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RIG SELECTION AND COMPARISON OF TOP DRIVE AND ROTARY TABLE DRIVE SYSTEMS FOR COST EFFECTIVE DRILLING PROJECTS IN KENYA

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ABSTRACT

Drilling rigs have been undergoing technological advancement over time. With this advancement has come a lot of improvements right up to the latest, modern AC top drive rigs that come with a high degree of automation. The depth capacity of the rig is determined by the rating of draw works, mast and mud pumps. Since drilling constitutes a high percentage of the geothermal development cost, the need to select rigs with a high efficiency and low drilling cost is paramount. There is also a need to identify drilling tools and equipment to be utilised to improve drilling performance. The top drive system is proving to be more advantageous than the convectional Kelly drive system. The automation of drill pipe handling and use of a iron roughneck improves safety and efficiency. The ability to circulate and rotate while running in the hole or pulling out of the hole reduces the chances of the bottom-hole assembly getting stuck. It also enables cooling of the bit, especially when running in the hole, thus increasing bit life. The advanced technology involved in top drive rigs comes with a higher cost and requires a highly skilled operating workforce. The use of downhole motors and good quality bits has also resulted in a faster drilling rate.

1. INTRODUCTION

Drilling costs constitute a large portion of the total investment in geothermal development; in Kenya it is estimated that drilling constitutes in excess of 65% of the total cost of steam field development for power generation (Mwangi and Mburu, 2005). Improving drilling technology and equipment results in higher efficiency, and therefore lowers cost. The drilling cost is increased by the inefficiency of the type of rig used, the drilling practice adopted, other factors beyond human control (for example the unrecoverable loss of circulation), and standby time paid to the driller during several backfill cementing jobs, especially on the top section of the hole. Locating more than one well in one pad with the use of directional drilling helps to reduce the cost of drilling. The number of trippings to change the bit or inspect the borehole assembly, tripping speed and the total number of bits used, all contribute to the overall cost of the well. This paper compares the performance of the top drive systems and the rotary table drive systems in geothermal drilling in terms of bit life, the rate of penetration, tripping time, and the overall time taken to complete the well while maintaining a good safety margin. It looks at problems encountered during drilling such as the probability of getting stuck, loss of circulation and environmental impact. It also gives the advantages and limitations of each drive system.

2. POWER STATUS IN KENYA AND DEVELOPMENT OF GEOTHERMAL RESOURCES

Kenya has a peak power demand of 1,172 MWe against an installed capacity of 1,286 MWe with geothermal contributing about 169 MWe – or 13% of the total national grid with the rest coming from hydro 56%, and thermal 31%. There are acute power shortages as a result of the current high (and escalating) oil prices, and frequent droughts that cause the hydro power stations to run below their installed capacities. Because of this the Government of Kenya, in collaboration with the Kenya Electricity Generating Company (KenGen), started an ambitious programme to develop the country's abundant geothermal resource.

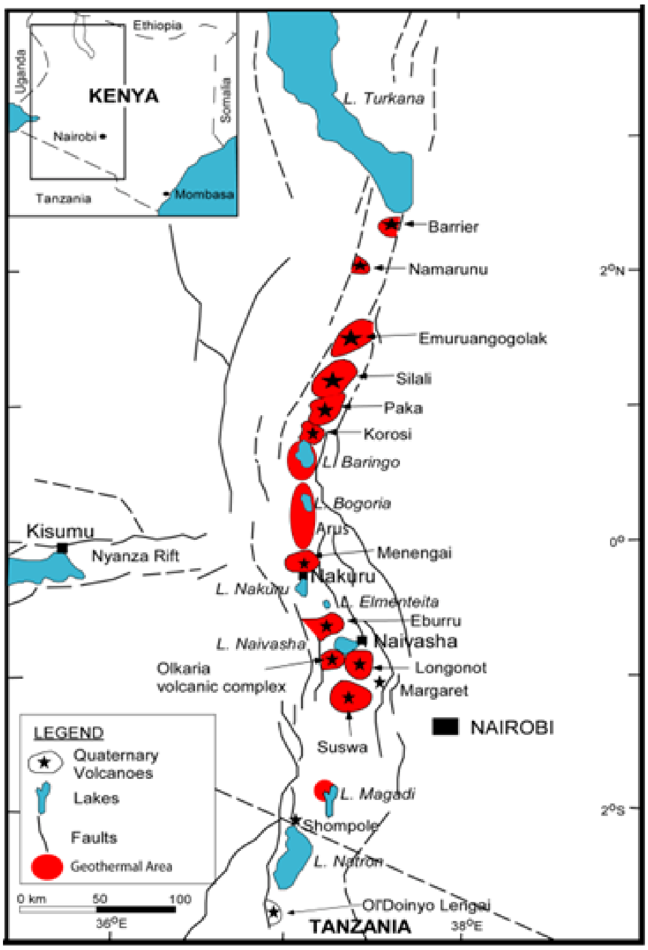

FIGURE 1: The Kenyan rift showing the location of volcanic systems and geothermal fields (Omenda, 2008)

The East African Rift System which runs from the Red Sea in the north to Mozambique in the south cuts through Kenya. There are many geothermal manifestations along the Kenyan rift which led to research starting in the 1960s. Research has shown that the geothermal resource in Kenya, if fully exploited, is estimated to be greater than 2,000 MWe (Mwangi and Mburu, 2005). The geothermal field which has been developed for power generation is Olkaria. Olkaria is divided into four sections. Olkaria I field was the first to be developed with an installed capacity of 45 MWe, followed by Olkaria II with an installed capacity of 70 MWe, along with an ongoing construction of a new, third unit of 35 MWe to be commission in early 2010. The Olkaria III field is owned by an independent power producer (IPP), Orpower, and generates 50 MWe by using a binary system. Production well drilling is ongoing at the Olkaria Domes field with an intention of building a 140 MWe power plant.

In the Menengai field, surface exploration has been completed and exploration drilling is expected to begin towards the end of 2009 or in early 2010. Surface exploration is ongoing in many other fields shown in Figure 1.

3. DRILLING PROGRAMME IN KENYA

3.1 Civil works

Before a drill rig is moved to a new site, the following needs to be done:

Access road construction: The rig needs to be moved to the site and material transport requires long, heavy trucks.

Site preparation: A drill rig is heavy and because of the high loads involved, the site should be properly levelled and fully compacted to prevent the rig from sinking or tilting. A cellar with the right dimensions needs to be constructed before the rig arrives at the site. A water supply pipeline is needed and a waste water disposal pond needs to be constructed prior to movement of the rig.

3.2 Well design

The wells earlier drilled in Olkaria I and II were vertical wells and were drilled using a N370 rig, which is an old mechanical rig with a draw works capacity of 550 HP. Because of the small capacity, it could only drill vertical wells up to a maximum depth of 2,200 m (Ngugi, 2002). However, with the current big rigs that weigh 250 and 450 tons more than the smaller rig, 3,000 m directional wells can be drilled. The first two sections of the hole are drilled with mud but if unrecoverable loss of circulation is encountered it is drilled blind with water but with high viscosity 2 m^3 mud pills being pumped after every 1-3 connections to ensure that there is no hole cleaning problem. The water level is very low in Olkaria. Hence, the last two sections that are drilled are 12½" and 8½" diameter holes using aerated water and foam. This is to attain balanced drilling for cuttings to be brought to the surface to attain good hole cleaning and therefore prevent the bottom hole assembly from getting stuck and reduce formation damage. Figure 2 shows a typical well design in Kenya.

