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ROTARY STEERABLE SYSTEMS TO REDUCE THE COST AND INCREASE THE ENERGY VALUE OF DRILLING DIRECTIONAL WELLS IN OLKARIA GEOTHERMAL FIELD

George Karimi
Kenya Electricity Generating Company Limited
Geothermal Resource Development
P.O. Box 785 20117, Naivasha.
KENYA
karimigtheuri@gmail.com

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ABSTRACT

One of the main goals while drilling a geothermal well is achieving the minimum drilling cost per unit of energy produced. Directional drilling makes it cheaper and easier to tap geothermal resource since we can have many wells on the same well pad and there is minimal environmental disturbance. Directional wells are more expensive to drill than vertical wells due to the use of down hole motors and the extra trip time incurred while trying to orient the well but are more cost effective because they give access to a greater geothermal resource from each pad. In Olkaria, we use varied combinations of the bottom hole assembly (BHA) to direct the bit to the intended path. In some formations however, holding or maintaining the desired well path is difficult and thus we are forced to change the BHA numerous times to correct the angle. To change the BHA, we need to pull out of hole and then run in hole with the desired assembly which we call a trip. Tripping is a very expensive process since more energy is consumed due to the draw works suspending the weight of the string which in turn inflates the operational costs incurred during this non-productive time. Wells drilled with very little control on the trajectory, lead to uncontrolled doglegs which cause high side forces on the string, which lead in turn to high torque, high drag and in some cases prevent the well getting to terminal depth (TD) as well as leading to drill string fatigue failures. Rotary steerable systems (RSS) allows the driller to steer the well to target with high precision. This paper seeks to illustrate the drilling challenges faced in the Olkaria field and how they might be avoided by the use of a rotary steerable system (RSS), inherently reducing the cost of drilling the well.

1 INTRODUCTION

A directional well involves drilling a well that is deflected in a specific direction from the vertical inclination. The angle of inclination varies from a few degrees to 90 degrees and the shape of the trajectory of directional wells also varies depending on the position of the target to be reached.

Directional wells can be J-shaped, S-shaped or horizontal. In a J-shaped well the angle is bult up to a certain inclination then kept constant till the final depth. This is the pattern adopted for geothermal wells in Olkaria with a target inclination angle of 20 degrees. The well bore has three sections:

- The vertical section from the surface to the kick off point (KOP)
- The curved section where the well angle is built up to the planned inclination.
- Inclined section to the target depth.

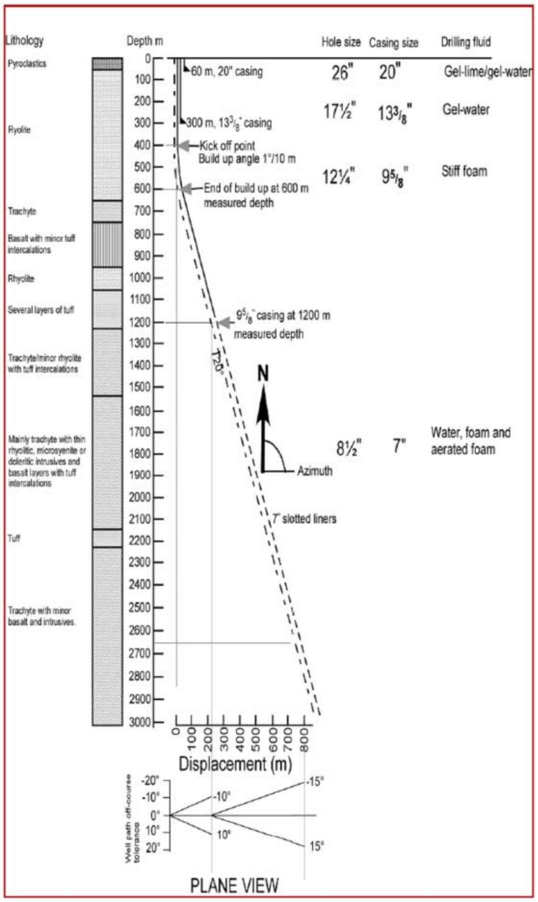

Figure1:Typical Olkaria Directional well Design

All directional wells drilled in Olkaria have a Kickoff point of 400mRKB which is normally 100m below the anchor casing shoe. The rate of angle build up per drilled depth is usually expressed in degrees per 30 meters. In Olkaria the rate of angle build up is normally 3 degrees per 30m. If the rate of angle build up is so rapid, abrupt change in the well angle results which may cause severe dog leg which in turn causes a high drilling torque and if not corrected will cause breaking of the drilling string.

