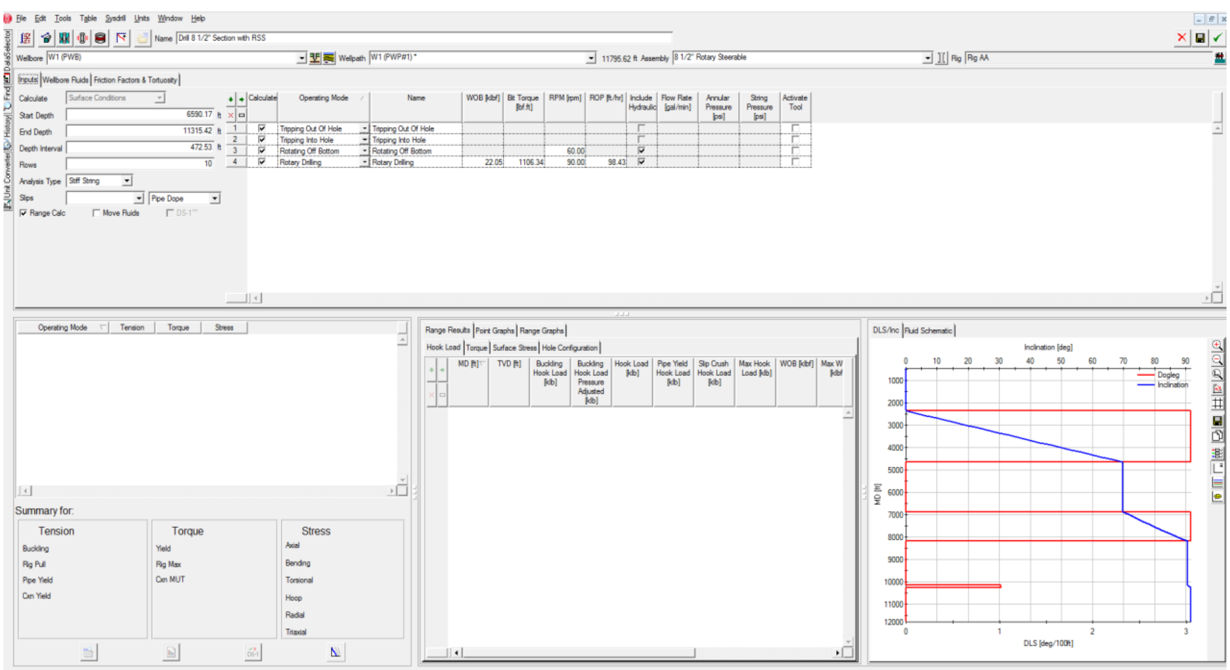


Figure 7-4. Sysdrill 10 Torque and Drag features (Sysdrill 10)

Defining wellbore fluid

Fluid must be defined for the torque and drag calculations as they are used in the calculation of buoyancy and viscous forces while circulating. Sysdrill allows the definition of one or more fluids and their position in the well. It is also possible to access predefined fluids from catalogues. The picture shows the wellbore fluid defined in the program. The figure bellow (figure 7-5.) shows input data for defining drilling fluids.

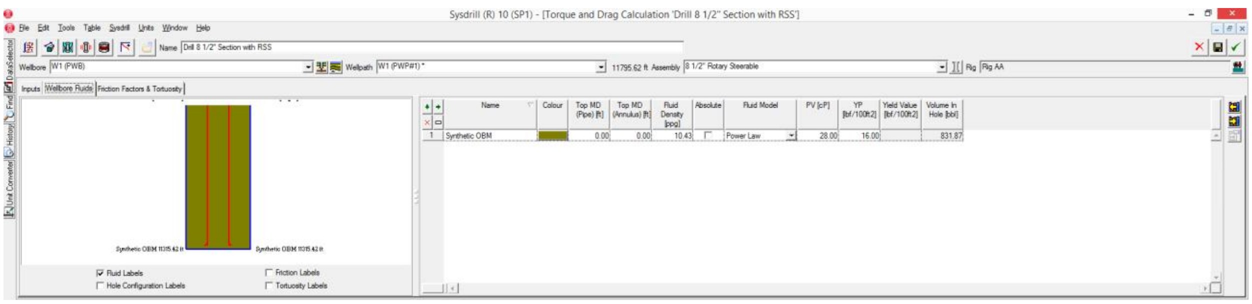


Figure 7-5. Defined drilling fluid (mud) (Sysdrill 10)

Friction factor & tortuosity

The friction factor sensitivity module performs analyses at varying depths using common friction factors, one for the open hole and for the close hole. The friction factor is defined as the ratio of the force required to move an object to the force between the object and the surface on which is resting.

Friction factors for synthetic OBM: Cased Hole (0.15 -2.0) and Open Hole (0.17-0.26)

Soft & stiff string analysis

Soft & stiff string analysis options allow calculations of all the forces acting upon the BHA, including torque, drag force, stresses and side forces.

By default Sysdrill uses soft string analysis for torque and drag calculations. This assumes that all the components lies on the low side of the hole and all of them are in contact; consequently all components contribute to the overall drag effect.

There is also a second method, stiff string. Stiff string assumes that only the tool joints or other external upsets are in contact with the wellbore. The position of the tubular elements can also be calculated. It can be seen that part of the string that is no in contact with the wellbore. This parts do not contribute to the overall drag force, resulting more exact analysis of torque & drag.

Advanced assembly definition

The Assembly Builder includes tools to allow definition of complex assemblies. Accessory components are those that can be inserted between or clamped on to a tubular item. Common Accessories are stand – off devices, torque reducers, pipe protectors, centralizers, casing couplings etc. All these complex assemblies can be find in the Sysdrill catalogue or be imported or defined directly in Sysdrill.

Jar placement

The position of the jar is determined by the operating parameters and hole conditions. In order for getting the proper position the drilling parameters such as: WOB, flow rate, bit total flow area (TFA), if drilling rotary should be defined. Also safety margins have to be defined.

Hydraulic analysis

The hydraulic calculations involves hydraulic analysis of a string within a particular hole section, such as:

- multiple calculation options, including pump pressure, flow rate, bit TFA and % bit pressure loss;
- calculation may be run as a static depth analysis or over a depth interval range;
- visualize fluid density, pressure and velocity against critical limits;
- calculating cuttings transport ratio throughout the annulus;
- swab surge, equivalent static density (ESD), flow rate, bit hydraulic horse power (BHHP) & jet impact force (JIF) and fluid volume calculators are also available within the hydraulics calculation window;
- support for simple and complex fluid rheology definitions, including HPHT effects.

Figure 7-6. shows the Sysdrill hydraulic module.

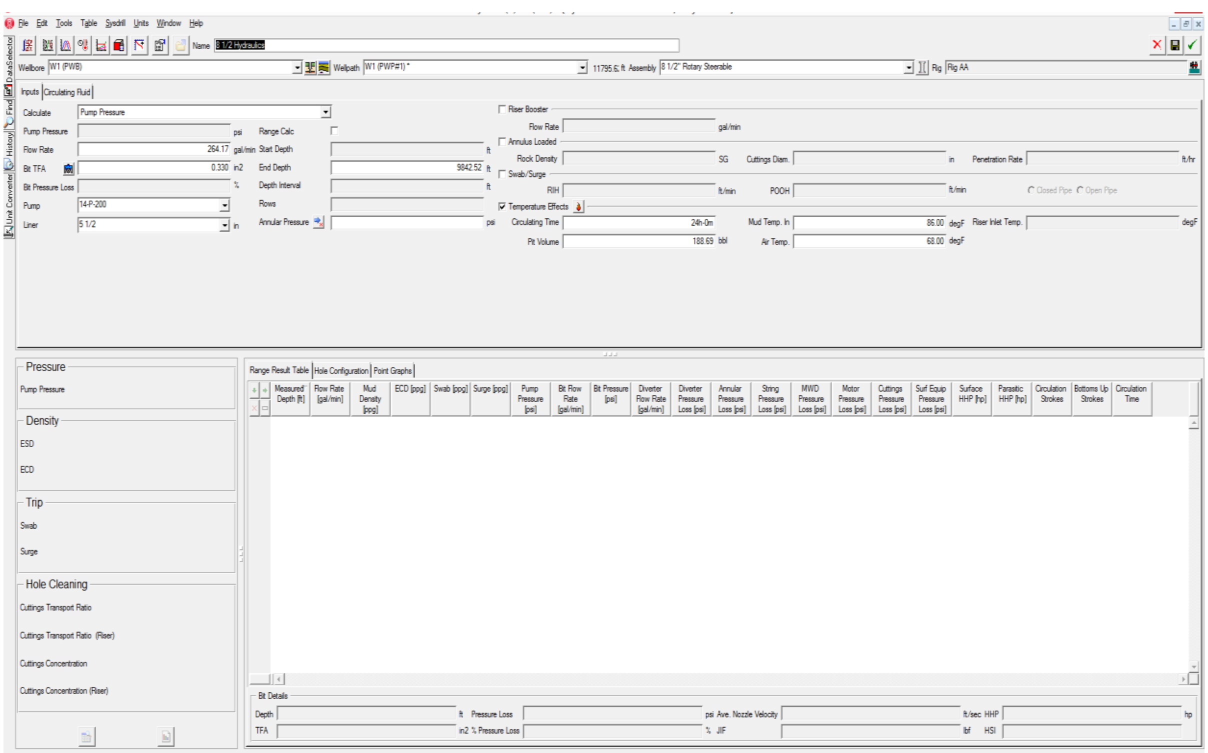


Figure 7-6. Sysdrill 10 Hydraulics (Sysdrill 10)

Rheology

The Fluid Builder allows accurate definition of fluid proprieties for use in all engineering calculations. Fluid can be stored in catalogues for re – use in another analysis. A rheology model selector can analyze drilling fluids and automatically select the most suitable rheology model based upon viscosimetar readings. Bingham plastic, power low, Herschel Bulkley & Robert Stiff models are supported.

HPHT can be defined using multiple HPHT readings.

Swab/Surge pressure

The Swab Surge calculator allows the evaluation of swab/surge effects over varying run speeds. It reports swab/surge densities at both the beginning and end of the currently selected hole section. The maximum running speed for BHA's and casing string (both open and closed pipe) can be calculated to improve efficiency and safely reduce rig costs reducing the risk of formation breakdown or swab induced influxes.

Edit the assembly (pressure loses)

The Assembly editor is used to set the hydraulic parameters of the various components. The system uses the body OD and ID for calculating frictional pressure losses. Tool joint OD & ID are used to calculate and additional pressure losses associated with them.

BHHP & JIF Optimization

The Sysdrill Hydraulics allows several modes of optimization, including bit hydraulic horse power (BHHP) and jet impact force (JIF) is possible by varying the flow rate and TFA against a fixed pressure or varying pressure and TFA against a fixed flow rate. BHHP curves and JIF curves can be generated, showing impact force and hydraulic power with different flow rate and bit TFA (figure 7-7.).

Nozzle configuration and TFA can be calculated based on flow rate and surface pressure.

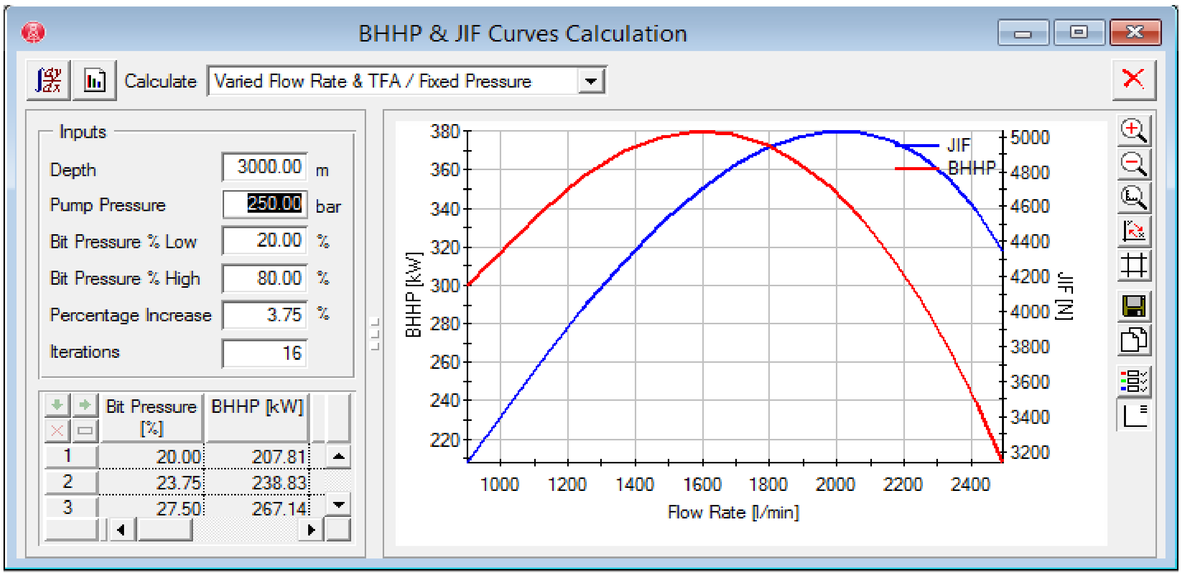


Figure 7-7. Graphical view of BHHP and JIF for different flow rate (Sysdrill 10)

ESD & ECD calculations

The ESD (Equivalent Static Density) allows evaluation of the transient thermal effects of the circulating system. ECD (Equivalent Circulating Density) can also be calculated at varying flow rates.

