



DRILLING IN MENENGAI FIELD – SUCCESS AND CHALLENGES

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ABSTRACT

Geothermal drilling in the Menengai field started in February 2011. The project was initiated following a detailed exploration conducted in 2004 that pointed to the existence of an exploitable geothermal resource within the caldera. Three exploration wells were done which prove the existence of the resource in Menengai. Six appraisal wells were drilled to appraise the size of the reservoir. A feasibility study was carried out to determine the extent of the geothermal resource in the field and the 100MWe area was determined. For the 100 MWe project 22 wells will be drilled and completed by the end of 2014. Currently production wells are being drilled. For the purpose of realizing the 100 MWe, geothermal development company (GDC) has since acquired 4 rigs for drilling in Menengai and is expecting 3 more by January 2014. Major problems experienced in Menengai are formation related while other problems include stuck pipe, high pressure and temperature and also obtaining specialized equipment and services locally.

1. INTRODUCTION

Menengai is a major Quaternary caldera volcano forming one of fourteen geothermal sites in Kenya. It is located within the axis of the central segment of the Kenya Rift (Figure 1) just north of Nakuru town and a few kilometres south of the equator. The Menengai geothermal field is characterized by a complex tectonic activity associated with two rift floor tectono-volcanic axes (TVA) Molo and Solai that are important in controlling the geothermal system (Njue, 2011).

Geothermal drilling in the Menengai field started in February 2011. The aim was to determine geothermal resource availability, hydrothermal capacity and chemical characteristics of the resource which is steam. The project was initiated following a detailed exploration conducted in 2004 that pointed to the existence of an exploitable geothermal resource within the caldera. Currently drilling of production wells is ongoing following completion of exploration and appraisal wells. By July 3, 2013 fifteen wells had been completed.

2. STAGES OF DRILLING

There are several stages of drilling and these include:

- **Exploration drilling** - prove existence of resource
- **Appraisal drilling** - prove the extent and size of the reservoir field to enable designing of power plant.
- **Production drilling** - drill wells with enough steam equivalent in megawatt to the design plant
- **Make-up wells drilling** - during utilization if the main steam pressure decline due to utilization more wells are drilled.
- **Work over wells drilling** - if deposit (e.g. calcite) occurs inside the casing, work over rig is brought in to drill out the deposit.

Drilling in Menengai started with three exploration wells which were then followed by six appraisal wells. A feasibility study was carried out to determine the extent of the geothermal resource in the field and the 100 MWe area was determined. A 100 MWe power plant has since been design.

Production drilling in the Menengai field is currently ongoing and 22 wells have been projected for the 100 MWe steam. 20 wells will be production wells while 2 will be reinjection wells. The 20 production wells are expected to averagely produce 5 MWe each. The plan is to drill 19 wells before 18-Oct-14