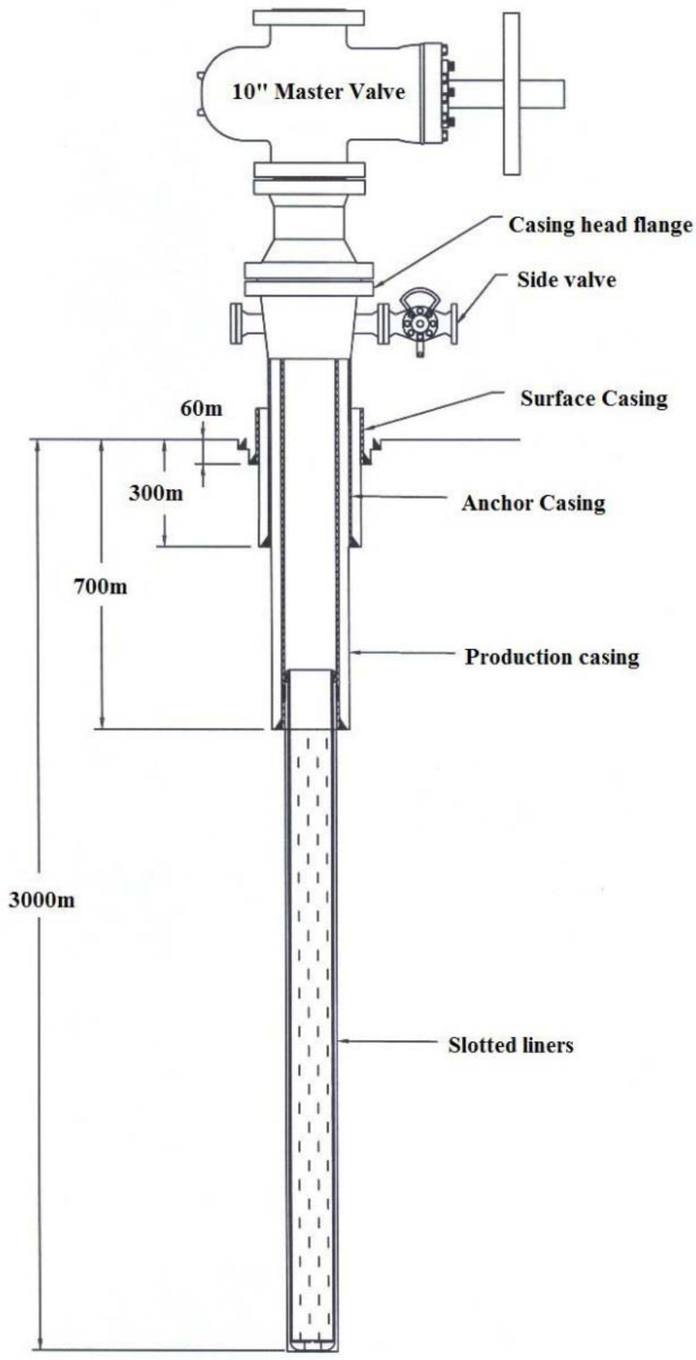

FIGURE 2: A typical Kenyan well design

3.3 Casing design

For surface casing, 20" 94 lbs/ft butt welded casing connections are used in a 26" hole and set to a depth in the range of 60-70 m. The casing is cemented to the surface using normal Portland cement with an average slurry weight of 1.6 kg/l. For anchor casing, the 13⅜" 54 lbs/ft buttress thread joint casing is used in a 17½" hole and set to a depth in the range of 300 to 330 m. The top two joints of the anchor casing have thicker walls (68 lbs/ft) for better strength of the wellhead. It is cemented to the surface using blended

Portland cement with an average slurry weight of 1.7 kg/l. Then after leaving the cement to cure for no less than 18 hours and backing off the landing joint, the casing head flange (CHF) is installed. For production casing, the 9⅝" 47 lbs/ft buttress thread joint casing is used in a 12¼" hole and set to a depth where the alteration mineralogy indicates a temperature in the range of 250°C which in Olkaria, Kenya is usually between 700 and 1,200 m. It is cemented to the surface using blended Portland cement with an average slurry weight of 1.7 kg/l and left to cure for no less than 18 hours before doing the next task. The well is drilled to the total depth usually between 2,600 and 3,000 m where 7" slotted liners are run into the 8½" open hole. The master valve is bolted in place to the expansion spool attached to the anchor casing. Then the well is left to heat up while the rig is moved to another location. After logging and flow-testing the well is then ready for connection for use in power generation.

3.4 Directional drilling

Direction drilling refers to a drilling practice where the well is deviated from the vertical inclination to a specific direction. Most of the earlier wells in Olkaria I and II were drilled vertically because of the capacity and design of the rig used at that time. But in 2007 directional drilling was adopted in Olkaria Domes. The well was drilled to a 400 m kick off point (KOP) just below the anchor casing shoe where the well was deviated using the bent sub, mud motor, and non magnetic drill collars (deviation tools). The angle was first built at a rate of 1^o per 30 m to a desired angle, usually 20° in Kenya, and then drilling was continued holding that angle to the total desired depth. There are several advantages in adopting a directional drilling practice (Hole, 2007a):

- When the reservoir is located in an inaccessible area, for example on bad terrain or below a mountain, then directional drilling will really help to reach the reservoir easier and at a lower cost.
- Directional drilling allows locating several wells in one well site, thus the road construction cost, water supply cost, and steam gathering system cost is combined.
- Directional drilling enables the intersection of several vertical structures in one well.

3.5 Aerated drilling and foam

The primary objective of aerated drilling is to enable the drill cuttings to be brought to the surface and to keep the hole clean to prevent the drill string getting stuck. This involves injecting compressed air and foam into the drilling fluid to reduce the density and achieve the static pressure within the borehole annulus to balance with that of the formation pressure. If the cuttings are not removed to the surface then they may be washed into the permeable zone and block the fractures leading to skin damage. This could cause a fill-in on the bottom of the hole causing the bottom-hole assembly (BHA) to become stuck. If the BHA gets stuck, fishing the well can sometimes become a very expensive task. In Kenya, aerated drilling was adopted between 1982 and 1997 while drilling in Olkaria (Hole 2007b) and is presently being utilised while drilling in Olkaria Domes. Aerated drilling has proved to be very successful especially because of the low groundwater table around Olkaria.

Table 1 shows data on output of some selected wells which have been drilled with and without aerated fluid. The values in Table 1 show that wells drilled with aerated fluid have a better output than the ones drilled either with water or mud.

Aerated fluid has a lower bit cooling effectiveness, thus, when drilling with aerated fluid the bit bearing tends to get damaged faster; or the tungsten carbide insert gets overheated, reducing its hardness and resulting in a shorter bit life and reduced rate of penetration. So it should only be used in the production zone and the loss zone if possible.

TABLE 1: Comparison of thermal output of wells drilled with and without aerated fluids in Olkaria, Kenya (Hole, 2007b)

Wells drilled blind with water		**Wells drilled with aerated fluid**	
Well No.	**Output (MWt)**	**Well No.**	**Output (MWt)**
1	43.31	A-1	37.05
2	12.75	A-2	98.73
4	22.15	A-4	58.86
5(drilled with mud)	14.75	A-5	105.49
6	21.38	B-1	27.59
		B-3	36.26
		B-7	32.72
		B-9	67.63
Average	**22.87**		**58.04**

3.6 Reservoir characteristics in Kenya

When selecting the kind of rig to use for drilling, the well design needs to be known and this in turn requires the reservoir conditions to be taken into consideration. This will help in specifying the size and rating of the mast and mud pumps.

3.6.1 Reservoir temperature

The reservoir temperature is obtained by direct downhole measurements or, for early wells, from geochemical estimates using geothermometers. In Olkaria the reservoir has a temperature >250°C at around 1,200 m depth. The formation temperature estimates help in designing the mud properties to contain the formation fluid coming into the wellbore to avoid a well kick, or cooking the drilling bit due to the lack of enough cooling from the drilling fluid used during drilling. Figure 3 shows the downhole temperature of selected wells in Olkaria. The data used was collected after the wells had heated up for more than 40 days and some of them had also been discharged.

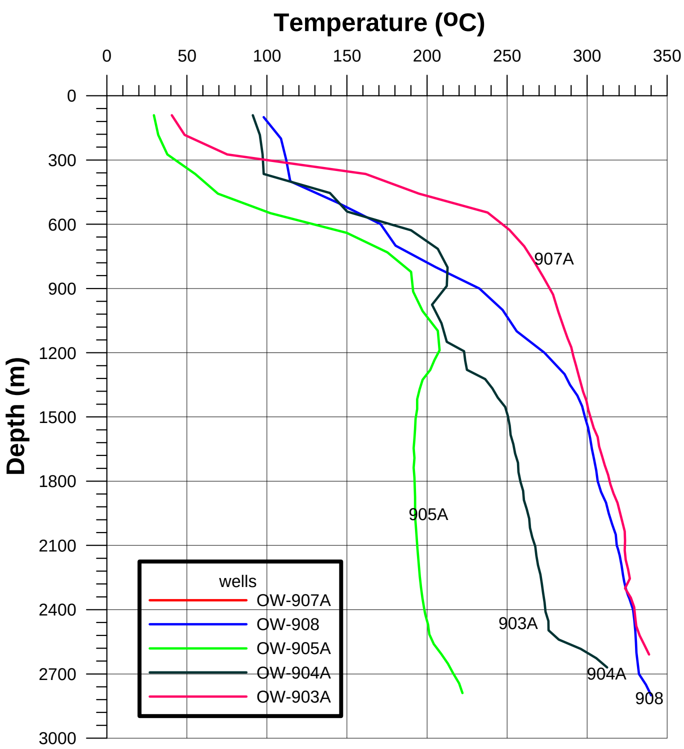

FIGURE 3: Temperature logs for a few Olkaria wells

3.6.2 Reservoir pressure

The formation pressure can be around 170 bars at 2,700 m depth (Figure 4). This means that in such a well that has cold water, the static water level would be at 1,000 m. However, the average water level in a hot well around Olkaria is about 400 m below the surface. Thus, at a lower depth, aerated water is used to bring the cuttings to the surface for proper borehole cleansing, which means additional cost in running the compressors.

