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A Study on the Production and Reservoir Performance of the Germencik Geothermal Field

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ABSTRACT

The Germencik geothermal field is located in the western part of the Buyuk Menderes Graben (Western Anatolia). The field was discovered by MTA (General Directorate of Mineral Research and Exploration) in 1968 and more than 38 wells were drilled since then. It is a liquid dominated reservoir, with temperatures close to 240 ºC, whose main feature is the high noncondensable gas (mainly CO_2) content as much as 2.5% by weight.

GURIS Construction and Engineering Co. Inc. is the operator of the field and constructed a 47.4 MW_e double-flash power plant in 2009. The early production performance of the field clearly indicates a great potential for further developments. GURIS intends to develop the field and to extend the power plant capacity in the near future.

In this study, the results of temperature profiles, well tests, and inflow performances of wells to characterize the Germencik geothermal reservoir underlying the GURIS area are evaluated and presented. Based on static temperature measurements obtained from the wells throughout the field, a 3-D temperature distribution map was constructed. The thermal energy stored and power generating capacity were estimated.

The modeling study to assess the impacts of the further developments on the reservoir is underway. Our in-house lumped parameter model is utilized to model the early production rate-reservoir pressure history and an almost perfect match is obtained. Results of the proper model obtained from the match will be used to estimate the production performance of the field under several production scenarios.

1. INTRODUCTION

Turkey is located on the active Alpine Himalayan tectonic belt that have produced a series of E-W graben systems particularly at the western part of the country. One of these major grabens is called the Buyuk Menderes graben. The Germencik geothermal field is located in the western part of the Buyuk Menderes Graben about 40 km from Aegean Sea and within Omerbeyli residential area in the Aydın province.

The conceptual geological model of the field is considered to be consisted of two reservoirs. The shallow reservoir is composed of the so-called the Menderes Metamorphic Group composed of sandstones and conglomerates whereas the deep reservoir is composed of gneiss, marble and schist which are brittle and impervious rocks. So the permeability of the deep reservoir is mainly secondary due to fracturation of these brittle rocks formed during the tectonic deformation which is still active (Simsek, 1984; Correia et al., 1990; Tekin and Akin, 2011). The reservoir is considered to be the primary target for power generation as already recognized by recent extensive drilling operations and has a potential of up to 200 MW_e (Satman et al., 2013).

The field was discovered by MTA in 1968. The geothermal exploration led to the successful drilling of nine exploration wells between 1982 and 1986, which identified a water dominated hydrothermal system with a temperature between 210 and 230 ºC, whose main feature is the high noncondensable gas (mainly CO_2) content. Then, GURIS Construction and Engineering Co. Inc. has become the operator of the field and drilled nine more wells between 2007 and 2008 and constructed a 47.4 MW_e power plant. Up to now, a total of more than 38 wells were drilled. The locations of the wells drilled in the field are shown in Figure 1. Eight wells are used for production, eight wells for reinjection, one well (OB-7) for observation, and the others are recently drilled wells to be used in future development stages of the field.

As a result of auctions of geothermal licenses in the region where the Germencik geothermal field is located, in 2011 a new development of 20 MW_e by another party went on-line in an adjacent area to the southwestern part of the field and two more power plants each 24 MW_e were added into operation at the same adjacent area in 2012. The analysis of production and reservoir performance of the Germencik field clearly indicated that the geothermal resource is shared by two leases. However all the studies and results presented in this paper pertain and concentrated on the GURIS lease of the reservoir.

A production/reservoir performance project (Satman et al., 2013), funded by the GURIS management, has been conducted at the Germencik geothermal field. Compilation of data related to geology, geochemistry, drilling and well test results, detailed production and injection histories-rates, wellhead pressures and temperatures of the active production and injection wells, and downhole pressure-monitoring data was succeeded and integrated to form the conceptual model of the field. The objectives of the study were to assess the energy production potential of geothermal resources within the GURIS's about 36 km^2 concession area in Germencik, mainly through reservoir modelling, and assess the feasibility of continued and increased production.

