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Artificial Lifting in Liquid Dominated High-Temperature Geothermal Fields in Turkey: Lessons Learned

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ABSTRACT

Due to the attractive feed-in-tariff mechanism, Turkish geothermal producers operate geothermal power plants at their maximum capacity. As a result, many geothermal reservoirs in Turkey have been exploited with an aggressive production strategy by multiple operators. A significant amount of production targeted natural fractures associated with normal faults in Western Anatolia. Wells produced at the maximum allowable capacity caused substantial reservoir pressure drops that affected reservoir dynamics. Premature temperature decline, local pressure drop, and the sharp decline of non-condensable gases (NCG) have been commonly observed in these geothermal reservoirs. All of these impacted the production performance of wells negatively. Artificial lifting methods such as airlifting and downhole pumps (Line shaft pumps or electrical submersible pumps (ESPs)) are commonly used to compensate for missing production. This study discusses the use of ESPs in liquid dominated high-temperature Alaşehir and Kızıldere fields. Observations, experiences, and lessons learned from the ESP applications in these fields are reported in detail.

1. INTRODUCTION

The economic viability of geothermal projects depends on the production performance of wells. Geothermal wells produce either with their natural energy (artesian flow) or artificial lifting systems such as gas lift and downhole pumps. Regardless of the production mechanism, pressure decline behavior is mostly observed due to large withdrawal from the reservoir in many Turkish geothermal fields (Aydin et al., 2020). Apart from drilling make up wells, the common practice for maintaining production rate and pressure on the surface is to use downhole pumps. Line shaft pumps (LSPs) and Electrical Submersible Pumps (ESPs) are widely used for geothermal applications. Kaya and Mertoglu (2005) compared the technical advantages and limitations of LSPs and ESPs for geothermal wells. They reported the following critical remarks:

- The location of the drive motor is the main difference between LSPs and ESPs.
- ESPs motor and cable failure are more frequent compared to LSPs.
- LSPs can only be installed in vertical wells, whereas ESPs can be used in both vertical and deviated wells
- The economic setting depth of LSPs is 250 meters. There is no strict limitation depth for ESPs as long as pump intake is below flashing depth
- Run-in-hole and pull-out-of-hole time is 15 to 20 days for LSPs and 2 to 5 days for ESPs.
- Due to harsh working conditions, the run time of ESPs and maintenance periods may be much less than LSPs.

Due to many advantages over LSPs, ESPs are widely used in geothermal wells. Molloy (2009) stated that ESPs are the most promising alternative to LSPs for hydrothermal systems and Enhanced Geothermal Systems (EGS). The common objective of ESP manufacturers is to adapt ESPs' critical parts such as motor and cable to work in the harsh working environment. High working temperature and corrosive gases pose the main challenges in geothermal wells. The schematic drawing of main parts of a typical ESP are shown in Figure 1. From downward to upward, the ESP string's main components are the drive motor, protectors, intake, and pump body. The electrical cable is connected to the drive motor, and the cable is tied to production tubing from the surface to the downhole ESP string. ESPs are typically suspended on a tubing string hung from the wellhead and are submerged in the production fluid. A variable speed drive mounted at the surface controls the motor and pump operation. Geothermal fluid is the cooling source of the motor. Geothermal fluid first flows around the motor, cools it, and keeps the motor internals from overheating. ESP failures are generally associated with drive motor and cable. The downhole gas separator is rarely used in geothermal wells. Thus, it is necessary to set the pump intake at a depth below gas flashing depth to prevent cavitation.