Cementing analysis

Cementing analysis allows simulation of cementing hydraulics for multiple fluids. Fluids are defined by their densities and rheological proprieties and they can be entered by volume or depth. Fluids are positioned in order to produce a fluid train in the annulus (Figure 7-8.).

A fluid flow regime is simulated by the program and shows in shematic displays fluid flow regimes, bottom hole pressures, ECD’s and flow rate as cement is circulated into position.

Also, hook load, volum pumped and velocıty are defined in the graphs (figure 7-8.).

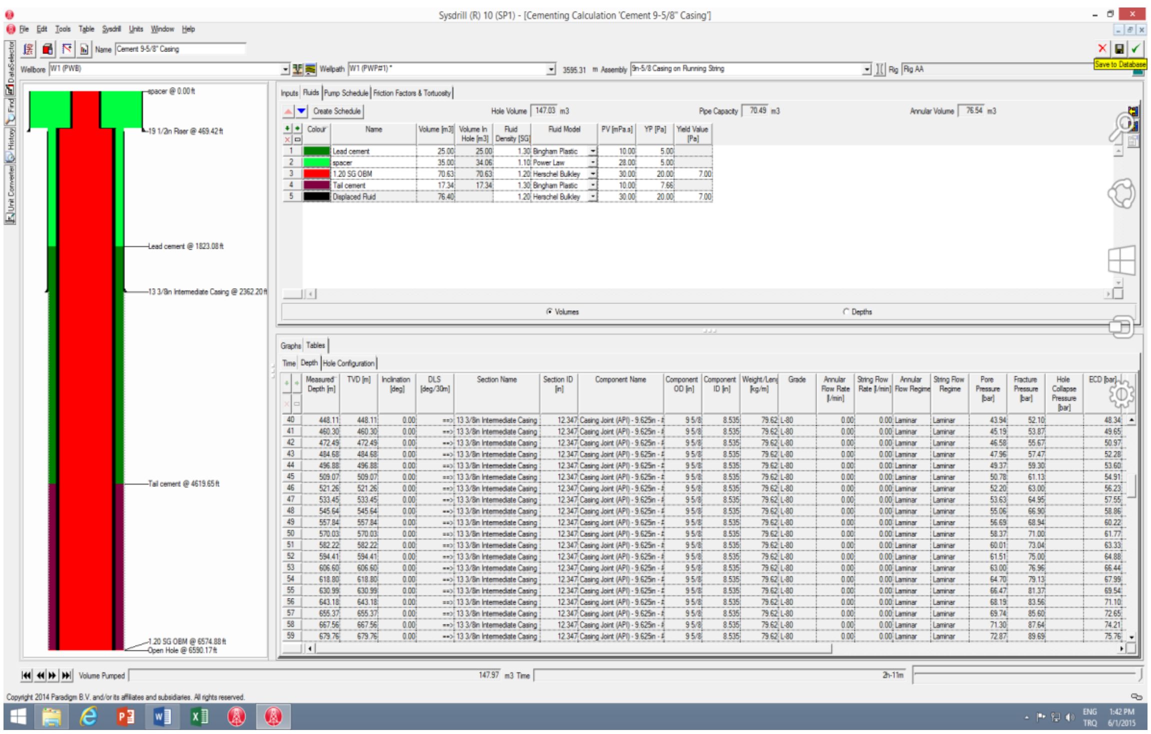


Figure 7-8. Sysdrill cementing simulation casing analysis (Sysdrill 10)

The casing analysis allows analysis of casing for a given wellbore and wellpath with various user defined pressure profile or load cases. A casing string design should be capable to withstand any load it may experience during the life of the well.

The load cases are generally set up to model the worst case scenario for all the stages of a well: instalation, drilling and production. every load case is defined by a combination of internal and external pressure profiles and specific design factor for each of the failure modes (axial, burst, collapse and triaxial). Figure 7-9. shows Sysdrill casing analyses module.

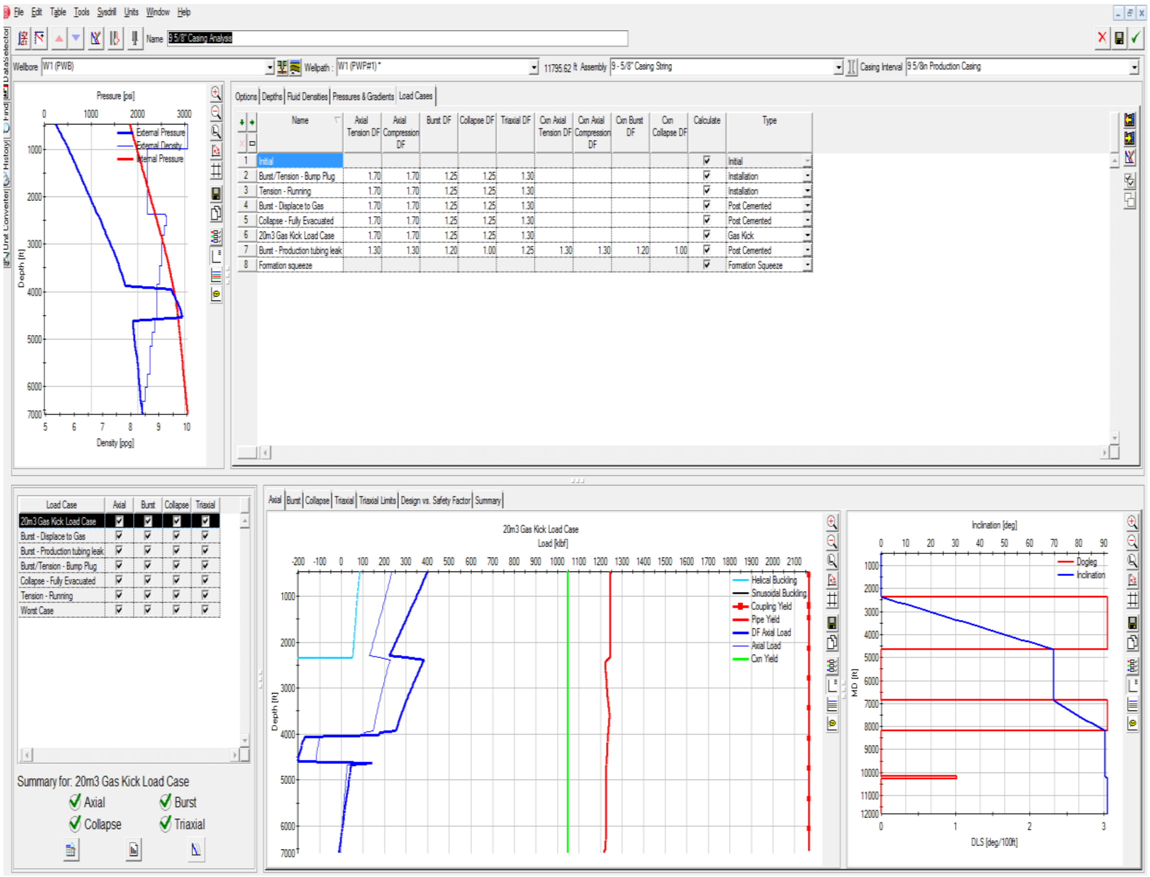


Figure 7-9. Sysdrill casing analysis (Sysdrill 10)

8. SYSDRILL TORQUE AND DRAG ANALYSES FOR DIFFERENT BHA'S APPLIED IN DRILLING A REAL GEOTHERMAL WELL

The meaning of geothermal comes from the Greek word gea which means Earth and thermal which means hot (Blankenship and Finger 2010). Geothermal resources include the natural heat of the Earth, concentrated in a place such the groundwater can transport the heat to the surface.

Geothermal reservoirs are distributed in unique positions in the Earth's crust. Spatial variations of the thermal energy within the deep crust and mantle of the Earth gives rise to concentrations of thermal energy near to the surface of the Earth that can be used as an energy resource. Heat is transferred from deeper portions of the Earth by conducting trough rocks, by the movement of hot, deep rock toward the surface, and by deep circulation of water. Most high – temperature geothermal resources are associated with the heat gained from the movement of magma (melted rock) to positions relatively close to the surface where the heat is stored (Blankenship and Finger 2010).

High temperature geothermal resources are generally found along the margins of crustal plates. Along the margins, molten rock is generated and moves upward through the crust (Ramey, 1981). The earth is broken in huge plates that move apart or push together. Convection of semi – molten rock in the upper mantle helps drive plate tectonics.

The theory of all applications of geothermal energy is to use a circulating fluid to carry the heat from depth to its use at the surface.

If geothermal resources are to be used for generation of electricity by conventional turbines, the necessary temperature from a geothermal reservoir must be greater than about 150°C. Even more important the reservoir must have a sufficient permeability and fluid content to permit movement of the heat to the surface of the Earth. The most efficient fluid for transmission is water (Ramey, 1981).

In most cases, when the fluid originates in the geothermal reservoir, but the permeability is lower, or where there is no fluid, there are techniques for injecting cooler water at the surface, cırculate the water through the fractures in the rock to gain heat, and then returning it to the surface for use.

Produced fluids with lower temperatures (bellow about 150°C) are suitable for space heating, product processing, agriculture heating, air conditioning and other process involving low – grade thermal energy. These applications can be very economical, effectively when the prices of conventional fuels are high, but the disadvantage is that they have to be near the resource.

With higher temperatures and sufficient flow rate, geothermal energy can be used to generate electricity, in that case there is no demand for the user to be geographically close to the geothermal resource (Blankenship and Finger 2010). However, this requirement emphasizes the need for drilling. Except for the few cases where direct use application can be supplied from natural hot springs, the usage of geothermal fluid can only be achieved through drilling in to the formation to get to the reservoir and in most of the cases the fluid must be re – injected in the reservoir.

Exploration for geothermal resources is mostly based on geologic mapping, geochemical analysis, geophysical analysis and exploration drilling (Blankenship and Finger 2010).

Geochemical analysis involve sampling waters and gases from hot springs. Chemical analysis of these samples provides data which may determine whether a potential geothermal system is liquid or vapor dominated system. Also, geochemical analysis can indicate the minimum temperature that we can aspect at the depth. (Ramey,1981).

Geophysical method involves direct measurement of physical parameters of the Earth which include geothermal temperature, electrical conductivity, propagation of elastic waves, measurement of density, lıquid saturation and other parameters (Ramey, 1981).

Exploration drilling is a method based on drilling shallow exploratory holes for the purpose of determining geothermal gradients and surface heat flux for determine the site for exploratory drilling. However the final proof of any exploration program, is the drilling of an exploratory well.

Typical rock types in a geothermal reservoir include, granite, granodiorite, quartzite, basalt, rhyolite and volcanic stuff. Geothermal formations are hot, hard compressive strength, abrasive, (content of quartz above 50%), highly fractured and under pressured (Blankenship and Finger, 2010). This conditions indicate that drilling is usually difficult, rate of penetration and bit life are usually low, corrosion is often a problem, and the most of this problems are related to high temperatures.

Geothermal systems almost always contain dissolved or free carbon dioxide (CO_2) and hydrogen sulfide gases. Those gases contribute to corrosion problems, H_2S particularly presents a substantial safety hazard during the drilling process. The material limitations and the associated safety hazards increase the cost of geothermal wells. The productivity of geothermal systems is related to the high fracture permeability, which is also the cause of lost circulation problems encountered when drilling geothermal wells.

Time and material for lost circulation treatment can achieve 15% of well cost, and the under pressured formation can also be the cause of differential sticking, so these can be major impacts on drilling costs (Blankenship and Finger, 2010). The loss of circulation is often massive, with complete loss of the drilling fluid is also common for geothermal wells to be abandoned because of the inability to get through a lost zone. Short bit life, due to hard, fractured, abrasive and high temperature conditions increases tripping time dramatically. Low penetration rates are common in hard, abrasive rock conditions.

Geothermal drilling is more expensive in cost per depth than onshore oil and gas drilling. There are three principal reasons:

- technical challenge – special tools and techniques are required for the complex down hole conditions;
- large diameters – because the produced fluids, either water or steam are of intrinsically low values, large flow rates and thus large holes and casing are required;
- uniqueness – geothermal wells, even in the same field, are more different then the oil and gas wells in the same field.

Figure 8-1. shows a typically used large diameter bit for geothermal drilling.

Figure 8-1. A tipical large diamter bit used in geothermal drilling (Aydin, 2015)

Another big cost comes from the fact that almost all produced fluids must be re – injected, that requires drilling other wells, so it is of major importance to drill the well as effectively and inexpensively as possible (Blankenship and Finger 2010).