This paper discusses some of the fundamental findings of the project conducted and presents the recent developments in the field. The GURIS management was interested in increasing the capacity of the power plant. Therefore, the purpose of conducting the project was to analyze and model the production performance of the field and then to study the various scenarios leading to increasing the capacity of the field. The modeling for the various scenarios is an ongoing part of the project, however the early results are discussed in this paper.

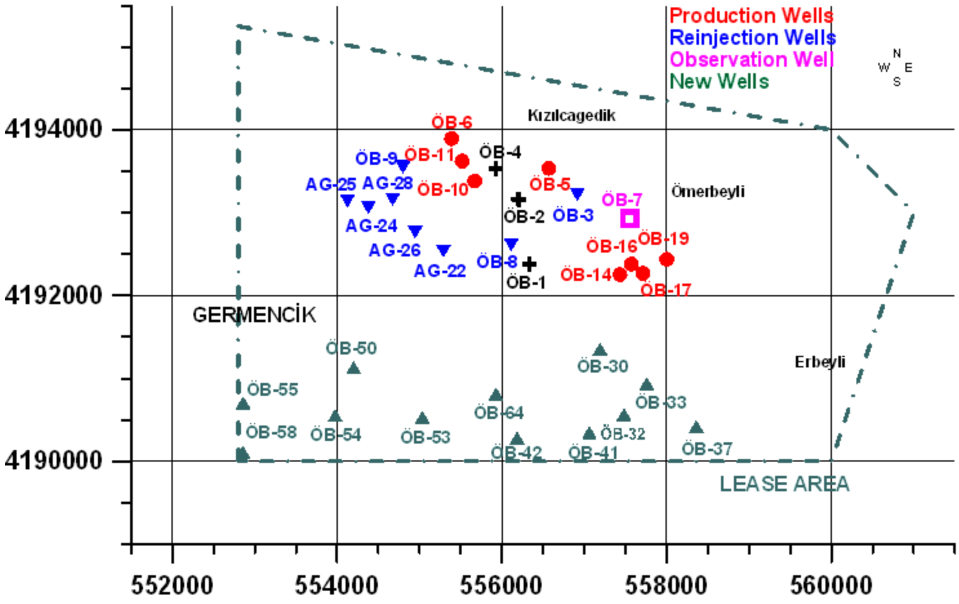

Figure 1: The locations of the wells drilled in the field.

2. RESERVOIR CHARACTERIZATION

The static and dynamic temperature profiles, well tests, and water analysis were evaluated to determine the reservoir and field properties. Some of them are discussed here.

To study the production performance, static and dynamic wellbore tests and as well as multi-rate wellbore flow tests were performed and analyzed. Multi-rate flow tests were carried out in adequate wells to obtain information and as a result, inflow performance relationship curves of those wells were determined.

2.1 Analysis of Static and Dynamic Wellbore Pressure and Temperature Profiles

Figure 2 shows the static temperature and pressure profiles of one of the deep wells, OB-30, drilled in the field. This well is located at the mid-southern part of the reservoir. The temperature profile given in Figure 2 indicates the presence of a relatively hot convective reservoir starting at about 1300 m with a temperature of 225 °C.

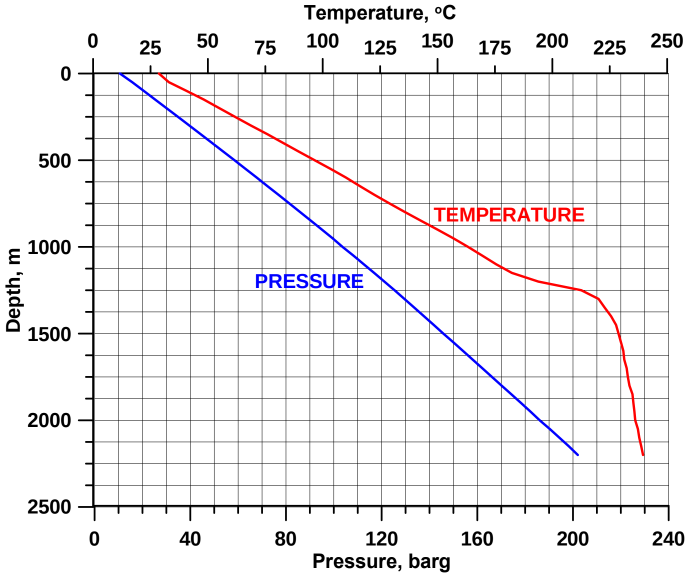

Figure 2: The wellbore static pressure and temperature profiles for the well OB-30.