2 CONVENTIONAL METHOD

Directional wells drilled by KenGen in Olkaria have kick off point (KOP) of 400m RKB. Up to a depth of 400m RKB, drilling is done using a Pendulum BHA. At this depth, the BHA is changed to include a Down hole Motor (Mud motor) with an Orientation Sub to initiate the deflection of the wellbore to the target direction. This is a common method used in the world which involves running a PDM (Positive displacement motor) to drive the bit without rotating the drill string. The motors used have inbuilt deflection angle of 0.75 degrees and an in build stabilizer. The 0.75 degrees angle of the mud motor ensures that the bit is pushed sideways as well as downwards. This sideways component of force at the bit gives the motor a tendency to drill a curved path, provided there is no rotation of the drill string. The degree of curvature (dogleg severity) depends on the motor angle and its OD and drill collars in relation to the diameter of the hole. It also depends on the length of the motor. The inbuilt stabilizer is to the bit end of the mud motor forming a near bit stabilizer assembly in the BHA which assists in building the inclination angle aided by the angled configuration of the mud motor.

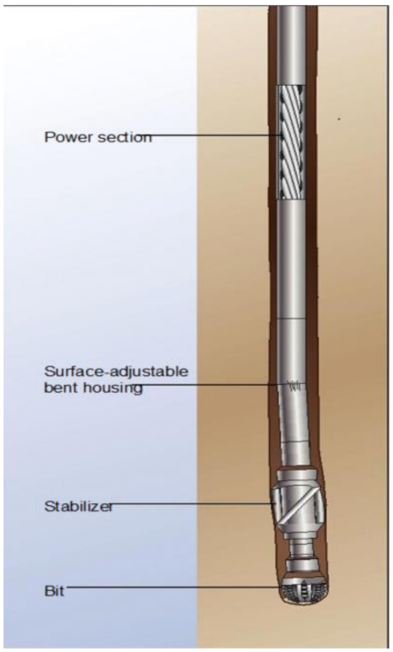

Figure 2: Positive Displacement Motor

Historically, these "single tilt" motors were used for difficult deviation jobs such as sidetracking over a short section of hole into hard formation. Since the bend is closer to the bit than when a bent sub is used, a smaller tilt angle (e.g. 0.750) can be used but still give a strong deviation tendency. In Olkaria, these single tilt motors are used as steerable motors. If the tilt (tool face) is orientated in a desired direction and there is no drill string rotation, the motor will drill a controlled curve but without an MWD in the hole it is difficult to actually steer the well and estimate the reactive torque, this leads to the use of low productivity roller cone bits to minimize reactive torque when the wells may be more efficiently drilled with PDC bits reactive torque changes the tool face when drilling commences, which may also make it difficult to keep a steady tool face. They can be used in most formations. In addition, since there is no rotation from the surface, it is possible to use a wire line "steering tool" for surveying and orientation while drilling.

Using a BHA to change inclination. By strategic placement of drill collars and stabilizers in the BHA, directional drillers can increase or decrease flexibility, or bowing of the BHA. They use this flexibility to their advantage as they seek to build, drop or hold angle. A fulcrum assembly uses a full gauge near-bit stabilizer and sometimes a string stabilizer. Bowing of the drill collars above the near-bit stabilizer tilts the bit upward to build angle. A pendulum assembly has one or more string stabilizers. The first string stabilizer acts as a pivot point that lets the BHA bow beneath it, thus dropping angle). A packed assembly uses one or two near-bit stabilizers and string stabilizers to stiffen the BHA. By reducing the tendency to bow, the packed assembly is used to hold angle. This technique is inherently unstable at low inclinations and makes frequent BHA trips inevitable as this variability causes the required profile to be lost whilst drilling.

