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OVERVIEW ON DIRECTIONAL DRILLING WELLS

Busahmin Bashir[1], Marek Piaskowy[2] and Gamal Alusta[3]
[1]Petroleum and Chemical Engineering, Universiti Teknologi Brunei, Brunei Darussalam
[2]Directional Drilling Service, Exalo Drilling Oil and Gas Exploration Company, Cracow, Poland
[3]Chemical and Petroleum Engineering, United Arab Emirates University, Alain, Abu Dhabi, United Arab Emirates
E-Mail: bashir.abusahmin@utb.edu.bn

ABSTRACT

Drilling a well is a cost intangible, because a well costs millions of dollars, so the more dollars that is spent in a well, the more oil and gas has to be produced over the life of a well. If costs are not accurate, the economics change after a well has been drilled, as a result, the estimated costs are risked i.e. a success factor is placed on the well. The lower the factor, the lower the chance of success and an estimated cost can change the risk profit of any well. These days the improvement of drilling technology is so challenging, however most of the wells drilled in around the world directional wells are. For effortlessness, a directional well is one that is not vertically drilled purposefully or inadvertently. As drilling activity expands more and more places are becoming inaccessible hence the need for directional drilling. It is essential to comprehend the requirement for directional wells, as well as planning and execution. The idea of directional drilling has changed the way wherein wells are drilled everywhere today, from simple deviated wells to horizontals and multilateral wells; the wells made an unavailable areas accessible while increasing the area for drainage by each well drilled, with the wide application of such methods in the world. This paper represents an overview for directional wells with emphasis of the application using real field data, a case study from Poland related to J-shape, S-shape drilling profile .Moreover, directional and horizontal drilling provides more access to the oil reservoirs, thereafter more oil will be produced over vertical wells.

Keywords: side-tracking, bottom hole assembly, directional wells, horizontal wells, relief wells.

INTRODUCTION

When drilling started in the early days of the search for oil and gas, it used to be vertical drilling only. The objective was to reach to a certain depth. True measurements of where the well was placed according to coordinates below ground were not considered critical. As drilling got more challenging, the field of directional drilling took off, as directional drilling is able to plan and execute very difficult well paths [1]. In everyday drilling, the objective is to stay the course and get the well to total Depth. The shape of the well could be vertical or directional. Keeping the well vertical is one of the most challenging tasks [2]. When the length of the drill pipe reaches three singles, or one stand, the pipe becomes bent because of its own weight sagging in air due to gravity [3], similarly, when this pipe is sent underground, it bends underweight and tends to deviate in any direction that the forces push it. In some instances, this can be acceptable, while in others it can be detrimental. Directional drilling is the art of intentionally deviating a wellbore along a fixed path [4], determined for numerous reasons by the operating company in conjunction with the directional company. In order to plan a directional well, one must know what the objective is of the well and the coordinates of the intended target below the surface. [5, 6], Side-tracking as shown in figure 1 was the first intentional method of directional drilling, which was to avoid a fish. A fish is an object that fell down the wellbore or got left in the wellbore once a piece of equipment broke off. The primary objective in this kind of a well is simply to get away from the obstruction, and direction is not important, some sidetracks are done to find out the extent of the reservoir, while others are done to create another wellbore in a different direction. Some wells are required to access resources below ground that are directly beneath an area where a drilling rig cannot be placed due to an obstruction at the surface, Inaccessible Location as shown in figure 2. These reasons could be the presence of populated area, river, mountain, jungle etc. In some instances, it is cheaper to place a land rig to drill a deviated well below the sea than to place an offshore rig directly above the target area [7], One of the most difficult wells to drill is a vertical well, so maintaining verticality is challenging, because getting a flexible pipe to drill a straight hole is quite a challenge [8, 9]. In several occasions, especially in the foothills region of Alberta, Canada, keeping a well vertical can be a huge task. The reasons are beyond the control of the operating company; high dipping beds of the formation are created because of tectonic forces in the area [10]. The solution has to come in the form of directional drilling, where specialized equipment is used to maintain the verticality of the wellbore. Conventional forms of using specialized bottom hole assemblies fail in such situations, because the dip of the formation throws the assembly in a different direction each time. One of the special applications of directional drilling is the drilling of relief wells [11], where a well is drilled to intersect another well, which has gone out of control, and is burning or flowing hydrocarbons at an uncontrollable rate. The best example is that of the Macondo well in Gulf of Mexico, which caused the biggest spill of oil in the history of the United States. The well was finally brought under control because of drilling a relief well that intersected the Macondo well. ‘Kill mud’ was then dumped into the relief well as per figure 3 to seal the flowing well. [12] Directional drilling has managed to reduce the costs of drilling offshore by enabling the operating company to utilize the limited amount of space available on an offshore platform and maximizing the reach of each additional well, and vast majorities of fields are located offshore, and more exploration is carried out each day to find resources beneath the sea. The cost of each platform is huge; as a result, extra effort is made to plan the wells to be drilled out of that platform so that they use all the available space. If the wells were to be only vertical, several platforms would be required to access the entire field, and that would be uneconomical. As a result, wells are directionally drilled to 'step-out' from the platform distances of up to 10 km each. [13] Since salt is a natural trap for hydrocarbons, many oil and gas fields are located in places where salt is the cap rock. Drilling through a salt dome can be very difficult, as salt is dissolved in the drilling mud and makes a huge cave, which then becomes difficult to handle. This difficulty arises as a result of not knowing the extent of the cave created by the drilling; in not knowing that information, one cannot predict the amount of cement required to set the casing in place. In such a situation, the best scenario is to keep the rig to one side of the salt dome and to drill directionally to reach below the salt dome and access the hydrocarbons. [14] Horizontal wells have found the most application in the industry today, especially in Canada where wells are drilled to produce heavy oil deep in the ground that was unable to be recovered with previous methods. A horizontal well was drilled to a curve section, to build the inclination of the wellbore to 90 degrees. Then held at that angle for a considerable length of the wellbore [15]. The horizontal wells are divided into several categories: medium, short and long radius. The radius refers to how quickly, in the rate of build, the well is brought to 90-degree mark [16]. Several types of directional wells named J-type and S-type these are known by their shapes of the wellbore path. J-type, in this type of the well, the wellbore is deviated after a certain depth to a planned inclination, and then is held to the target depth. It has another name as 'kick-off & hold,' or slant well. This is the most common type of directional well drilled due to the simplicity of its design. The S-type well is similar to the J-type in the first part, and then the well is brought back to vertical or near vertical to get to the target. S-type well is most suited in conditions where a specific geological formation or complexity needs to be avoided.

