A Directional Geothermal Well in Turkey: GK-4 Case Study

Özgür Çağlan Kuyumcu, Umut Z. D. Solaroğlu, Sertaç Akar, and Bahadır Ipek

BM Holdings Inc., Ankara, Turkey

ABSTRACT

Directional wells provide significant advantages in fracture permeability dominated systems, especially in the presence of parallel faulting dipping close to vertical. Directional wells also help overcome topographical limitations that constrain small geothermal fields. GK-4 well in the Gümüşköy Geothermal Project Area was planned as a directional re-injection well for up to 750 tons per hour of brine produced from the interim (1000-1400m depths) and deeper (below 1900m depths) reservoirs. A TWD of 2600m was planned, with the target of injecting upstream into the recharge zone at the western boundary of the reservoir. The well was drilled successfully and completed at 1934m MD (1844m TWD) with total loss, albeit facing a high number of problems ranging from well pad size limitations, mud losses, faulting-related unwanted deviations, a temporarily stuck drillpipe and ultimately a compromised well completion configuration owing to an unstable zone at 1200m depth.

1. Introduction

The study area is located within the Gümüşköy Geothermal Field, which also constitutes the western side of the Büyük Menderes Graben (BMG) in Aydın, Turkey. Menderes Massive Metamorphics, has been affected by an extensional tectonic regime since Oligocene (Bozkurt and Satir 2000; Bozkurt and Oberhansli, 2001; Gessner et al., 2001). Neotectonic domain of southwestern Turkey is characterized by a tensional tectonic regime and distributed stress system with the multidirectional extension. Main structures characterizing and shaping this neotectonic domain are the graben-horst systems and their margin-boundary normal faults. The E-W-trending Menderes Graben is divided into several sub-grabens and sub-horsts along its western tip around Ortaklar, Gümüşköy, Argavlı, and Kirazlı (Koçyiğit, 2009). Active faults in the SE-NW and E-W direction provide the main geothermal system in this region, where E-W directional north sloping normal faults of Gümüşköy have formed the geothermal system in this area (Tüysüz, O., Genç, Ş.C., 2010).

The geothermal field was discovered in 2008 with the wildcat exploration well GK-1, which was followed by development well GK-3 (Figure 1). GK-1 was completed on 28 May 2009 at a total depth of 2100 meters. Flow tests confirm presence of a geothermal reserve in the Gümüşköy formation, yielding a flow rate of 230 tons/hour and a maximum reservoir temperature of 181 °C. Exploration drilling was continued with development well GK-3 reaching 2057 m depth with a maximum temperature of 165°C and a flow rate of 115 tons/hour (Kuyumcu et al, 2011).

Reservoir modeling studies revealed the system to have significant secondary permeability resulting from faults and fractures, where the upflow was realized through a multitude of parallel SE-NW and E-W directional north sloping faults, on average dipping at an angle of 70° with horizontal. These faults were determined as primary targets in order achieve higher productivity and injectivity values from wells.

Figure 1. Location Map showing Well Locations.
It was observed from the completed wells that vertical wells presented a number of shortcomings in this geology. These were as follows:

- Extreme vertical depths were required in order to intersect multiple parallel faults in a single well. This situation was further worsened by the uncertainty in exact subsurface geometry of the fault zones since Gümüşköy geology lacks a sedimentary basin and contains a very high number of hidden faults, which limits reliable results from seismic methods. Since faults are almost vertical, vertical wells drilled off-target require the multiple of this offset distance in additional well depth.

- Vertical wells suffered from high natural deviations (up to 15°) while drilling, which occur at faults intersections owing to steep fault dip angles. This decreased drilling target accuracy of wells, potentially jeopardizing well success.

- The study area, being part of a narrow and deep valley, offered adverse topographical conditions significantly limiting well pad location possibilities. Topography likewise limited the total number of vertical wells that may be drilled into the reservoir at the required spacing, thereby decreasing total production capacity.