An in-house wellbore flow simulator was used to analyze the dynamic flow tests. The purpose was to understand the flowing phase behavior, to estimate the amount of CO_2 dissolved in geothermal water, the depth where the flashing occurs, and to determine the flow rate-wellhead flowing pressure relationship.

Analysis of the dynamic pressure-temperature profiles indicate that two-phase flow exists in the wells. The flashing point depths are determined. To prevent the calcite deposition in wells, an inhibitor is injected into the production wells.

Figure 3 shows the dynamic pressure and temperature profiles for the well OB-33. The test was conducted on Jan. 2, 2013 at a mass flow rate of 184 t/hr, and the profiles are typical of a well with compressed water entering into the bottom hole and then the formation of the two-phase flow occuring in the wellbore.

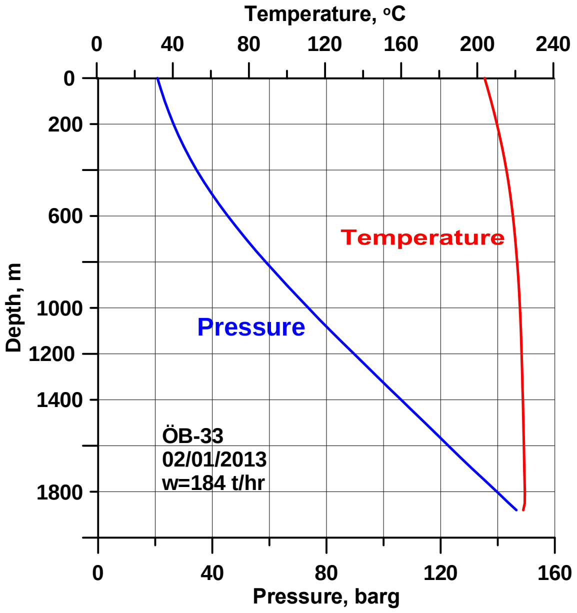

Figure 3: The wellbore dynamic pressure and temperature profiles for the well OB-33.

Figure 4 shows the dynamic pressure and temperature profiles for the well OB-16 and the matching results obtained from the in-house simulator. A good match was obtained for the CO_2 content of 0.021 (2.1% by weight). Matching indicates the CO_2 flashing point depth at 666 m.

To confirm the CO_2 content of the geothermal water obtained from the match, the measured values using a mini-separator at the wellhead were compared. The measured values at various times range between 0.017 and 0.026, which support the 0.021 value obtained from the in-house simulator.

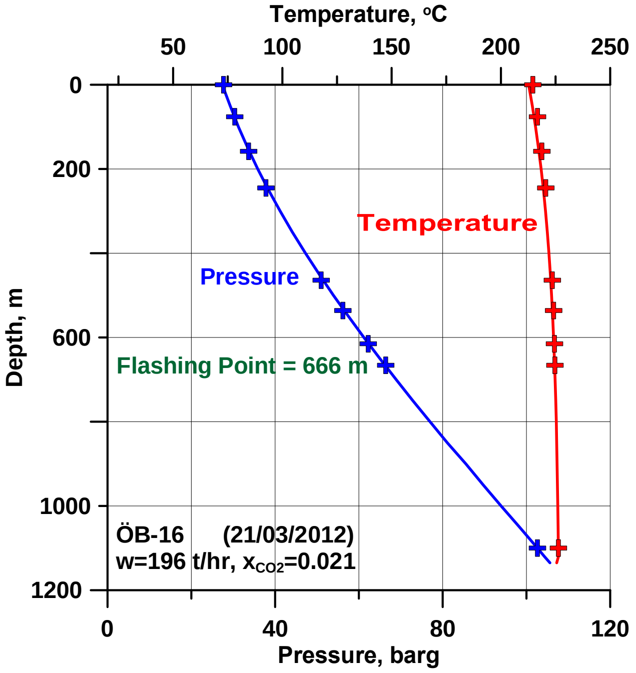

Figure 4: Comparison of measured and modeling results of the wellbore dynamic pressure and temperature profiles for the well OB-16 (+ signs representing the modeling results).