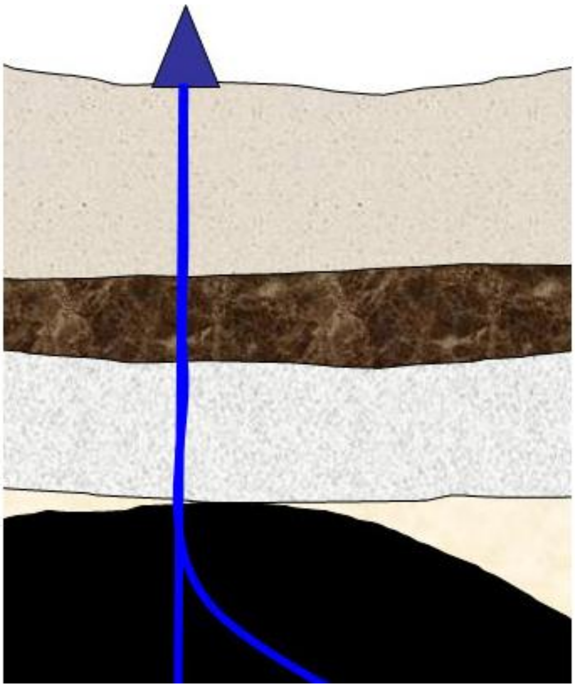

Figure-1. Sidetrack applied on different geological formations.

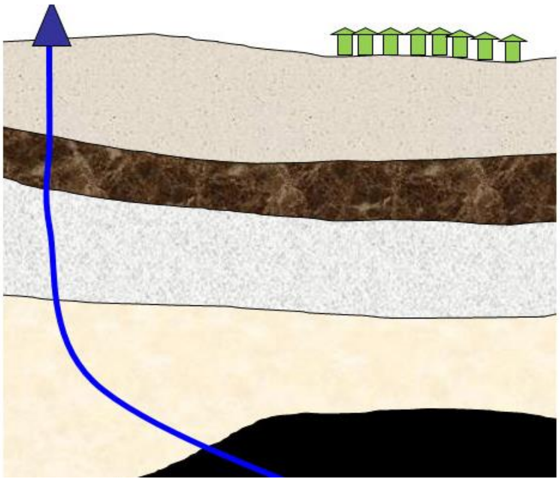

Figure-2. Inaccessible location (Target).

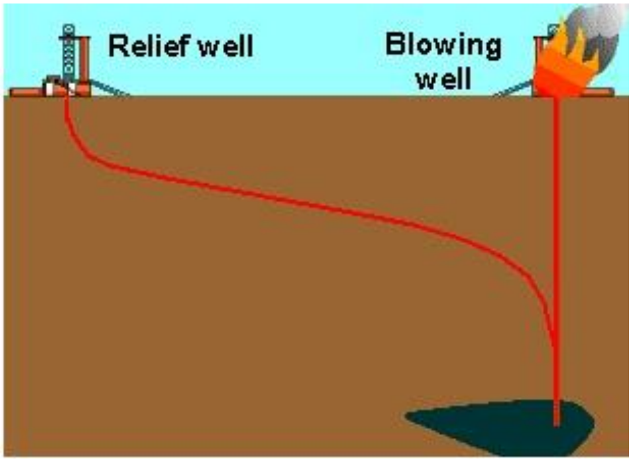

Figure-3. Relief well for well control.