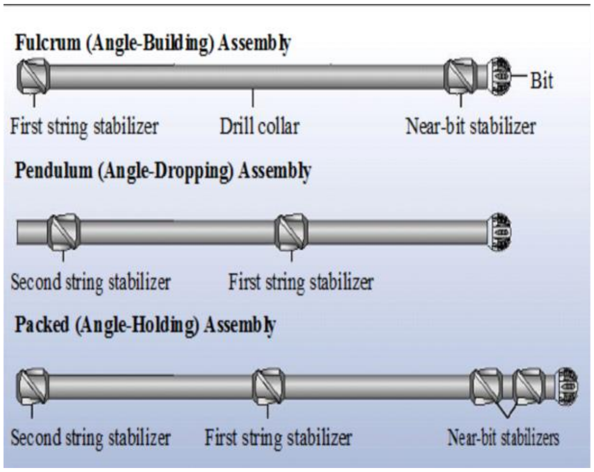

Figure 3: Bottom Hole Assemblies

3 ROTARY STEERABLE SYSTEM

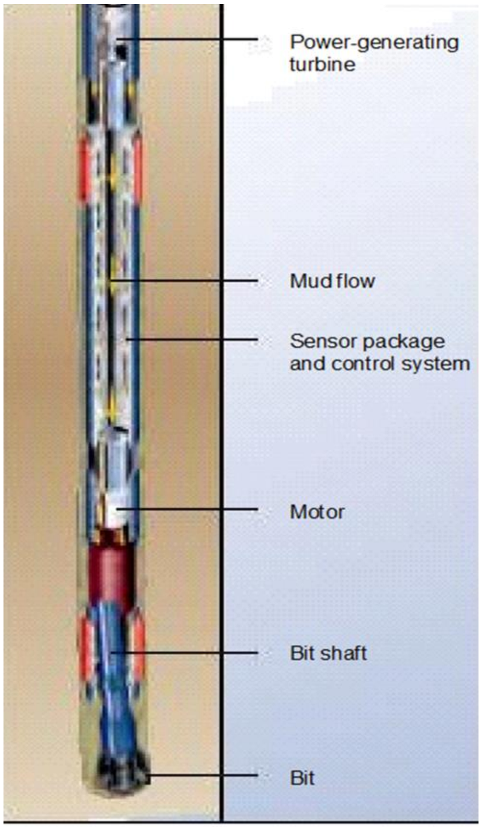

Figure 4: Components of an RSS

A rotary steerable system (RSS) is a form of drilling technology used in directional drilling. It employs the use of specialized down hole equipment to replace conventional directional tools such as mud motors.

A rotary steerable system drills directionally with continuous rotation from the surface, there is no need to slide the tool, unlike drilling with a steerable motor. Continuous rotation transfers weight to the bit more efficiently, which increases the rate of penetration (ROP). Rotation also improves hole cleaning by agitating drilling fluid and cuttings, allowing them to flow out of the hole rather than accumulating as a cuttings bed. Advanced rotary steerable systems are designed to improve fluid circulation and cuttings removal.

Efficient cuttings removal reduces the chance for the bottom hole assembly (BHA) to become stuck. Continuous rotation and better hole cleaning reduce the chance of mechanical and differential sticking of the drill string. No stationary components contact the casing or borehole. In addition, rotary steerable technology improves directional control in three dimensions. The net result is a smoother, cleaner and longer well-bore, drilled faster with fewer stuck-pipe and hole-cleaning problems. The higher quality of the resulting wellbore makes formation evaluation and running casing less complicated, and reduces the risk of getting stuck.

4 CASE STUDIES

4.1 OW-710A

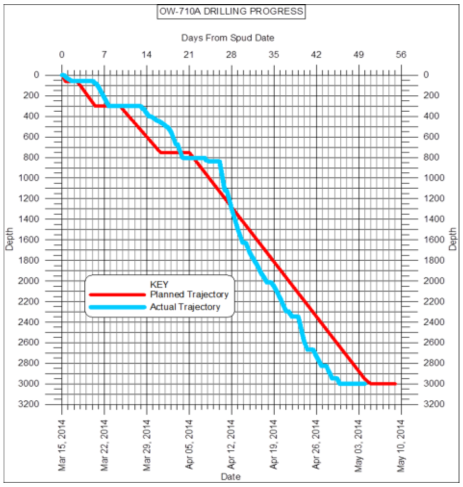

Figure 6: 710A Drilling Progress Chart

There were 10 BHA changes relating to trajectory which add up to like about 7 days of time tripping pipe from what I counted from the daily drilling logs of this well. This could most likely have been eliminated using an RSS with instant tool face control. There were also 19 surveys from what I count. The dogleg severity of this well was not bad, and the well was completed before schedule but I believe there is further cost beneficial room for improvement.