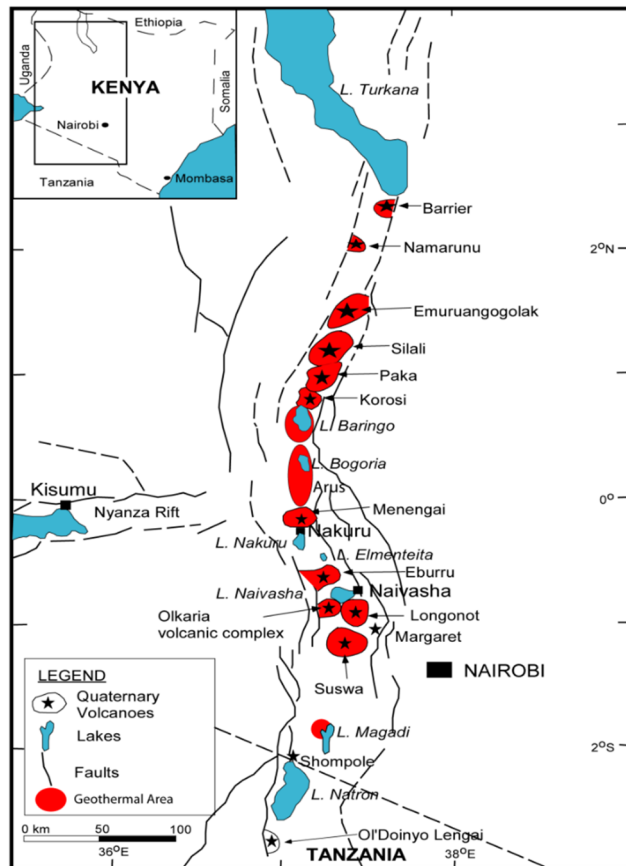


FIGURE 1: Position of Menengai within the

2. DRILLING IN MENENGAI

2.1 Rigs

GDC acquired two new ZJ70D rigs (Figure 2), (Simba 1 and Simba 2) in 2010 and later in 2012 acquired two more ZJ70D rigs (Kifaru 1 and Kifaru 2). Simba 1 and Kifaru 2 are top drive rigs while Simba 2 and Kifaru 1 are Kelly driven. All the rigs have the capacity to reach a depth of 7000 m 3-1/2" drill pipes with a max hook load of 4500 kN, 45 m open front mast and approximately 10m platform floor height. The drive mode is AC-SCR-DC. The rigs are equipped with 4 diesel generator sets and 1 auxiliary generator for power supply and uses AC-SCR-DC drive. In addition the rigs are equipped with a complete air drilling system containing five air compressors and two boosters. Figure 2 shows one of the ZJ70D rigs used in Menengai

GDC has procured more 3 more rigs that are expected in the country by January 2014. These will fast track drilling operations to enable the company realise its vision of delivering 100 Mw by end of 2014.

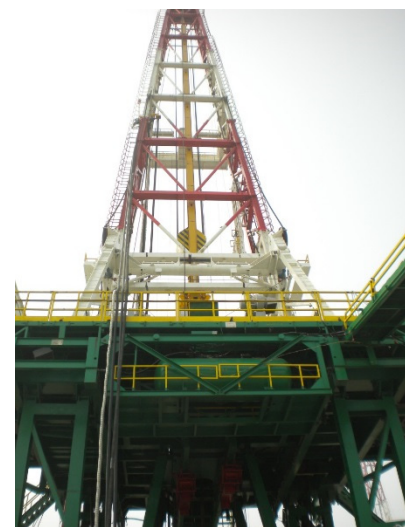


FIGURE 2: One of the ZJ70D rigs

2.2 Bits

The aim of drilling is to i) make hole as fast as possible by selecting bits which produce good penetration rates, ii) run right bits to achieve long working life to reduce trip time, iii) use bits which drill a full-size or full-gauge hole during the entire time they are on the bottom.

Tricone roller tungsten carbide insert bit (Figure 3) has been used in the Menengai field because of their versatility and performance. The bit type is available with a large variety of tooth design and bearing types and, thus, is suited for a wide variety of formation characteristics. Figure 4 shows a bit selection chart. Code 517 indicates a soft formation bit while code 617 indicates a medium formation bit both used in the Menengai field. In surface section of the hole only 1 bit is used before running in the 20" surface casing. This section is so shallow that one bit usually lasts for several wells. As the well gets deeper several bits are used for each section before casing depth is reached and even more bits are required in the final hole section. The 26" hole is drilled using a tri-cone roller mill tooth bit down to 80m, while the other hole sections are drilled with tri-cone roller tungsten carbide insert bit.

Rotary bits drill the formation using primarily two principles; 1) rock removal by exceeding its shear strength and; 2) removal by exceeding the compressive strength. Shear failure involves the use of the bit tooth shearing, or cutting, the rock into small pieces so it can be removed from the area below the rock bit. Shear failure mechanism requires that the formation exhibits low compressive strength that will allow the insertion of the tooth. The mechanism is employed while drilling softer formations (Ngugi, 2008).



FIGURE 3: A typical roller cone bit used in Menengai

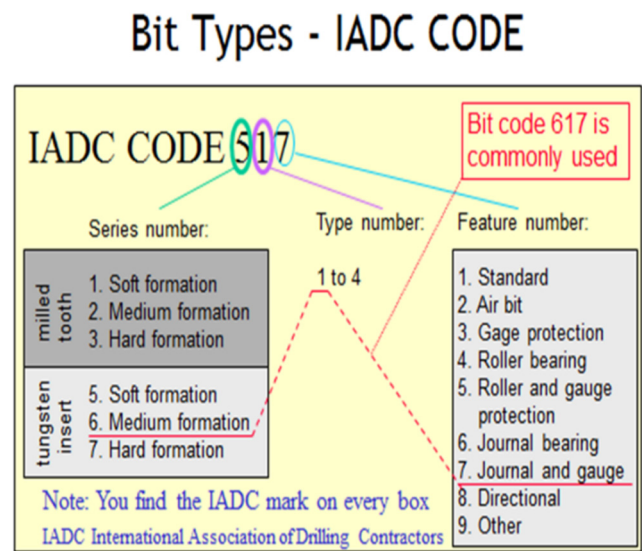


FIGURE 4: A chart used for bit selection

For hard formation rocks a compressive failure mechanism is used since shearing wears the bit tooth as it is twisted or dragged across the formation face. Compressive failure of a rock segment requires that a load be placed on the rock that exceeds the compressive strength for that given rock type. The load must remain, or dwell on the surface long enough for rock failure to occur. This is the basis for hard-rock drilling characteristics of high bit weight and low rotary speeds (Ngugi, 2008).