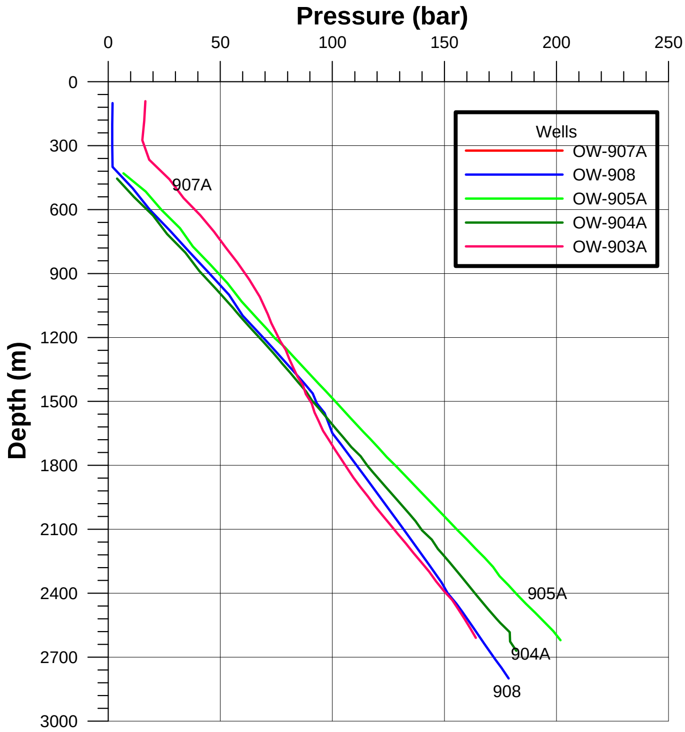

FIGURE 4: Pressure logs for a few Olkaria wells

4. COMPARISON OF TOP DRIVE AND ROTARY TABLE TYPES OF RIGS

Drilling is considered to be an industry where the final product is a borehole. Geothermal drilling technology is borrowed from the petroleum industry with some modification to fit the geothermal conditions of high temperature and pressure, hard formation and large diameter casing design. In Iceland, before 1958 the rigs being used could only drill wells to less than 250 m depth, but with the arrival of "The Steam Rig" in 1958 the drilling of deep high-temperature wells to more than 500 m began. With advancements in technology, the rig industry now offers a selection of modern electric or hydraulic rigs with different degrees of automation for the handling of drill pipes and casing. The successful completion of a geothermal well on time and with a good safety margin depends on the efficiency of the rig and the level of skill of the rig crew members plus the proper planning and coordination of all the pre-drilling activities like civil works, procurement of spare parts and consumables required in the drilling operation. The first step is choosing the right type and size of rig with a good safety margin that can fit into the wellbore planning design.

4.1 The drive mechanism of a rig

The main difference between the top drive rig and the convection system rig is the position of the drive mechanism. The top drive system is situated on the mast and moves with the drill string up and down along the mast guide. The top drive system torque comes from a hydraulic or electrical motor drive. The rotary table drive system is situated on the rig floor. The rotary table drive system is mechanical where the torque is transmitted to a hexagonal pipe called the Kelly, through a chain and a sprocket.

4.2 Drill string design

The drill string is a very important component of the rig; it is the conduit for the drilling fluid to cool the bit, power the mud motor and to enable the drill cuttings to be brought to the surface. It transmits the rotary torque to the bit to do the drilling. The heavy drill collars that are above the bit, perhaps the first 100 m of the drill string provide the weight on the bit.

A sketch of a drill string for a rig with top drive is shown in Figure 5, consisting of the top drive motor at the mast which is connected directly to the drill string. The string's rotation is achieved by a hydraulic or electrical motor. The rotary table rig has on the other hand a swivel which is connected to the Kelly to provide rotation of the string; the set up is shown in Figure 6.

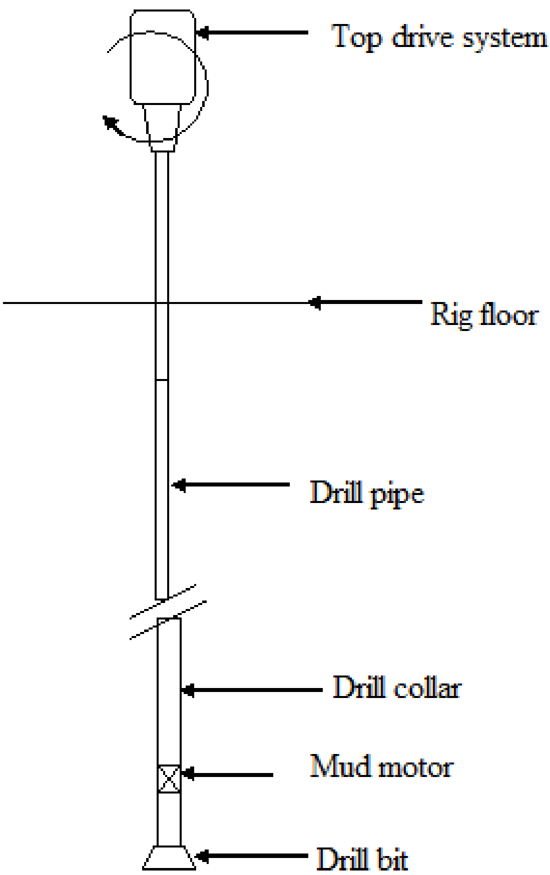

FIGURE 5: Top drive rig drill string sketch

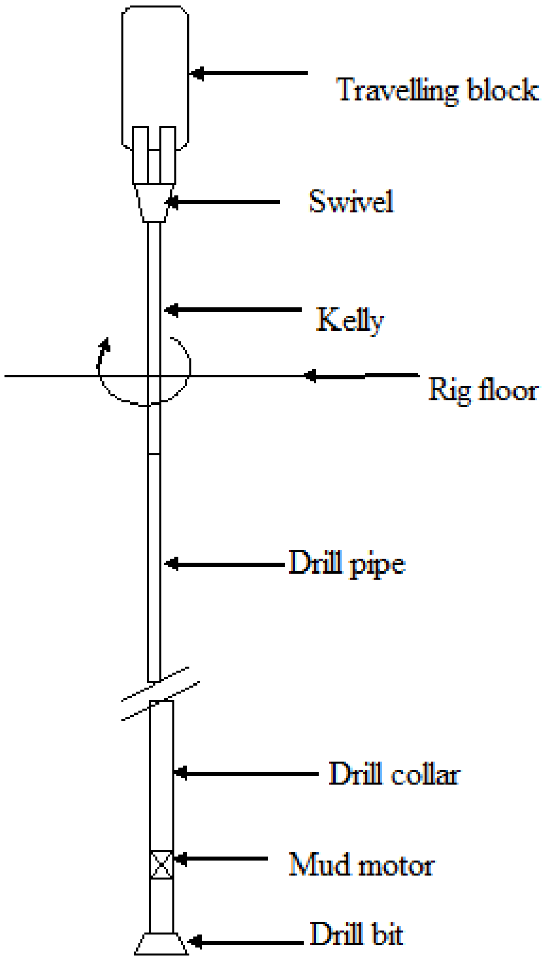

FIGURE 6: Convectional rig drill string sketch

4.3 Bit life

The drill bit is the most critical part of the bottom-hole assembly (BHA). Drilling efficiency is largely dependent on the drill bit life (total drilling hours) and the rate of penetration (metres/hour). The weight on the bit comes from the heavy drill collars and maintaining correct weight on the bit is important, for too much weight will cause crooked holes to be drilled or place a drag on the drill surface resulting in high frictional forces and thus excess heat which can cook the bit.

There exists a relationship between the bit cost, bit life and bit performance (rate of penetration). For a bit to have a long drilling life, more advanced technology needs to be applied during manufacturing, resulting in a higher cost. For geothermal wells it is most common to use drill bits with tungsten carbide inserts, gauge protection, and journal bearings. Most bit manufacturers tend to play with these factors to strike a balance between cost effectiveness and bit performance.

Geothermal drilling mainly uses tri-cone bits with tungsten carbide inserts which perform better than other bit types. However, the bearing O-ring seals are made of rubber and have a temperature limitation of 150-200°C and are, therefore, affected or damaged by high temperatures during drilling, especially while running in hole where the bottom part of the borehole has a static formation temperature which sometimes exceeds 250°C. This high temperature affects the O-ring seal and diaphragm; without proper cooling and better drilling practices, the bit life may be reduced substantially because of bearing failure. Frequent changing of the bit introduces the cost of tripping time, and if it is done frequently over a short drilled depth, then that will increase the total cost of drilling.