2.2 Production Performance of Well OB-64

Well OB-64 is one of the recently drilled wells (Erkan, 2013). The various well tests conducted indicate a fairly promising production performance. Thus the analysis results are discussed in detail.

Figure 5 shows the dynamic pressure and temperature profiles for the well OB-64 and the matching results obtained from the wellbore simulator. The match was obtained for the CO_2 content of 0.021 and yields the flashing point depth at 546 m.

A further modelling study was conducted to study the effect of reservoir pressure drop on the wellbore pressure and temperature behavior. Changes of the wellbore dynamic pressure and temperature profiles for the well OB-64 after a 30 bar pressure drop at bottom hole flowing pressure are illustrated in Figure 5. Decline at bottom hole pressure results in deepening the flashing depth from 546 m to 916 m and thus yielding a two-phase flow column in a greater portion in the wellbore. This causes a lower hydrostatic pressure change in the two-phase flow column and thus results in a lower pressure drop at the wellhead as compared to drop at the bottom hole. Notice that the 30 bar pressure drop at bottom hole yields about 10 bar pressure drop at wellhead. As expectedly a slight temperature change also occurs at the wellhead.

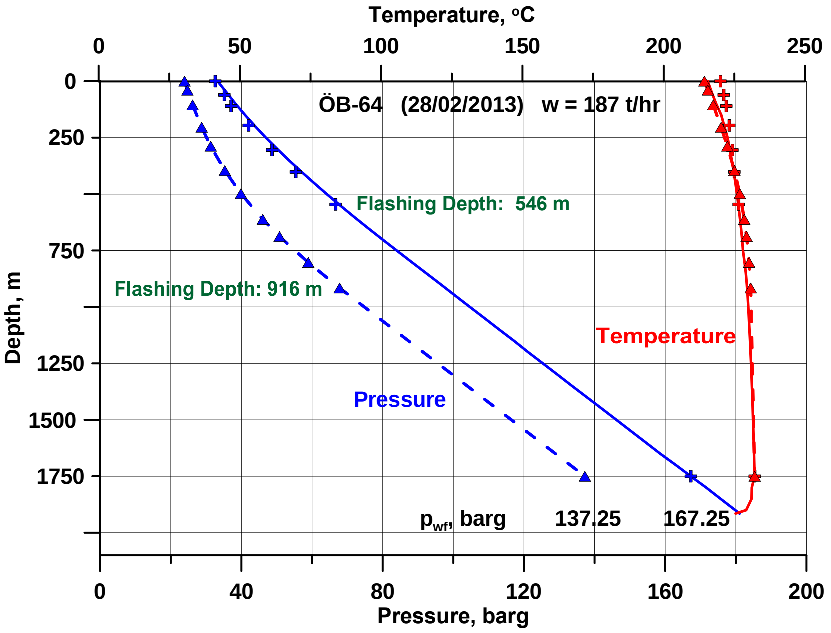

Figure 5: Change of the wellbore dynamic pressure and temperature profiles for the well OB-64 after a 30 bar drop at bottom hole flowing pressure (symbols and dashed line representing the modeling results for x_{CO2}=0.021).

Although not discussed in detail here, a pressure buildup test was conducted at OB-64. Results obtained from the analysis of the buildup test and from the modeling of the dynamic and static pressure and temperature profiles for various mass flow rates were combined to understand the reservoir pressure behavior and the wellbore pressure behavior as a function of mass flow rate (the inflow performance curve).

Figure 6 gives the plot of mass flow rate-pressure drop in reservoir relationship for well OB-64 indicating the turbulent flow in the reservoir. The shape of Figure 6 is typical of flow tests for geothermal wells under the turbulent flow conditions. The graph of the logarithm of the pressure difference vs. the logarithm of the mass flow rate provides a straight line whose slope is n (the performance exponent, ranging from unity for laminar flow to 0.5 for turbulent flow).

