Well Design and Well Workover to Land Deep Production Casings in the Menengai Field

Abraham W. Khaemba
PO BOX 17700- 20100 Nakuru, Kenya
akhaemba@gdc.co.ke

Keywords: Production casings, cement slurry, cold flow, external casing packer, tie back casing, cemented liner

ABSTRACT

Drilling has been ongoing at Menengai high temperature field since 2011. The wells are regular well design wells with the 20" surface casing set at 60-70m. 13⅜" anchor casing set at about 400m depth and the 9⅝" production casing set at between 800-1400m. The wells are targeted to be drilled to a total depth of 2500-3000m, with the slotted 7" liners run to the bottom. All the casings used are grade K55 with threaded couplings.

Data from offset wells drilled earlier have helped design the depth of the production casing to avoid cold inflows into the wells. Wells located at the center of the field which is at a higher elevation have the production casings set at about 850m, while wells sited further away, the production casing has been designed to be set further deeper, to up to 1400m.

With a good number of wells at the Menengai field having the production casing being set at 1400m, this paper looks at designing wells with 9⅝" K55 production casing, slurry design and the most effective cementing method for cementing the casing to ensure an effective cement job. Cementing methods that will be discussed include cementing with cementing head and plugs, two stage cementing, cementing with C-Flex RPL from peak using the inner string method, reverse circulation cementing with inner string and flap gate valve collar and use of foam cementing.

The paper looks at a number of wells which have already been completed. Pressure and temperature logs of the wells are analyzed as well as the borehole geology to identify the cold inflow zones in the wells already drilled. The remedial mechanisms available for sealing off the cold zones in completed wells are then researched and the most effective method to be applied at the Menengai field identified. The methods include use of External casing packer (ECP) and tie back design.

1. INTRODUCTION

This paper will use data from the first twenty wells drilled at Menengai. All the wells are of standard size and are vertical.

The design of Menengai wells, drilling fluid program and the geology is as shown in Figure 1. The well is designed with:

- The conductor casing of diameter 30" 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.
- 17⅜" 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.
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.

From Figure 2, the location of wells that have already been drilled is shown on the geological map of Menengai. The Menengai caldera is an elliptical depression with minor and major axes measuring about 11.5km and 7.5 km respectively. As per Mungania (2004), the circular rim of the caldera ring fault is well preserved with vertical cliff at some places measuring up to about 400m. The ring structure 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 such that it is not possible to estimate the collapse depth or any structures that may be marking the caldera floor. However, most of the caldera infill lavas are fissure eruptions that prefer 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. This sharp trend change is associated with the extent of Cambrian craton/orogenic belts contacts.

From Table 1, wells located at the center of the field have their production casing depth between 800m and 1100m. In most of these wells the casing has been sufficient to isolate cold zones. Wells drilled on the edge of the field have had the production casing set deeper, from 1100m to 1400m to isolate cold zones which could be as deep as around 1300m.

Presence of cold zones below the production casing shoe indicate that the production casing has been set shallow.
2. ANALYSIS OF MENEN GAI WELLS

From temperature profiles of wells drilled at Menengai, from completion tests, during heat up and after discharge the temperature along the wells can be noted and feed zones identified. The study takes a look at two wells: Menengai MW02, located on the edge of the field, with production casing at 802.04m and Menengai MW19 at the center of the field with production casing at 847m. The two wells have the production casing having been set at a shallow depth compared to the other wells in the field.

2.1 Menengai MW02

Menengai Well 2 (MW 02) was completed on 1st May 2011. Aquifers in MW-02 were observed in zones shown by changes in the temperature logs. In addition, they were also characterized by an increase in circulation losses of drilling fluid, an increased proportion of high-temperature hydrothermal alteration minerals and changes in penetration rates. MW-02 encountered aquifers with relatively low temperature (<80°C) at 400-600 m and 1100-1300 m. Four aquifers were notable at 500 m (~75°C), 1200 m (~80°C), 2300 m (~90°C) and 3200 (~120°C). Figure 10 shows temperature and pressure plots for MW02 during heating up after drilling. The well is located right at the western promontory fault, almost at the edge of the caldera floor as shown in Figure 2. The rock formations in the well are heavily fractured and pyritized with partial circulation losses all through the well column. There is a sudden inflow of warm water flowing into the well at 2300 m. There is an increase in temperature at 3100 m, implying a hot geothermal reservoir beneath the massive intrusion.