TERMINOLOGIES

In order to plan a directional well, terminologies related to different inputs are so essential. These terminologies including, for example, kick-off point, and that is well-defined as a point in the wellbore at a given vertical depth below the surface up to a given inclination at a given build rate. The selection of the kick-off point is made by considering the geometrical well path and the geological characteristics, the optimal inclination at 200 ft. KOP depth since the maximum inclination is 18.87º, which is beneath 35º, where if the trajectory planned at 600 ft. hole problem might happen. [17]. Another example is related to build-up rates, initially inclination is built from vertical, or dropped back from an existing inclination angle at these rates as well as inclination, azimuth, hole section, dogleg severity and measured depth are considered to play a major role in the terminologies mentioned [18]. Several pieces of information are required in the calculations of directional drilling, for example, the target and that includes the size, shape, primary and secondary [19]. Geology is vital like structural description, Dips, Fault locations, and Formation hardness [20]. In addition, offset well data, directional tendencies, formation tops, bit records and problems encountered. Moreover, well rig limitations, which involves in pumps, rotary, and a draw works. Bottom hole assembly, mud motor, drill collars, stabilizers, and others. Drilling parameters, like mud type and dogleg severity permissibility. As well as a survey available, accuracy requirements. Pipe and collar data, which involves in stuffiness factor, buoyancy factor and deviation factor. Furthermore, expected well productivity and casings [21]. All effort should be made to ascertain an achievable target size; the smaller the target is, the more difficult it will be to achieve during execution. Survey tools required would need to be more accurate, and hence the cost of drilling such a well could go up. In ideal situations, a circular target size is a 50m radius. Target can also have a primary and secondary objective (i.e., the geologist might want to obtain information from two different zones or formations). In such a case, information regarding what angle to approach the second target with, or the difference in height between the two targets, would determine if the well planning can be achieved or not for that specific target [22]. Most of the well planning relies heavily on subsurface geological information, and each piece of information is critical in proper well planning. For instance, formation tops determine casing depths [23], which then determine what possible angle the well would have to be at each casing depth. The formation tops also determine what angle might be planned for a specific formation if that formation tends to ‘throw’ the bit into a particular direction or tends to drop/build in rotary drilling. Similar to geology, the offset well data is another set of information crucial to planning a directional well. If an offset well had encountered certain problems with relation to the directional BHA response, then the lesson learned would help in determining the correct BHA for a particular section of the well. Having information on formation tops could help prevent entering a zone of high pressure without a change of the mud system, and thereby prevent a catastrophic consequence. Information related to bit usage can be best utilized to maximize the rate of penetration for each section planned. On a similar note, if adverse experiences were recorded in a particular section of the well, a change of bit type or structure can be planned for optimizing the rate of penetration. Having knowledge of key seats, sloughing shale, tight hole and directional tendencies can help in averting disasters while drilling [24].

RIG EQUIPMENTS

In many circumstances, what the rig can deliver is the deciding factor in terms of what bottom hole assembly can be run in the hole to deliver the desired results. For example, if the plan is to drill to a certain depth and the calculated rotary torque will exceed the rig limitations, then either the well will need to be re-planned or a different rig will need to be sought, depending on the planning stage. Similarly, if the well is supposed to have a certain length of casing run in a hole size, the rig draws works/drilling line should be able to pick up the weight of the casing string to be run. When planning directional wells, a consideration needs to be made for the directional tools; these tools tend to have a certain pressure loss associated with them, and could result in a higher pressure at the standpipe than with conventional rotary drilling. The pumps, therefore, need to be able to sustain the required pressures in order to successfully drill the desired well [25, 26]. Depending on the task, bottom hole assembly, BHA selection needs to be carefully analysed [27]., by knowing what drill pipes, drill collars, stabilizers and down hole tools are required, planning can be done to ensure that the proper makeup of tools is available at the well site. In most contracts, the drilling contractor supplies the basic drilling equipment but if there are special requirements, those must be supplied by the operating company. These specialized drilling equipments can be non-magnetic drill pipes/collars, non-magnetic stabilizers, casing wear protectors, high torque connections etc. Depending on the hole size to be drilled, directional equipment would need to be communicated to the directional service provider. If rotary, build/drop or hold, bottom hole assembly are planned, then knowing the size of available stabilizers would help in planning for these bottom hole assembly. Each section must have the bottom hole assembly, BHA, which has the ability to pass thorough the previous casing; therefore, the outer diameter of the BHA must be less than the drift of the previous casing [28].

DRILLING PARAMETERS

A critical factor in planning is the type of drilling fluid to be utilized for the well. Knowing the type and formulation of the drilling mud can assist with the proper selection of BHA. In some invert mud systems, the presence of silicate can be detrimental to the rubber in the down hole tools and surface equipment. This can reduce the life of a mud motor [29], measurement while drilling (MWD) tools and mud pump liners. Together with offset data, optimum mud parameters can be obtained at the planning stages to prevent bad hole conditions, which can

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be detrimental to the execution of the directional well. The right properties can aid in the directional well execution stage by helping the directional driller to slide the BHA when required and prevent BHA hanging. On the other hand, having an improper drilling mud can result in BHA being lost in hole, resulting in either a sidetrack being planned or abandonment of the hole. In some cases, there is a limitation on the severity of the build or drop rate coming from production. This could be due to the completion string to follow at the end of the well. As a result, the well must be planned to conform to the requirements of the build/drop rates [30]. In all directional wells, survey instruments play a major role in determining the coordinates of the wellbore being drilled in three-dimensional space. Without the survey tools, the location of the BHA (and therefore the wellbore trajectory) cannot be monitored. Knowing the presence of nearby wells can help to determine which type of survey tool to use in order to overcome possible interference in readings due to the presence of magnetic casing string. In addition, in cases where multiple wells are planned from one main hole, having the survey tool with the proper tolerances and accuracy would ensure that the well is drilled within the window allowed. The survey instrument with the best accuracy in the industry is the gyro tool [31], which is used in wells where nearby magnetic interference is of concern (as is the case with offshore platforms). The basic property of the drill pipe and collars are required for effective well planning. When drilling short radius wells, these properties play a major role in determining the life of the pipes/collars. These properties also determine the flow and hydraulics requirement of the bottom hole assembly, (BHA), as well as flow regimes in and around the BHA. Turbulent flow is required for effective hole cleaning and proper lifting of cuttings from the bit to the surface [32, 33]. Wellbore pressures [34], and completion can determine the size of the casings to be utilized, and that determines the different casing sizes to use. These sizes would in turn determine which tool sizes can be planned for in-the-hole sizes to be drilled. Some specialized tools can only be run in specific hole sizes; therefore, by knowing what is required, the proper string can be selected. For mud motors, knowing the drift of the casing will determine the maximum bend housing angle that can pass through the casing, which would result in the limitations on the build rate severity of the bottom hole assembly.