4.2 OW-710B

While drilling the 12¼" hole, the string got stuck, most likely as there was no circulation/reciprocation due to waiting on a survey. This resulted in an additional 17 days of time to plug back losing part of the BHA down hole and reach the 804 meter depth mark again. After that point the following BHA changes resulted in an additional 7 days of additional time. At one point the wire line snapped leaving the survey tool down hole resulting in an additional lost day. An RSS with MWD would have delivered the survey info in real time so there would be continuous circulation/reciprocation of the pipe keeping free of stuck pipe incidents. An RSS would have saved at least 24 days.

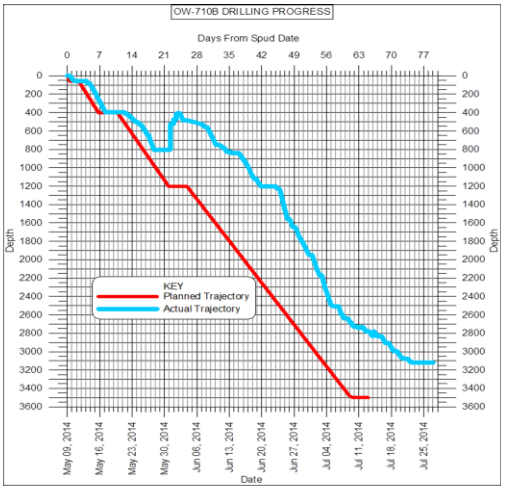

Figure 5: 710B Drilling Progress Chart

4.3 OW-49A

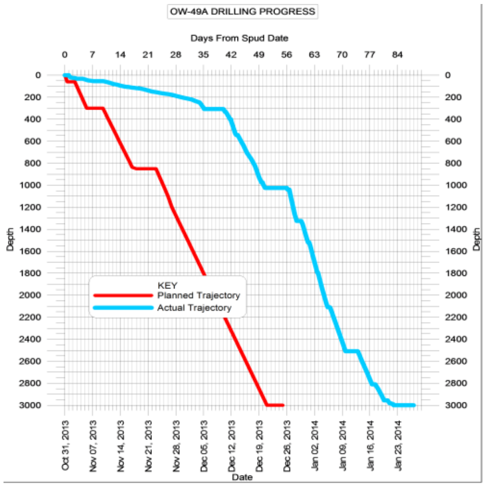

Figure 7: OW-49A Drilling progress chart

In this well slick BHA was used to drill out cement after casing. It may be possible to drill out cement with a holding/ building/pendulum and continue on drilling until poor ROP to save a bit trip. An RSS would also provide a smoother wellbore which will reduce stick slip and high torque events and mitigate possibility of twist offs and fishing operations like the one they encountered at 2509m where a non-magnetic drill collar snapped. I counted 4 days as non-productive time from the fishing job.

4.4 OW-49B

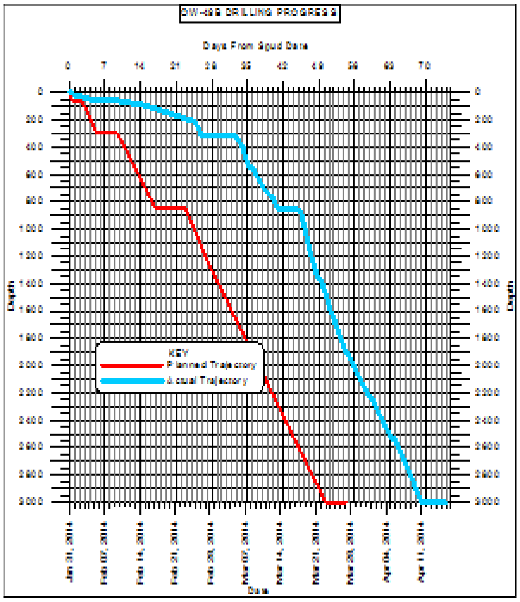

Figure 8: OW-49B Drilling progress chart

There were no major trajectory issues on this well. The angle built well to 20 degrees and it managed to hold to terminal depth. The rate of penetration on the shallower depths was significantly low due to the very hard formation present in that area.

