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DRILLING IN MENENGAI HIGH TEMPERATURE FIELD - THE EXPERIENCE AND LESSONS

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ABSTRACT

Drilling in Menengai high temperature geothermal field commenced in February 2011. Drilling has been on-going using four (4), 2000HP SCR land rigs. Three additional 2000HP rigs are currently being commissioned to commence drilling towards the end of 2014. An additional smaller capacity rig, the Atlas Copco predator rig has been in use since mid-2013, for drilling the top sections to anchor casing depth of between 400-500m, and then the bigger capacity rigs drill the wells to completion. It was necessary to deploy the top holing rig, since it uses the hammer bits to effectively drill the hard surface formations. Most of the wells drilled are vertical wells. Drilling of directional wells commenced recently and so far three (3) directional wells have been completed. The wells are drilled to a total depth from 2100m to 3000m. Production drilling to avail steam for the first phase of power plants development has been completed and currently drilling for the second phase of production and drilling of step out wells to demarcate the field.

1. INTRODUCTION

The Menengai caldera is an elliptical depression with minor and major axes measuring about 11.5km and 7.5 km respectively located in the Eastern rift as shown in Figure 1. The field has a ring structure that has only been disturbed by the Solai graben faults on the NE end and one prison fracture at the SSW end. The caldera floor is covered with post caldera lavas. Most of the caldera infill lavas are fissure eruptions with fracture openings. The floor of the Menengai geothermal prospect area depicts extensional tectonics with the main trough trending N-S over north of Menengai and NNW-SSE for section south of Menengai (Mungania, 2004). Wells are drilled targeting mainly these faults.
Menengai wells are designed with:

- The conductor casing of diameter 30" which is driven to ground to about 3m;
- 26" diameter hole is drilled to 80m, then cased with 20" surface casing and cemented back to the surface;

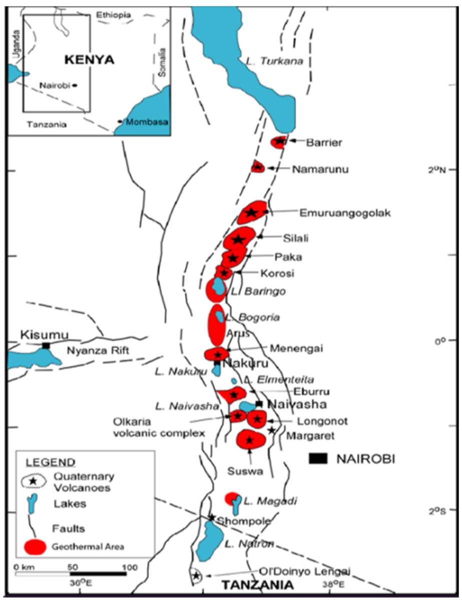

FIGURE 1: Location of Menengai

- 17½" diameter hole is drilled to a depth of 400m. The 13⅜" anchor casing is run and cemented back to the surface;
- 12¼" diameter hole is drilled to between 800-1400m, the 9-5/8" production casing is run and cemented back to surface; and
- 8½" production section is drilled to TD (total depth) of 2500-3000m. A slotted 7" liner is then placed at the bottom of the 9 5/8" casing with a liner hanger and it stretches down to the bottom of the production section.

2. WELL DESIGN

Conditions to consider while designing wells at Menengai include; sub surface conditions to be encountered, equipment to be used, material performance and recognition of drilling practices needed to ensure performance.

Design steps necessary to drill a deep well safely include:

I. Taking geological and reservoir engineering advice on likely sub surface rock and fluid properties.
II. Determining depths for casing and well completion.
III. Selecting casing diameters, thicknesses, cementing materials and cementing programs.
IV. Deciding on drilling fluids, drill string assemblies and well heads.
V. Nominating necessary equipment, tools, materials, support facilities and site requirements.

Particular geological information required for well design includes:

I. Rock type or formation, location of any specific stratigraphic marker beds.
II. Compressive strengths, degree of consolidation.
III. Faulting, fracturing and gross permeability.
IV. Effects of drilling activities on formation like swelling of water sensitive clays.