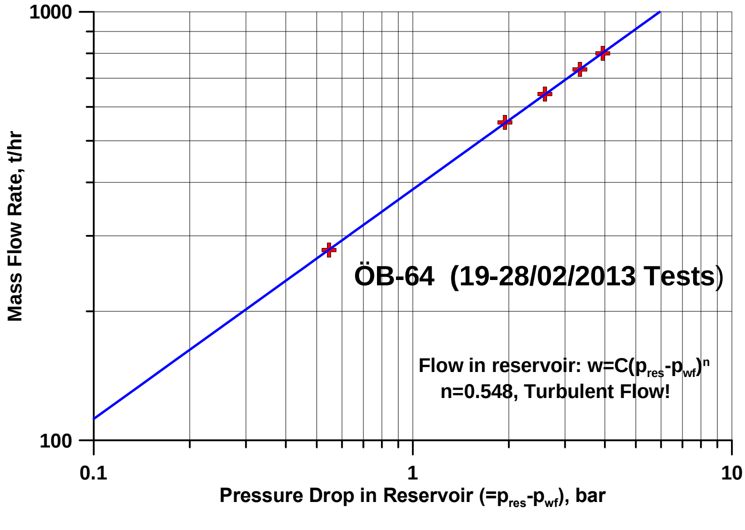

Figure 6: Plot of mass flow rate-pressure drop in reservoir relationship (inflow performance relationship) for well OB-64 indicating the turbulent flow in the reservoir.

Figure 7 presents the results of the modeling study on mass flow rate vs. various pressure parameters relationships. The changes in wellbore flowing pressure, wellhead flowing pressure, wellbore pressure drop and pressure drop in reservoir as a function of mass flow rate are given.

For a constant reservoir pressure, the wellbore flowing pressure at bottom hole decreases and the pressure drop in reservoir (difference between reservoir pressure and wellbore flowing pressure) increases as the mass flow rate increases. The behavior of wellbore pressure drop (difference between wellbore flowing pressure and wellhead flowing pressure) and wellhead flowing pressure as mass flow rate increases, however, deserve some attention. Generally speaking, increase in mass flow rate causes higher pressure drop in wellbore due to turbulent flow and thus leads to lower wellhead flowing pressure. This behavior is valid whenever the well is thermally stabilized. However, at low mass flow rates when the wellbore is relatively cool, the wellbore performance is affected by the temperature and fluid density. As the mass flow rate increases, the wellbore pressure drop decreases due to heating of the fluid column in the wellbore, and wellhead flowing pressure increases. But as mass flow rate is increased further, a point is reached where wellbore pressure drop increases and wellhead flowing pressure decreases as discussed earlier.

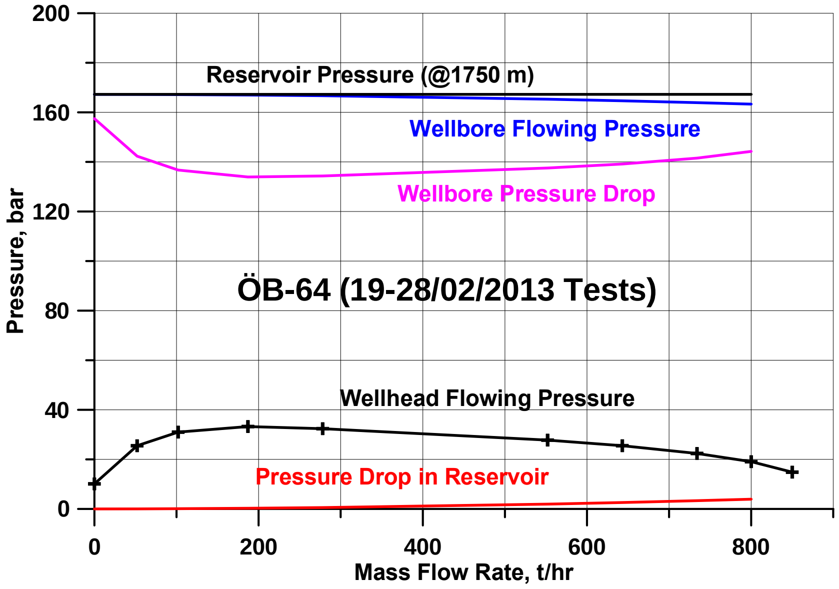

Figure 7: Plot of mass flow rate vs. various pressure parameters for well OB-64.