<table>
<thead>
<tr>
<th>WELL</th>
<th>LOCATION</th>
<th>PRODUCTION CASING DEPTH (M)</th>
<th>DEPTH (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW-01</td>
<td>171847</td>
<td>9977684.9</td>
<td>2064</td>
</tr>
<tr>
<td>MW-02</td>
<td>171599.63</td>
<td>9979477.57</td>
<td>1898</td>
</tr>
<tr>
<td>MW-03</td>
<td>177332</td>
<td>9977854.9</td>
<td>2032</td>
</tr>
<tr>
<td>MW-04</td>
<td>177331.4</td>
<td>997607</td>
<td>2085</td>
</tr>
<tr>
<td>MW-06</td>
<td>172853</td>
<td>997676.1</td>
<td>2095</td>
</tr>
<tr>
<td>MW-07</td>
<td>170488.1</td>
<td>9977450.9</td>
<td>1924</td>
</tr>
<tr>
<td>MW-08</td>
<td>173231.3</td>
<td>9978225.3</td>
<td>2015</td>
</tr>
<tr>
<td>MW-09</td>
<td>172848</td>
<td>9977442.1</td>
<td>2105</td>
</tr>
<tr>
<td>MW-12</td>
<td>172433.5</td>
<td>9976892.7</td>
<td>2106</td>
</tr>
<tr>
<td>MW-11</td>
<td>172374</td>
<td>997536.1</td>
<td>1993</td>
</tr>
<tr>
<td>MW-05A</td>
<td>173688</td>
<td>99777481</td>
<td>2052</td>
</tr>
<tr>
<td>MW-15</td>
<td>175197.39</td>
<td>99777481.5</td>
<td>1959</td>
</tr>
<tr>
<td>MW-13</td>
<td>172464</td>
<td>9977193</td>
<td>2081</td>
</tr>
<tr>
<td>MW-16</td>
<td>171196</td>
<td>9978355</td>
<td>1965</td>
</tr>
<tr>
<td>MW-17</td>
<td>171275</td>
<td>9975756</td>
<td>2060</td>
</tr>
<tr>
<td>MW-19</td>
<td>172629</td>
<td>9977753</td>
<td>2085</td>
</tr>
<tr>
<td>MW-20</td>
<td>172017</td>
<td>9977442</td>
<td>2105</td>
</tr>
<tr>
<td>MW-21</td>
<td>171473.52</td>
<td>9977800</td>
<td>2131.4</td>
</tr>
<tr>
<td>MW-22</td>
<td>172080</td>
<td>997780.79</td>
<td>2055</td>
</tr>
<tr>
<td>MW-10A</td>
<td>172016.79</td>
<td>9977442.1</td>
<td>2085</td>
</tr>
</tbody>
</table>
Temperature logs show an increase at about 1100 m of slightly hotter water flowing into the well. At about 1300 m, cold water flows into the well and, at about 2250 m, hot water (probably only just above 100°C) flows in and mixes with the cold water. At about 3000 m, the water flows out of the well. The rock formation between 1300 and 2250 m seems relatively cold but significantly hotter below 3000 m according to Njue (2013).

2.2 Menengai MW19

Menengai Well 19 (MW19) was completed on the 12th December 2013. In MW19, high temperature alteration minerals epidote, wollastonite and actinolite, indicating temperatures of 250°C appear from a depth of 1464 m. Wollastonite is noted from depths of 1464 m to 1504 m. The well has several feed zones. The upper feed zones are at 500 m, 900 m and 1300 m. These feed zones have a cold zone up to 1300 m, thus need to be cased off and utilize the deeper feed zones in the well. After 14 days of heating up, the upper reservoir between 800 m - 1000 m had temperatures up to over 170°C while after 1 day of discharge the temperatures at the bottom of the well was up to 280°C as shown in plots in Figure 11.

Data from the two wells shows presence of more than one aquifer in the wells. There is an upper aquifer and lower aquifer with a cold zone between the two aquifers from 1000-1300 m in both wells. The presence of cold zone which has not been cased off has had an effect on the production of the wells, thus the need to land deep production casings up to a depth of 1400 m and cement the casing effectively for effective and durable well according to Lopeyok (2014).

Because of the relatively low temperature in the upper zone, production from this zone has led to precipitation of calcite in some wells and leading to decrease in production leading to costly work overs.

FIGURE 3: Menengai MW02 Temperature-pressure profiles
3. MENENGAI PRODUCTION CASING DESIGN AND CEMENTING

3.1 Casing design calculations for production casing

Grade K55 casings are used. K55 casing properties are shown in Table 3 while standard parameters for calculating casing loading are as shown in Table 2.

