PROCEEDINGS, Thirty-Second Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 22-24, 2007
SGP-TR-183

A STUDY ON PRODUCTION AND RESERVOIR PERFORMANCE OF OMER-GECEK/AFYON GEOTHERMAL FIELD

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ABSTRACT

The Omer-Gecek geothermal field is situated about 15 km northwest of Afyon city in the Central Aegean Region of Turkey. It is a liquid dominated reservoir. At Omer-Gecek, there are 30 wells with depths from 56.8 to 902 m. The geothermal water produced with a maximum temperature of 111.6 ^{o}C has been utilized to support a district heating system with a capacity of approximately 4500 residences since 1996. The reservoir water has a dissolved CO_2 content of 0.4% by weight. The maximum discharge rate is close to 236 kg/s.

In this study, the results of temperature profiles, well tests, pumping tests, well logging surveys and chemical analysis to determine the rock and fluid properties and as well as to characterize the Omer-Gecek geothermal reservoir 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 reservoir limits are studied and the volume of water in place and stored heat are estimated by various methods. About 50% of the produced fluid by AFJET, the district heating system company, has been reinjected into the reservoir without any cooling and injectivity problems so far.

Our in-house lumped parameter model was utilized to model the production rate-reservoir pressure history and an almost perfect match was obtained. Results of the proper model obtained from the match were used to estimate the production performance of the field under several production scenarios.

INTRODUCTION

The Afyon area is one of the most extensive geothermal fields in Turkey. One of those fields is called the Omer-Gecek geothermal field. It is located 15 km northwest of the city of Afyon (Figure 1).

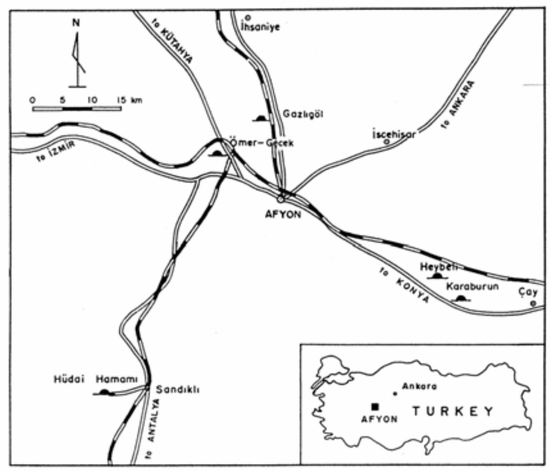


Figure 1: Location map of the Omer-Gecek field.

The basement in the Omer-Gecek field is represented by mica schist and marbles of Paleozoic age. Neogene deposits composed of conglomerate, sandstone, clayey limestone-sandstone, and volcanic glass-trachandesitic tuff uncorformably overlie the Paleozoic basement. The area was affected by the volcanic activity which prevailed between upper Miocene and Pliocene. Quaternary deposits are mostly found in flat plains and stream beds. The travertine deposits, which are currently precipating, are observed dominantly in the western part of the field (Mutlu and Gulec, 2005).

The Omer-Gecek field contains a liquid dominated reservoir. At Omer-Gecek, there are 30 wells. The first well, R-260, was drilled by General Directorate of Mineral Research and Exploration (MTA) in 1971. The field started to feed a district heating system with a capacity of 4 500 residences in 1996 and the district heating system is operated by AFJET, Afyon Geothermal Company.

The depths and the temperatures of the wells drilled by MTA are presented in Table 1. Six wells, namely AF-11, AF-16, AF-18, AF-20, AF-21, and R-260 are being continuously or periodically used for production by AFJET. Two wells, AF-4 and AF-13, have been used for reinjection by AFJET. Three other wells, AF-1, AF-8, and AF-19 have been used as observation wells.

Geothermal field supplies thermal water not only to the AFJET district heating system but also to some thermal sites. Two wells, AF-7 and AF-23, belong to Omer Bath and one other well, AF-14, belongs to Gecek Bath. AF-23 and AF-14 continuously used for production by those baths. Besides those 24 wells listed in Table 1, there are 6 more wells, believed to be producing from the same reservoir, and used by nearby thermal hotels, Orucoglu Thermal and Hayat Thermal. Figure 2 shows the location of wells in the Omer-Gecek geothermal field.

Table 1: The depths and the temperatures of the wells in the Omer-Gecek geothermal field.