2.3 Subsurface 3D Temperature Distribution

Static temperature surveys taken in the Germencik wells were evaluated and a 3D temperature distribution was obtained (Figure 8). All available temperature data were utilized.

Figure 8 shows distribution of T>180 °C contours. Result of 3D temperature distribution study suggest that the Germencik reservoir extends southward, and the western part of the field is an outflow of the reservoir.

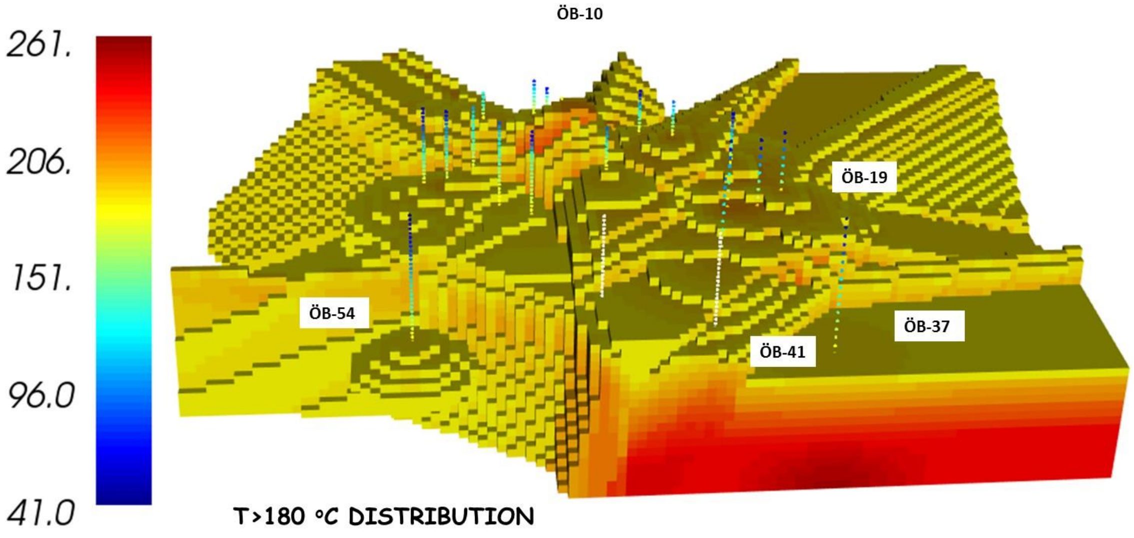

Figure 8: The subsurface temperature (T>180 °C) distribution for Germencik geothermal field.

The volumetric assessment method indicated an estimate of $2.2\text{x}10^{19}$ J of the total thermal energy stored underlying the GURIS lease of the Germencik geothermal field, where 20 °C is used as base temperature. Based on a 1500 m thickness assumption, the possible power generating capacity in the concession area is estimated to about 200 MW_e. Therefore a capacity of about 160 MW_e or probably more still remains untapped, according Satman et al. (2013) estimates.

As a summary; the Germencik geothermal system is a convective hydrothermal type, that commonly occurs in areas of active geological faulting and folding, and in areas where the regional heat flow is above normal, as in much of western Turkey. The simplified conceptual hydrogeological model of the field assumes a resource located along the graben and fault systems in depth. The subsurface 3D temperature distributions (Figure 8) indicate that the hot recharge water rises along the southeastern part of the field. This simple model is believed to represent the basic mechanism for the graben and fault related moderate-temperature Germencik geothermal resource.

Upcoming drilling and test data from the already drilled wells and/or to-be-drilled wells in the southern area should significantly enhance our understanding of the geothermal system and enable us to reduce the uncertainties associated with the conceptual geological model.

3. PRODUCTION AND RESERVOIR PERFORMANCE

3.1 Production and Reinjection History

Figure 9 illustrates the historic monthly production and reinjection rate data between April 2009 and June 2013. About 80% of the produced fluid has been reinjected into the reservoir without any cooling and injectivity problems so far.