In geothermal, directional wells have been utilized for some time to overcome such limitations preventing the drill rig from being directly over the geologic target, as well as to enable the wellbore to intersect as many formation fractures as possible. Directional wells also allow several wells to be drilled from one prepared site, thereby improving overall economy (Finger & Blankenship, 2010). Early applications of deviated wells were utilized in Takigami geothermal field, Japan by utilizing a high-torque downhole directional drilling motor and Measurement While Drilling (MWD) tools for a total of 10 high-angle (up to 50° with vertical) directional wells (Jotaki, 2000).

Hence, a similar approach was also adapted for the Gümüşköy Geothermal Field, where the next well in the development pipeline was also devised as a vertical well. Coded as GK-4, this well was designed as a re-injection well to transmit up to 750 tons per hour of circulated geothermal brine back into the reservoir.

2. Geothermal System Outline

Horst-Graben systems and their margin-boundary active normal faults in Söke major graben and the Gümüşköy sub-graben create pathways for underground circulation of hot fluids and their upwelling up to the shallower depths and even coming to surface as hot water springs.

Main sources of the heat in the study area are extremely thinning of the Earth’s crust and relatively young felsic igneous rocks intrusions. Hisartepe Volcanics exposed in the form of necks and domes in near north and northwest of Söke County in the study area may be another source of heat.

Suitable reservoir rocks of the geothermal system are the Upper Paleozoic to Mesozoic highly fractured marbles and intensely sheared, crushed, and brecciated Schists. These thick and highly porous reservoir rocks are overlain with an angular unconformity by a 0.5 km thick and strongly lithified cover sequence composed of fluvio-lacustrine sedimentary sequence of mostly conglomerate, sandstone, siltstone, shale, marl and lacustrine limestone alternation which prevents escape of hot underground fluids from the out of the reservoir forming a sealed cap rock (Koçyiğit, 2009).

The geothermal system of Gümüşköy area can be identified as a hot-water dominated convective hydrothermal resource which results from deep circulation of water along fractures settled in the BMG. The Gümüşköy geothermal system consists of three different reservoir levels: one shallow system, which is basically an up-flow zone, and two deep systems one with a depth of around 1,000 m to 1,400 m, another with depths greater than 1,900 m. (Tarcan & Gemici, 2010; Akar et al., 2011).

3. Suggested / Planned Deviated Well Program

GK-4 was planned as a re-injection well for up to 750 tons per hour of brine produced from the interim (1000- 1400m depths) and deeper (below 1900m depths) reservoirs. Gümüşköy is a topographically constrained project area having its production wells towards the eastern border of the reservoir. GK-4 was therefore required to inject upstream into the recharge zone at the western boundary of the reservoir. On the other hand, since topography severely limits the total number of wells that can be fitted into the area, a re-injection well extending as much towards the west as possible was considered to be a dire necessity for attaining feasible power generation levels.

The necessity of a deviated well was further substantiated by the need to intersect multiple parallel NE-SW and secondary NW-SE directional north sloping faults, most dipping on average at an angle of 70°.

The well program for GK-4 was strongly influenced by the topography as shown in Figure 1, where the westernmost well pad available could be placed only 440 m from the closest pro-
duction well, GK-5. A TWD of 2600m and 34° inclination was selected in order to intersect 6 of parallel NE-SW faults starting at depths of 1240m, 1600m, 1700m, 1950m, 2150m and 2440m respectively (Figure 2).

The proposed well program is presented in Table-1, Table-2 and Figure 3.

Table 1. Formation (as planned).

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (m)</th>
<th>Depth Interval (m)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>0</td>
<td>0-50</td>
<td>Alluvium</td>
</tr>
<tr>
<td>Mesozoic</td>
<td>50</td>
<td>50-530</td>
<td>Re-crystallized limestone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(fractured)</td>
</tr>
<tr>
<td>Palaeozoic</td>
<td>530</td>
<td>530-950</td>
<td>Mica schist, calcereous schist,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>quartz schist</td>
</tr>
<tr>
<td>Palaeozoic</td>
<td>950</td>
<td>950-1400</td>
<td>Gneiss</td>
</tr>
<tr>
<td>Palaeozoic</td>
<td>1400</td>
<td>1400-2400</td>
<td>Gneiss-schist</td>
</tr>
<tr>
<td>Palaeozoic</td>
<td>2400</td>
<td>2400-2600</td>
<td>Marble, calcereous schist,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>quartz schist</td>
</tr>
</tbody>
</table>