TABLE 2: Bit performance while drilling in Kenya

	8 ½" bit performance						
	903B	**904B**	**905A**	**906A**	**907A**	**908**	**909**
Directional well	Yes	Yes	Yes	Yes	Yes	No	No
Total drilled depth (m)	1,575	1,533	1,517	1,515	1,314	1,754	1,793
No. of 8½" bits used	6	8	7	8	8	6	4
Total bits drilled hrs.	456	224	439	400	495	565	270
Average depth per bit	262.5	191.6	216.7	189.4	164.3	292.3	448.3
Average hrs. per bit	76	28.1	62.7	49.9	61.9	56.5	67.5
Rate of penetration (m/h)	3.5	6.8	3.5	3.8	2.7	3.1	6.6
Bit bearing condition	Worn out	Worn out	Worn out	Worn out	Worn out	Worn out	Worn out

In Kenya, rotary table rig have been used and the 8½" bit failures at a depth greater than 1,800 m where the static reservoir temperature is greater than 250°C are mostly due to bearing failure. The analysis also shows that directional wells have a lower average drilled depth per bit than vertical wells.

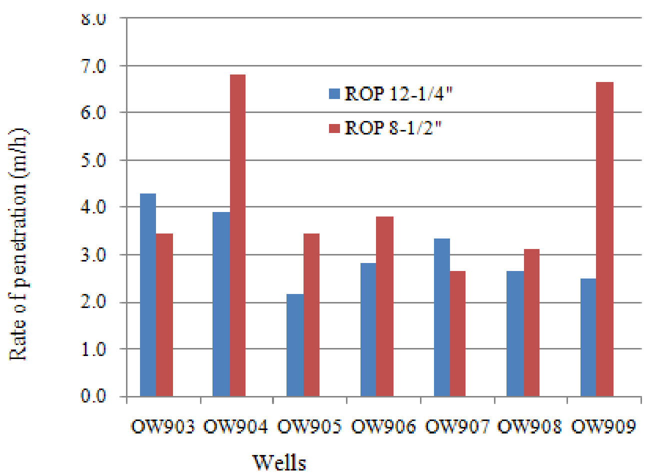

FIGURE 7: Average rate of penetration for seven wells in Kenya

Figure 7 shows the rate of penetration while drilling the 12¼" and 8½" section of the holes in seven wells in Kenya. In this analysis, OW 909 is a vertical well and has the longest drill depth per bit compared with the other wells in the 8½" section, though they have almost the same formation and the same drilling conditions.

The top drive system has been shown to overcome this bit heating problem better than the convectional technique because of the continuous pumping while running in hole, thus providing better cooling of the bit. Figures 8 and 9 show sketches of top drive set up and convectional rigs while running in hole.

Research was done in Japan to show the efficiency of the top drive system in improving bit life (Saito and Sakuma, 2000). Two high-temperature wells were drilled using two types of rigs, top drive and rotary table rigs. Well WD21 was drilled using the rotary table technique, and well WD1a using a top drive system. In well WD21 three bits managed an average of 28 drill hours with their O-ring seal before failing. The deepest depth of the well the O-ring seal survived was 2,105 m with a static

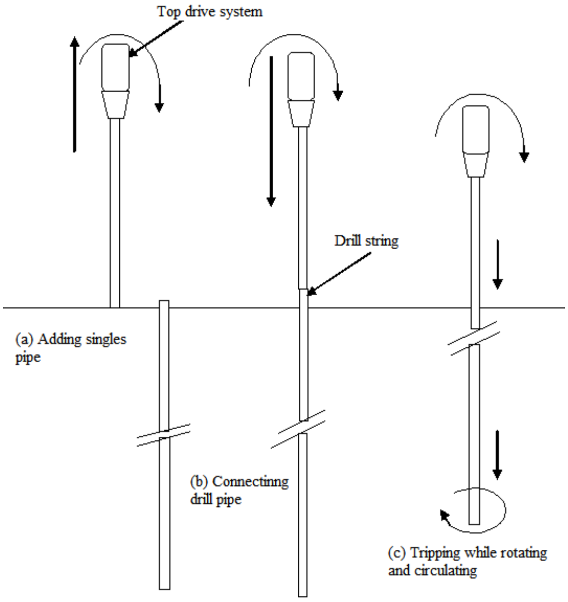

FIGURE 8: Top drive set-up showing circulation while running in hole

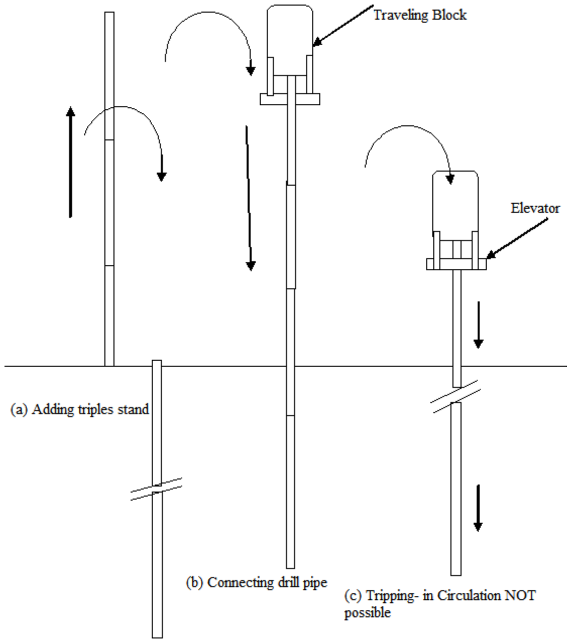

FIGURE 9: Rotary table set-up cannot circulate while running in hole

formation temperature of 350°C. In the WD1a well, the deepest depth the O-ring seal survived was 3,451m with a static formation temperature of 450°C and 5 bits had an average of 50 drill hours without the O-ring seal failing. Judging from these two examples, the bit life of a top drive system is 3-6 times longer than that of the convectional system under the same drilling conditions.

4.4 Rate of penetration

Due to the worldwide increase in petroleum prices and material costs, there is a need to lower the well cost, e.g. by increasing the rate of penetration (see Figure 7) and minimising as much as possible the non-drilling costs. The rate of penetration depends mainly on the weight on the bit (WOB), the revolutions per minutes (RPM), the cutting condition of the bit and the formation hardness. There is a rule of thumb that the weight on the bit should be about 1 ton per 1" of the diameter of the drill bit but the rotation applied depends mainly on the hardness of the rock being drilled. The weight on the bit comes from the drill collars. The cutting condition of the drill bit inserts is very important, for example if the teeth are dull it overrules all other factors. Also the circulation fluid is important in improving the rate of penetration; the drill cuttings need to be removed in order to have a clean surface for the next teeth to cut the new surface. This is common while drilling on a medium hard formation where the rate of penetration is high, thus generating a high volume of cuttings that need to be removed. Because the top drive has a better bit life management than the convectional rig type, a higher rate of penetration can be achieved. Underbalanced drilling sometimes improves the rate of penetration by as much as 50% as compared to overbalanced drilling.

There exists a relationship between the bit life and its cost. The bits with a journal bearing, tungsten insert are at the higher end of the cost spectrum while milled tooth bits with ball bearings are at the lower end.

4.5 Probability of getting stuck and the fishing process

Drilling is an industry where everyone knows that time is money. To lower drilling costs one should design drilling programmes that can minimise any non-productive drilling operation time. One of the biggest non-productive operations in drilling is fishing. Fishing can be defined as the removal of unwanted items in the borehole or the drill string in the hole becoming stuck. Several phenomena can cause the bottom-hole assembly (BHA) to become stuck, for example, the collapse of the borehole walls, or poor hole cleaning where the fill-in can jam the string, especially when a second loss zone appears. If the drill cuttings are not brought to surface from the borehole by the drilling fluid then high viscosity polymer pills are used. It is important to monitor the fill-in by pulling out every 50-100 m and reducing the circulation and then lowering the drill string to tag the top of the fill. Should there be much fill then it is necessary to clean the hole by slowly regrinding the fill and then applying a pill to flush it out into the formation. Frequently, a large fill-in in a well with a total loss of circulation is the reason for drilling to stop. But there is also increased danger of getting stuck.

Since the top drive can allow the rotation of the BHA and circulation while at the same time being able to pull out of the hole, then it has a better chance of not getting stuck over the convectional system where you cannot circulate through the swivel while pulling out with the Kelly disengaged (see Figure 9).