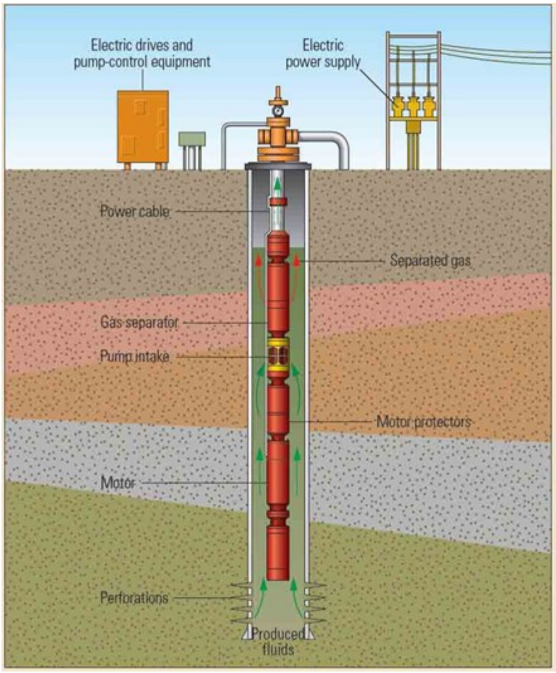

Figure 1: ESP main parts (Flatern, 2015)

Since the 1980's, advances in design, operating practices, and material selection of ESPs have increased mean time-to-failure (MTTF) more than 3 months in a high-temperature environment. Ellis (1988) reported MTTF of ESPs as less than 1000 hours. Novomet (2020), an ESP manufacturer, declared that they modified existing ESP technology which is proven reliable and efficient for years in oil production to perform in the high temperature, high scale, and high flow environment found in geothermal wells. The permanent magnet motor with heat resistant components are filled with high-temperature synthetic motor oil. Two independent thrust bearings and multiple hydro protectors are the other vital components to increase the reliability of the recent technology in ESPs. With this technology, it is claimed that ESPs works efficiently in harsh environment geothermal wells with a temperature up to 200°C. DOE (2013) reported a limit on the operating temperature of the ESP internals around 288°C, and the produced fluid temperature was reported as 218°C. In geothermal industrial operation practice, economically viable ESPs are operated at resources where the fluid temperature is less than 175°C. ESPs are well-suited for EGS projects due to delivering large volumes and deep setting depths. DOE (2013) stated that EGS needs long-term high temperature, deep-well operation, advanced materials, and seals. ESPs must survive for more than 3 years at a resource temperature of 300°C to be viable for EGS projects. Lobianco and Wardani (2010) reported that Schlumberger performed more than 20 geothermal well ESP installations in Austria, Germany, Italy, and Poland. The fluid temperature changed between 85°C and 141°C, and the flow rate changed between 400 m^3/day to 6720 m^3/day. All of the installations were used for direct-use applications except one installation used for electricity generation. An ESP was installed in Soultz EGS project in France. The pump was expected to operate at 185°C at 25 L/s in a very salty brine. The ESP was operated for more than one year, and the production rate decreased by half of the initial rate. Failure was not identified because the string was not pulled out from the well, and a dismantle and failure analysis was not performed. Very low flow rate suggested motor overheating above the limit of internal insulation that caused short-cut was responsible for the failure.

ESP design is the most important step for a successful ESP operation. Determining the pump setting depth, pressure at this depth, desired flow rate and wellhead flowing pressure at the surface, and electricity consumption are important points to be addressed. Throughout ESP design, characteristic properties of the particular well are crucial. Non-condensable gas content, productivity index, reservoir pressure, casing setting depths and geometry of the well are important parameters that determine the pump deliverability. Therefore, it is essential to perform an appropriate well testing program to obtain the important reservoir parameters. As the ESP design is completed, the next step is to check the well's diameter changes using a caliper log. This will prevent stucking of the pump during the run-in hole. In case of inconvenient well diameter, mechanical cleaning needs to be performed before the ESP installation. ESP intake should be set to a depth below the gas flashing depth. Inhibitor line is attached to ESP string, and injection chamber is set to a depth that is 50 meters below pump intake setting depth to prevent inhibitor clogging at the pump intake.

In this study, we report ESP application status in Kızıldere and Alaşehir geothermal fields in Turkey. The study aims to provide a workflow by sharing experiences and lesson-learned from the ESP operations in high-temperature geothermal wells.