Well	Depth (m)	Temperature (°C)
AF-1	902	102.9
AF-2	56.8	-
AF-3	250	97
AF-4	125.7	95
AF-5	207.4	79
AF-6	211.4	92
AF-7	210	93
AF-8	250	91
AF-9	320	50
AF-10	320.4	100.7
AF-11	185	111.1
AF-12	59	88
AF-13	560	82.4
AF-14	122	105.6
AF-15	170.7	111.4
AF-16	218	111.6
AF-17	260.5	105.3
AF-18	363.6	98
AF-19	305.3	95.3
AF-20	230	106.9
AF-21	212	107.8
AF-22	227	104
AF-23	235.8	94
R-260	166	103.4

Among the wells listed in Table 1, the most productive well in the field is AF-21 and its flow rate is about 55-65 kg/s whereas the flow rates for other wells vary between 15 to 50 kg/s. On an average, the field is about 1 030 m above the sea-level.

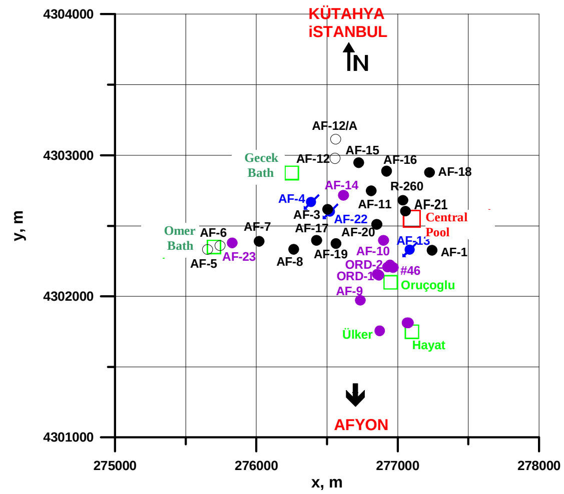


Figure 2: The location of wells in the Balcova-Narlidere geothermal field.

Figure 3 shows a schematic view of the AFJET district heating system. The geothermal field is 15 km away from the city. The water produced is collected at the central pool in the field and then pumped to the AFJET Center in the city thru a pipeline. The cooled water from the heat exchanger system is returned thru a second pipeline and then reinjected.

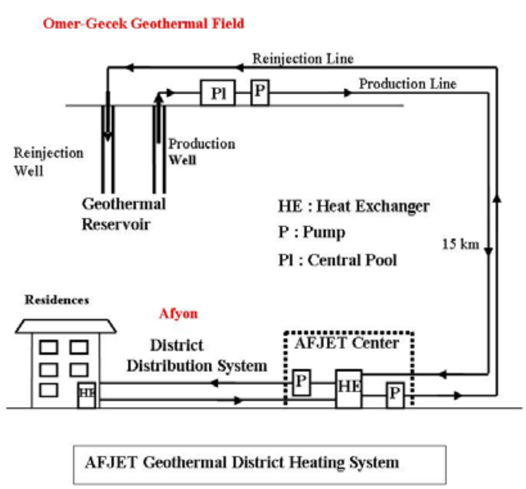


Fig. 3: Schematic view of the AFJET district heating system.

A production/reservoir performance project (Satman et al., 2005), funded by the management of the field, was conducted at the Omer-Gecek geothermal field. This paper discusses the fundamental findings of the project conducted and presents the recent developments in the field.

The AFJET management was interested in increasing the capacity of the district heating system. 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.

RESERVOIR CHARACTERIZATION

Temperature profiles, well tests, well logs, and water analysis were evaluated to determine the reservoir and field properties. Some of them are discussed here. A companion paper (Onur et al., 2006) discussed the analysis of well test in the field and so well test results are not discussed here.

To study the production performance, static and dynamic wellbore tests and as well as multi-rate wellbore flow tests were performed. To prevent the calcite depositon in wells, inhibitor has been injected into the production wells. For this purpose inhibitor pipes were set to about 70 m depth in all wells.

Figure 4 shows the static temperature and pressure profiles of the deepest field, AF-1, drilled in the field. This well is located at the southeastern flank of the reservoir. The temperature profile given in Fig.4 indicates the presence of a relatively cool convective field around 300 m depth, and the deep aquifer has a temperature of 102.9 ^{o}C. The cool convective field was also observed in temperature profiles of some other southern flank wells.

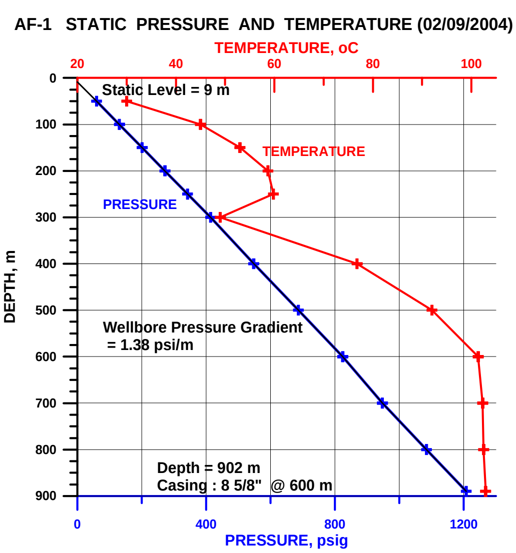


Fig. 4: Static pressure and temperature profiles for the well AF-1.