Depth of all casings and liners are chosen to ensure safety and to safely contain well conditions from surface operations. The wells drilled are either vertical wells or directional wells as shown in Figure 2. Directional wells have a kick off point at 400m, just below the anchor casing setting depth. Other considerations during design of Menengai wells include:

I. BHA and drill string design.
II. Drilling fluids.
III. Casing program.
IV. Well cementing.
V. Well completions.

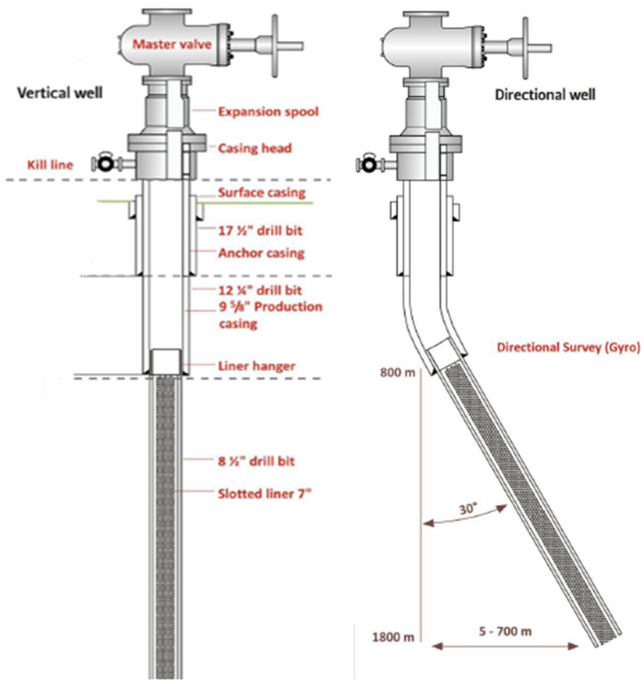

FIGURE 2: Vertical and Directional well profiles

2.1 BHA and Drill string design

For the bit to drill, it requires rotary motion. The drill string provides this rotation motion from the surface to the bottom of the hole. It provides the connection between the rig and the bit (Ngugi, 2008). The lower part of the drill string, is called the Bottom hole assembly (BHA). The main function of the BHA is to provide weight to be exerted on the bit for drilling. The drill string provides these functions:

- Provide the fluid conduits to the drill bit;
- Impart rotary motion to the drill bit;
- Provide and allow weight (force) to be set on bit; and
- Lower and raise the bit.

The different components of the drill string and their functions are:

I. Bit sub/ NRV sub- Placed above the bit. It's used to connect the bit and the first collar. It has recess to accommodate the non-return valve that ensures the fluid does not flow backwards.
II. Drill collar- stiff steel components about 10m, weighing 2 to 3.5 tons. They provide weight for the bit, strength needed to run in compression, minimizes vibrations, wobbling and jumping and also minimize directional control problems by providing stiffness to the BHA. Most commonly used collars are round (slick) and spiral grooved.
III. Heavy weight drill pipes (HWDP)- Have weight 2-3 times the weight of drill pipe and offer a safer transition from drill collars to drill pipes therefore minimizing drill pipe failure.
IV. Drill pipes- Are the longest section of the drill string. Consist of tube body welded to two tool joints with male (pin) and female (box) threads. Most common sizes are 3½", 4½" and 5".
V. Kelly saver sub- Fitted between the Kelly and drill pipe. It's a sacrificial tool to save the Kelly from wear arising from frequent connections.
VI. Kelly- Designed in a square or hexagonal shape. It's fitted into a Kelly drive bushing, with it, it imparts rotational motion on the drill string which is transmitted to the bit.
VII. Stabilizers- Run as part of the BHA. They provide stabilization to the BHA and for directional control.
VIII. Jar- Run as part of the BHA, when drilling at deep depths to help free a stuck string.
IX. Positive Displacement Motor (PDM)- Used for deviating while drilling directional wells to desired targets.

2.2 Drilling fluids

Primarily the drilling fluid removes the cuttings from the bottom of the as fast as they created to facilitate efficient hole making process. Other functions of the drilling fluids are:

- Cleaning of the hole bottom;
- Carry cuttings to the surface;
- Cool and lubricate the bit and drill string;
- Minimize formation damage;
- Control formation pressure;
- Maintain hole integrity;
- Assist in well logging operations;
- Minimize corrosion of drill string and casing;
- Minimize torque, drag and pipe sticking; and
- Cooling of the formation.