2.3 Drilling each hole section and casing

Based on the expected well operation condition and the expected drilling site geology, the casing depths are prescribed and detailed in the drilling programme but actual depths are chosen by reference to geology and hole conditions. Menengai geothermal wells have targeted depths of 2500 and the drilling programme is as follows. Figure 5 represents a Casing programme for Menengai wells.

- Drilling a 26" hole (0 – 80 m) for the Conductor (surface) casing with 20" diameter. This section is usually hard and rough with a low ROP of 0.5 m - 0.7 m/hr. the WOB is usually high leading to high vibration. Water is commonly used as the drilling fluid. This section takes 7 to 10 days.
- Drilling a 17½" hole to (80 - 400 m) for the Intermediate casing of 13⅜" diameter. This section is medium hard and rough. The ROP is between 1.5 m - 2 m/hr. Drill with water and if hole cleaning problems arises, aerated water and foam is used. This section take between 10-15days
- Drilling with a 12¼" hole (400 -1000 m) for the Production casing of 9⅝" diameter. The formation is medium soft formation with layers of soft. Drilling is carried out using aerated water and foam with hi-vis mud gel sweeps done every half and full kelly to condition the well The formation in this section is incompetent and tends to collapse.
- Drilling with an 8 1/2" hole to the final depth of 100 – 2200 m for the Slotted liner of 7" diameter set.

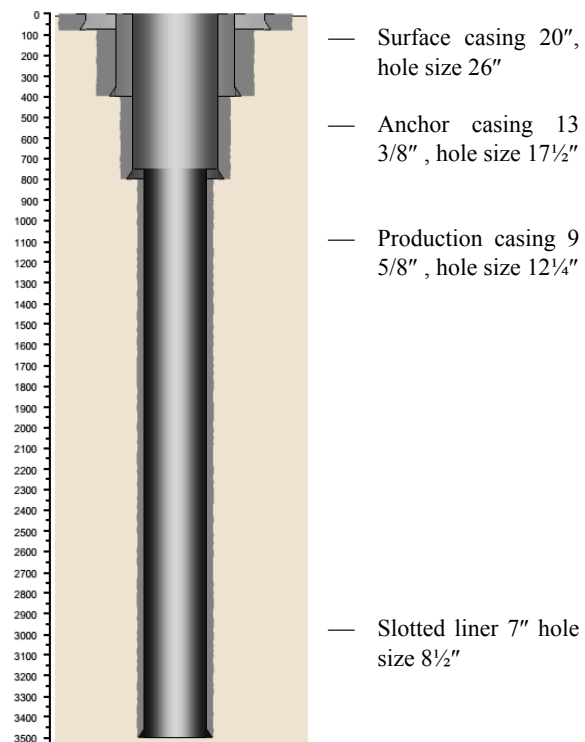


FIGURE 5: Casing programme for Menengai wells

There are many purposes to be considered for casing and cementing related to the need to mechanically and hydraulically isolate a well for its entire life. They include:

- I. Securing weak formations that may collapse into the well bore and trap the drill string;
- II. Sealing leaky intervals to prevent lost circulation; covering bulging shale intervals that can stick the drill string;
- III. Isolating high-pressure zones to allow safe drilling; and allowing safe entry and retrieval of equipment.

The casing string is screwed together to form longer lengths of casing and a thread compound is used on the two ends to ensure a tight seal. Centralizers are placed on the exterior of the casing string to centralize the casings within the wellbore and ensure that all voids are filled and channelling does not occur during cementing. The bow spring centralizer is usually used.

The liner string is run into the well in the final section reaching from the lower end of the production casing to the bottom. The liner string is left to rest at the bottom.

2.4 Cementing

Casing requires a sheath of cement, which must endure for long periods and must be able to withstand large variations in temperature and all the rigours of drilling, completion and production. Below is a mention on reasons of cementing.

- Seal off ground water
- Seal unwanted aquifers
- Support the well to prevent cave in
- Anchor the wellhead
- Provide conduit for the well fluid to flow to surface

After landing casing and before commencing pumping cement slurry, a drilling fluid is circulated in the hole to clean the well and ensuring the flow path is clear, cooling the wellbore to prevent hardening of cement due to high temperatures and to scrap off mud wall cakes.