4.6 Tripping time

Tripping speed can be improved by using automation for pipe handling and using an iron-roughneck to make-up or break the connections. Thus the total amount of time that goes into pulling out of the hole, or running in-hole, is less when using the top drive system, especially when the mast can handle three drill pipes at a time ("triples") with 90 feet long stands. Some masts are only made to handle single lengths of drill pipes ("singles") and then the tripping time becomes greater. The rotary table rig can pull out of the hole or run in-hole using the "triples", providing a faster rate of tripping. Also, if an obstruction is encountered while running in-hole while using the top drive, the driller can circulate and rotate the bit right away to ream the hole. But in the case of a rotary table setup, the driller has to pull out one drill pipe and connect the Kelly, then run in to circulate and ream the hole and thereafter disconnect the Kelly to continue running in–hole, or do it one step at a time which is time consuming.

4.7 Rig move

Rig transport is an important part of the drilling operation. There are two types of rig movement: mobilisation, and well to well rig movement. Mobilisation is where the rig is transported either from the rig manufacturer workshop, or overseas contractor yard, to the well site and the other is simply to move the rig from a completed well to a new well site. The two wells can either be in the same well pad (multi well pad) or at different sites. When they are on the same well pad the rig is just pulled or can slide on steel beams to the next location. If the new well is at a different pad, then after completing the well the rig crew is mobilised to dismantle the rig into movable parts, load it onto trucks and move it to the next well site. The time taken to rig down, transport, then rig up, and the number of hired trucks and cranes determines the cost of a rig move operation.

The data shown in Table 3 are based on personal observations working on rig moves in Kenya and the observation of one rig move in Iceland during the training period. The rig in Kenya is an electric rotary table rig with a capacity of 2,000 hp and 450 tonne hook load capacity. The Icelandic rig is a 1,500 hp hydraulic top drive one, with 200 tonnes hook load capacity.

Table 3 shows the rig move comparison between the two rigs; the distance factor between the completed and new well sites for each rig was not taken into consideration as it was almost the same (2.5 km).

TABLE 3: Rig move statistics for the top drive and rotary table drive rig

Rig type	No. of trucks used	No. of cranes used	Total no. of trips	Total no. of days	Total crane hrs	Total truck hrs
Top drive (Icelandic)	4	2	40	4	64	128
Convectional rig (Kenyan)	10	4	100	6	192	480

If an analysis of the data in Table 3 is done with each rig working 8 hours a day, then the convectional rig has four times the number of total truckload hours, and three times the total crane hours than the top drive. This may be attributed to the design and component parts of each rig. For example, the mast and rig floor of the top drive is just towed by one truck while that of the convectional rig has several parts which, when dismantled, takes 10 trips to move.

The crane is an expensive piece of equipment to hire for the owners are paid on an hourly rate; therefore, the modern hydraulic rig only uses two cranes, one at the completed well used in rigging down, and the other in the new well site used in rigging up. Thus, the crane is hired for a total of 64 hours in the Icelandic case and for 192 hours in the Kenyan case. The modern top drive has less components that make it more compact, and the rig is designed for ease of transport, e.g. the mud tanks are on wheels, much easier in loading and transportation compared to the convectional rig where the structures are more robust and thus take more space and time during transportation.

4.8 Safety

Like any other industry, the drilling industry is actively involved in innovations to improve the safety within the operational area of the rig, of paramount importance for every worker. Research has shown that machines are more accurate than human beings especially when it comes to routine jobs, therefore the less people involved in a certain job where they have been replace by machines, the higher the safety factor. The top drive rig has fewer people working manually on operations, thus achieving a higher safety factor than with the convectional system, where more people are involved.

4.8.1 Iron roughneck

The iron roughneck is a pipe handling machine, able to do the spinning and make up or break up the pipes. The roughneck is remotely controlled and operated by the driller, providing a high level of automation for the rig and insuring proper make-up torque. This increases the level of safety to the rig crew and the overall drilling operation. Since it is able to simultaneously perform pipe handling and make-up functions it saves time on every connection. This gives the top drive system some advantageous points over the convectional system.

4.8.2 Casing running tools

The development of casing running tools has also improved safety and the time taken to run the casing. The top drive can accept a bushing that allows the casing to be screwed together and made up to the proper torque. In the top drive it is possible to circulate while running in-hole thus allowing for a faster rate of lowering and maintaining a good borehole wall for the cementing job.

4.8.3 Workforce size and their skills

Because of the automation of the modern rig, the number of people required to work in the rig is reduced. The fewer people involved in a certain job tends to improve safety as opposed to when more people are crowded into an area to do a task. A rotary table rig requires three people to work on the rig floor, driller and derrick man jobs, but the top drive has eliminated the derrick man and has only two people on the floor. The fewer people involved at a certain task, the more the safety margin is improved. A skilled workforce tends to know what they are doing and observes safety more than a non-skilled workforce. Table 4 shows the number of people working in the two rig types, both in Iceland and Kenya.

TABLE 4: Number of people working on different rig types

		Iceland Drilling Co. Ltd. rigs				Kenyan rigs			
		Top drive		Rotary table		Contractor		KenGen	
		No. per shift	Total no. per rig	No. per shift	Total no. per rig	No. per shift	Total no. per rig	No. per shift	Total no. per rig
1	Rig manager	1	1	1	1	1	1	1	1
2	Tool pusher	1	4	1	4	1	4	1	4
3	Driller	1	4	1	4	1	4	1	4
4	Ass. driller	1	4	1	4	1	4	1	4
6	Floor men	2	8	2	8	4	16	3	12
7	Derrick man	-	-	-	-	1	4	1	4
8	Mainten. team	1	4	1	4	2	8	3	12
9	Compre. air team	1	4	1	4	2	8	1	4
10	Crane operator	-	-	-	-	1	1	1	1
11	Shift driver					1	4	1	4
	Total	**7**	**29**	**7**	**29**	**15**	**54**	**14**	**50**

4.9 Environmental impact

In most countries nowadays, an Environmental Impact Assessment (EIA) is required to be done before commencing the development of an industry. The drilling industry is not exempt from that, so an Environmental Impact Assessment should be done and a system designed that will minimize environmental impacts.

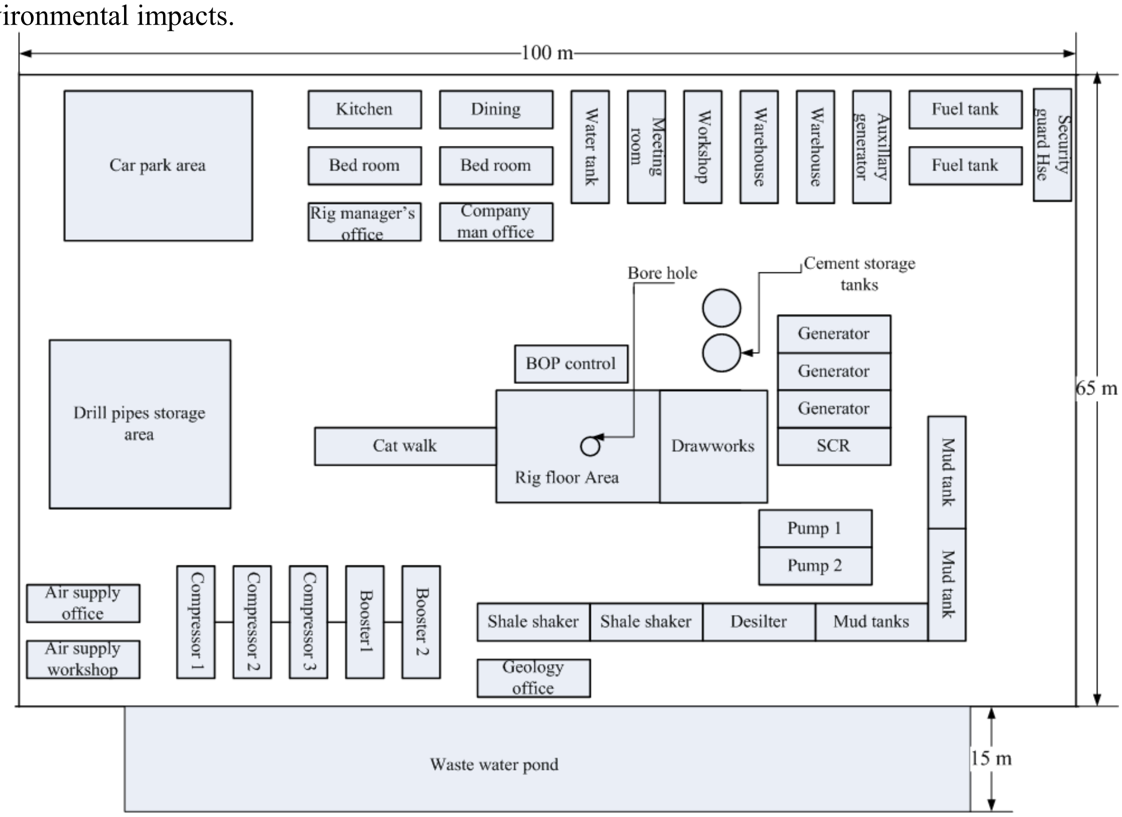

FIGURE 10: Rotary table rig well platform layout used for drilling in Olkaria, Kenya

4.9.1 The size of the well pad

Before drilling commences, access roads, water lines and the well pad are prepared. The well pad size depends on the specific layout of the rig in use. Most of the geothermal reservoirs are located in national or game reserve parks, thus the need for the drilling operation to minimise environmental degradation, especially with regard to the well pad design size. Since the top drive rig is compact in area, the size of the well site is small, thus the environmental impact is reduced. This gives the top drive an advantage over the other, especially when drilling in a restricted area such as inside national parks or in a residential area where space is limited.