2. GEOTHERMAL FIELDS IN TURKEY

High enthalpy geothermal resources in Western Turkey are the main target locations for geothermal power projects. The total installed geothermal power plant capacity is 1613 MWe as of the end of 2020. Büyük Menderes Graben and Gediz Graben host more than 99 % of the installed power plants in Turkey (Figure 2). Kızıldere and Alaşehir geothermal fields are among the most popular targets for geothermal developers in Turkey.

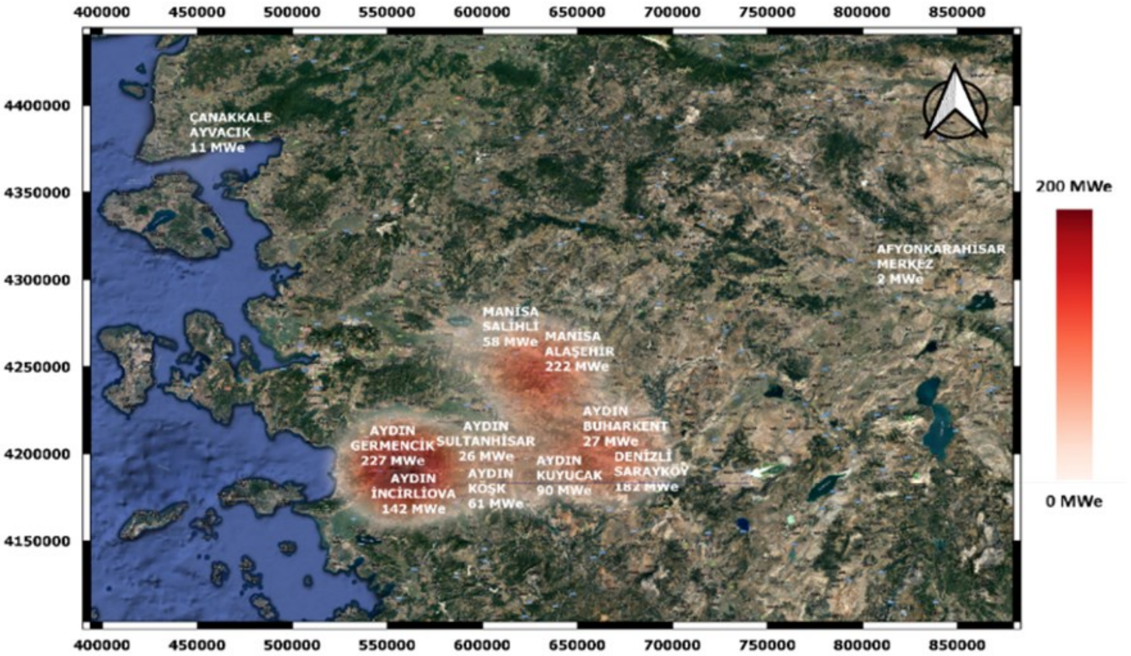

Figure 2: Distribution of Geothermal power plants in Turkey (Aydin et al. 2020)

2.1 Kızıldere Geothermal Field

The Kızıldere geothermal field was discovered in 1968 by MTA (Mineral Research and Exploration Institute of Turkey). The first power plant was installed with a power capacity of 15 Megawatt in 1984. In 2013, a double flash-binary combined power plant was installed with a capacity of 80 Megawatt. The last and the newest discovery was made at the deeper reservoir section, ranging from 3000 to 4000-meter depth. The highest bottom hole temperature recorded in these wells is 246°C. The largest geothermal power plant of Turkey with triple flash-binary combined and the capacity of 165 Megawatt was put on operation with two units in 2017 and 2018. Senturk et al. (2020) emphasized substantial pressure and NCG decline due to the operation of new production wells. In addition to re-injection optimization and changing production strategy, artificial lifting methods like downhole pumps have been implemented in the field to supply the required flow rates to power plants.