On the other hand, numeric modeling studies also recommended a re-injection distance of 1000m, where 700m was seen as the permissible minimum based on the planned flow rates. Although a west trending directional well would eventually steer a safe distance from the production area, the interim reservoir (1000-1400m depths) carried the risk of prematurely receiving re-injected brine resulting in thermal breakthrough.

The deviated drilling method selected for GK-4 was hydraulically powered downhole motor technique in which drilling fluid flowing through the motor that turns the drill bit without rotating the drillstring (Finger & Blankenship, 2010). Aerated fluid and stable foam directional drilling operations (Lyons & Plisga, 2004) were not preferred owing to their availability limitations in the region.

4. GK-4 Drilling

Drilling commenced on 16.11.2011 and was completed in 49 days on 5.01.2012, according to the time schedule given in Figure 4:

Average fuel consumption during different stages of drilling was calculated as 6400 lt/day for directional drilling, 3500 lt/day for vertical drilling and 850 lt/day for stand-by periods.

Upon completion, the well was air-lifted at 19 bars, yielding a pre-acidizing flow rate of 38.4 lt/sec at a flowline temperature of 105.4°C, with PT logs showing 139.7°C temperature at 1925m depth. The temperature was lower than that of the reservoir, which ranges between 150°C to 182°C. Offset wells and extrapolation puts GK-4 wellbore temperature at around 150°C, which makes it a successful attempt in touching the western border to the reservoir. The pre-acidizing flow rate for 7” slotted-liner completion was also seen as satisfactory - if not excellent – given the high elevation of the wellpad that works against production but contributes to reinjection pressures.
5. Problems Encountered

The drilling period was extended by a total of 16 days, owing to a multitude of problems based on the following reasons:

1. Pad space was below recommended size owing to topographical limitations. This occasionally forced units to queue in wait for one another causing time losses (Figure 5). Most critical losses were encountered during cementing operations, rig-up of directional drilling tools and setup of silencer & weir assembly for flow testing. A second consequence of size limitation was the compromised mud pit design, which was often clogged with circulated materials, requiring constant maintenance and cleanup (Figure 6).

2. Adverse weather conditions caused unexpected collapses in well pad excavation abutments, leading to minor interruptions in drilling progress (Figure 7).

3. Top Drive vibration at shallow drilling depths caused electronic (protection) lock-up and frequent engagement of torque limiter, slowing progress during drilling of the 26" well section.

4. Mesozoic re-crystallized limestone formation (estimated) down to 530m depth contained karstic cavities and highly permeable zones leading to total mud losses. In order to ensure well stability as well as quality of 13-3/8" casing cement, plug cementing was carried out 5 times at depths of 175m (day 8), 466m (day 13), 512m (3 repetitions on days 14, 15 and 16).

5. Well program estimated paleozoic schists at a depth of 530m. The casing depth was set at 550m according to program. On the other hand, continued drilling showed repeated layers of marbles leading to total losses. As a consequence, additional plug cementing was carried out also within the 12-1/4" well section 4 times at depths of 595m (2 repetitions on days 22 and 23), 660m (2 repetitions on day 25).

6. Gradual mud losses between 1289 – 1374 meters required repetitive use of LCM pills in order to control losses.
7. Parallel faulting intensifying below 1420m caused azimuth deviations in the borehole. As a result, drilling carried out between 1420-1820m was realized in frequently alternating fashion between sliding and rotating modes in order to try keep the desired azimuth.

8. Gradual mud losses between 1852 – 1928 meters required repetitive use of LCM pills in order to control losses. Drilling was completed following the total mud loss encountered at 1934m depth.