Figure 10 shows the layout of a platform for one of the rotary rigs used in Olkaria, Kenya, and it covers an approximate area of 8,000 m^2 with dimensions of 100×80 m. The Icelandic well pad, as shown in Figure 11, has an approximately area of 3,850 m^2 with dimensions of 70×55 m. Comparing the two well pads, it can be seen that the Kenyan well pad has twice the area compared to that of the Icelandic well pad. One factor that contributes to this is that the Icelandic site office containers are placed on top of one another, thus reducing the total space they occupy.

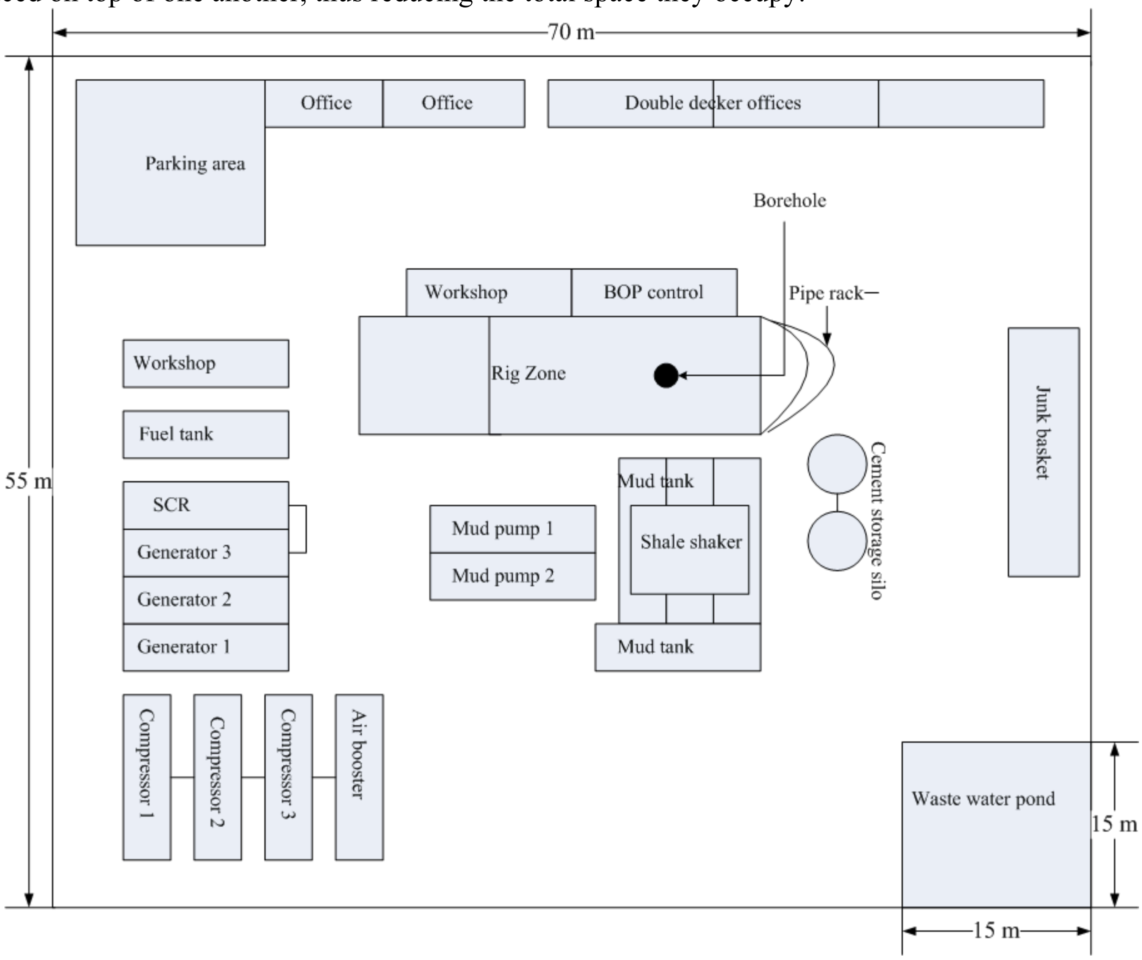

FIGURE 11: Icelandic well platform using a top drive rig

4.9.2 Noise level

Sometimes the rig is required to drill in a residential area where the noise level from the rig operation needs to be kept as minimal as possible. The main source of noise in the rig operation are the big generators which supply power for rig operation, therefore the exhaust of the engine should be inside sound insulated containers and fitted with silencers to minimise the noise level. Most of the modern rigs have their components fitted with a noise insulation system meeting the European standard noise level of no more than 85 dB at 1 m distance within an 8 hour exposure.

5. TYPES OF RIGS AND THEIR SPECIFICATIONS

Modern drilling industry requires diversity, quality and value for money. The rig chosen should be able to provide a comprehensive drilling solution, advanced technology with high efficiency, enhance the health and safety factors of the workers, and minimise environmental impacts. There are several rig designs in the global market today. The rig maker should be able to provide after sale service and spare parts for routine maintenance to ensure the efficient operation of the rig to minimise breakdowns, and thereby minimising the operational cost. The selection of a rig depends wholly on the depth of the borehole and the diameter to be drilled, and also whether or not directional drilling is needed in order to achieve the objective of the client. The rigs can be classified broadly as offshore and land rig with this paper dealing with the latter. The rigs can be described by using the following headings.

5.1 Power

Mechanical power: Major drive component are driven by the diesel engine power transmitted through the torque converter and clutches. It is common in the rotary table rig types.

Electrical power: Major drive components are run by electrical AC or DC motors. The power can come from the grid or diesel generators on site, and conversion from AC to DC is done at an SCR system.

Hydraulic power: Here the rig drive torque is mainly provided via hydraulic power, common with the top drive system rig. The hydraulic pumps are driven by electrical motors. The mud pumps are either direct diesel or driven by electrical motors.

5.2 Rotation

Rotary table: Rotation of the drill string is achieved through torque applied at the rotary table and by the hexagonal Kelly on the drill floor.

Top drive: The top drive can be defined as a hydraulic or electrical motor suspended in the mast of the drilling rig; it drives and rotates the drill string and bit, thereby doing the drilling. It is also a conduit for the circulation fluid. Some of the top drives have pull down chains to allow the rig to utilise some of its weight to provide weight on the bit, especially while drilling at shallow depths.

Hammer: The hammer uses rotation and a pneumatic percussion hammer located at the bottom end of the drill string with 100 psi compressed air to drill, and is commonly used to drill very hard igneous rocks in low-temperature wells or in water wells. The hammer face has a tungsten carbide insert to do the chipping and the hammer’s exhaust of compressed air is used to clean the well and bring the cuttings up the annulus to the surface.

5.3 Geothermal rig modification

Geothermal drilling is a borrowed technology from the oil industry but there have been modifications made to fit into geothermal conditions as follows:

Substructure: Geothermal rigs have a high substructure to accommodate the installation of a blowout preventer (BOP) to allow for a well shut-in in case of a kick. They are also fitted with a rotating head to divert flow returns and prevent it from reaching the rig floor.

Size of the casing: The casing design is very important because this indicates the diameter of the hole on the rig floor.

Circulation system: Geothermal reservoirs have high temperatures and pressures; therefore, a high pump flow is necessary to provide sufficient cooling and to contain the formation pressure. The mud pump should have a discharge of 60 l/s and a pressure of 200 bars for 12¼" holes. This requires mud pumps to have a power of 800 kW each. A cooling tower is required for the mud due to the high reservoir temperature. Mud circulation constitutes the highest energy consumption in the rig operation, therefore improving the efficiency of the mud circulation system means energy savings.

Draw works: The main function of the draw works is to reel the drill line in or out, to raise or lower the travelling block which is coupled to the drill string thus enabling it to run in hole, and to pull out of the hole, or drilling by giving the weight on the bit to exert the force. Hydraulic rigs employ a piston inside the mast tube for the purpose of lifting.