2.2 Alaşehir Geothermal Field

Alaşehir geothermal field has become the most attractive target for geothermal exploration activities and construction of geothermal power plants in the last decade. More than 100 wells have been drilled in the area by six different geothermal developers. There are 6 binary power plants, and a combined flashing-binary power plant actively generating electricity from the field with a total installed capacity of 210 MWe. The reservoir is liquid dominated and the Paleozoic aged reservoir rock consists of marble, mica-schist, calcshist, and quartz. The reservoir temperature ranges from 140°C to 250°C (Aydin and Akin, 2019). Significant pressure and NCG decline were reported due to aggressive production strategies employed by the geothermal developers (Aydin and Akin, 2020).

3. LESSONS LEARNED

Reservoir management applications may not be sufficient to maintain the production performance of the wells. Especially in the fields with multiple operators, it is challenging to reach production goals due to the neighboring producers' aggressive production strategy. As a consequence, a significant decline may occur in reservoir pressure, NCG weight, and temperature. Thus, the production performance of the wells may decrease to the undesired levels. Kızıldere and Alaşehir geothermal fields have experienced such changes. A new production program has been implemented to increase some of the wells' production capacity to their original rates using downhole pumps while keeping others produce with artesian flow. Although mixed production is not desired from the point of reservoir engineering, preliminary indications are not pessimistic, and performance improvement has been achieved. .

Schematic drawing of a typical casing program of a geothermal well drilled in Turkey is shown in figure 3. In order to reduce cost 7-inch slotted liner is usually hanged on the 9 5/8” casing. The ESP string is usually installed with 6 5/8” production tubing. Calculated performance of a well with ESP in Kızıldere field is illustrated in figure 4. Table 1 summarizes design parameters of the 16 stage ESP that provides 227 m3/h rates at 10 bar wellhead flowing pressure.