The drilling fluid is pumped through the string to the bottom, then back to the surface through the annulus as shown in Figure 3. The returns are passed through the shakers to take out the cuttings then the fluids are reused.

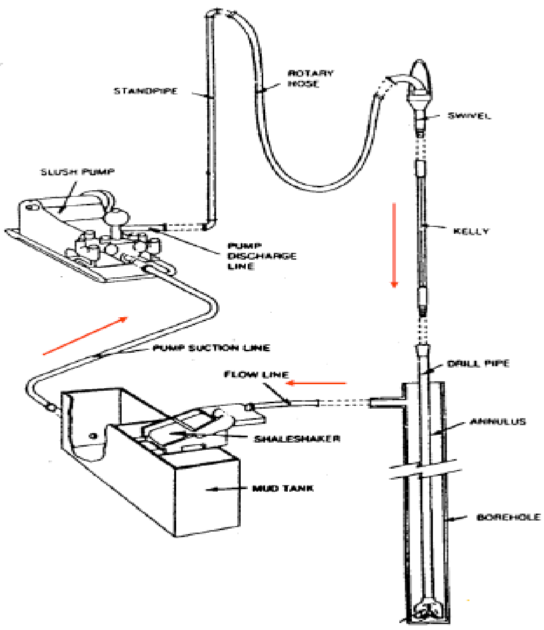

FIGURE 3: Drilling fluids system

The basic properties of drilling fluids that are mostly important for successful drilling are: Density for controlling hydrostatic pressure, viscosity affects the efficiency of cuttings lifting capacity and filtrate loss property which determines the amount of water lost to the formation.

2.2.1 GDC drilling fluid practice

26" Surface hole
The well is spud with mud, bentonite mud with a funnel viscosity of 60-80 seconds. If returns are lost and cannot be regained with loss circulation materials (LCM), drilling continues blind with water and high viscosity gel sweeps at every connection or more frequently depending on the hole problems.

17½″ Intermediate hole
Section is drilled with mud. If loss of circulation occurs, attempts are made to regain returns using LCM. Drilling blind with water and frequent high viscosity mud slugs. In extreme circumstance of poor cleaning stiff foam is used if losses cannot be healed

12¼" Production hole
This section is drilled with mud and when mud circulation cannot be sustained, aerated water with foam is used.

8½" Main hole
Drilled entirely with water, and when signs of lost circulation occur, partial or total, aerated water with foam is used

2.3 Casing program

Design of casings shall include the effects of pressure and temperature change that may occur at any time or depth during drilling or operation of the well. For each of the stress regimes, calculations should be done to establish that there is an adequate margin of strength at all depths in casing string. Casing specifications shall be selected or well conditions restricted to ensure that the minimum design factors are met. Information needed for casing design include: Mud weights, formation pressures, fracture gradients, casing seats, casing sizes, directional plans, cement program, temperature profiles and produced fluid chemical composition. K55 grade of casing is used at Menengai. Casing strings normally run are:

Conductor pipe: Run from the surface to shallow depth to protect near surface unconsolidated formations and seal off shallow water zones, provide protection against shallow gas flows and protect foundation platform.
Surface casing: Run to prevent caving in of weak formations that are encountered at shallow depths. It should be set in a competent rock. It provides protection against shallow blow outs and should be deep enough to support the BOP for drilling to the anchor casing shoe depth. Used to case off poorly consolidated soil and loose surface material.
Anchor casing: Set in transition zone, below or above an over pressurized zone to seal off severe loss zone and protect against problematic formations. Protects surface aquifers against contamination during drilling and acts as a second pressure barrier during the life of the well. This casing supports the BOP and later the final production well head. Casing should be deep enough to allow for the well to be killed while drilling to production casing depth.
Production casing: Run to isolate producing zones and provide reservoir fluid control. Depth chosen on the basis of expected depth and the temperatures of fluids to be included and isolated. It conveys steam and water to the surface.
Liner casing: string of casing that does not run to surface but hangs inside the production casing. Can be slotted or perforated to allow reservoir fluid to flow into the well. Types of liners include; drilling liners, production liners, tie back liner, scab liner, scab tie back liner.