Drill string: The drill string provides a conduit for the drilling fluid to be transmitted to the bit for cooling, and brings the drill cuttings to the surface. It uses impact rotary motion on the bit to do the drilling. The heavy drill collars that are part of the drill string provide weight on the bit. The drill pipes are always kept under tension. The size of the drill pipes determines the maximum depth the rig can drill in relation to the hook load capacity of the rig. For a rig capable of drilling to 3000 m, the weight of a 5" drill string plus 20 tonnes of drill collars is 105 tonnes, but 33% should be added for overpull and drag force just in case the need arises, like for example during fishing. Therefore, the hook load rating must be above 140 tonnes.

5.4 Drilling fluid

The main purpose of the drilling fluid is the following (Hole 2007b):

- Remove cuttings from the bottom of the hole – at the bit face.
- Return cuttings to the surface (circulating conditions).
- Hold cuttings in suspension when circulation is stopped.
- Release cuttings from the drilling fluid at the surface.
- Cool and lubricate the drill bit.
- Lubricate the drill string.
- Cool the hole and prevent liquid in the well from boiling.
- Control the downhole pressure preventing the well from flowing.
- Carry weighting material to increase fluid density to prevent the well from flowing and possibly blowing out.
- The fluid also provides power to the mud motor and measurement while drilling (MWD) when they are used.

The drilling fluid can be water, mud (water and additives like bentonite), air or aerated water and foam. The capacity of the mud pumps determines the outlet pressure and maximum flow of the circulation fluid. Usually the typical flow is 40 l/s while drilling an 8½" hole and outlet pressure of the pump is 100 bars. Depending on groundwater level, it is able to carry the cuttings to the surface, clean the hole, and prevent the drill string from sticking. If the groundwater level is low, as it is in Olkaria (around 400 m), then at lower depths there is a need to use compressed air to be able to bring the cuttings to the surface.

Rotation speed: Mechanical rigs have a low rotation speed, typically 100 rpm, but electrical rigs and top drive rigs have a high speed of up to 220 rpm. For geothermal drilling, rotation is usually in the 55-80 rpm range for conventional drilling and 150-250 rpm for drilling with a mud motor.

Table 5 shows different hydraulic rig models made by different companies with different technical specifications. The data was downloaded from the companies' websites.

TABLE 5: Hydraulic rig types
(Drillmec, 2009; National Oilwell Varco, 2009; Bentec, 2009, Tesco, 2009)

Company's name	Model	Rated capacity (tons)	Max speed (RPM)	Rated input (HP[KW])	Top drive make up torque (ft*lbs)	Top drive stroke (ft)
Drillmec	HH-200	181		1340[1000]	26,035	52.5
	HH-220	200		1340[1000]	26,035	52.5
	HH-300	272		1542[1150]	36,141	52.5
National Oilwell Varco	TD-150P	150	155	234	11,500	43.5
	TD-250P	250	200	585	33,000	43.5
	TD-350P	250	200	585	33,000	43.5
Tesco Corp.	250HXI 700	250	200	700	32,000	
	500HCL750	500	160	750	44,600	
	650HS750	650	150	1100	45,500	
Bantec	TDS11SA	320	228	800	55,000	

5.5 Total depth of the well to be drilled

The target depth for future wells to be drilled in Kenya is about 3,000 m, most of them to be directional (Figure 2). The depth of the first geothermal wells was about 500 m; the technical knowledge about the deep reservoir at that time was limited. As technology has advanced, more robust rigs came into play which could drill to 3,000 m, and are now deployed in Olkaria Domes.

5.6 Automation and computers

By the mid 1990s the drilling industry, like most other industries, adopted computers as an integral of part of the drilling components, used in electronic monitoring, recording the rig drilling parameters, and displaying the data on a human machine interface (screen) for better understanding and control. Now they are also used in the electronic control of robots like the roughneck for efficiency and safety within the drilling environment. Drilling fluid instrumentation helps to monitor the physical properties of the drilling mud, especially the injection or return temperature, losses, viscosity, pH, density, and conductivity of the mud.

5.7 Measurement while drilling (MWD)

The measurement while drilling tool (MWD) is deployed in directional drilling to provide information on the well trajectory and to aid in steering towards the target. The MWD consists of a detection device and an analysing device. The bottom-hole unit consists of a sonde and a sensor sub in which the sonde is located on a non-magnetic drill collar in the BHA just above the drill bit. It senses and collects data on the direction, inclination and tool face. The data collected by the sensor is transmitted to the sonde by means of an electromagnetic coupler where it is then converted into mud pulses generated by the sonde pulsar valve located at the top of the sonde and sent to the surface read-out equipment. The surface equipment has both a pressure transducer for sensing mud pulses and a processor for interpreting pulses into information data. The disadvantage of the MWD system is that it only works where drilling fluid reaches the surface; unrecoverable loss of circulation means that no pulse is transmitted to the surface.

5.8 Cementing

The main purpose of cementing is to hold the casing in place, to prevent the migration of fluid outside the casing, and to prevent corrosion of the casing. There are different methods used in cementing but here two case studies will be analysed, one from Kenya and one from Iceland.

Kenya: A calculation was done to establish the volume of the shoe joint and annulus to the loss zone, and then excess was factored in. The total volume of cement that was calculated was pumped through the casing, and then the top plug was released. The cement was followed by water that displaced the cement until the top plug rested on the float collar and the cement in the annulus was at the loss zone. The system was kept under pressure for 12 hours then backfill was done till the cement returned to the surface.

Iceland: Inner string - the cement was pumped through the drill pipe, stab-in at the float collar, and float shoe cement flowed up the annulus till the cement was received on the surface.

When there are large losses in the well, as frequently is the case, the method is modified. The inner string cement is then pumped through the drill pipe, stab-in at float collar and float shoe up the annulus to the loss zone; the loss zone is kept open by pumping water simultaneously from top through the annulus. Immediately backfill is done by pumping through the annulus until the cement is returned to the surface. This is the most commonly used method.

Top down cementing - all cement was pumped through the annulus of the casing and allowed to displace water through the inner part of the casing until the cement reached the casing shoe. The water returned to the surface up the inside of the casing or drill pipe, flowing through a throttle valve to prevent the free flow of the cement being pumped. The volume of backflow was measured to balance the cement being pumped into the well. This is called the reverse cementing procedure, and is very rarely used.

5.9 Energy use in the rig

The energy needed in the drilling operation accounts for about 10-30% of the operational cost of the rig. Since most of the drilling sites are located off grid areas, the rigs must generate their own power by way of big diesel generators. Depending on the size of the rigs they must use three to four 1 MWe generators each. This power is used mainly by the drive system, circulation system, draw works and hoisting, and the auxiliary supply. The mud circulation system takes the largest percentage of the energy use in the rig operation, thus, improving the efficiency of the mud circulation system means power is saved. Hydraulic rigs consume more energy because of the conversion loss, for example AC to DC, DC to hydraulic.

5.10 Case study

5.10.1 Overall drilling time for directional well OW-38A

Figure 12 shows a planned drilling programme against the actual drilling operation. The green arrows marked 1, 2 and 3 show the cementing points. The arrow marked 4 shows the well completion test point. The neon purple arrows marked '*a*' show the bit change points. As you can see there were a total of ten bit changes in the 8½" hole section. Considering the high cost of bits on the market, research needs to be done to establish the exact cause of bit wear and failure. One possible cause can be attributed to O-ring seal and diaphragm damage which leads to bearing failure. The bit cone rotation on its axis is affected, therefore the bit tends to drag on the drilling surface causing a faster wearing off of the tungsten carbide insert.