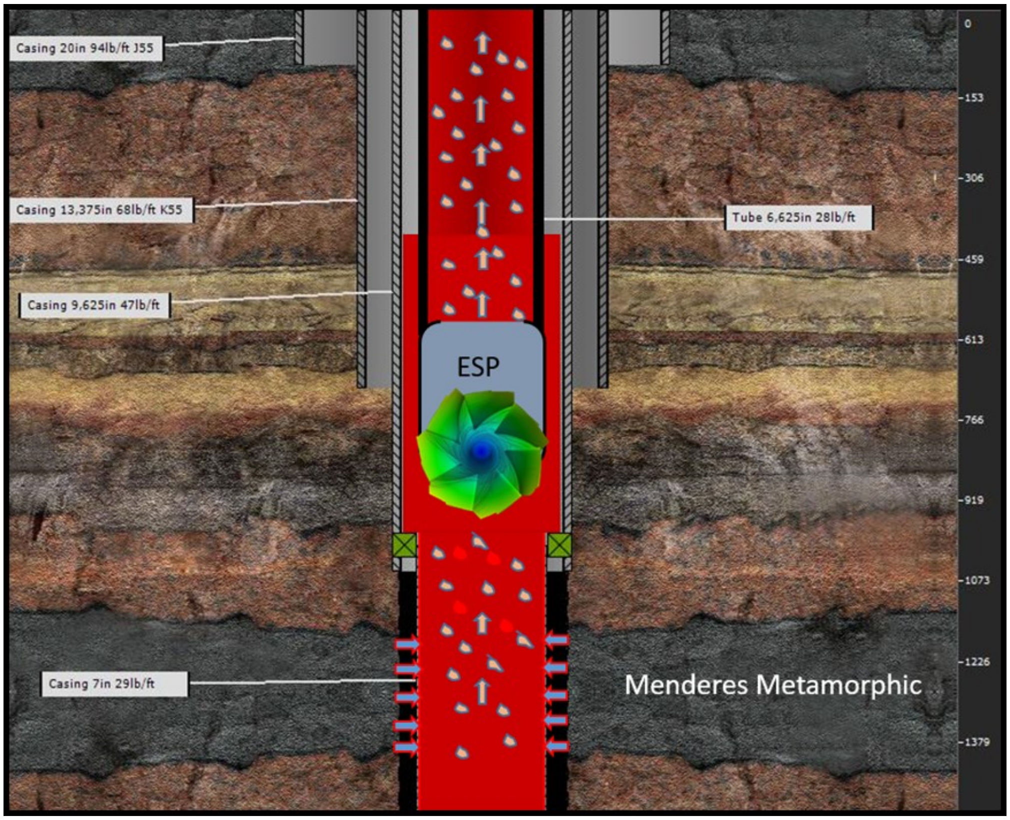

Figure 3: Well-scheme of a typical geothermal well in Turkey

Table 1: Design parameters for a well in Kızıldere field

Pump Intake Pressure [Bar]	27
Pump Intake Temperature [°C]	180
Motor Temperature [°C]	201
NCG content by weight [%]	0.26
Pump setting depth [m]	450
Desired Wellhead Pressure [Bar]	10
Desired Flowrate [m3/h]	227
Pressure development [Bar]	25
Number of stages	16
Motor Power Consumption [kWt]	250