**TABLE 2: Parameters used to calculate production casing loading**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>Casing capacity</td>
<td>9.625 Inches</td>
</tr>
<tr>
<td>Depth</td>
<td>Casing capacity</td>
<td>38.18 litres/m</td>
</tr>
<tr>
<td>Casing wall thickness</td>
<td>Gravity</td>
<td>1.400m</td>
</tr>
<tr>
<td>Casing weight</td>
<td>Gravity</td>
<td>0.472 Inches</td>
</tr>
<tr>
<td>Casing Grade</td>
<td>Density of water</td>
<td>47 pounds/foot</td>
</tr>
<tr>
<td>Collapse resistance</td>
<td>Density of cement</td>
<td>API-K55</td>
</tr>
<tr>
<td>Internal yield</td>
<td>Thermal stress constant for steel</td>
<td>2.68 MPa</td>
</tr>
<tr>
<td></td>
<td>Pipe body strength</td>
<td>32.5 MPa</td>
</tr>
<tr>
<td></td>
<td>Casing cross sectional area</td>
<td>8756 mm²</td>
</tr>
</tbody>
</table>

Worst case theoretical axial load when cementing is when casing is full of cement and annulus full of water.

Total axial load = Casing self-weight + Weight of casing – Buoyancy

For calculations in standard units, the conversion factors are;

**Conversion factors**

<table>
<thead>
<tr>
<th>Conversion factors</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>meters to feet</td>
<td>3.28084</td>
</tr>
<tr>
<td>DaN to lbf</td>
<td>2.2482014</td>
</tr>
</tbody>
</table>
Tensile loading during primary cementing, casing is full of cement, using Equation (1)

\[ F_p = \left[ L_z W_z - (L_z - L_w) \frac{A_p n}{\pi} \right] g \]  
Tensile loading at the surface from casing weight

Casing self-weight = Depth * Weight \( \frac{328084}{22482014} \) daN

= 1400 * 47 * 1.4593 = 96,023.10 daN

Weight of cement = Depth*Capacity*Density = 1400 * 38.19 * 1.8 = 96,238.8 daN

Buoyancy Force = Density of Fluid * Volume displaced (Cross sectional Area * Depth) * Acceleration due to gravity = 1400 * \( \frac{(0.625-0.0254)\times3.142}{4} \) * 1000 * 0.981 = 64,478.087 daN

Total axial load = Casing self-weight + Weight of cement – Buoyancy

= 96,023.10 + 96,238.8 - 64,478.087 = 127,783.813 daN

K55 casing body yield strength = 332,000 daN (Gabolde and Nguyen, 2014)

Safety Factor = \( \frac{332,000}{127,783.813} \) = 2.598

The factor of safety is above the recommended minimum of 1.8, it’s safe to run 9⅝", grade K55, 47lb/ft. casing to 1400 as recommended by Hole (2008).

Internal yield pressure while cementing to 1400m (Burst) is calculated using Equation (5)

\[ P_i = [(L_f G_f + P_p) - (L_z G_z)] g \]  
The maximum differential pressure

= [(1400 * 1800) - (1400 * 1000)] g = 10.987 MPa

Design limit for 9⅝", grade K55, 47lb/ft. casing is 32.5 Mpa (Gabolde and Nguyen, 2014)

Safety Factor = \( \frac{32.5}{10.987} \) = 2.96 is above the design Factor of Safety as shown in Hole (2008).

Collapse during cementing

\[ P_i = [(L_f G_f + P_p) - (L_z G_z)] g \]  
The maximum differential pressure

= [(1400 * 1000) - (1400 * 1800)] g = -10.987. The pressure could be less depending on pumping pressure while displacing.

Design collapse resistance for 9⅝", grade K55, 47lb/ft. casing is 26.8 Mpa (Gabolde and Nguyen, 2014)

Safety factor = \( \frac{26.8}{10.987} \) = 2.43

It’s safe to run 9⅝", grade K55, 47lb/ft. casings to 1400m, since the factor of safety is above the design factor of safety of 1.2 from Hole (2008)

All the casings have Buttress thread connections. They have a longer thread and coupling run out and the threads are squarer resulting in a stronger connection than the strength of the casing body. The connection is stronger 445 and 416 *10³ for buttress standard and buttress special clearance (Gabolde and Nguyen, 2014), thus the connection is safe to run K55, 9⅝", 47ppf casing to 1400m. Thread compound should be used to provide sealing mechanism.