EXECUTION OF DIRECTIONAL WELLS

Once the plan is in place and proper equipment has been sourced, the next phase is to carry out the drilling of the directional well. Having the right people on the job cannot be emphasized enough. One of the major reasons for problems while drilling a directional well goes back to incorrect inputs when measuring the offset angle [35], on the motor bend housing from the survey tool. A directional driller who knows the area where the well is being drilled is an important part of a successful planning and execution of the well plan. If the well is being drilled off a pad or an offshore platform, colliding with other wells becomes the major concern. This concern is heightened even more should the wells nearby be producing hydrocarbons. Planning for anti-collision [36], starts with a collection of survey data from all the nearby wells. These are input into well planning software to map out the distances between wells. This information is then used by the directional driller on the well site to navigate through the web of other wells in the vicinity. One of the plots generated to view this data is referred to as a spider plot. Due to the intricacies of well planning and execution, a proximity analysis is also performed to measure more accurately the distances to the nearby wells. This analysis is referred to as a travelling cylinder. This involves imagining a cylinder with a given radius enclosing the wellbore from one depth to the next. Any well entering this cylinder or approaching closer than the radius of the cylinder to the central well is plotted and displayed graphically. Another way to understand this plot is to consider someone riding a water slide. The person is always in the Centre of the slide as he/she slides down, but in three-dimension, the relative position to the ground is always changing. If that person stops at some point and looks outside, he/she can see where the other wells are with respect to his or her position. This same scenario is displayed in a travelling cylinder with the subject well always at the Centre of the plot. As with all programs, there is limited accuracy to the tools used in calculating the surveys for a directional well [37] and some of these tools are more accurate than others in determining the position of the wellbore, while others are prone to some degree of error. Besides the error from the mathematical model of calculations for each tool, there is another source of error which is introduced by the down hole changes in magnetic field. This change in magnetic interference could possibly remain undetected, thereby resulting in error associated with azimuth. A study was carried out in this regard by (Wolff & De Wardt, 1981), where an ellipsoid of uncertainty was proposed along the well path to show the probable envelope of the likely position of the well based on the **error** of the survey measurement. This method attempted to quantify the systematic error associated with either a gyro or other measurement tools, and the error due to misalignment of the tool in the hole, depth measurement and inclination. Understanding this uncertainty is paramount to understanding the problems associated with drilling a directional well. As briefly mentioned earlier, formations have a natural tendency to push the drilling assembly in a certain direction. Having the knowledge of the existence of these tendencies can aid a directional driller in making the right decision about ‘sliding’ or rotating [38]. In the process of sliding, the bend housing of the mud motor is utilized and the drill string is held stationary from the surface and slowly lowered in the hole allowing the bit, which is rotated by the power section of the mud motor, to be directed towards the intended course of the well path. As can be inferred from this action, this process slows down drilling considerably; sometimes lowering the rate of penetration to less than half of the rotating rate of penetration. Using the tendency of the formation, the directional driller can plan for the turn, cut down on the sliding, and hence increase the overall rate of penetration. For proper execution procedure, a directional driller always 'looks ahead' to know what to expect from his BHA in hole. Due to the makeup of BHA, the survey tools are always behind the mud motor by a distance that varies with the service provider, but is around 15 m behind the bit. Given the action carried out, the directional driller calculates the probable course that the BHA [39], the directional driller updates his model and takes the necessary course of action to keep the well on the well plan. Since not everyone in the team has access to the well planning software, a well plot is usually displayed in the shack of the directional driller, the company representative's office and in the town office of the operating company. On the well site, the responsibility of updating the well plot lies with the directional driller, while the drilling engineer updates the well plot in town. The idea is to have a one-look assessment of the progress being made on the directional drilling.