Potentional problems

The major potential risks are driven by increased temperatures and fractured rocks. This may lead to situations lıke lost circulation, wellbore instability and may complicate cementation and even require additional casing strings.

a) Lost circulation

The most expensive problem encountered in geothermal drilling is lost circulation, which is the loss of drilling fluid to pores or fractures in the rock formation being drilled .The lost circulation can represent 10% of total well cost in mature geothermal areas (Blankenship and Finger, 2010). Loses of drilling fluids in the pores or into existing fractures of the formation result into wellbore instability or wellbore control problems such as blowout. The following problems occur through lost circulation.

- Drilling fluids, especially those used in high temperature formations, are expensive and loosing them into the formations instead of recirculating is costly.
- In geothermal wells, the production zone is usually a lost circulation zone, so it is sometimes difficult to cure a harmful lost circulation zone while preserving its productive potential and try to seal the lost zones with some materials that can be drilled out as the borehole advances.

If fluid loss occurred while drilling with mud motors, the addition of fresh mud sometimes makes it possible for the bit to drill ahead into the hole. Trips back into the hole are often the reason of motor failure in addition high temperature problems. The ability of a top drive unite to circulate while tripping into or out of the hole is a significant advantage for this operating method. High temperature in geothermal wells can also be a major problem for electronic parts and steering tools.

In addition to temperature limitations, down hole motors sometimes can also restrict drilling parameters, such as hydraulics and WOB that can be used. When drilling through aggressive formations motors can also be the mechanical weak point of the BHA.

As the direction of the well becomes more extensive, the drill string will be affected by more torque and drag. That can be a big problem, and finally limit the well depth.

b) High temperature

The high temperature in geothermal reservoirs is transferred through the whole steel drill pipe, and it has a big effect on the down hole equipment due to the bath in hot fluids. There are different problems due to high temperature (Bracke et al, 2013):

- Elastomer components (seals, down hole motor stators, bridge plugs) are challenged;
- high temperatures tend to increase corrosion rates;

- expensive and delicate electronic steering and logging tools can be damaged or destroyed.

c) Wellbore instability

Wellbore instability results for a number of reasons which can cause widely varying kind of problems. The wellbore may become mechanically unstable because of the pre – fractured rock or due to degradation of the well from the invasion of liquid from the drilling fluid (Bracke et al, 2010).

- When the drilling fluid fails to clean the hole and doesn't return cuttings to the surface due to missing height, the cuttings may fall back on the BHA assembly and bury the drill bit and BHA.

- Lost circulation can suddenly lower the fluid level in a well, decreasing the static head of drilling fluid in a hot formation can allow the formation gas, hot water or steam to enter the wellbore, causing a loss of well control.

- In the intervals that are not to be produced, the lost circulation zone must be "sealed", to provide the wellbore to be cased and cemented to the surface. This represents a major cost.

The most common ways to combat these losses are as follows:

- Drill ahead with lost circulation. Drill with a light weight fluid that will have a static head less than the pore pressure in the formation, mix the drilling fluid with fibrous materials or particles that will plug the loss apertures in the formation, when the wellbore is completely clean, it can be considered to pause the drilling process and try to seal the lost zones with some materials that can be drilled out as the borehole advances.

The wellbore hole, especially in formations with significant clay content may become unstable by adsorption of water into the clay of the wellbore rock.

Under consolidated formations from the overburden can deteriorate hole cleaning problems, can fall in around the drill pipe to stick it, in addition a very large diameter can be washed. Large washout not only complicate cementing, but also lower fluid velocity in the larger diameter, which leads to a reduce carrying capacity for cuttings.

Swelling or squeezing clays may reduce hole diameters to a point that will either stick the pipe or prevent running casing.

Differential stresses may cause the borehole to become unstable. This is a particular problem whenever boreholes are deviated away from vertical.

A solution to advance drilling is to slow the water adsorption process into clay. The way to reduce the swelling is to use CMC, which acts inhibitive for clays.

Cementation and casing

Casing requirements for geothermal wells include the following: nominal well production rate, depth of the production zone, expected temperatures, brine chemistry, whether the completion will be open hole or slotted liner, well trajectory, KOP, length of individual casing intervals, need for special casing or connection material (Blanckenship and Finger, 2010).

Because geothermal casing must be cemented completely back to the surface, there is often a problem getting a quality cement job done where the formations have shown either low strength or lost circulation. This results from the cement higher density, and thus higher hydrostatic head compared to drilling fluids. Additionally, it is also critical that no water is trapped between the cement and casing, for the possibility that it can collapse the casing as the wellbore goes through its temperature cycles (Bracke et al, 2013).

Methods using very light – weight cement (less than 1, 5 g/cm3) have been successfully used in low pressure and low strength zones. Lost circulation during cementing often results in bed cement jobs where the cement either does not reach the surface or falls back after reaching the surface. İf the cement is not very far from the top where the cement is placed into the annulus via small diameter tubing, called "tremie" pipe.

Casing and cement can account for 30 to 35% of the total well cost (Valmor et al, 2013). This is particularly important in geothermal wells, where the economically necessary mass flow rates requıre larger diameters production intervals compared to typical oil and gas wells.

Failed cement jobs are very difficult to repair. As a last resort, the casing can be perforated and squeeze cemented, but another casing string will have to be run over the perforations, in addiction to that, the production casing will become smaller than planned, reducing the potential flow rate. To guard against such situation the casing program is often designed with the upper casing on size larger than required, in case a contingent string is required.

8.1. Wellpath planning

For well planning, data including measured depth, inclination and azimuth, of some characteristically points were given by the drilling company Cougar that operates in the south west part of Turkey. Input data are shown in Table 8-1.

Table 8-1. Survey values (Cougar, 2015)

MD (m)	Inc (deg)	Azi (deg)
0	0	0
736,400	0,490	137,550
778,00	1,180	255,700
951,00	10,390	249,410
1076,00	16,270	246,410
1307,00	17,500	239,990
1509,00	20,710	245,210
1711,00	20,340	242,400
1865,00	21,050	244,840
1990,00	19,770	245,720
2234,80	21,030	243,750

Given data were implemented in the Sysdrill well planning module, getting additional survey data regarding TVD (m), North (m), East (m), Dogleg (deg/30m), shown in the table 8-2. In this case the survey data was updated in accordance with the procedure and it lunched a 2D and 3D view of the proposed wellpath. Schematic view of the wellpath is shown in the Figures 8–2. and 8–3.

Table 8-2. Cougar well planning path (Sysdrill 10)

Slot

Name	AYG-9
Grid Northing	4188729.540
Grid Easting	579083.360
Latitude	N37 50 33.2812
Longitude	E27 53 55.7587
North	0.000
East	0.000

Installation

Name	AYG-9
Easting	579083.360
Northing	4188729.540
Coord System Name	WGS84-UTM-35N on WORLD GEODETIC SYSTEM 1984 datum
North Alignment	Grid

Field

Name	AYG
Easting	579236.000
Northing	4188919.500
Coord System Name	WGS84-UTM-35N on WORLD GEODETIC SYSTEM 1984 datum
North Alignment	Grid

Wellpath Report

MD[m]	Inc[deg]	Azi[deg]	TVD[m]	North[m]	East[m]	Dogleg [deg/30m]	Vertical Section[m]	Station Position (Grid North)	Station Position (Grid East)
0.000	0.000	0.000	0.000	0.000	0.000		0.000	4188729.540	579083.360
736.400	0.490	137.550	736.390	-2.320	2.130	0.020	-0.940	4188727.220	579085.480
749.600	0.520	191.060	749.590	-2.420	2.150	1.040	-0.920	4188727.120	579085.510
758.800	0.690	220.810	758.790	-2.510	2.110	1.150	-0.850	4188727.030	579085.470
768.300	0.800	231.280	768.290	-2.590	2.020	0.550	-0.730	4188726.950	579085.380
778.000	1.180	255.700	777.990	-2.660	1.870	1.730	-0.570	4188726.880	579085.230
787.600	1.870	263.110	787.580	-2.700	1.620	2.240	-0.320	4188726.840	579084.980
797.200	2.450	260.150	797.180	-2.760	1.260	1.850	0.030	4188726.790	579084.620
806.900	3.030	255.330	806.870	-2.860	0.810	1.930	0.480	4188726.680	579084.170
816.500	3.720	250.840	816.450	-3.020	0.270	2.310	1.040	4188726.520	579083.630
826.000	4.430	249.680	825.930	-3.250	-0.370	2.260	1.710	4188726.290	579082.990
835.700	5.170	251.330	835.590	-3.520	-1.130	2.330	2.520	4188726.020	579082.230
845.300	5.470	248.820	845.150	-3.820	-1.970	1.190	3.400	4188725.720	579081.390
854.900	6.050	246.230	854.700	-4.190	-2.860	1.990	4.370	4188725.350	579080.500
864.400	6.690	248.480	864.140	-4.600	-3.830	2.170	5.420	4188724.940	579079.530
873.900	7.240	249.040	873.570	-5.020	-4.910	1.750	6.570	4188724.530	579078.460
883.600	7.420	249.830	883.190	-5.450	-6.060	0.640	7.800	4188724.090	579077.300
893.100	7.550	247.600	892.610	-5.900	-7.220	1.000	9.040	4188723.640	579076.150
902.700	7.660	248.920	902.130	-6.370	-8.400	0.650	10.310	4188723.170	579074.970
912.400	7.930	248.930	911.740	-6.840	-9.620	0.840	11.620	4188722.700	579073.740
921.900	8.440	249.040	921.140	-7.330	-10.890	1.610	12.970	4188722.210	579072.480
931.600	9.080	249.390	930.730	-7.850	-12.270	1.990	14.440	4188721.690	579071.100
941.200	9.650	249.480	940.200	-8.400	-13.730	1.780	16.000	4188721.140	579069.630
951.000	10.390	249.410	949.850	-9.000	-15.330	2.270	17.700	4188720.540	579068.040
960.500	10.880	248.860	959.190	-9.620	-16.970	1.580	19.450	4188719.920	579066.400
970.200	11.140	249.410	968.710	-10.280	-18.700	0.870	21.290	4188719.260	579064.670
979.600	11.480	249.360	977.930	-10.930	-20.420	1.090	23.130	4188718.610	579062.940
989.300	11.790	248.370	987.430	-11.640	-22.250	1.140	25.080	4188717.900	579061.120
998.900	12.010	246.930	996.820	-12.390	-24.080	1.150	27.060	4188717.150	579059.290
1008.600	12.390	245.010	1006.300	-13.230	-25.950	1.720	29.110	4188716.320	579057.420
1018.200	12.840	244.770	1015.670	-14.120	-27.850	1.420	31.210	4188715.430	579055.520
1027.800	13.590	245.090	1025.020	-15.050	-29.840	2.350	33.400	4188714.500	579053.530
1037.500	14.390	245.010	1034.430	-16.040	-31.960	2.470	35.750	4188713.510	579051.410
1047.100	15.060	245.550	1043.710	-17.060	-34.180	2.140	38.190	4188712.490	579049.190
1056.800	15.540	245.480	1053.070	-18.120	-36.510	1.490	40.740	4188711.430	579046.860
1066.400	15.930	246.630	1062.310	-19.170	-38.890	1.560	43.350	4188710.370	579044.490
1076.000	16.270	246.410	1071.530	-20.230	-41.330	1.080	46.010	4188709.310	579042.040
1085.900	16.820	247.210	1081.020	-21.340	-43.920	1.800	48.830	4188708.200	579039.450
1095.400	17.220	246.830	1090.110	-22.430	-46.480	1.310	51.610	4188707.120	579036.900
1105.100	17.660	246.930	1099.360	-23.570	-49.150	1.360	54.510	4188705.980	579034.220
1114.700	18.200	246.810	1108.490	-24.730	-51.870	1.690	57.460	4188704.820	579031.510
1124.300	19.060	245.810	1117.590	-25.960	-54.680	2.870	60.530	4188703.580	579028.700
1133.800	19.490	245.530	1126.560	-27.260	-57.540	1.390	63.670	4188702.290	579025.840
1143.500	19.900	245.050	1135.690	-28.620	-60.510	1.360	66.930	4188700.930	579022.870
1153.100	19.800	245.540	1144.720	-29.990	-63.470	0.610	70.190	4188699.560	579019.910
1162.700	19.400	245.860	1153.760	-31.310	-66.400	1.290	73.410	4188698.240	579016.980
1172.400	19.770	245.140	1162.900	-32.660	-69.360	1.370	76.670	4188696.890	579014.020
1182.000	20.320	245.560	1171.920	-34.030	-72.350	1.780	79.960	4188695.520	579011.030
1191.700	20.560	244.670	1181.010	-35.460	-75.420	1.210	83.340	4188694.090	579007.960
1201.400	20.210	244.800	1190.100	-36.900	-78.480	1.090	86.720	4188692.650	579004.900
1210.800	19.980	244.520	1198.930	-38.280	-81.400	0.800	89.950	4188691.270	579001.990
1220.500	19.670	244.020	1208.060	-39.710	-84.360	1.090	93.240	4188689.840	578999.020
1230.100	19.300	243.930	1217.110	-41.110	-87.240	1.160	96.440	4188688.440	578996.150
1239.800	19.260	243.850	1226.260	-42.520	-90.120	0.150	99.650	4188687.030	578993.270
1249.500	18.940	243.990	1235.430	-43.920	-92.970	1.000	102.820	4188685.630	578990.420
1259.100	18.850	242.530	1244.510	-45.320	-95.740	1.500	105.930	4188684.240	578987.650
1266.400	18.870	242.930	1251.420	-46.400	-97.840	0.540	108.280	4188683.160	578985.550
1297.400	17.690	240.360	1280.860	-51.010	-106.400	1.380	117.990	4188678.550	578977.000
1307.000	17.500	239.990	1290.010	-52.450	-108.920	0.690	120.880	4188677.100	578974.480
1316.700	17.870	240.290	1299.250	-53.920	-111.470	1.180	123.820	4188675.640	578971.920
1326.300	18.340	241.900	1308.370	-55.360	-114.080	2.150	126.790	4188674.200	578969.310
1335.900	19.000	243.580	1317.470	-56.770	-116.820	2.660	129.870	4188672.790	578966.580
1345.400	19.420	244.150	1326.440	-58.150	-119.620	1.450	132.990	4188671.410	578963.780
1355.000	19.790	245.250	1335.480	-59.520	-122.530	1.630	136.210	4188670.040	578960.870
1364.600	20.380	247.240	1344.500	-60.850	-125.550	2.820	139.510	4188668.710	578957.850