Table 1 shows the different considerations during design of casing setting depth.

TABLE 1: Factors affecting casing loading (Southon, 2005)

STRESS	INSTALLATION	INJECTION	PRODUCTION
Collapse	Cement column outside and water inside the casing. Biaxial tensioning	Biaxial load	Trapped water in uncemented sections in annulus
Burst	Surface pressure to lift cement. Gas accumulation	Injection pressure. Gas accumulation and depression of water table	Well head pressure
Tension/ Compression	Cooling load. Support of own weight	Axial load due to cooling	Thermal expansion

2.4 Cementing

2.4.1 Cementing procedure

For cementing of Menengai wells, single stage cementing method shown in Figure 4. The spacer is first pumped then followed by the cement slurry. The spacer provides barrier to avoid cement slurry mixing with mud. After the slurry volume calculated to be pumped has been pumped, the top plug is released and displacing fluid pumped. The volume of displacing fluid is calculated. Upon displacement of the cement in the casing and bumping the plug, float collar keeps the cement in place. If cement returns are not received on surface after primary cementing, backfills are done through the annulus until cement returns are received on surface.

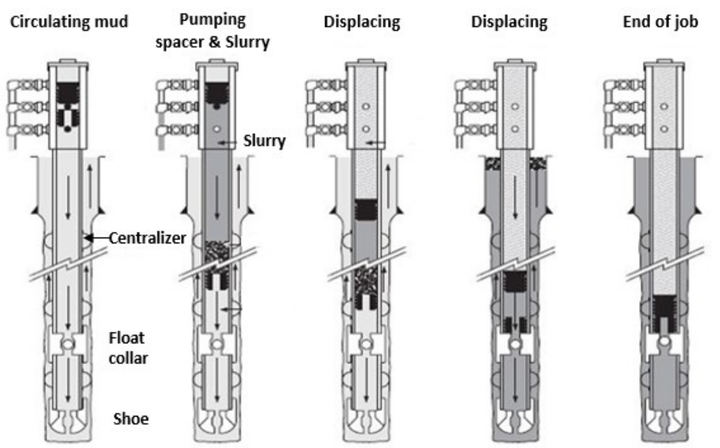

FIGURE 4: First stage cementing method (Nelson, 1990)

2.4.2 Cement slurry design

Slurry design is affected by well depth, bottom hole circulating temperature (BHCT), bottom hole static temperature (BHST), type of drilling fluid, slurry density, pumping time, quality of mix water, fluid loss control, flow regime, settling and free water, quality of cement and dry or liquid additives (Bett, 2010). Cement slurry performance properties tested before cementing are:

1. Thickening time; designed to determine how long cement slurry remains pumpable under simulated down-hole conditions.
2. Slurry density; should be specified to be high as possible throughout cementing interval without causing formation breakdown during placement.
3. Free water; tested to help determine the amount of free water that will gather on top of cement slurry between the time it is placed and the time it gels and sets up.
4. Fluid loss; is designed to measure slurry dehydration during and immediately after cement placement under simulated wellbore conditions. Slurry tested for filtrate loss.
5. Compressive strength; pressure it takes to crush the set cement is measured in this test. Test indicates how the cement sheath will withstand the differential pressures in the well.

6. Rheology testing; to properly predict the frictional pressures that will occur while pumping the various fluids in the well the rheological properties should be known as a function of temperature.

Figure 5 shows a cementing design for cementing deep 9⅝" production casing.

Portland cement is used for cementing wells at Menengai with these additives:

1. Retarders: Used to prolong thickening time to avoid the risk of cement setting prematurely inside the casing.
2. Lightweight additives (Extenders): Used to reduce the slurry density for jobs where the hydrostatic head of cement may exceed fracture gradient of formation.
3. Friction reducers (Dispersants): Added to improve flow properties of slurry. Lower friction and lower pressure during pumping enhancing turbulent flow at reduced pumping rates.
4. Fluid loss control additives: Used to prevent dehydration of cement slurry and premature setting.
5. Loss of circulation (LOC) additives: The additives help control the loss of slurry to the formation.
6. Antifoam additives: Used to decrease foaming and minimise air entrapment during mixing. Excessive forming can result in an underestimation of density down hole.
7. Accelerators: Added to cement slurry to shorten setting time. Used for surface casing and cement plugs.