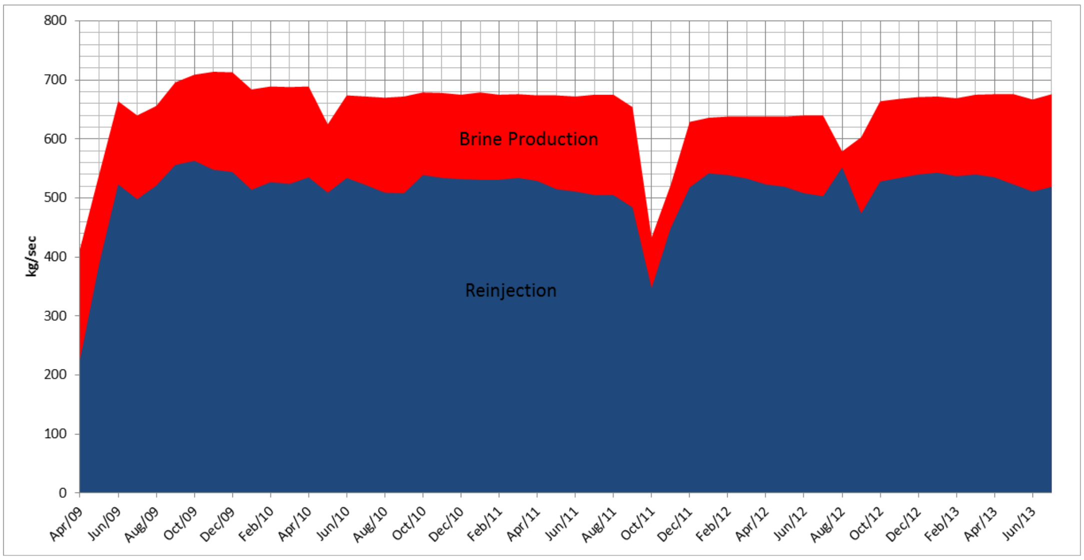

Figure 9: Production and reinjection flow rate history.

3.2 Lumped Parameter Modeling

History matching was applied to data between Febr. 2009 and November 2011 that covers the period in which only the power plant operated by GURIS is on-line and the neighboring power plans did not start to operate yet. Thus it is the period when the reservoir response is affected by the production and reinjection in the GURIS field.

The modeling approach is based on history matching of the pressures in the observation well, OB-7, obtained since 2009. This pressure measurement is critically important for the sustainability of a geothermal reservoir as it represents how much pressure in the reservoir has declined since the start of commercial operation (Satman, 2010).

A lumped parameter model (Sarak et al., 2005) was run with the aim of matching the measured pressure data obtained from observation well OB-7. Pressure in OB-7 is measured at 125 m depth (at an elevation of -54 m above sea level), and the initial pressure drop on 15.02.2009 is assumed to be zero. Mass flow rate represents the net mass flow rate defined as the difference between the production rate and the reinjection rate.

The match to observed pressure drops in OB-7 is shown on Figure 10. Measured data are denoted by the black diamonds, while calculated pressure drops are represented by the solid red line. Reservoir pressure data showed a strong correlation with the increased production, showing initial high pressure drop followed by a transition to a stable pressure drop rate. As seen on Figure 10, the model has been able to match the OB-7 observation pressure very well. The difference between measured and calculated pressure data is very minimal throughout the production history.

Final results of the history matching were considered to be excellent, as very good matches between measured and calculated were achieved. According to the results obtained from the lumped parameter model, a very strong natural recharge exists and the parameters determining reservoir pressure performance are production rate, reinjection rate, and natural recharge. Since it is not possible to change the natural recharge, production and reinjection rates should be controlled for the sustainable exploitation. While the production increases the pressure decline in the reservoir, the reinjection and the natural recharge decrease it. Therefore, if an increase in the production from the reservoir is required, the reinjection should be proportionally increased.