4.5 OW-49C

I counted 20 POOH's that could be directly attributed to directional issues (not building angle, not holding, dropping, stuck survey tool, plugging etc). The time implication from this as I count from the DDR's adds to 35 days of nonproductive time that could have been solved through using an RSS having real-time tool face control ensuring proper build and holds to TD.

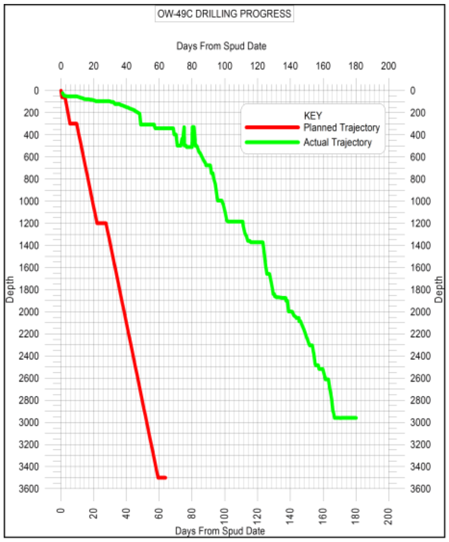

Fig 9:OW-49C Drilling Progress Chart.

5 COST ANALYSIS

Well	Rig	Terminal Depth	Days Drilled	Well Cost
OW-49A	GW-188	3000	88	$6,528,378.19
OW-49B	GW-188	3000	75	$4,515,895.46
OW-49C	Kengen 2	3000	180	$6,300,000
OW-710A	GW-192	3000	50	$3,910,997.13
OW-710B	GW-192	3120	79	$6,966,183.70

$$\text{Immediate cost saving} = \frac{\text{Estimated time savings (hrs)}}{24} \; x \; \text{Average daily cost}$$

Well	**Average daily cost**	**Number of Single Shot Surveys from Report**	**Estimated Immediate time savings from RSS usage (hours)**	**Immediate cost savings using RSS**
OW-49A	$55,000	19	9.5	$21,770.83
OW-49B	$55,000	20	10	$22,916.67
OW-49C	$35,000	27	13.5	$19,687.50
OW-710A	$55,000	19	9.5	$21,770.83
OW-710B	$55,000	24	12	$27,500.00

$$\text{Expected cost savings} = \text{Expected saved days x Average daily cost}$$

$$\text{Total cost savings} = \text{immediate cost savings} + \text{Expected cost savings}$$

Well	**Expected saved days through RSS usage:**	**Expected Cost savings through using RSS**	**Total Cost Savings using RSS**
OW-49A	4	$220,000.00	$241,770.83
OW-49B	1	$55,000.00	$77,916.67
OW-49C	35	$1,225,000.00	$1,244,687.50
OW-710A	7	$385,000.00	$406,770.83
OW-710B	24	$1,320,000.00	$1,347,500.00

6 CONCLUSIONS

From the analyzed data we can see that in some wells, the formation challenges make it harder to hold a desired path and this gives rise to some additional costs. These costs can be mitigated by drilling smoother and cleaner well bores which can be achieved by an RSS. There are some hidden costs further associated to this like the cost of repair of the drill string subjected to wear during this non-productive time.

In Olkaria we drill wells with limited inclination, however the 20 degree inclination chosen is the most difficult to get any BHA stability in for Rotary BHA design. Limiting Inclination limits the reach of each pad to exploit the geothermal resource and increases the production costs for the energy produced. An RSS would enable us drill complex wellbores which can access the resource more efficiently and enable us get more flow from our wells hence an increased energy output at the well head, inherently reducing the drilling cost per unit of energy produced.

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