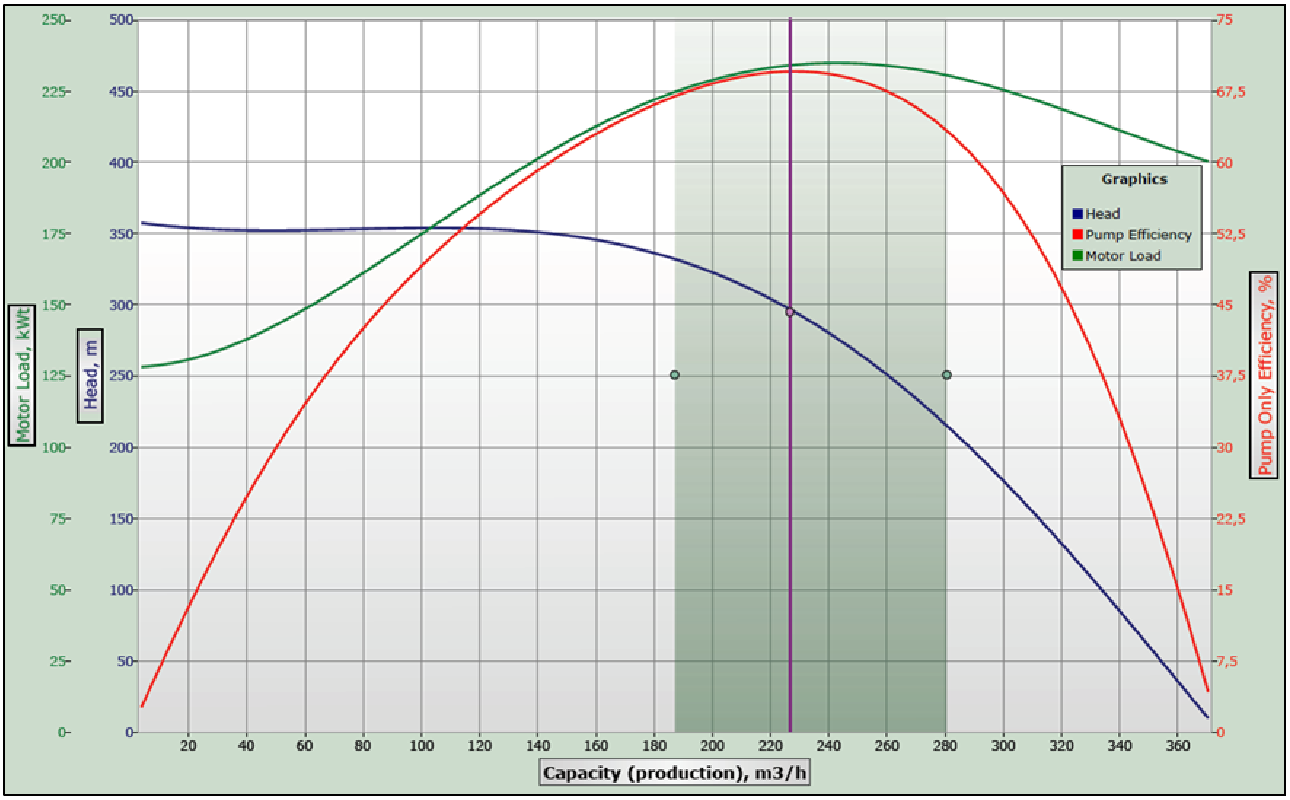

Figure 4: ESP performance of a well in Kızıldere field

In the Kızıldere field, 10 ESPs were successfully installed in wells with low wellhead pressure. Eight of these ESPs were put on operation with good results. Due to the casing program of the wells, 6 5/8" casing was used as production tubing. However, in a well with a larger casing diameter (13 3/8") an ESP with a larger diameter producing from 9 5/8" production tubing provided 400 tons per hour. The temperatures of the artificially lifted wells change between 160°C and 230°C. Prior to installation a caliper log was taken in all wells for understanding wellbore-diameter across the ESP interval before running in the well. In order to ensure calcite scaling is not an issue mechanical cleaning may be needed. In this regard, a production well was mechanically cleaned using a well-completion rig before ESP installation. Taking a cement-bond-log (CBL) is also crucial to understanding the risk of collapse due to poor cementing job between 9 5/8" casing and 13 3/8" casing. The deepest ESP installation in the Kızıldere field was performed at a setting depth of 1331 meters with a fluid temperature of 230°C. The ESP survived for 26 days in the harsh downhole conditions. In the Alaşehir field, an ESP was used for the first time due to sharp pressure decline in an artesian well. The summary of the ESPs in the Kızıldere and Alaşehir field is shown in table 2. ESPs failed for a variety of causes in 7 out of 10 wells. The average mean time to failure was 144 days. The ESPs failure root-causes were found to be related to motor and cable failures associated with high-temperatures. VSD failure was another less frequently observed problem that occurred during the operation. The shorted failure time in the Kızıldere field after an ESP was put on operation was one hour. The failure was found to be related to either cable or motor (no isolation). However, as ESP was tried to be pulled out of the well, there was no movement in the ESP string at all. To understand if there is a collapse in the wellbore or not, the well was cooled down, and a slick-line camera was run into the wellbore. A view of the collapse was captured in the wellbore, as shown in figure 5. To understand the casing diameter after the collapse, a caliper log was run. It was observed that the well profile diameter at depths between 235 meters and 241 meters was reduced from 5.71 inches to 3.8 inches (figure 6).

Table 2: Summary of ESPs in Kızıldere and Alaşehir Field

WELL ID		Working Days	Reservoir Temperature (°C)	Flow rate (t/h)	NCG content by weight %	Setting Depth (m)	Failure root-cause
KD-14	No failure	199	182	180	0.26	334	
KD-15	No failure	201	184	157	0.29	322	
KD-16	Failed	225	185	220	0.34	450	VSD Problem
KD-20	Failed	83	178	152	0.37	460	Unbalance motor current
KD-22	Failed	113	185	210	0.36	459	Unbalance motor current
KD-18A	Failed	0	200		0.90	802	Motor and cable problem
R-1A	Failed	160	187	173	1.00	796	Unbalance motor current
KD-50	No failure	230	162	400	0.10	477	
KD-90A	Failed	26	230	95	1.20	1331	VSD Problem
Alkan-3	Failed	200	182	209	0.34	549	Unbalance motor current
	1st Failure Av.	144					
	Total Failure	7					
	Working Days Av.	193					