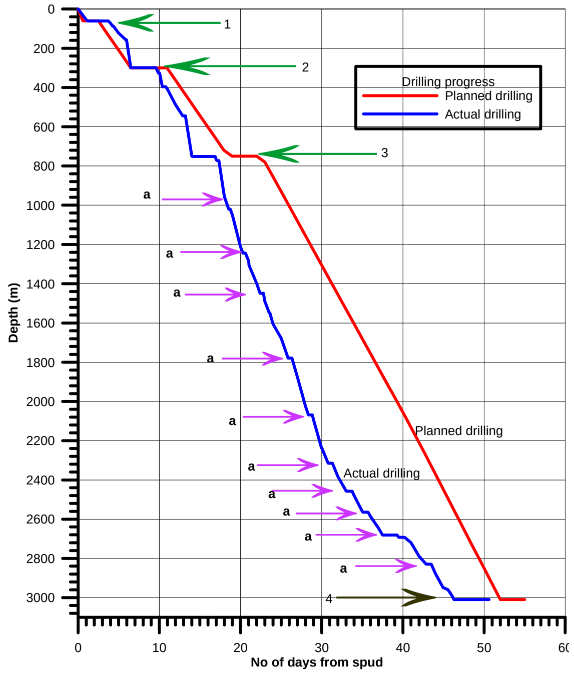

FIGURE 12: Drilling progress of Olkaria well OW-38A against the planned schedule

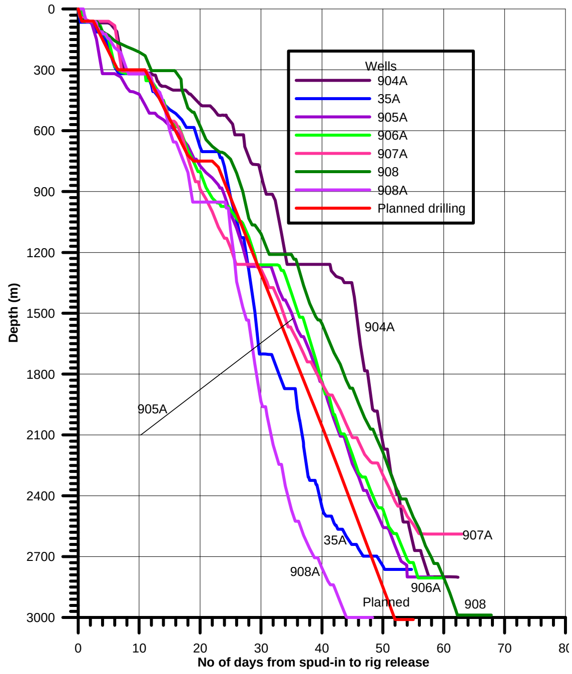

FIGURE 13: Drilling performance of several selected Olkaria wells against the planned schedule using a rotary table rig

5.10.2 Overall drilling time for several wells, case study in Kenya and Iceland

In Figure 13 the drilling performance for several geothermal wells in Kenya is compared. It shows the number of days it took to complete the well. The counting began from the time of spud–in until the time of rig release after the well completion tests. In Kenya it takes between 48-68 days to complete a well with an average depth of 2,600-3,000 m. There are several factors which determine the time it takes to complete a well but the main ones are formation hardness, bit life, rate of penetration, and problems encountered during drilling like the BHA getting stuck, unrecoverable loss of circulation, and a longer cementing time due several backfills.

In the Icelandic case, as shown in Figure 14, the first section of the hole 0-90 m was drilled using a small portable rig. This saved the bigger rig time, and cost to the client. It took an average of 45 days to drill a directional well to a total depth of 2,500-3,000 m. As can be seen it required two bit changes at the 8½" section. This proves the efficiency of the top drive system in terms of bit life management.

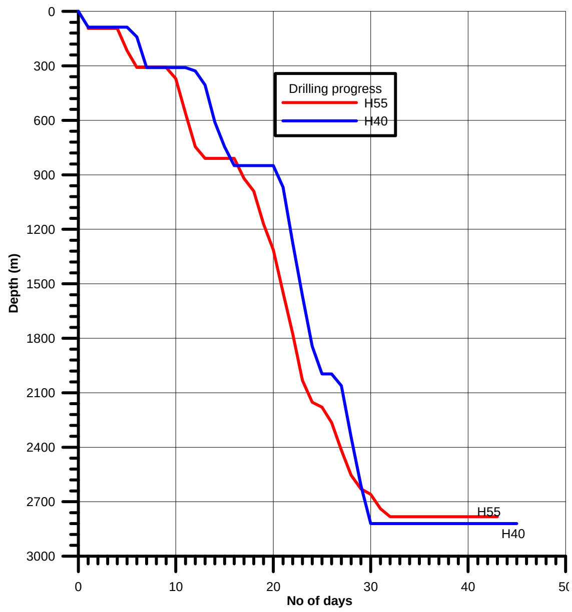

FIGURE 14: Top drive drilling progress by Iceland Drilling Company (Iceland Drilling Company, 2009)

6. ADVANTAGES AND DISADVANTAGES OF TOP DRIVE RIG AND CONVECTIONAL RIG DRIVE SYSTEMS

In general there are several advantages and disadvantages of the top drive drilling system as compared to the convectional Kelly drive system.

Advantages of top drive systems:

- No use of manually operated tongs for make-up and break-out and Kelly bushing on the floor, improves the safety of the floor environment hence contributes to the health and safety of the drilling operation.
- Automation and accurate tool joint make-up and break of the top drive system extend the life of the drill pipes, therefore reducing the drilling cost somewhat since the pipes are used for longer drilling hours before replacement.
- In some top drive systems with high masts, it is possible to drill with three stand pipes "triples" with an approximate length of 90 feet, which means fewer connections, thus reducing the tripping time by up to about 30%.
- Since the top drive system allows the circulation of the drilling fluid and rotation while pulling out of the hole, this prevents the settling of the drill cuttings which can be responsible for the bottom hole assembly becoming stuck, thus saving the rig crew time and improving the time it takes to complete the well.
- Circulation of the drill fluid during running in hole by the top drive system allows effective cooling of the drill bit thus protecting the O-ring seal and diaphragm which have temperature limitations of 150-200°C. This reduces the bearing failure rate and frequent bit changes.
- It takes fewer days to move the top drive rig to a new well location with fewer trucks and cranes on hire, thereby reducing the rig move cost.
- Greater control of directional drilling tools helps to provide a quick orientation of the tool which means the desired target is reached, thus providing a better production borehole.
- The development of the casing running tools helps to improve safety and reduces the time taken to run the casing.
- The ability to circulate the casing using the top drive while running in-hole helps improve cementing jobs.
- The compactness of the rig reduces the size of the well site, minimizing environmental impacts.

Disadvantages of top drive systems:

- The high automation applied in the top drive system requires a highly skilled and experienced operational and maintenance crew. Hence, when there is a lack of such personnel, then the advantages desired from the top drive system may not be realised.
- The modern top drive rig is more expensive than the convectional rig, thus more investment capital is required which can be out of reach for some companies.
- The top drive system does not favour the direct job creation motto of the Government of Kenya, since it tends to need a smaller workforce.
- If the mast of the top drive is not high enough to allow tripping using triples, then the tripping rate is slower.

Advantages of a rotary table rig:

- Tripping using the three stand "triples" is much faster.
- Being able to lift the bit off the bottom by the length of the Kelly (12 m) helps to reduce chances of getting stuck in case there is a fill-in, especially while adding a drill pipe.

Though the modern top drive rigs are more expensive, this is compensated for by better drilling performance. Old rigs can also be fitted with a top drive system to improve their performance.

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REFERENCES

Bentec Ltd., 2009: *Product information*. Bentec Ltd., website: *www.bentec.de/product/drilling_rigs/index.html.*

Drillmec, 2009: *Products information*. Drillmec Drilling Technologies, website: *www.drillmec.com.*

Hole, H., 2007a: Directional drilling of geothermal wells. Lecture 2 in: *Lectures on geothermal drilling and direct use.* UNU-GTP, Iceland, report 2006-3, 13-20.

Hole, H., 2007b: Aerated fluids for drilling of geothermal wells. Lecture 1 in: *Lectures on geothermal drilling and direct use.* UNU-GTP, Iceland, report 2006-3, 1-12.

Iceland Drilling Co., 2009: *Drilling progress of well H55 and H40*. Iceland Drilling Company, drilling logs records (unpublished).

Mwangi, M., and Mburu, M., 2005: Update of geothermal development in Kenya and other African countries. In Mwangi, M. (lecturer): *Lectures on geothermal in Kenya and Africa*. UNU-GTP, Iceland, Report 4, 1-13.

National Oilwell Varco, 2009: *Drilling solutions*. National Oilwell Varco Company, Ltd., website: *www.nov.com/drilling/Top_drive_systems.asp.*

Ngugi P., 2002: Technical, economic and institutional evaluation of adopting directional drilling by KenGen , Kenya. Report 9 in: *Geothermal training in Iceland 2002.* UNU-GTP, Iceland, 2002 113-*144.*

Omenda, P., 2008: Status of geothermal exploration in Kenya and future plans for its development. In: Georgsson, L.S., Holm, D.H., Simiyu, S.M., and Mariita, N.O. (eds.), *Short course III on surface exploration for geothermal resource.* UNU-GTP, Iceland and KenGen, Kenya, CD SC-07, 13 pp.

Saito, S., and Sakuma, S., 2000: Economics of bit life in geothermal wells by cooling with a top drive system. *Proceedings of World Geothermal Congress 2000, Kyushu-Tohoku, Japan,* 2405-2410.

Tesco, 2009: *Product information site*. Tesco Corporation, Ltd, website: *http://tescorp.com/ bins/content*, 2-9.