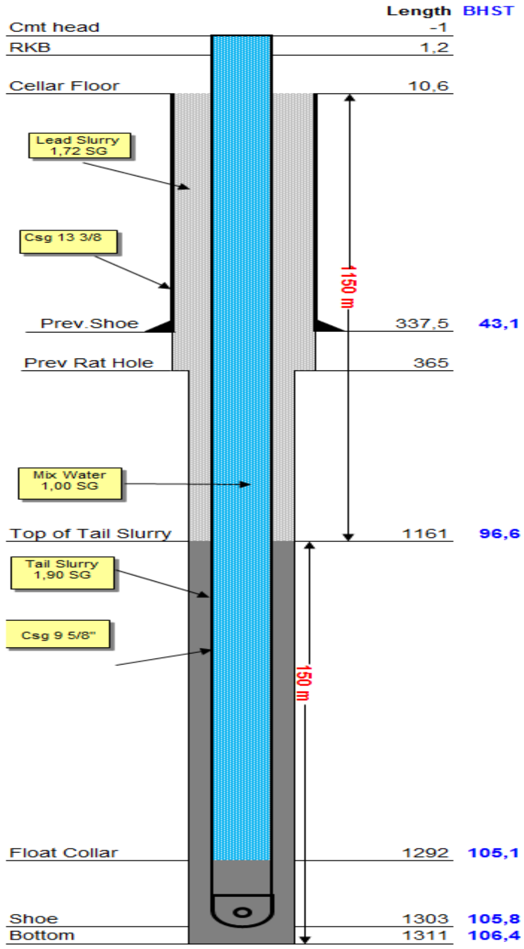

FIGURE 5: Cementing production casing

2.5 Well completion tests

After completion of drilling, well completion tests are carried out before the final well head (master valve) is installed on the well. The tests allow for an early assessment of the likely production or injection capacity of the well. Well completion tests involve:

- Spinner test. This is used to identify the location of the permeable zones within the well and to quantify the relative permeability of each of the zones identified. The spinner tool also measures and records the down hole temperature and pressures;
- Water pumping test to obtain Injectivity and thus the gross permeability of the well; and
- Casing condition survey to obtain an initial graphical image of the casing in the well.

After drill rig has been moved from the well, the well is allowed to heat up. The heat up period provides additional opportunity to collect data before the well discharges. A series of heating temperature and pressure profiles are taken on an expanding time scale after pumping of water is ceased.

2.5.1 Pressures during initial heating

As the well heats up, the pressure gradient in the well reduces. The pressure profiles pivot about a particular pressure point, indicating the location of a single major permeable zone

2.5.2 Temperatures during initial heating

As the well heats there are four heating mechanisms:

- Conduction through the surrounding formation;
- Flow of fluid into the wellbore at one level and out into the formation at another interzonal flow;
- Convection cells within the well bore; and
- Flow directly across the well bore.

The convective process transfer significantly greater quantities of heat than the conductive process. Wells heated by conduction (smooth featureless curves) have less permeability than wells heated through convection. Interzonal flow in the well is indicated by rapid but uniform heating of one section of the well more quickly than the other sections in the well bore. Cross flow within the well bore is characterized by a single isolated peak in the heating profiles.

3. RIG EQUIPMENT

GDC operates two kinds of rigs at the Menengai geothermal field. Mainly drilling has been done with the 2000HP DC Electric land rigs with a hook capacity of 4,500KN. GDC owns 7 rigs, 4 of which have been drilling at the field and 3 which are under commissioning. Also there is a hired Atlas Copco predator rig for top holing top sections of wells to anchor casing. The predator rig is an integrated system with a mobile rig, rig support structure and a pipe skate with a hook load capacity of 200,000 pounds (Atlas Copco, 2011). The predator rig uses both hammer drilling and the contemporary rotary drilling. The two rig systems are shown in Figure 6a and 6b.