Figure 5: A view of collapse in 6 5/8" tubing in ESP string in Kızıldere Field

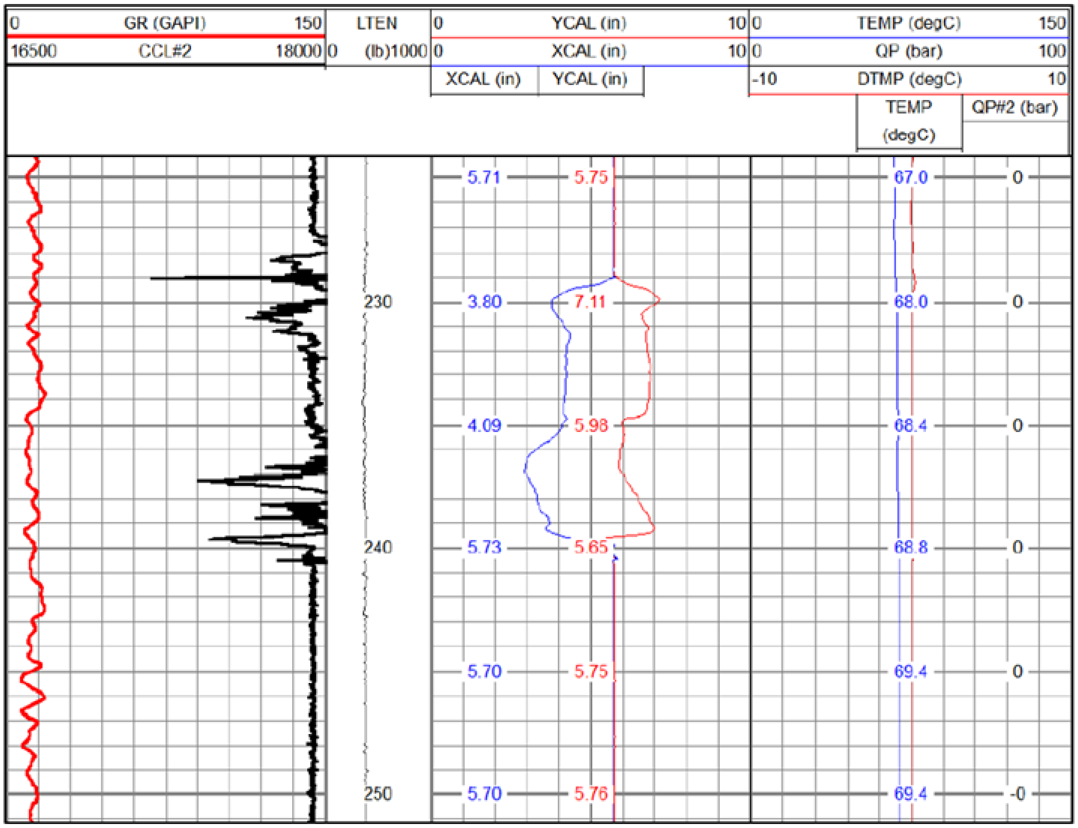

Figure 6: Caliper log was taken from an ESP collapse well in Kızıldere Field

4. CONCLUSION

The application of ESPs in Turkey has gained acceleration due to gradual to severe declines in the reservoir parameters such as NCG content and reservoir pressure. In order to compensate missing production many geothermal developers opted to use ESPs as opposed to drilling make up wells. The first ESP application in Kızıldere and Alaşehir fields is reported in this study. Promising results have been obtained in moderate temperature wells where the average flow rate of the wells is around 180 tph. It is important to note that the casing program of the wells determines the wells' deliverability. Typical 6 5/8” tubing provides an average flow rate of 200 tons/hour. A maximum of 450 tons/hour can be produced from 9 5/8” production tubing with appropriate ESP string provided that PI of the well is appropriate. The mean time to failure was found to be around 144 days in moderate temperature wells, and 26 days for a high temperature well. The experiences showed that obtaining correct reservoir and well parameters are crucial for a proper ESPs design. It is suggested to conduct caliper and CBL logs before installing an ESP for reducing the risks associated with casing collapse and pump stucking.

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