1374.300	20.700	248.600	1353.580	-62.130	-128.700	1.780	142.910	4188667.430	578954.700
1383.900	20.920	250.000	1362.560	-63.330	-131.900	1.700	146.310	4188666.230	578951.510
1393.500	21.070	250.200	1371.520	-64.500	-135.130	0.520	149.730	4188665.060	578948.270
1403.100	21.380	250.570	1380.470	-65.670	-138.400	1.060	153.190	4188663.890	578945.000
1412.600	21.480	249.450	1389.310	-66.860	-141.660	1.330	156.650	4188662.700	578941.740
1422.400	21.660	248.800	1398.420	-68.140	-145.030	0.920	160.240	4188661.420	578938.380
1431.900	21.600	247.210	1407.250	-69.450	-148.280	1.860	163.740	4188660.110	578935.130
1441.400	20.670	246.510	1416.120	-70.800	-151.430	3.040	167.160	4188658.770	578931.980
1451.100	20.570	246.150	1425.190	-72.170	-154.560	0.500	170.580	4188657.390	578928.850
1460.700	20.500	246.900	1434.180	-73.510	-157.640	0.850	173.940	4188656.050	578925.770
1470.300	20.230	247.550	1443.180	-74.800	-160.730	1.100	177.280	4188654.760	578922.690
1479.900	20.030	246.500	1452.200	-76.090	-163.770	1.290	180.580	4188653.470	578919.650
1489.600	20.370	246.300	1461.300	-77.430	-166.840	1.070	183.930	4188652.130	578916.580
1499.300	20.470	245.880	1470.390	-78.810	-169.930	0.550	187.310	4188650.760	578913.480
1509.000	20.710	245.210	1479.470	-80.220	-173.040	1.040	190.720	4188649.350	578910.380
1518.600	20.660	245.130	1488.450	-81.640	-176.110	0.180	194.110	4188647.920	578907.300
1528.300	20.780	245.230	1497.530	-83.080	-179.230	0.390	197.550	4188646.480	578904.190
1537.900	20.920	244.220	1506.500	-84.540	-182.320	1.210	200.960	4188645.030	578901.100
1547.500	20.930	243.090	1515.460	-86.060	-185.390	1.260	204.390	4188643.500	578898.030
1557.100	20.550	242.980	1524.440	-87.600	-188.420	1.190	207.790	4188641.960	578895.000
1566.800	20.350	242.120	1533.530	-89.170	-191.430	1.120	211.170	4188640.400	578891.990
1576.400	20.240	241.910	1542.530	-90.730	-194.370	0.410	214.500	4188638.840	578889.060
1586.000	20.110	243.040	1551.550	-92.260	-197.300	1.280	217.810	4188637.310	578886.120
1595.600	20.060	245.610	1560.560	-93.690	-200.270	2.760	221.100	4188635.880	578883.150
1605.200	20.030	247.790	1569.580	-94.990	-203.300	2.340	224.390	4188634.580	578880.130
1614.900	19.810	248.960	1578.700	-96.210	-206.370	1.410	227.690	4188633.360	578877.060
1624.500	19.700	249.160	1587.740	-97.370	-209.400	0.400	230.930	4188632.200	578874.030
1634.200	20.090	248.410	1596.860	-98.560	-212.480	1.440	234.220	4188631.010	578870.950
1643.800	20.570	248.710	1605.860	-99.780	-215.580	1.530	237.550	4188629.790	578867.850
1653.400	21.110	248.640	1614.830	-101.020	-218.760	1.690	240.960	4188628.550	578864.670
1663.000	21.490	247.820	1623.770	-102.320	-222.000	1.510	244.440	4188627.260	578861.430
1672.800	21.680	247.380	1632.890	-103.690	-225.330	0.760	248.040	4188625.880	578858.100
1682.200	21.640	246.950	1641.620	-105.040	-228.530	0.520	251.510	4188624.540	578854.900
1691.900	21.490	245.460	1650.640	-106.470	-231.790	1.760	255.070	4188623.100	578851.640
1701.400	20.730	243.030	1659.510	-107.960	-234.870	3.660	258.490	4188621.620	578848.560
1711.000	20.340	242.400	1668.500	-109.500	-237.870	1.400	261.860	4188620.070	578845.570
1720.600	20.210	242.490	1677.500	-111.040	-240.820	0.420	265.180	4188618.530	578842.620
1730.300	20.020	243.220	1686.610	-112.560	-243.780	0.970	268.510	4188617.010	578839.650
1739.900	19.720	243.950	1695.640	-114.020	-246.710	1.220	271.780	4188615.560	578836.730
1749.500	19.490	243.790	1704.680	-115.430	-249.600	0.740	275.000	4188614.140	578833.840
1759.100	19.560	244.250	1713.730	-116.840	-252.480	0.530	278.200	4188612.740	578830.960
1768.800	20.020	244.210	1722.860	-118.270	-255.440	1.420	281.490	4188611.310	578828.000
1778.400	20.150	245.370	1731.870	-119.670	-258.420	1.310	284.780	4188609.910	578825.020
1788.000	19.940	245.860	1740.890	-121.030	-261.420	0.840	288.070	4188608.550	578822.020
1797.600	19.580	246.670	1749.930	-122.340	-264.390	1.410	291.320	4188607.240	578819.050
1807.400	19.480	246.730	1759.160	-123.630	-267.400	0.310	294.590	4188605.950	578816.050
1817.000	19.750	245.890	1768.210	-124.930	-270.350	1.220	297.820	4188604.650	578813.100
1826.600	19.730	245.560	1777.240	-126.260	-273.310	0.350	301.060	4188603.320	578810.140
1836.300	20.230	245.490	1786.360	-127.630	-276.320	1.550	304.370	4188601.950	578807.130
1845.800	20.870	244.410	1795.250	-129.050	-279.340	2.350	307.710	4188600.540	578804.110
1855.400	21.080	245.210	1804.220	-130.510	-282.450	1.110	311.140	4188599.070	578801.000
1865.000	21.050	244.840	1813.180	-131.970	-285.580	0.430	314.590	4188597.620	578797.870
1874.700	20.890	244.850	1822.230	-133.440	-288.720	0.490	318.060	4188596.140	578794.730
1884.300	20.710	246.600	1831.210	-134.840	-291.830	2.020	321.470	4188594.740	578791.620
1893.800	20.670	247.630	1840.100	-136.150	-294.920	1.160	324.830	4188593.440	578788.530
1903.400	20.280	247.720	1849.090	-137.420	-298.030	1.220	328.180	4188592.160	578785.430
1913.100	20.190	246.570	1858.190	-138.730	-301.120	1.260	331.530	4188590.860	578782.340
1922.600	20.340	244.590	1867.100	-140.090	-304.120	2.220	334.820	4188589.500	578779.340
1932.300	20.220	243.400	1876.200	-141.560	-307.140	1.330	338.180	4188588.030	578776.320
1941.900	20.180	242.840	1885.210	-143.060	-310.090	0.620	341.500	4188586.530	578773.370
1951.600	19.940	243.000	1894.320	-144.570	-313.060	0.760	344.820	4188585.010	578770.400
1961.300	20.000	244.440	1903.440	-146.040	-316.030	1.530	348.130	4188583.550	578767.440
1970.900	19.850	245.520	1912.460	-147.420	-318.990	1.240	351.410	4188582.160	578764.470
1980.300	19.830	245.000	1921.310	-148.760	-321.890	0.570	354.600	4188580.830	578761.580
1990.000	19.770	245.720	1930.430	-150.130	-324.880	0.780	357.880	4188579.460	578758.590
1999.600	19.880	245.230	1939.460	-151.480	-327.840	0.620	361.140	4188578.110	578755.630
2009.200	20.120	243.390	1948.490	-152.900	-330.800	2.100	364.420	4188576.690	578752.670
2018.700	20.400	241.910	1957.400	-154.420	-333.720	1.840	367.710	4188575.170	578749.750
2028.300	20.650	241.750	1966.390	-156.000	-336.680	0.800	371.070	4188573.590	578746.780
2037.900	20.570	241.330	1975.370	-157.620	-339.660	0.530	374.440	4188571.980	578743.810
2047.500	20.410	242.560	1984.370	-159.200	-342.620	1.440	377.800	4188570.400	578740.850
2057.200	20.410	243.040	1993.460	-160.740	-345.630	0.520	381.180	4188568.850	578737.840
2066.800	20.020	244.040	2002.470	-162.220	-348.600	1.630	384.490	4188567.370	578734.870
2076.400	19.970	243.180	2011.490	-163.680	-351.540	0.930	387.780	4188565.910	578731.930
2086.100	19.690	242.840	2020.610	-165.170	-354.470	0.940	391.060	4188564.420	578729.000
2095.700	19.590	241.530	2029.650	-166.680	-357.320	1.410	394.290	4188562.920	578726.150
2105.300	19.580	242.020	2038.700	-168.200	-360.160	0.510	397.500	4188561.390	578723.320
2114.700	19.250	242.580	2047.560	-169.650	-362.930	1.210	400.620	4188559.940	578720.550
2124.400	19.000	243.160	2056.730	-171.100	-365.750	0.970	403.800	4188558.490	578717.720
2133.900	19.530	243.740	2065.700	-172.500	-368.560	1.780	406.930	4188557.090	578714.920
2143.600	19.540	245.420	2074.840	-173.890	-371.490	1.740	410.170	4188555.700	578711.990
2153.200	20.050	245.440	2083.870	-175.250	-374.440	1.590	413.420	4188554.350	578709.040
2162.700	20.380	246.440	2092.790	-176.580	-377.440	1.510	416.710	4188553.010	578706.040
2172.300	20.470	245.320	2101.780	-177.950	-380.500	1.250	420.060	4188551.640	578702.980
2182.000	20.510	245.520	2110.870	-179.370	-383.590	0.250	423.450	4188550.230	578699.900
2220.200	21.030	243.750	2146.590	-185.170	-395.830	0.640	437.000	4188544.430	578687.660
2234.800	21.030	243.750	2160.210	-187.490	-400.520	0.000	442.230	4188542.110	578682.960

Survey Tool Program

Reference	Survey Name	MD[m]	TVD[m]	Survey Tool	Error Model
1224386.000	CDS MWD S	2220.200	2146.590	ISCWSA MW	Rev 3 + Fixed Rig + Rotating
1224700.000	Proj to TD	2234.800	2160.210	Blind Model	Blind Drilling