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 maximum flow rate.

Analysis of the dynamic pressure-temperature profiles indicate that two-phase flow exists in the wells. The flashing point depth varies between 80 to 110 m for wells, and therefore, the inhibitor pipes currently set at 70 m were suggested to be relocated properly.

Figure 5 shows the dynamic pressure and temperature profiles for the well AF-11 (MTA, 2000) and the matching results obtained from the in-house simulator. A good match was obtained for the CO_2 content of 0.4%. Matching indicates the CO_2 flashing point depth at 106.5 m.

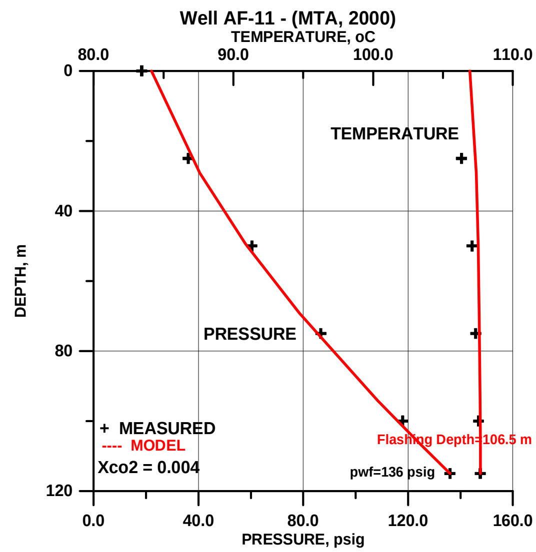


Fig. 5: Dynamic pressure and temperature profiles for the well AF-11 and the matching results obtained from the in-house simulator.

To confirm the results obtained from the match, the CO_2 content of the geothermal water was measured by using a mini-separator at wells AF-11 and AF-18. It was measured to be 0.38 and 0.4%, respectively, which supports the 0.4% value obtained from the match.

Figure 6 shows the dynamic pressure and temperature profiles for the well AF-21 which is the productive well in the field. Interestingly enough, the temperature profile shows a relatively cool water inflow into the wellbore. The temperature of the geothermal fluid is 107.8 ^{o}C at the bottomhole whereas a fairly sharp temperature drop of 2 °C occurs between 150-175 m interval.

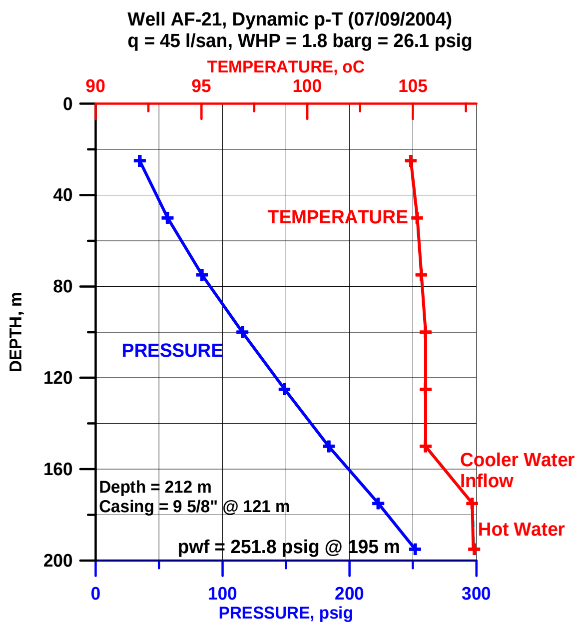


Fig. 6: Dynamic pressure and temperature profiles for the well AF-21.

Multi-rate flow tests were carried out in adequate wells to obtain information and as a result, inflow performance relationship (IPR) curves of those wells were determined. Figure 7 shows the results of multi-rate test conducted in well AF-21. The IPR curve clearly shows the effect of turbulence on flow to wellbore.