### 3.2 Effective cementing method

In Menengai only single stage cementing has been used. Casings are run with shoe and float placed one joint off the bottom. The wells are circulated to clear the annulus and cool down the wells before the cementing lines are pressure tested to 1500 psi (10Mpa). Pre flush
fluid is pumped at 1.00SG, then the spacer at 1.5 SG. The lead slurry is mixed in the cementing equipment and pumped at about 1.72 SG with the tail slurry being pumped at 1.85 SG. The density is checked using pressurized mud balance on the cementing unit. The wiper plug is bumped then displaced with casing capacity volume. Pressures are recorded while displacing and before bumping the plug. If returns are not received on surface, annulus is flushed with water then cement top fill done after 8 hours. Top jobs are done until cement returns are received on surface. Cement bond logging has not been done, but the top of cement is noted before commencement of drilling the next hole section. Instances have been recorded where the plug is tagged at a depth but there is no cement between the plug and the shoe. Using inner string cementing to the loss zone is a more appropriate cementing method. While using the single stage cementing, displacing the cement has been a challenge. While displacing the cement in the large diameter casings, most instances water separates from the cement and free water has been found below the top plug used while displacing the cement. Inner string cementing method is more appropriate since cement is displaced more effectively since the displacement capacity of the drill pipes is a lot less than in the casings thus we can displace faster. Water should be pumped through the annulus at a constant rate to ensure the loss zone remains open, and then pump cement to the loss zone. The primary cementing job should be followed immediately with a backfill targeting to fill up the annulus to the surface while the annular rams on the BOP are closed. The inner string method is more advantageous as its faster to circulate and cool the well as circulation is done through drill pipes (capacity of 9.05l/m- Gabolde and Nguyen, 2014) compared to single stage cementing where circulation is done through the 9½" casing (Capacity of 38.18l/m- Gabolde and Nguyen, 2014) taking more time to circulate and effective having less annular pressure to lift cuttings that may have dropped below the shoe. Due to the differences in the capacities it takes a shorter time to perform the inner string cementing. Cement should be tagged after 6 hours. If the cement level has dropped, the cement should be filled up to surface by pumping via the kill line.

4. RECONSTRUCTION OF MENENGAI WELLS

4.1 Tie back casing- Menengai MW02

Menengai MW02 has its production casing set at 790.8m as shown in Figure 5. The well has a cold inflow at 1300m. A cemented casing needs to be run to a depth of 1400m to seal off the cold inflow. The procedure will involve;

I. Run in hole a casing cutter and cut the liners at a depth below 1400m.
II. Run in hole plain 7” casings with a bridge plug at the bottom.
III. Run the casings with an expandable casing packer (ECP) as part of the casing string.
IV. After running in hole, inflate then ECP by pressurizing the casing.
V. Once the ECP is inflated cement the annulus through slots in the non-return valve above the ECP.
VI. Wait for the cement to set.
VII. Drill out the cement and the bridge plug to access the 7” slotted liners below. Figure 22 shows cementing of the tie back casing using ECP.

FIGURE 5: Tie back casing reconstruction for MW02
4.2 Scab liners

Another approach used for casing reconstruction is use of scab liners or straddle packer assemblies is another casing repair method. These approaches are more reliable and are longer-term solutions than cement squeezes, but they are somewhat limited in the length of damage that can be covered. In addition, they result in a vastly reduced hole size, which can severely affect both productive capacity and access for subsequent remediation. This method is mostly applicable in oil and gas industry.

5. CONCLUSION

It’s feasible to run 9 ⅞” K55 production casing to 1400m. This seals off shallow upper feed zones. Setting the production casing at deeper depths of up to 1400m will help prevent scaling which is a common problem in the Menengai field due to production from the shallow reservoirs. Caliper logs should be run before casings are run to accurately determine the amount of cement to be pumped.

To cement the production casings effectively, inner string method of cementing should be used targeting to fill up the cement during the primary cement job. For wells with major losses, temperature logs should be run to determine the loss zone. Primary cementing should be done to the loss zone then an immediate top job done. Inner string cementing method provides a more accurate way of determining the cement slurry volumes to be pumped and it takes less time to displace the cement since less displacement capacity is used. Inner string cementing takes less time to execute and there is less chance of cement contamination by water. Cement bond logs should be done as part of the cementing process to evaluate the effectiveness of the cementing job and where it’s noted that the cementing is not done properly remedial cementing should be done before proceeding and drilling the next phase. Completed wells that have a cold inflow below the production shoe can be reconstructed by installing an extra casing string and cementing in order to seal the cold inflows. This can be done most effectively using the tie back casing design. The tie back casing design with an external casing packer (ECP) provides better sealing to the formation once the packer has been inflated and cementing done. The design can also stand high temperatures and high pressures in geothermal conditions.

REFERENCES