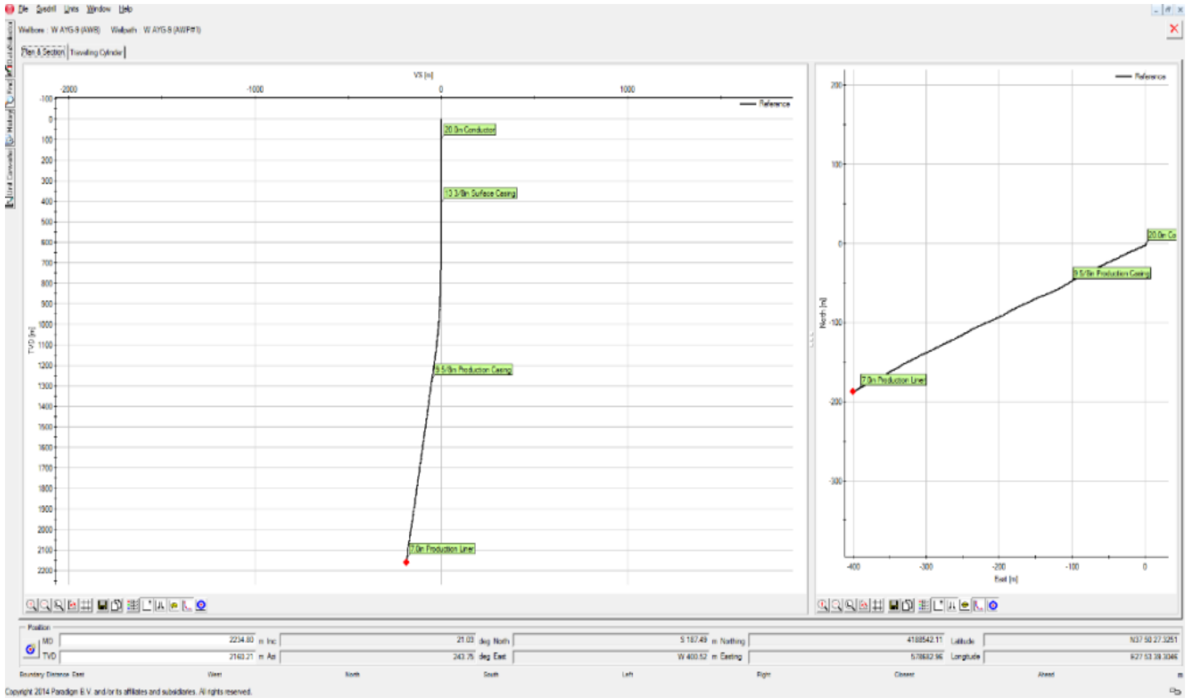


Figure 8-2.2D view of the well (Sysdrill 10)

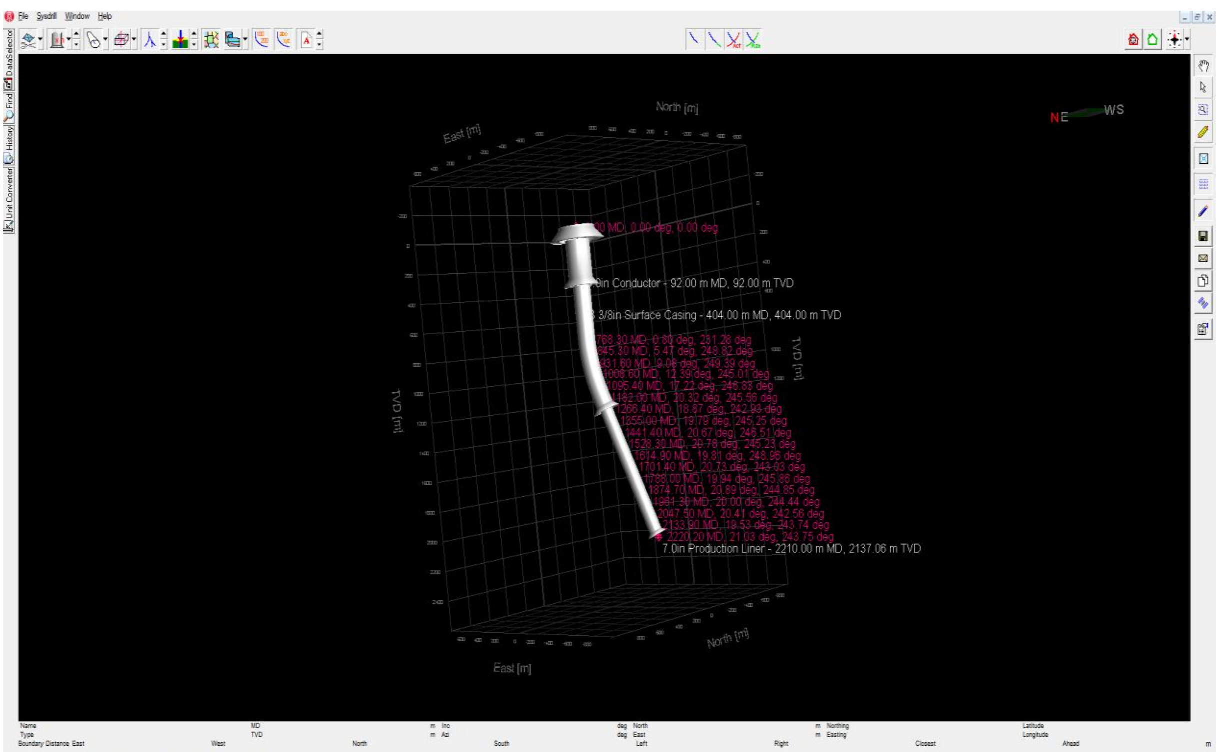


Figure 8-3. 3D view of the well (Sysdrill 10)

8.2. Well design

The well design defines the desired final well performance. The design defines: casing sizes, grades, weights, connections and sitting positions, positions of permanent packers, perforation intervals, down hole sand control measures, required completion design, wellhead and x -mas three. Surface locations and directional requirements are also part of the well design.

Once the well design is known, then the drilling program can be written to achieve the proper well design.

The steps to obtain a proper well design include:

- identify all potential hazards, surface and subsurface problematic areas. Establish the problems and determine how they can be controlled or solved;
- identify completion design, including fluid, necessary sand control measures and down hole equipment. This should be done before running the casing string;
- chose casing setting depth that allows kick tolerance, minimize potential down hole hazards and drilling problems. Define the casing properties (outside diameter, weight, grade connections, etc.), for each casing string.
- define the wellhead and x - mas three requirements;
- estimate time and cost for each step.

Fluid gradients, temperatures and potential surface pressure will dictate the minimum strength of the casing required during production. Where a well intersects several zones where the production should be achieved, from it is possible to run two completion strings using pakers to separate two zones.

The design of a geothermal well is based on a “bottom – up” approach. The required flow rate determinates the diameter at the bottom of the hole and the location of the pay zone determines the well’s overall length. The well profile above the production zone is set by iteration of successively larger casing strings. Because geothermal well’s producing relatively low – value fluids (hot water or steam) , flow rate must be much higher (often > 100, 000 kg/hr.) than for oil and gas wells and produce directly through casing from the reservoir instead through tubing string inside casing like most of the oil and gas wells. The typical casing sizes in geothermal production are from 20 to 34 cm (Blankenship and Finger, 2010) .

Figure 8-4. shows a possible casing profile for a geothermal well, with defined casing and hole size.

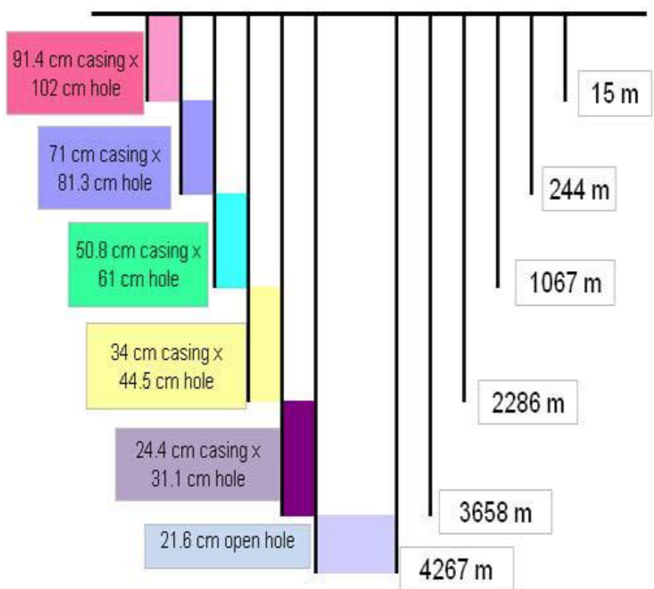


Figure 8-4. Example of a geothermal well design (Blankenship and Finger, 2010)

8.3. Well design of the geothermal well

The hole section and casing of the geothermal well were also defined by their nominal OD and MD as shown in the table 8–3.

Table 8-3. Hole section profile (Cougar, 2015)

Diameter (in)	From MD (m)	To MD (m)
24	0,00	92,00
17	92,00	404,00
12 1/4	404,00	1281,00
8 1/2	1281,00	2234,80

Properties of the chosen casings are shown in table 8-4.

Table 8-4. Casing profile

Diameter (in)	Start MD (m)	Shoe Depth (m)	Material (N/m)	Type
20,0	0,00	92,00	127,45 N/m, K55	Conductor
13 3/8	92,00	404,00	82,7 N/m, K55	Surface Casing
9 5/8	404,00	1281,00	58,98 N/m, L80	Production Casing
7,0	1216,00	2210,00		Production Liner (Sloted)

The program allows a graphical view of the hole sections and casing strings, with setting depths of each casing and hole section, both in MD and TVD as it is shown in the Figure 8-5.

By defining the casing OD and material, it was possible to choose the production liner and casing string from the Sysdrill catalogue (Figure 8-5.).

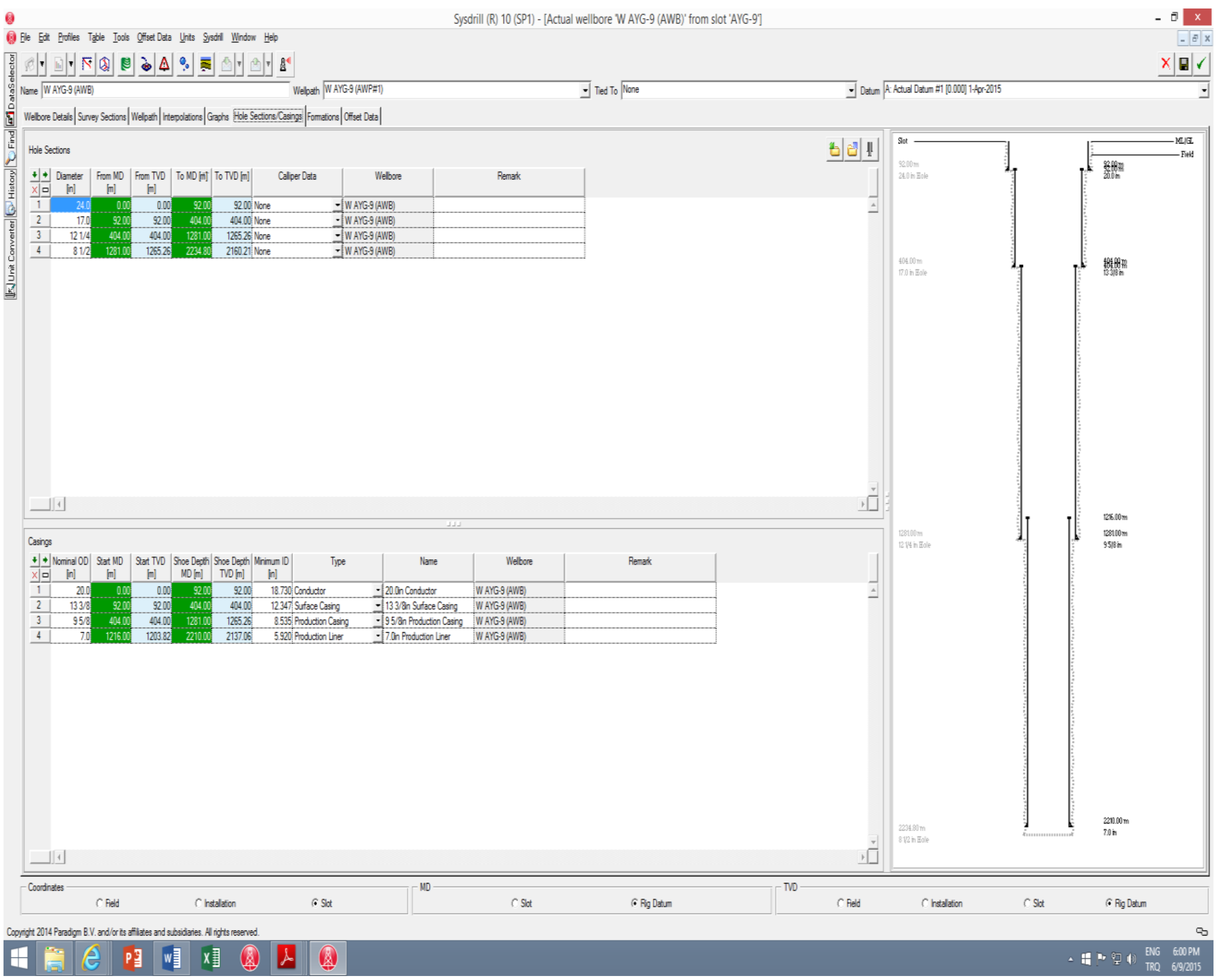


Figure 8-5. Casing and hole section depths (Sysdrill 10)

Torque and drag increased values can represent a big problem while drilling a directional well. In the next part will be applied Sydrill 10 Torque and Drag module for the previously designed wellpath.