SURVEY TOOLS

Several types of survey tools are utilized, with the most common, cheapest tool known as a Totco. This tool only provides inclination and is primarily used for measuring the inclination in a vertical well. It carries a disc of negative film, similar to the one found in old camera, along with a timer which, when activated, takes a snapshot of the deflection unit. The Totco can be dropped or run on a slick line through the drill string. Once the timer is activated, the Totco is then retrieved with a slick line or pulled out of hole along with the drill string, and the disc is developed to know the deviation of the hole [40]. Gyros are the most reliable surveying tools in the market today, and they are referenced as the benchmark for all surveys. A significant advantage of these tools is the fact that they do not require a non-magnetic medium to take the surveys; they have the magnetic compass replaced by a gyro compass disc [41] controlled by a high revolution electric motor. Just like the single/multi-shot tools, the gyro can measure both inclination and azimuth of the wellbore. It consists of a camera, timer and the gyrocompass. Figure 4 displays the compass section of the gyro tool. The operation of a gyro tool is different from a multi- or single-shot tool. A gyro first need to be oriented to a known direction and the timer is set. It is then run in hole to the survey point where the survey is acquired and the tool is then retrieved to the surface and the survey is downloaded. When run on wireline, the Gyro tool is powered by the wireline and the surveys can be taken at different places and sent to the wireline logging unit in real time. This method gives instantaneous results to enable the directional driller to make necessary decisions. In some scenarios, the gyro tool is run in hole with a side-entry sub and sliding is done based on the tool-face provided by the gyro. The only problem with this method is that the string cannot be rotated. Regardless of the manner in which the gyro tool is run, one thing is certain: it has to have the instrument properly centralized within the drill string. For this to happen, two methods are utilized: steel centralizers and rubber fingers. Measurement while drilling (MWD) tools are the most common surveying tools in directional wells these days. The biggest advantage these tools have with respect to the other tools is that normal drilling can be carried out while surveying. In the case of a gyro or single/multi-shot tools, one needs to stop drilling while the tools are run in hole and retrieved before the survey can be retrieved. [42]. this can cause the string to get stuck in a hostile environment, with a possible worst-case scenario of losing the string in the hole. With the MWD, surveys are sent on the fly and decisions are made with respect to the next course of action by the directional driller, MWD is based on the principle of sending pressure pulses up the mud column inside the drill string, where a pressure transducer installed on the standpipe picks up the pulses. The computer to meaningful numbers to be displayed then translates these pulses. The directional driller to orient his motor bend housing to the desired direction uses the rig floor display. It also displays the survey data for the wellbore. There are two types of MWD tool modulation mechanisms: positive pulse and negative pulse [43]. In the negative pulse modulation method, the tool diverts part of the drilling fluid to the wellbore by a side port. This lowers the standpipe pressure by a certain amount. When this is done in sequence, pressure pulses are created and picked up by the pressure transducer on the surface. In the other method, a pressure wave is created by closing and opening a port inside the drill string with no loss towards the annulus. This momentary closing of the port raises the pressure inside the string and then creates a drop in pressure when opened. Each closed position translates to a binary one, and each open translates to a binary zero. The surface computer into meaningful data then translates the sequence of zeros and ones. With advancements in technology, this positive pulse mechanism has been upgraded to a continuous siren technology where a rotor and stator are utilized with the speed of the rotor varied to produce the zeros and ones. This upgrade in technology resulted in faster data rates to the surface and revolutionized the data streaming. Another form of MWD is known as the electromagnetic (EM) tool [44]. In this form of the tool, the signal is sent via electromagnetic waves up through the formations and to the receivers strategically placed in a grid on the surface. The signal is picked up by the receivers and translated into data by the surface computers. This method eliminates the need for using the drilling fluid as a medium to transport the signal to the surface. As a result, the best application for this type of tool is in an underbalanced drilling environment where air, nitrogen or foam is utilized as the drilling fluid. Since the mode of transmission is not drilling fluid, the data rate is much higher when compared with regular mud pulse systems. A limitation of the EM tool is the depth to which drilling needs to be conducted; deeper depths would require a signal boost, which would result in faster draining of batteries and hence shorter battery life. Another limitation could be from the formation; certain formations tend to attenuate the electromagnetic signal more than others. In this case, prior field knowledge would

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help to plan better and could, in some cases, determine that an EM tool cannot be run.

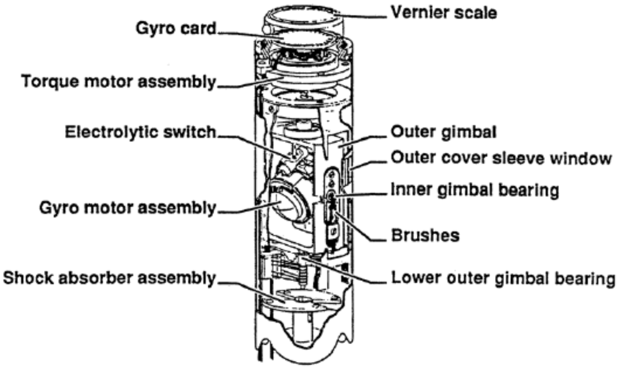

Figure-4. Gyro compass section (Courtesy Baker Hughes).

ROTARY STEERABLE SYSTEM

With conventional directional drilling done with the aid of mud motors, there was a need for a system that would be able to steer the well to the desired direction and inclination without the need for stopping the drill string to slide. A new tool was sought which would enable the steering in a completely rotational mode only. This idea translated into what is known as Rotary Steerable Systems (RSS) [45, 46], RSS deploys two methods of deflecting the string into the desired direction: point and push. In the push-the-bit system, the drill string is pushed into a specific direction by mechanical means in the form of metallic pads. The system comprises of electronics, a power section and a mechanical section that delivers the push to the wellbore. Once the directional driller decides on the course of action, he sends a command down to the tool via a sequence of flow variations, and the electronics in the tool recognizes these pre-programmed sequences. It then translates them into the direction of push required, which is opposite of the desired direction (i.e., if the directional driller wishes to turn the wellbore to N 40 degree E, the tool would activate the pad to be pushing in the direction of S 40 degree W in order to achieve a direction of N 40 degree E). There are a set of three pads placed at 120 degree apart. The push is generated by a pointing device inside the housing, which diverts a fraction of the flow towards the pads. This squirt of fluid is enough to generate a push; the pads collapse after they pass the point where the push was required and give way to the next pad, which then pushes and collapses, and so on. The pointing device is held stationary with respect to the collar so the pointing can take place in one direction only. The tool has a set of accelerometers and magnetometers [47], which update internally the inclination and azimuth so that the tool can self-correct if the command is to hold at a particular inclination or azimuth. This provides an extra piece of information to the directional driller, enabling him to know the survey right at the bit. This feature facilitates quick decision-making and helps to keep a smooth wellbore. The tool is powered by a set of turbines, which enables the tool to stay inside the hole longer without a need to replace batteries. One advantage of this system is that it has a completely rotating collar along with the pads; no part of the collar is stationary at any point. Unlike the push-the-bit system, point-the-bit system utilizes mechanisms by which the bit is 'pointed' in one direction so that the rotation of the drill string would be guided in one particular direction only. Several vendors have developed RSS systems to achieve the pointing mechanism, that have similarities yet technically different from one another. Figure 5 shows point-the-bit system developed by Baker Hughes. The tool has a set of 'fins' that engage with the wellbore and keep the steering unit stationary while the rest of the string rotates. This helps the unit to be pointed in one direction; the fins are collapsed by sending commands to the RSS before the tool is pulled out of hole to prevent damage to the fins. The tool has a modular design, which enables the tool to receive commands from the MWD tool that is attached to it; this eliminates the need for sending commands via flow rate change. Instead, the surface computers are used to send the command down to the MWD [48], the tool comprises of a power module, steering head and electronics module. Another system is the Halliburton Geo-Pilot point-the-bit system. It consists of a shaft supported by two bearings inside an outer housing measuring almost 18ft in length. Rotary seals at each end completely enclose the tool.