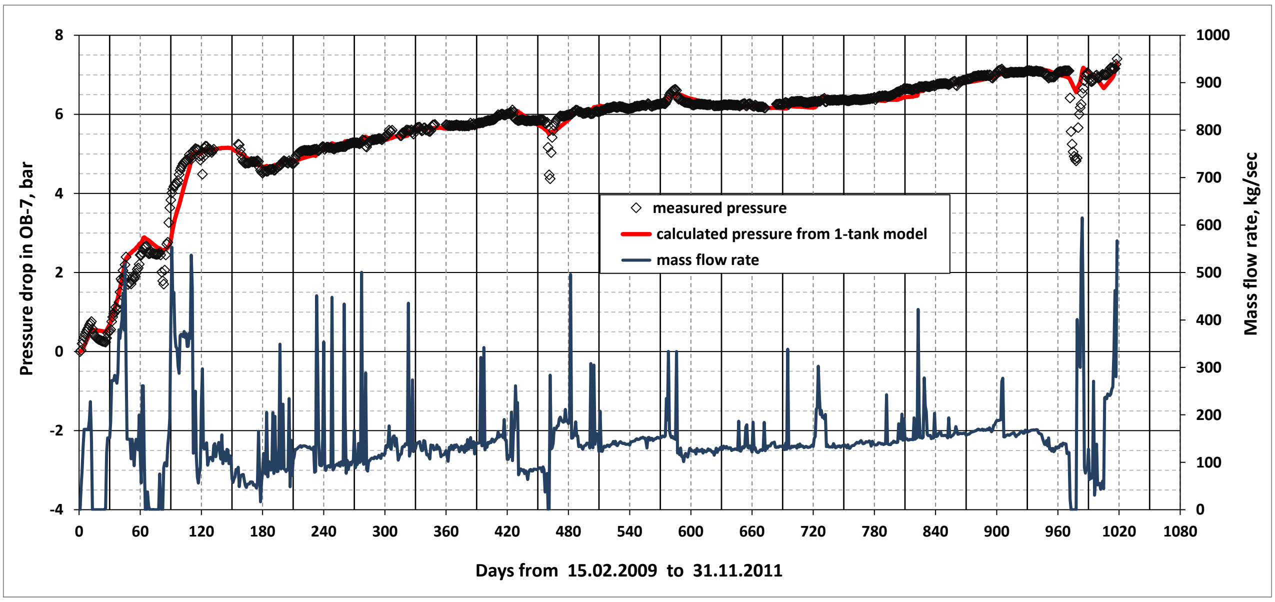

Figure 10: Matching of pressure response at Well OB-7.

Once the proper lumped parameter model simulates pressure data from a geothermal system as demonstrated here, it can be used to predict future pressure changes, which can consequently be used to estimate the production capacity of the given system. After having a quite satisfactory history matching (Figure 10), the model obtained is considered to be ready for modeling the various scenarios of development.

4. CONCLUSIONS

A production and reservoir engineering study was carried out within the context of Germencik project. Systematical investigation and development of a geothermal field from the production and reservoir engineering viewpoint is discussed as a main theme in the project work conducted. Modeling studies whose results are partially presented in this paper were conducted to identify better the geothermal system and the reservoir.

On the basis of this work, we state that:

1. The deeper part of the reservoir should be investigated and possibly targeted for production purposes.
2. The preliminary results have been encouraging as they suggest that the Germencik reservoir extends southward, and the western part of the field is an outflow of the reservoir.
3. The lumped parameter modeling study indicates that the whole hydrological system, encompassing the Germencik geothermal system, is quite large, providing fairly strong natural recharge to the geothermal system.
4. The principal result of the lumped parameter modelling is that brine reinjection is essential if GURIS’s future plans of greatly increased electrical generation are to materialize and it is vital to the sustainable management of the field.
5. Increasing the capacity of the field should be best accomplished by drilling new deep wells, and keeping the reinjection-production ratio as high as possible.

It should be noted that the results from the lumped parameter model were based on the available data up to December of 2011. The lumped parameter model used in this study represents our best understanding of the reservoir given the currently available data. The history matching of the recent data is subject to the ongoing study. The new wells have been tested, and the results from the testing will be incorporated into the modeling study thereafter.

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