TABLE 1: Cement consumption for 5 wells in Menengai

Cement consumption for Menengai geothermal project					
Well	Casing cementing		Cement plugs		Total per section
	Casing size	Amount (tons)	Hole section	Amount (tons)	
MW-01	20"	54.33	26"	0	54.33
	13 3/8"	102.92	17 1/2 "	0	102.92
	9 5/8 "	46.96	12 1/4 "	0	46.96
Total consumption for MW-01					204.21
MW-07	20"	27.55	26"	0	27.55
	13 3/8"	35.26	17 1/2 "	36.81	72.07
	9 5/8 "	71.17	12 1/4 "	0	71.17
Total consumption for MW-07					170.79
MW-09	20"	180.34	26"	0	180.34
	13 3/8"	110.750	17 1/2 "	0	110.750
	9 5/8 "	57	12 1/4 "	0	57
Total consumption for MW-09					348.09
MW-12	20"	72.87	26"	0	72.87
	13 3/8"	76.89	17 1/2 "	87.79	164.68
	9 5/8 "	79.69	12 1/4 "	17.17	96.86
Total consumption for MW-12					334.41
MW-16	20"	34.46	26"	0	34.46
	13 3/8"	140.59	17 1/2 "	25.42	166.01
	9 5/8 "	154	12 1/4 "	12.24	166.24
Total consumption for MW-16					366.71

The cementing technique used is usually the inside casing. Cement slurry is mixed in the pumping truck and the cement slurry pumped inside the casing string through the cementing head. After the entire slurry volume has been pumped, the cement slurry within the casing is displaced down to the float collar using water. The water and cement are separated using of cementing plugs. The heavier cement in the annulus is prevented from U-tubing by back-pressure valves in the bottom of the casing string. If cement is not received on the surface the cement job is let to set for 8 hours then a back fill is carried out through the annulus with 8 hours in between backfills until cement is received on the surface. Normal Portland cement is usually used. The process is time and temperature dependent.

Cementing jobs are also done to plug major drilling fluid loss zones. Major fluid circulation losses result in loss of data obtained from cutting. They further lead to poor hole cleaning and the rock cuttings repeatedly fall back into the well bore as soon as the pumps are stopped. The falling cuttings at time result into stuck drill string. To stop circulation losses cement slurry without additives is prepared and placed at the point where the losses are and the cement is allowed to set, thereby sealing out the formation fractures (Ngugi, 2008).

Table 1 shows cement consumption for 5 wells drilled in Menengai. It shows that the 17 ½ “ hole consumes a lot of cement as there were several loss zones in this section.

2.5 Circulation and drilling fluids

Drilling fluid used in the upper parts of the well is simple water based bentonite mud. When fractured zones are encountered above the production casing shoe depth, attempts are made to seal these losses using Loss of Circulation Materials (LCM), and in extreme cases cement plugs are done. The final hole section is drilled with water and in areas of lost circulation aerated water and foam is used.

The purpose of drilling fluids primarily is to remove the cuttings from the bottom of the hole as fast as they are created to facilitate further and efficient hole making process. In addition, the fluid transports the cuttings to surface. The two functions constitute what is normally referred to as hole cleaning. (Ngugi, 2008). Cooling of the wellbore is also an important function of the drilling fluid in geothermal wells. In that case the ingoing fluid is usually maintained at a maximum temperature of 40°C, which is the maximum recommended operating temperature for the pumps. High temperature may also cause damage to the drill bit.

Water is the major drilling fluid used in Menengai other drilling fluid include water based bentonite mud, air and aerated water and foam. The choice of drilling fluid depends on the formation of the section being drilled. In case of lost circulation, loss circulation materials (LCM) are used. In instances where circulation cannot be regained only water is used with sweeps of high viscosity gel each time a new drill pipe is added or more frequently depending on the hole problems. During the drilling of the final section for 7" (perforated or slotted?) liner, only water or aerated water with foam is used. This is done to avoid sealing the production zones with mud. From the well the drilling fluid is usually pumped to a pond to cool before it is pumped back down hole.

Drilling water in Menengai is supplied from 10 drilled boreholes and sometimes brine from discharging wells. The water from the boreholes is pumped to 4 tanks of 4 million litres at an elevated ground. The water is the supplied to the wells trough gravity. Brine from discharging wells is used to supplement drilling water.