Figure-5. Point-the-Bit RSS system. (Courtesy of Baker Hughes).

RESULTS AND DISCUSSIONS

Approaches to True Vertical Depth

This is the projection of the measured depth along the vertical axis. In other words, if the well is vertical, the true vertical depth and measured depth would be the same from start to finish but if the well deviates, there would be a difference between the two depths depending on the inclination of the wellbore. In the following figures (Figures 6-9), the difference would be displayed graphically.

Approaches to J-type Well Calculations

Figure-6 displays the schematic of a J-type well where the radius of curvature for the build section, R, is less than the total displacement of the target presented by D2. Here, V1 is the TVD at the start of kick-off point, V2 is the TVD at the end of the curve at B and V3 is the final TVD of the target. B signifies the point at which the curve

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has been completed, and C points out the depth at TD (Total Depth) of the well.

Build-up Rate is defined as BUR = $\frac{^\circ/30m}{30}$ …………. [1]

Radius of Curvature R = $\frac{180 \times 30}{BUR \times \pi}$ …………………. [2]

Ø = 90° - Cos -1 [$\frac{R}{\sqrt{(V3-V1)^2+(D2-R)^2}}$] + Tan -1[$\frac{D2-R}{(V3-V1)}$] …. [3]

Note: If the value of (D2-R) turns out to be negative, then the absolute value needs to be considered for calculation purpose. In addition, if calculating in feet, the BUR and radius calculations would have the 30 replaced with 100. Once Ø is calculated, the rest of the variables are calculated as follows:

MD @ B = V1 + $\frac{Ø}{BUR}$ ……………………………. [4]

V2 = V1 + R Sin Ø ……………………………. [5]

D1 = R (1 – Cos Ø) ……………………………. [6]

MD @ C = MD @ B + $\sqrt{(V3-V2)^2+(D2-D1)^2}$. [7]

For a case where the radius of curvature R is greater than the total displacement of the target D2 shown in Figure-7, the rest of the calculations are the same except the calculation of Ø. Figure-8 represents the schematic of a J-type well from Jasionka where the outcome looks similar to Figure-7.

Ø = 90° - Cos -1 [$\frac{R}{\sqrt{(V3-V1)^2+(R-D2)^2}}$] - Tan -1[$\frac{R-D2}{(V3-V1)}$] [8]

Approaches to S-type Well Calculations

For calculating the different parameters of an S-type well and that is allied with other scholars like [49], Figure-9 displays the basic definitions and similar to a J-type well, there are two scenarios to consider. In the first scenario, the sum of the two radii (R1+R2) is less than the total target displacement, referred to as D3. BUR is calculated in the same manner as before and so is the drop-off rate, DOR. DOR is the rate of drop from point C to point D in Figure-8.

R1= $\frac{180 \times 30}{BUR \times \pi}$, R2 = $\frac{180 \times 30}{DOR \times \pi}$ …………………………. [9]

In order to calculate Ø, several steps have to be taken:

X = D3 – (R1+R2), Angle β = Tan -1 ($\frac{X}{(V4-V1)}$) ……. [10]

OF =$\frac{V4-V1}{Cos\ \beta}$, OG =$\sqrt{OF^2-(R1+R2)^2}$, Angle FOG = Sin-1 ($\frac{R1+R2}{OF}$) ………………………… [11]

Ø = Angle FOG + β……………………………………. [12]

Given Ø, the rest of the variables are calculated as follows:

MD @ A = V1 + $\frac{Ø}{BUR}$………..………………………. [13]

V2 = V1 + R1 Sin Ø…………………………………. [14]

D1 = R1 (1 – Cos Ø) ………………...………………. [15]

MD @ C = MD @ A + OG….………………………. [16]

V3 = V2 + OG Cos Ø……….………………………. [17]

D2 = D1 + OG Sin Ø……………...…………………. [18]

MD @ D = MD @ C + $\frac{Ø}{DOR}$ ………………………. [19]

MD @ E = MD @ D + (V5 – V4) …………………. [20]

In the second scenario, the sum of radii (R1+R2) is greater than the final target displacement D3. Figure-10 graphically displays the scenario. Figure-11 shows the results from Banaka PGP-3 Well and similarly looks the same as figure 10. In this scenario, the calculations are the same as the last, with the exception of the following:

X = R1 – (D3 – R2) ……………………………. [21]

Ø = Angle FOG – β ……………………………. [22]

The above scenarios of S- and J-type well calculations assumes that the well is vertical from the surface to the kick-off point, and that the trajectory is in a single plane d that is allied with other scholars like [50]. In cases where the trajectory is in three-dimension with changes in azimuth besides inclination, formulas that are more sophisticated would be required. For such cases, advanced well planning software is available. In addition, if the target coordinates are provided in horizontal plane coordinates N/S, E/W, then the horizontal displacement of the target can be calculated as follows:

D3 = $\sqrt{N/S\ Coordinate^2 + E/W\ Coordinate^2}$ …. [23]