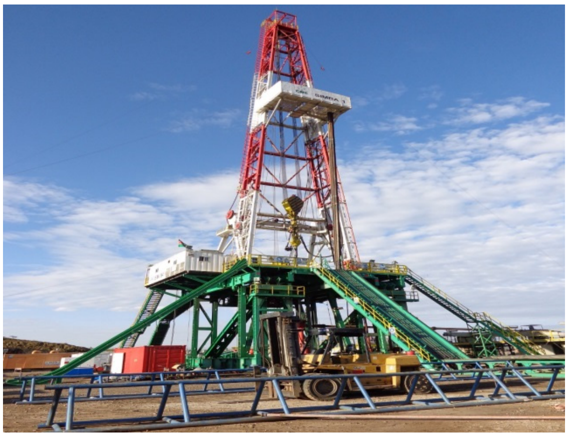


FIGURE 6a and 6b: 2000HP land rig and Atlas Copco predator rigs used at Menengai

The rig comprises of six distinct systems:

1. Hoisting system. Primary function is to support, lift and lower rotating drill string while drilling is in progress. Consists of supporting structure (mast, substructure and rig floor) and hoisting equipment which includes the drawworks, crown block, travelling block, hook, links, elevators, and the drilling line.

2. Power system. Consist of prime mover, primarily diesel engines and means of transmitting power to the auxiliary equipment. Transmission may be in the form of mechanical drives like chains, DC generators and motors or AC generators, SCR (Silicon control rectifiers), DC motors.
3. Circulation system. Consists of pumps, standpipe, rotary hose, swivel, Kelly, drill string, shale shakers, tanks and mud pits and its mainly used to clean cuttings from the well bottom.
4. Rotary system. It's responsible for imparting a rotating action to the drill string and bit, main components are the Kelly, rotary hose and drill string. In top drive systems, the top drive provides the drive.
5. BOP system. The blow out preventer (BOP) is used to seal the well to prevent uncontrolled flow or blowout of formation fluids. Consists of annular preventer, drill pipe or casing rams and blind rams and an accumulator system.
6. Auxiliary rig equipment. Include additional items added to the rig which include drill string handling tools, instrumentation system, air hoists and rig floor tools.

4. CHALLENGES AND RECOMMENDATIONS FOR DRILLING IN MENENGAI

4.1 Challenges

Drilling at Menengai has had challenges which include:

1. Formation challenges. The surface formation at the Menengai field is a hard trachytic formation, making the initial drilling hard with lots of vibrations causing damage to the drill string and rig equipment's like the top drive. The formation is also highly fractured leading to drilling fluid losses and collapsing formation during drilling.
2. Drill string failures. There have been frequent cases of drill string failure leading to frequent fishing operations or side tracks which lead to increased downtime.
3. Challenge of insufficient drilling water due to the high number of rigs operating and frequent total loss of circulation experienced in the field.
4. Calcite scaling in some of the drilled wells, leading to work overs to be done to the same wells for them to continue being productive.
5. Cold inflow in some of the wells, as deep as 1200 m, below the shallow aquifer. The cold inflow affects the production ability of some of the wells.
6. Long procurement process leading in delays in sourcing of drilling materials, drilling tools and rig spares.

4.2 Recommendations

Some of the recommendations for the drilling challenges are:

1. Hammer drilling for the top formation which increases the rate of penetration for the top hard formation.
2. Regular drill string inspection and refurbishment. The drill string rotating hours are monitored and inspection done after 300 rotating hours for the new string and 250 rotating hours for used but premium string to avoid failures. Drill string that fails the inspection is refurbished before it's used.
3. Use of PDC bits and hybrid bits to increase the rate of penetration while drilling.
4. Enhanced logging should be done, especially temperature and calliper logging before casing and cementing to determine location of loss zones and volume of cement to be pumped. Cement bond logs should also be carried out to determine the quality of cement job done to determine the effectiveness of cement job.

5. Better cementing techniques, like the inner string cementing method to effectively cement the deep production casing as pumping time is less and plug cementing method and displacement is faster.

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