8.4. Torque and drag analyses

For the analyses, Sysdrill 10 torque and drag module was used, to give a presentation of the Sysdrill 10 capability. The scope of the analysis was to observe the differences in surface torque, torsional yield and Von Miesses stress, using different BHA's for the same depth of 1000 m. The BHA used were: Packed hole BHA, Pendulum BHA and Steerable BHA.

In order to run the calculations, it was necessary to define parameters such as: WOB, RPM and flow rate (table 8-5.).

Table 8-5. Defined values for torque and drag calculations

WOB (tons)	RPM (rotation/min)	Flow rate (l/min)	Fluid density kg/m^3
6	40	1500	1030 – 1130

8.4.1. Torque and drag results for Packed Hole BHA

Data regarding the components of the Packed Hole BHA (type, grade, length, OD, ID, weight, wall thickness) are shown in the figure 8-6.

Figure 8-6. Graphical view of Packed Hole BHA (Sysdrill 10)

Torque and drag results were obtained using the Sysdrill Torque and Drag module (Table 8-6.).

Table 8-6. Torque and drag results for Packed Hole BHA

Density (Kg/m^3)	Surface Torque (N x m)	Torsional Yield (N x m.)	Von Miesses Stress (MPa)
1030	1692,54	99614,25	121,132
1040	1695,49	99616,59	120,969
1050	1698,47	99618,92	120,806
1060	1701,47	99621,26	120,644
1070	1704,5	99623,58	120,481
1080	1707,57	99625,91	120,319
1090	1710,67	99628,23	120,156
1100	1713,82	99630,54	119,994
1110	1717,01	99632,86	119,832
1120	1720,25	99635,17	119,67
1130	1723,54	99637,48	119,508

By looking at the charts bellow, it is clear that by increasing mud density, surface torque and torsional yield will increase almost linearly (figures 8-7. and 8-8.), while for Von Miesses stress, increasing mud density will result as a decrease of Von Miesses stress (Figure 8-9).

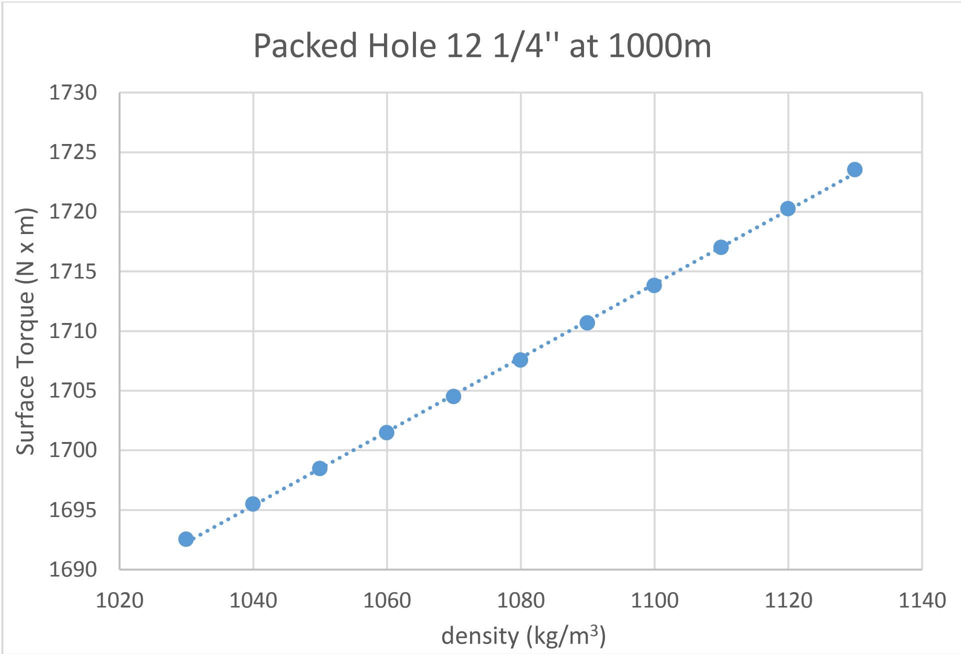


Figure 8-7. Surface torque vs. density for Packed Hole BHA (Sysdrill 10)

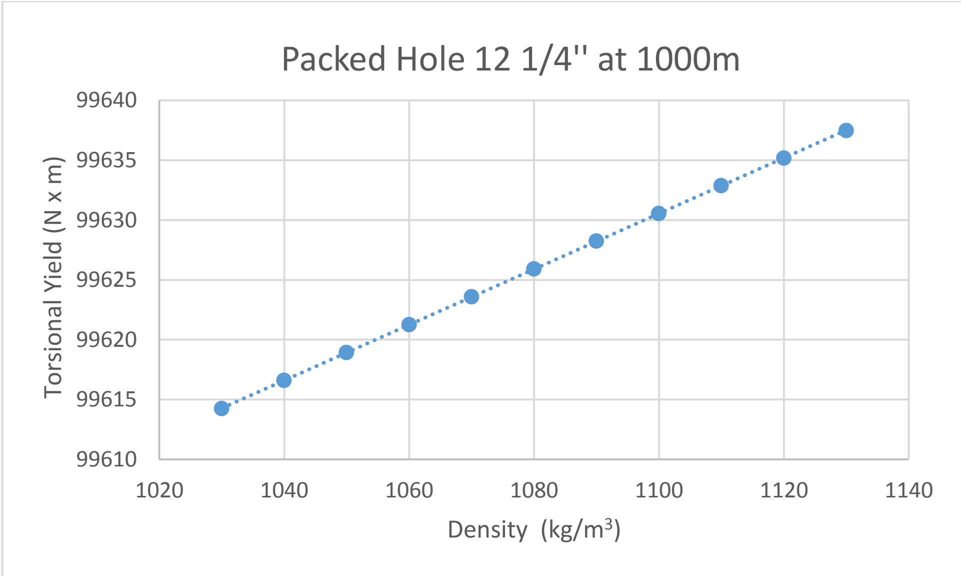


Figure 8-8. Torsional yield vs. density for Packed Hole BHA (Sysdrill 10)

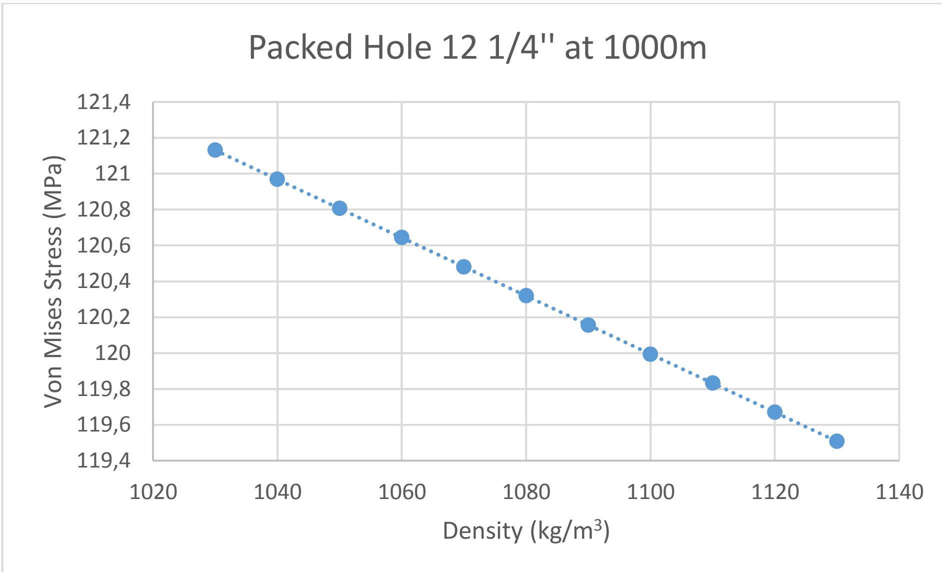


Figure 8-9. Von Miesses stress vs. density for Packed hole BHA (Sysdrill 10)

8.4.2. Torque and drag results for Pendulum BHA

Data regarding the components of the Pendulum BHA (type, grade, length, OD, ID, weight, wall thickness) are shown in the Figure 8-10.

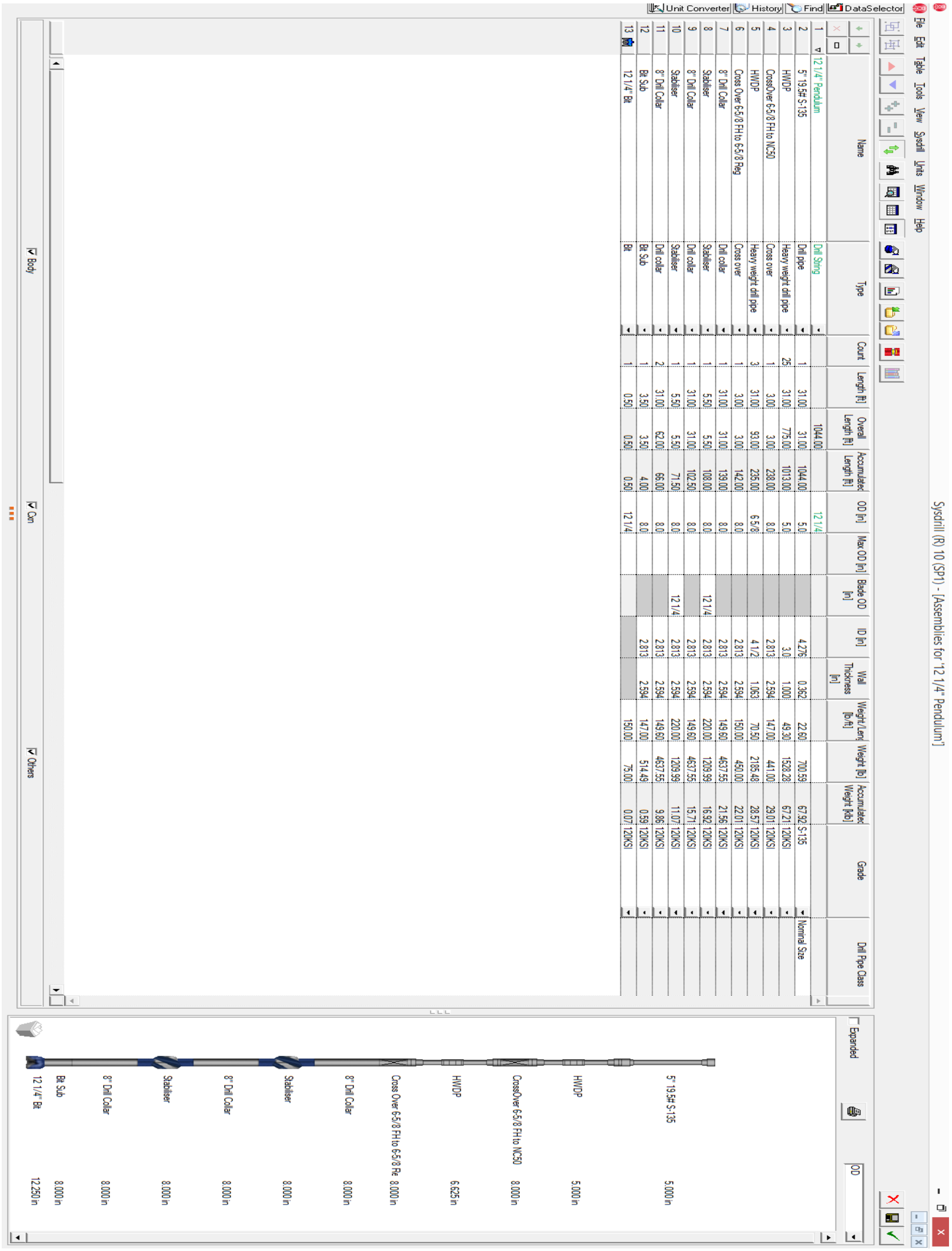


Figure 8-10. Graphical view of Pendulum BHA (Sysdrill 10)

Torque and drag results were obtained using the Sysdrill Torque and Drag module (table 8-7.).

Table 8-7. Torque and drag results for Pendulum BHA

Density (kg/m^3)	Surface Torque (N x m)	Torsional Yield (N x m)	Von Misses Stress (Mpa)
1030	1629,71	99594,95	122,397
1040	1632,78	99597,35	122,232
1050	1635,85	99599,75	122,066
1060	1638,93	99602,15	121,9
1070	1642,03	99604,54	121,735
1080	1645,13	99606,4	121,569
1090	1648,24	99609,32	121,409
1100	1651,37	99611,7	121,23
1110	1654,5	99614,08	121,073
1120	1657,65	99616,46	120,907
1130	1660,8	99618,83	120,742

Same as for Pendulm, increasing mud density, surface torque and torsional yield will increase almost linearly (figures 8-11. and 8-12.), while for Von Miesses stress, increasing mud density will result as a decrease of Von Miesses stress (Figure 8-13.).