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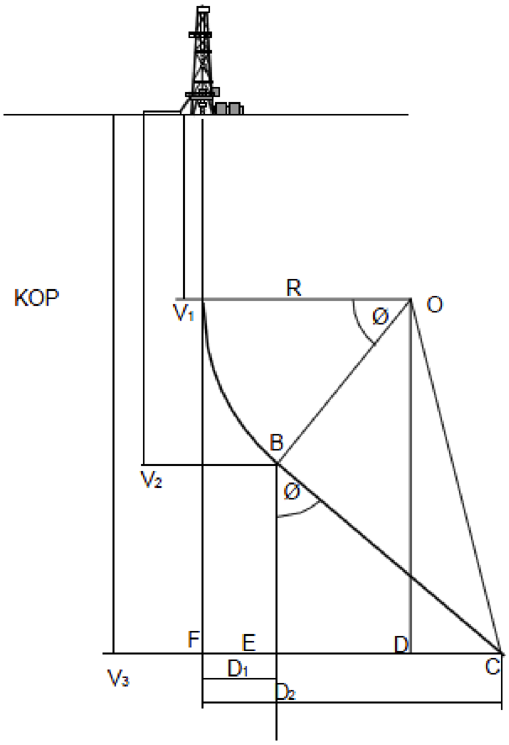

Figure-6. Schematic of a J-Type Well, R<D.

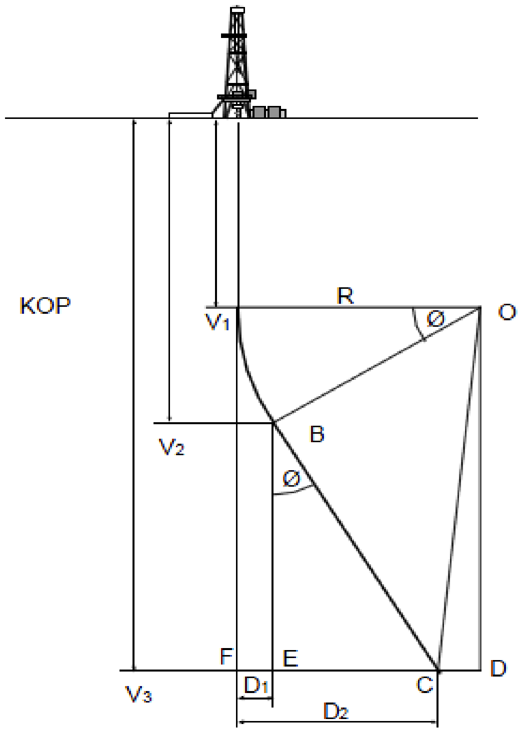

Figure-7. Schematic of a J-Type Well, R>D.

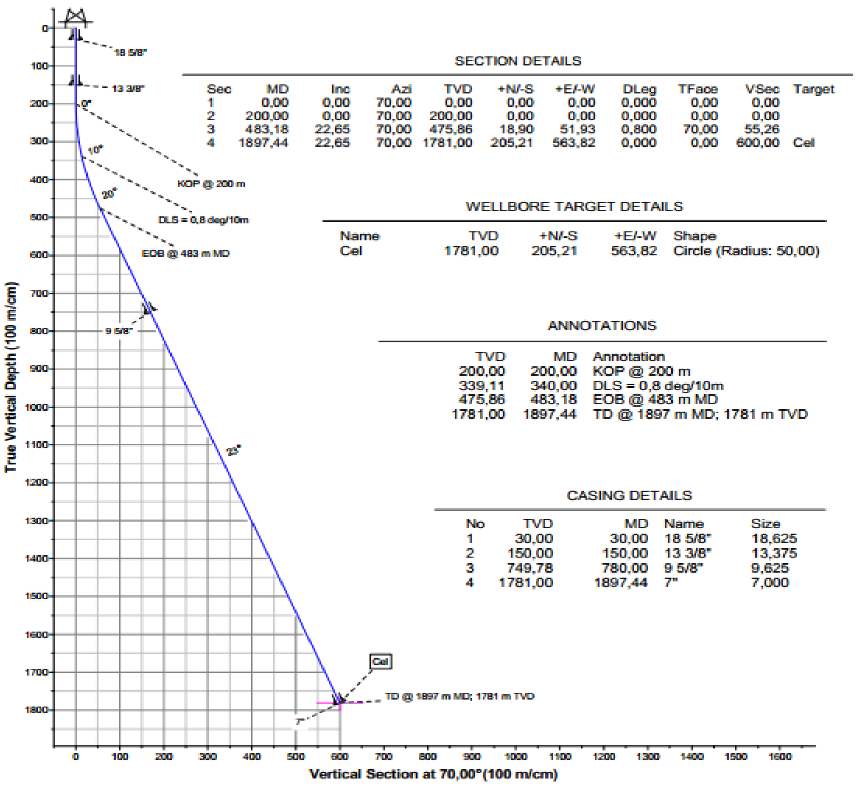

Figure-8. Schematic of a J-Type from Jasionka 10K Well Plan #1.

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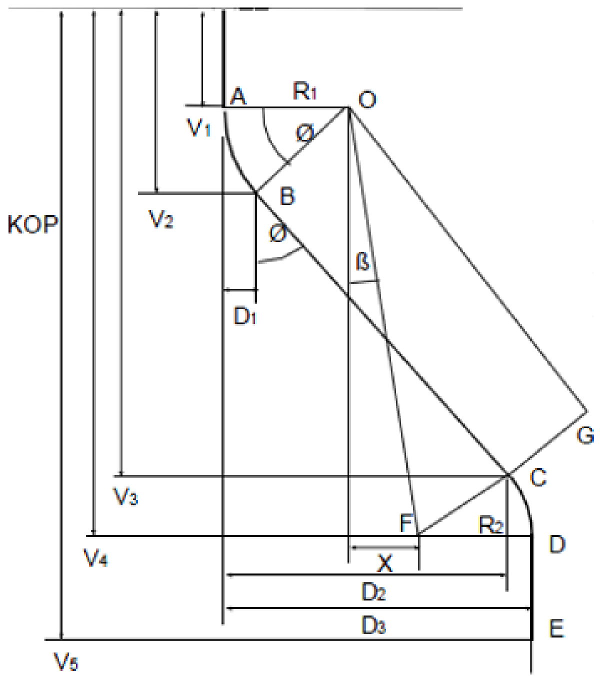

Figure-9. Schematic of an S-Type Well, R1+R2 < D3.