2.6 Advantages and disadvantages of top drive rigs over kelly driven rigs

Advantages of top drive:

- Top drive drill is faster-it is possible to drill with three pipes (stand), which means fewer connections, thus reducing the tripping time.
- Top drive drilling is safer- Fewer instances of personnel contact with the equipment hence reducing chances of accidents.
- Top drive reduce instances of sticking - 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.

Disadvantages of top drive:

- Highly automated – 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. It is also sensitive and prone to breakdown especially in hard formations as experienced in Menengai.

3. DRILLING CHALLENGES

Water supply for drilling - Currently four rigs are drilling in the Menengai caldera and all depend on the same supply. The rigs consume approximately 1500-2000l/min each. Drilling water in Menengai is supplied from 10 drilled boreholes and sometimes brine from discharging wells. The water from the boreholes is pumped to 4X 4 million litres tanks at an elevated ground. The water is supplied to the wells through gravity. The formation in Menengai is highly fractured and drilling crew experience frequent long lost circulation periods. This means that there should be a constant supply of drilling water in to the drilling sites.

Formation challenges - The geology in Menengai presented the biggest challenge to drilling, slowing down drilling activities creating drilling problems:

- Hard formation especially on the top sections which causes large vibrations resulting in surface equipment damage. The top section is usually drilled using a tricone bit that depends on rotary action to drill. This section is usually shallow, therefore the rigs have no place for collars hence the weight on bit is far too low and large vibrations are experienced. Consideration to use air hammers in the future are underway. This goes to show that bit selection is an important factor and so is the weight on bit.
- Lose formation that keeps on collapsing during drilling. Such was experienced severely in well MW05.
- Lost circulation problem is pronounced in Menengai and this is due to the fractured nature of the Menengai formation. Drilling practices may also lead to induced fractures aggravating lost circulation problems.
- Changing lithologies at various depths also create a set of variables that affect bit durability. The crooked hole is a result of change in formation that is beyond control of the driller but with the right choice of BHA it can be minimised while a tapered wellbore is usually a result of under gauge bit. Reaming is usually done to straighten a crooked hole or to enlarge a tapered or tight well bore. This in turn slows down the drilling progress.

Information on geology is obtained from drill chips/cuttings and lithology logs. Too little knowledge about the formation being drilled may lead to the wrong choice of bit. Incorrect bit type causes low ROP and eventually equipment failure. Having the right information on the geology of the area is paramount in making sound decision in planning for the well.

Severe loss of circulation - Due to the fractured nature of the rock in the Menengai field severe loss of circulation is experienced.

Kicks and blowout - Reservoir conditions affecting drilling in Menengai include extremely high temperatures and pressure especially at depths of below 1000m. This results in kicks and blowouts.

Stuck pipe - Sticking is a major problem experienced in Menengai. Most of the sticking followed a period of problematic circulation and moment of stopped circulation such as after pipe connection.

Stopped circulation meant that the cuttings were not removed from the hole and were left suspended as a result these cuttings fall to the bottom and on the string. Loss of circulation results in poor hole cleaning and if enough efforts are not made to regain it, sticking is inevitable.

Lack of specialized services tools and service - Drilling is relatively new in Kenya and the rig is a new equipment in the market therefore most critical rig parts and services are not readily available in Kenya.

Drill string failure and fishing - Drill string failure experienced in Menengai was as a result of drillstring failure from stuck pipe. In the effort to free the stuck pipe the drillstring was subjected to high torque and large weight on bit causing it to strain and eventually fail. Excessive tension from over pull and fatigue from repeated stress can also lead to drillstring failure. Some of the drill string failure experienced include twist off due to high torques and snap pipe due to over pull.

Fishing is carried out to remove any foreign unwanted objects in the well bore by using special fishing tools. The foreign objects in the wellbore are majorly as a result of drill string failure.

Addressing Challenges

1. Plugging loss zones & high viscous mud- this is done to regain loss of circulation in the problematic loss zones.
2. Hammer drilling- The hammer technology is being considered for future drilling especially for the hard abrasive top section to increase the rate of penetration.
3. Brine from discharging wells is used to supplement drilling water.
4. Drill string inspection after 200 rotating hrs. to reduce instances of drill string failure.

REFERENCE

Ngugi, P.K., 2008: Geothermal well drilling. *Paper Presented at Short Course III on Exploration for Geothermal Resources, organized by UNU-GTP and KenGen, 2008, Lake Naivasha, Kenya, 23 pp.*

Njue L.M., 2011: Stratigraphy and hydrothermal mineralogy of well MW-02, Menengai geothermal field. *Proceedings of the Kenya Geothermal Conference KGC2011, Nairobi, Kenya, 5 pp.*