9. Most importantly, drilling parameters showed that the interim reservoir section at 1200-1230 meters was not sufficiently stable as originally estimated. It was decided to run a 7" slotted liner to maintain well stability. However, it was discovered during the POOH maneuvers that this section was indeed slowly coming loose and filling the wellbore from the bottom up, necessitating a couple of consecutive wiper trips, each showing excessive over-pull reaching 25 tons. The liner was immediately run into the hole, but tagged at 1815m unable to reach the well bottom. This was followed by a difficult decision to not re-ream the wellbore but instead hang the casing at tag depth and prepare a second BHA running 3-1/2" DPs, HWDPs and 4-3/4" DCs with a 5-1/2" drill bit. The casing shoe was drilled and the remaining wellbore was reamed down to 1934m until total loss was re-attained. Had the mud circulation from the 5-1/2" drill bit not been able to clean the loose formation filling up the well, the backup plan would be to run a 6" to 8-1/2" under-reamer to clean the wellbore. Luckily, this was not required since the required under-reamer would necessitate some days’ expensive standby.

10. Meanwhile, an initially unexplained problem was encountered at 1837m depth, while reaming below the 7" liner shoe. Increased torque was followed by an initial drill string overpull of 22 tons, where the string was pulled up to 1834m depth. Continuing drilling operation, the pipe was stuck, also without any rotation. The pipe was eventually freed following 4 hours of tedious backreaming for 30cm. It was later concluded that a piece of the shoe had broken free during drilling and got wedged from the top, between the drill bit and the formation. The back-reaming had slowly milled down the stuck piece until the pipe could pull up past it.

6. Conclusions and Recommendations

Although GK-4 had originally been planned with 2600m MD, it was completed at 1934m MD after encountering total mud loss at 1930m MD. This outcome was seen as adequate in consideration of the re-injection purpose of GK-4 and the well was thereby completed without taking further drilling risks. Post analyses revealed that the targeted faults at 1240m, 1600m, 1700m, 1950m had been successfully intersected, the last providing the highest injectivity. Experience gained through tackling the wide range of problems encountered during drilling GK-4 directional well has led to the following conclusions and recommendations:

1. Well program must be carefully reviewed for lithology, especially in terms of expected well stability from offset wells. Although this is a very generic comment, the critical importance of this particular task was reflected in the resulting compromised completion configuration of GK-4. A more thorough study of offset well logs and core samples might have provided a more accurate understanding of the formation in GK-4, where the necessary precautionary measures could have been implemented in the well program.

2. Well pad design studies must be carefully assessed for abutment stability and excess rainwater discharge for at least Q25 (25 years’ peak flood conditions) when operating within rainy seasons. Adequate space must be allowed for storage of directional drilling tools as well as for maneuvering during rigging and demobilization of the same.

3. Most geothermal areas contain high permeability formations and are often faced with mud losses. Keeping a cementing unit standby at the well site and the cement silo well stacked is strongly recommended for enabling immediate plug cement operations. Good plug cementing is in turn recommended for proper cement bonding of casings so that long well service lives can be possible.

4. A second recommendation in line with the high permeability expectations above is to either pre-drill multiple of water wells or otherwise add a large water pit to the existing mud pit in order to store and supply large quantities of water during total losses. Momentary efforts to meet high water demands without these precautions are very costly and yet seldom adequate.

5. Unexpected problems such as the stuck drillpipe incident at 1837m depth may be encountered in most wells. In order to be able to quickly remedy the situation, it is recommended to have the most frequently used set of fishing and milling tools at the wellsite.

6. Deviated drilling makes a significant addition to the total fuel consumption of drilling owing to incorporation of additional mud pumps to drive the downhole motor. This increase, which reached up to 3000lt/day in GK-4, must always be considered alongside directional drilling service charges when making budgetary calculations. More importantly for countries like Turkey where diesel costs can run as high as 2.3 USD/lt, it is highly recommended to switch to electricity for mud and down-hole motor pumps and keep generators only on contingency standby.

References


1 In Gümüşköy Geothermal System acidizing has been implemented with successful gains in flow rate.