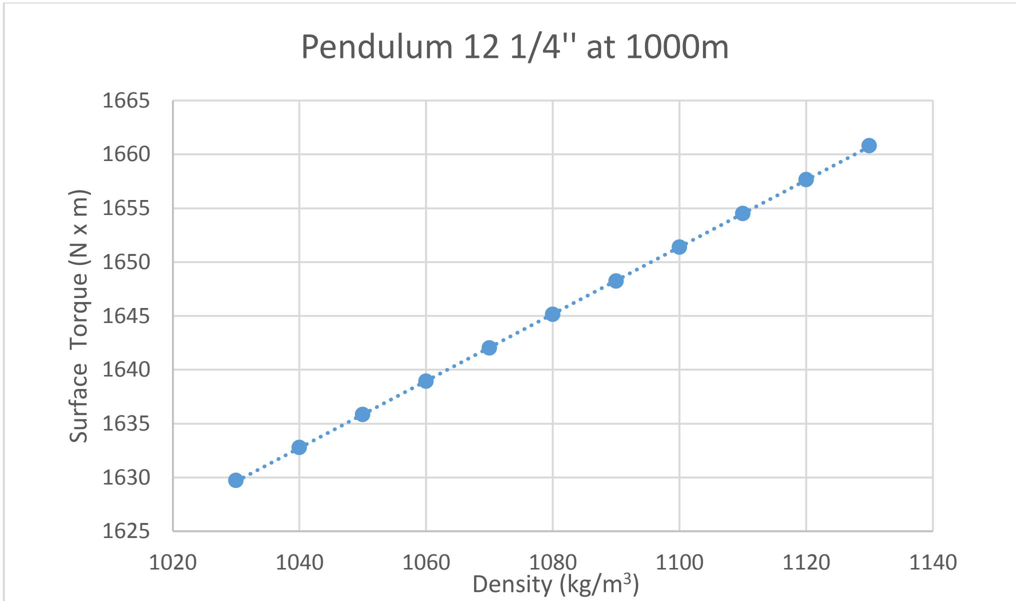


Figure 8-11. Surface torque vs. density for Pendulum BHA (Sysdrill 10)

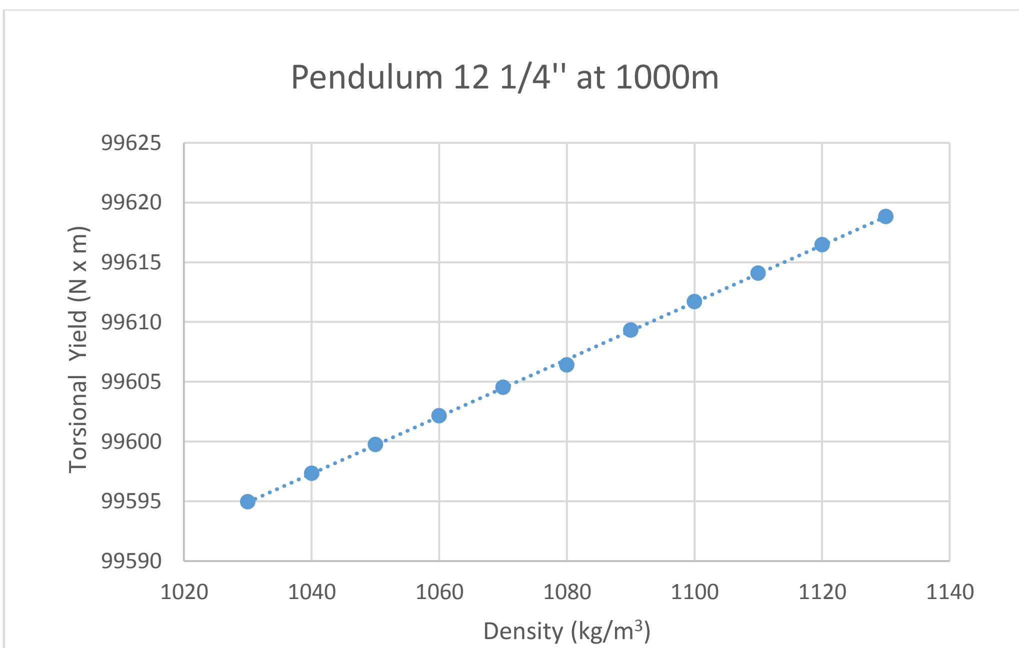


Figure 8-12. Torsional Yield vs. density for Pendulum BHA (Sysdrill 10)

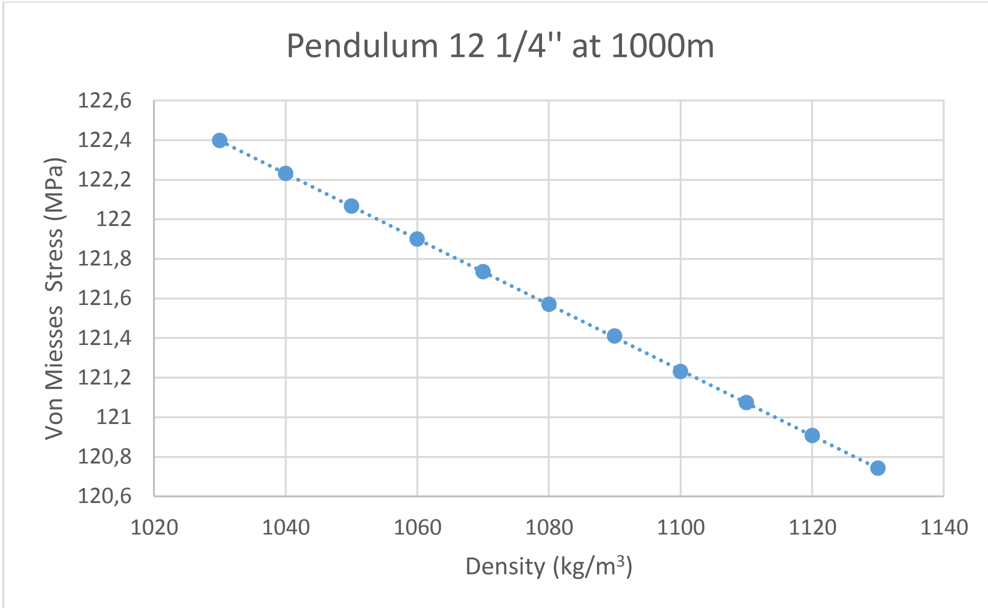
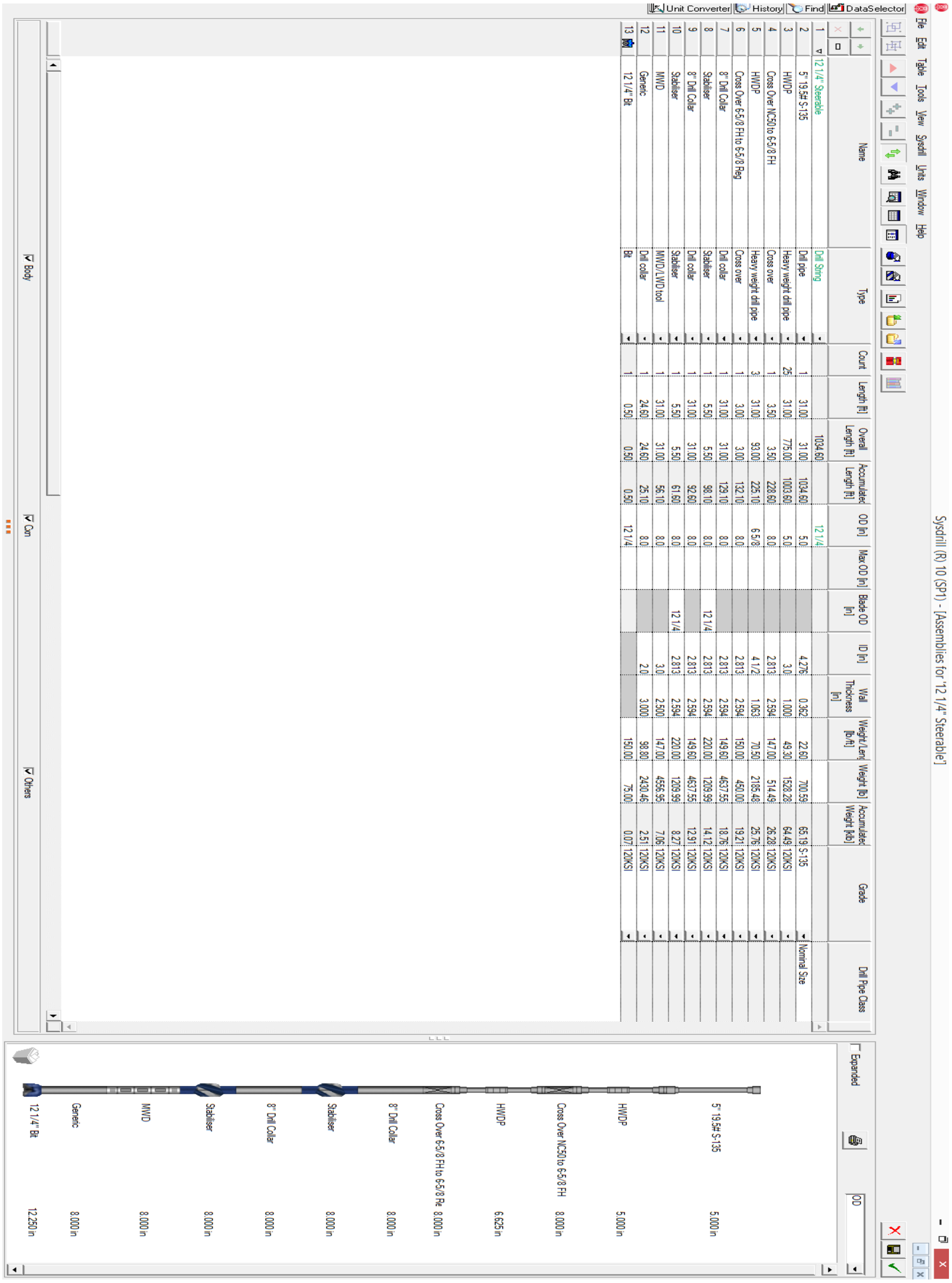


Figure 8-13. Von Miesses Stress vs. density for Pendulum BHA (Sysdrill 10)

8.4.3. Torque and drag results for Steerable BHA

Data regarding the components of the Pendulum BHA (type, grade, length, OD, ID, weight, wall thickness) are shown in the Figure 8-14.



	Name	Type	Count	Length [ft]	Overall Length [ft]	Accumulated Length [ft]	OD [in]	Max OD [in]	Blade OD [in]	ID [in]	Wall Thickness [in]	Weight/Length [lb/ft]	Weight [lb]	Accumulated Weight [klb]	Grade	Drill Pipe Class
1	12 1/4" Steerable	Drill String			1034.60		12 1/4									
2	5" 19.5# S-135	Drill pipe	1	31.00	31.00	1034.60	5.0			4.276	0.362	22.60	700.59	65.19	S-135	Nominal Size
3	HWDP	Heavy weight drill pipe	25	31.00	775.00	1003.60	5.0			3.0	1.000	49.30	1528.28	64.49	120KSI	
4	Cross Over NC50 to 6-5/8 FH	Cross over	1	3.50	3.50	228.60	8.0			2.813	2.594	147.00	514.49	26.28	120KSI	
5	HWDP	Heavy weight drill pipe	3	31.00	93.00	225.10	6 5/8			4 1/2	1.063	70.50	2185.48	25.76	120KSI	
6	Cross Over 6-5/8 FH to 6-5/8 Reg	Cross over	1	3.00	3.00	132.10	8.0			2.813	2.594	150.00	450.00	19.21	120KSI	
7	8" Drill Collar	Drill collar	1	31.00	31.00	129.10	8.0			2.813	2.594	149.60	4637.55	18.76	120KSI	
8	Stabiliser	Stabiliser	1	5.50	5.50	98.10	8.0		12 1/4	2.813	2.594	220.00	1209.99	14.12	120KSI	
9	8" Drill Collar	Drill collar	1	31.00	31.00	92.60	8.0			2.813	2.594	149.60	4637.55	12.91	120KSI	
10	Stabiliser	Stabiliser	1	5.50	5.50	61.60	8.0		12 1/4	2.813	2.594	220.00	1209.99	8.27	120KSI	
11	MWD	MWD/LWD tool	1	31.00	31.00	56.10	8.0			3.0	2.500	147.00	4556.95	7.06	120KSI	
12	Generic	Drill collar	1	24.60	24.60	25.10	8.0			2.0	3.000	98.80	2430.46	2.51	120KSI	
13	12 1/4" Bit	Bit	1	0.50	0.50	0.50	12 1/4					150.00	75.00	0.07	120KSI	

Figure 8-14. Graphical view of Steerable BHA (Sysdrill 10)

Torque and drag results were obtained using the Sysdrill Torque and Drag module (Table 8-8).