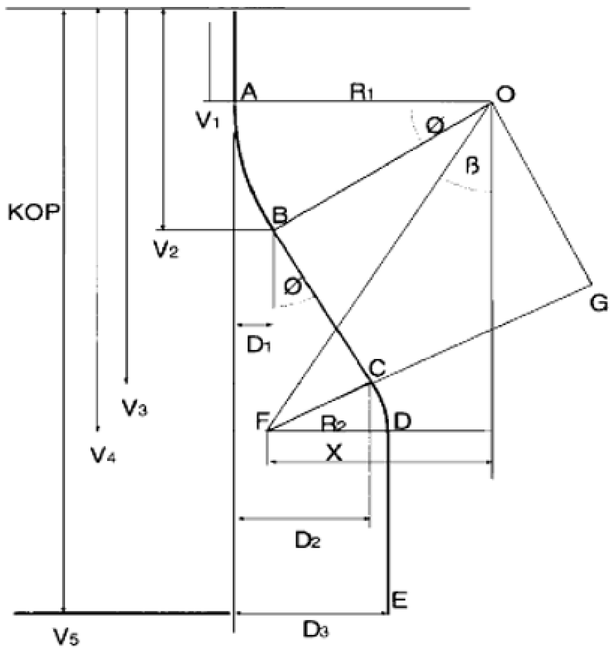

Figure-10. Schematic of an S-Type Well, l, R1+R2 > D3.

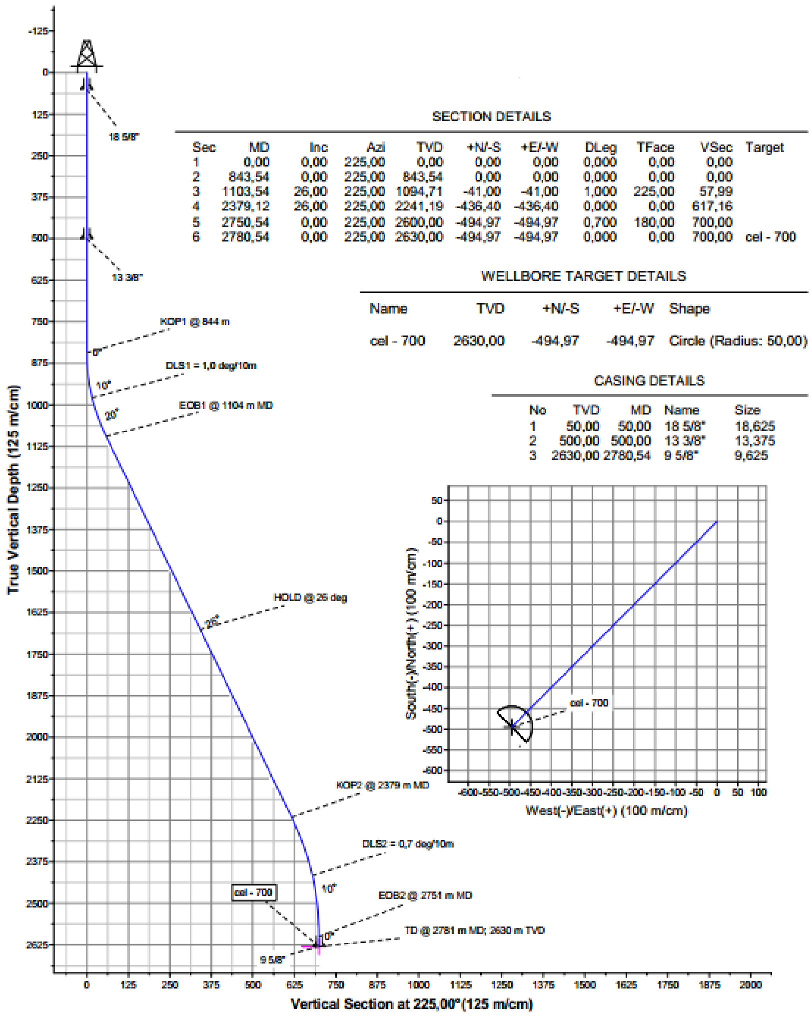

Figure-11. Schematic of a S-Type from Banaka PGP-3 Well Plan #1.

CONCULSIONS

For drilling a directional well, a survey tool is necessary. There are many survey tools available in the market and their selection is dependent on the application desired. These survey tools range from Totco and gyro to MWDs. For benchmarking surveys, the best survey tool is the gyro that is run after the well is drilled. Knowing the exact placement of each well would help to determine the well plan for the other wells on the pad in order to avoid collision. Having looked at the most common RSS systems, their advantage lies in an environment where high day rates are encountered. Their excessive cost in such environments are justified with their ability to continuously steer through tough and challenging environments, providing higher rates of penetration compared with conventional mud motors. In areas that have, extremely low sliding ROP compared with rotary ROP, RSS systems are certainly an advantage. Areas that have stratigraphic challenges also present a strong case for the use of RSS, with their ability to place the well in best part of the reservoir by geo-steering within thin beds. The agitator tool was designed with a specific goal in mind: to help the operator in drilling longer horizontals by overcoming the torque and drag experienced while sliding a steerable motor assembly through the section.

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