Table 8-8. Torque and drag results for Steerable BHA

Density (kg/m^3)	Surface Torque (N x m.)	Torsional Yield (N x m.)	Von Misses Stress (MPa)
1030	2913,05	99312,41	142,19
1040	2911,26	99315,39	142,08
1050	2909,42	99318,51	141,815
1060	2907,62	99321,64	141,623
1070	2905,87	99324,76	141,432
1080	2904,17	99327,87	1412,4
1090	2902,52	99330,98	141,048
1100	2900,91	99334,09	140,856
1110	2899,35	99337,15	140,665
1120	2897,84	99340,29	140,473
1130	2896,37	99343,38	140,282

By looking at the charts bellow, it is clear that by increasing mud density, surface torque and Von Miesses stress will decrease almost linearly (figures 8-15. and 8-17), while for torsional yield , increasing mud density will result as an increase of torsional yield (figure 8-16).

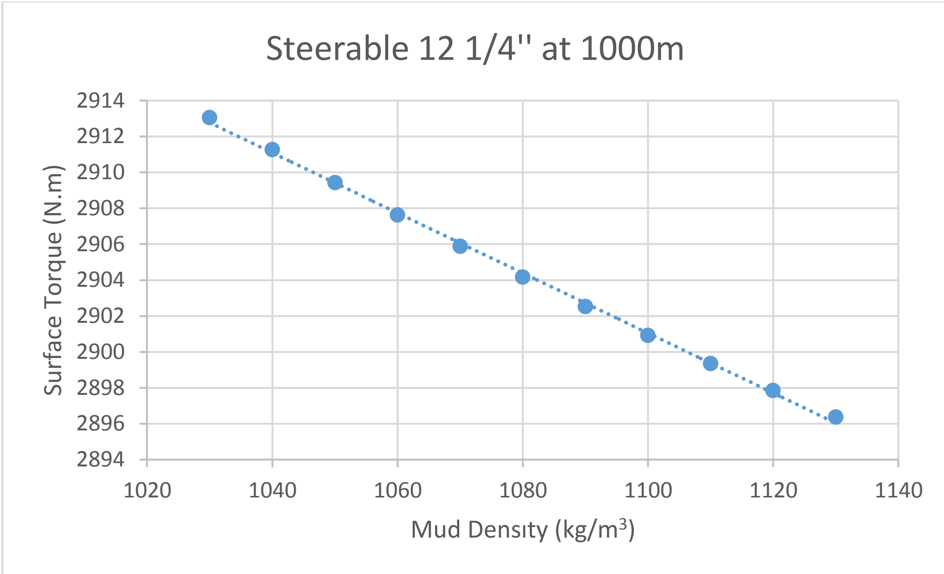


Figure 8-15. Surface torque vs. density for Steerable BHA (Sysdrill 10)

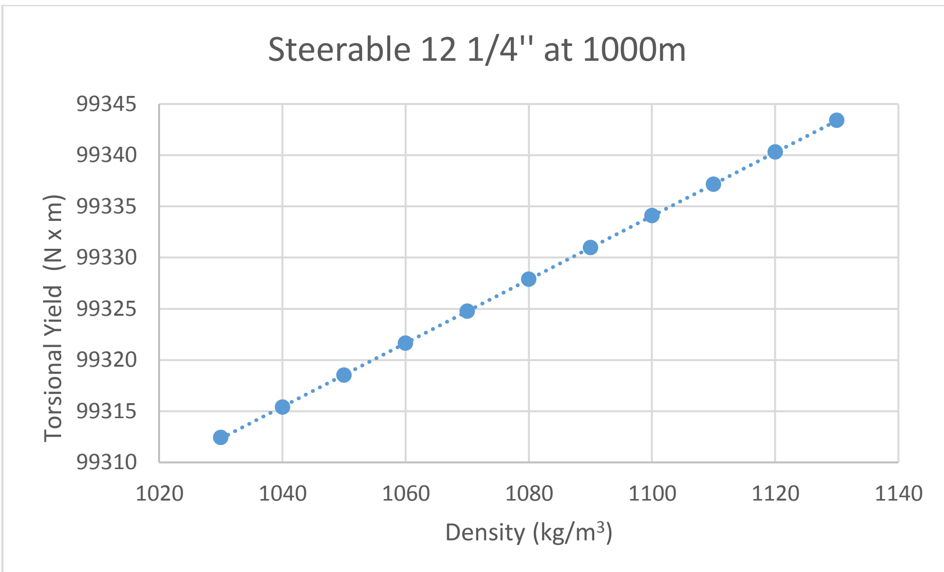


Figure 8-16. Torsional Yield vs. density for Steerable BHA (Sysdrill 10)

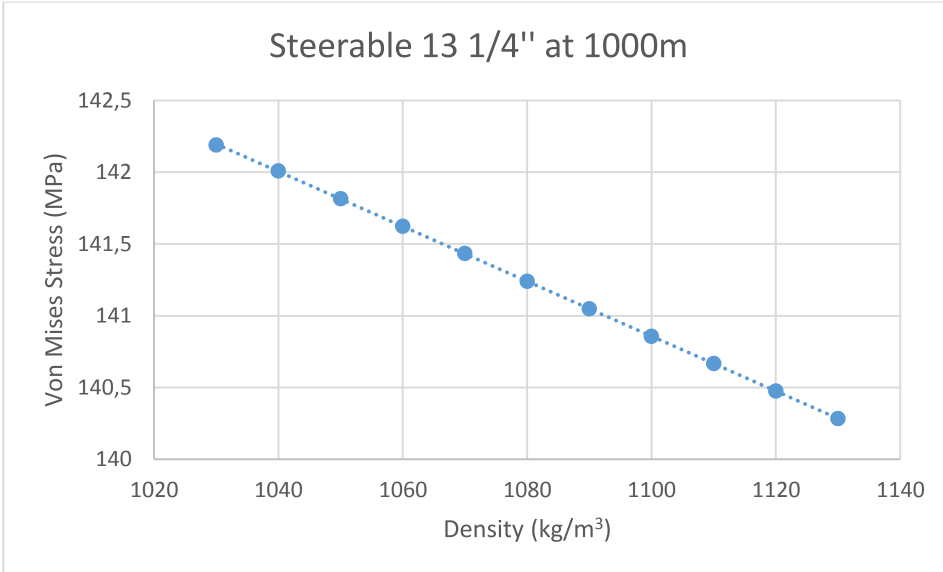


Figure 8-17. Von Miesses Stress vs. density for Steerable BHA (Sysdrill 10)

8.5. Observation and results

Comparing the results for different BHA's for the same depth (1000m), it was possible to obtain the following results:

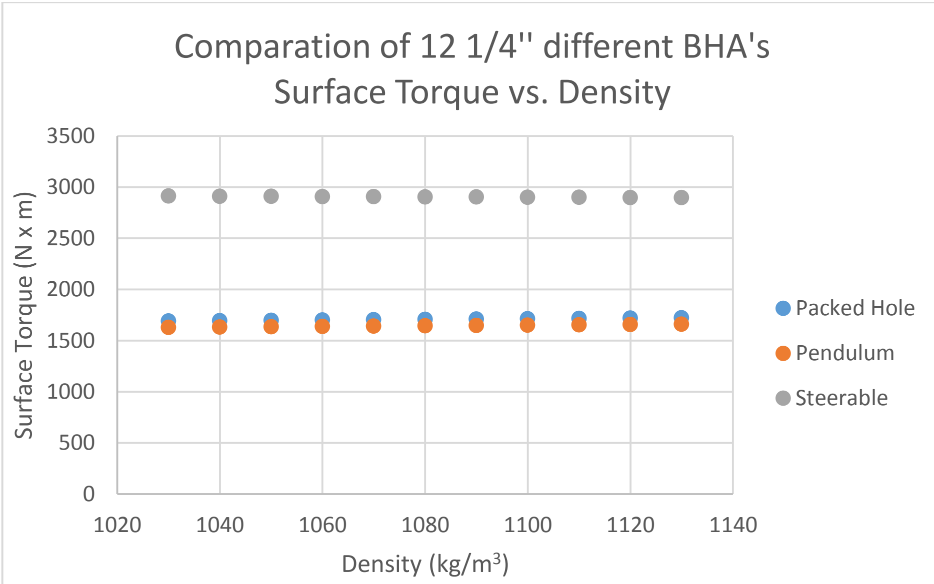


Figure 8-18. Surface torque vs. density for different BHA's

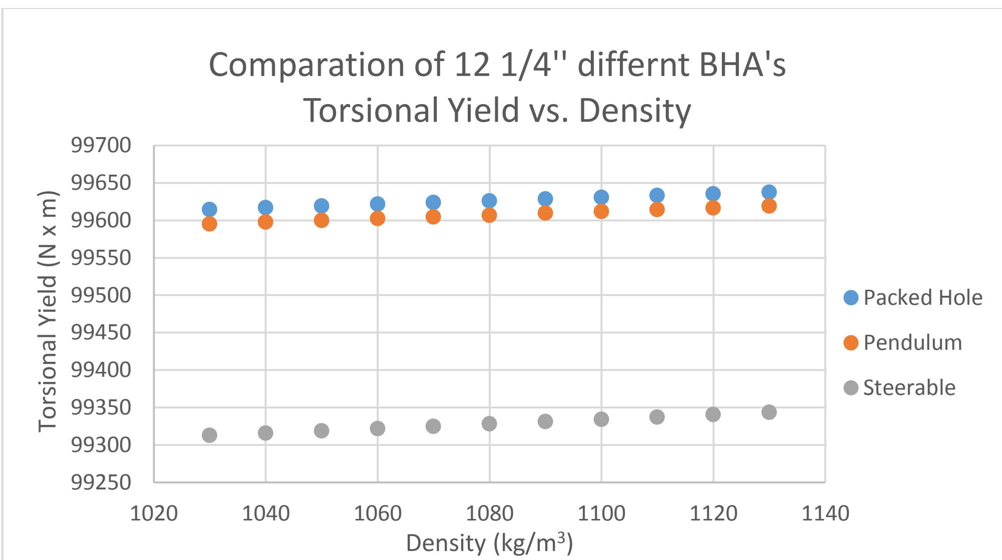


Figure 8-19. Torsional yield vs. density for different BHA's

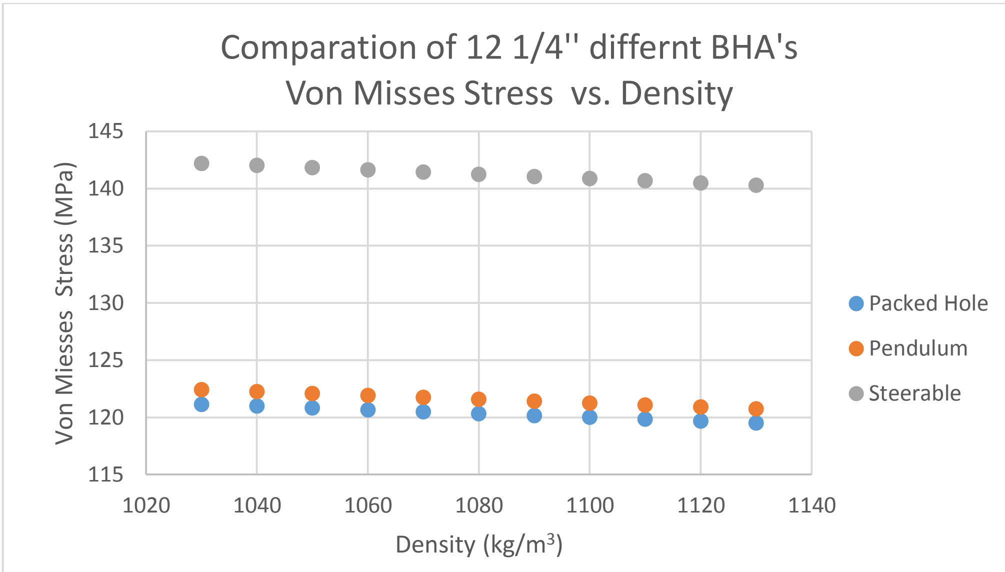


Figure 8-20. Von Miesses stress vs. density for different BHA's

By looking at the charts it is clear that surface torque values will be less if it is used pendulum BHA, in terms of torsional yield the lowest values will be using a steerable BHA and the minimal values for Von Miesses stress would be obtained by using a packed hole BHA.

9. CONCLUSION

To get a general overview of the Sysdrill 10 capacity using the actual geothermal well data, it was necessary to present the complexity of geothermal directional drilling.

Today, most of the directional well planning is done using well planning software's. Modern computer technologies, such as 3D visualization, have provided engineers integrated and interactive tools to create, visualize, and optimize well paths.

Drilling directional wells can be very complex, and an increased knowledge of torque and drag modeling and interpretation can be very useful. High costs and increased risks in these wells make torque and drag analysis important part of the drilling process.

Sysdrill 10 also offers significant engineering solutions in terms of applying hydraulics, casing design, cementing and well control modules.

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Statement

I declare that this thesis is my own work, and that it was made based on the knowledge gained at the Faculty of Mining, Geology and Petroleum Engineering using the specified literature.

Silvio Japundžić