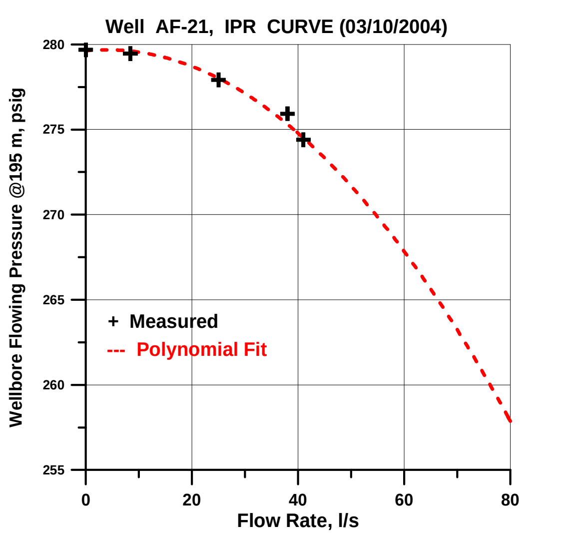
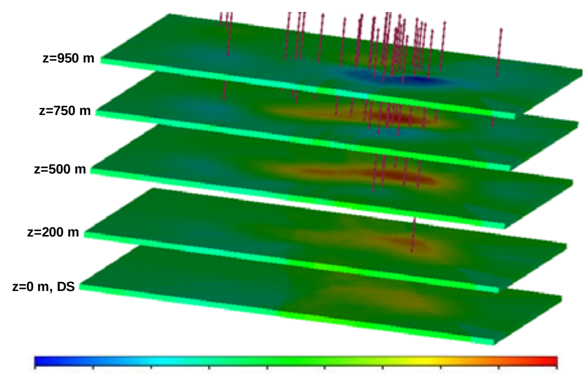


Figure 7: IPR curve for well AF-21, obtained from multi-rate test.

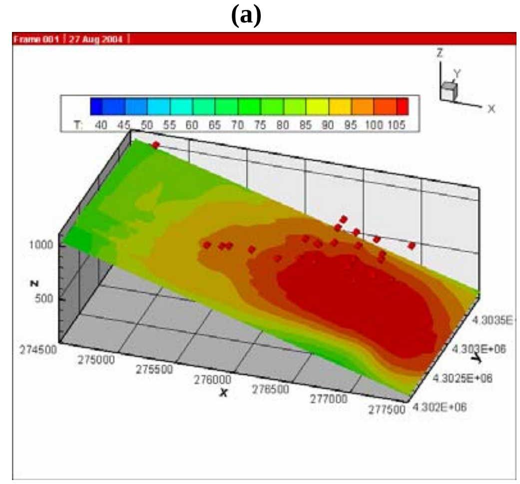
After the evaluation of those tests, productivities and dynamic water levels were determined in addition to static water levels and maximum flow rates of wells. Besides, performances of the wells were compared and an evaluation of the field was made on the basis of individual wells.

Geochemical investigation was carried out after the analysis of water samples taken from wells and natural discharge points. The Omer-Gecek geothermal waters have total dissolved solids varying between 4 000 and 6 000 ppm. Significantly high Cl contents may suggest the circulation of water is deep and water has a long residence time in the reservoir. A study by Mutlu and Gulec (2005) gives a detailed analysis of thermal water of the Omer-Gecek field. They concluded that the water is generally enriched in Na-Cl-HCO_3, and chalcedony, K-Mg, and Na-K-Ca-Mg geothermometers suggest the reservoir temperature around 155 °C.

Static temperature surveys taken in the Omer-Gecek wells were evaluated and a 3D temperature distribution was obtained (Figure 8). All available temperature data including the ones in MTA (2000) were utilized.



(a)



(b)

Figure 8: 3D temperature distributions for Omer-Gecek geothermal field.

Figure 8 shows some results of the 3D temperature distribution study. Figure 8a gives cross sections of the temperature distributions at various vertical depths whereas Fig. 8b shows the temperature field on a downward slice of the reservoir from west to east in a 1000 m depth.

Three interpolation techniques, inverse distance, kriging, and triangulation, were studied (Isaaks and Srivastava, 1989). All techniques yielded similar results qualitatively. Results obtained by the kriging technique are shown in Fig. 8.

Other results obtained from 3D temperature distributions enabled us to reasonably estimate the volume of the Omer-Gecek reservoir. The reservoir volume within a range of 90-112 ^oC in the geothermal system is around 1.2 km^3. For a range of 75-112 ^oC, it is estimated as 3.6 km^3.

As a summary; the OmerGecek geothermal system is a convective hydrothermal type commonly occur in areas of active geological faulting and folding, and areas where the regional heat flow is above normal, as in much of the western Turkey. The simplified conceptual hydrogeological model of the field assumes a resource located along the fault systems in depth. The water infiltrates down in the northern part of the fault zone to a depth where it is sufficiently heated that it can rise along the southern part of the same fault zone. This simple model is believed to represent the basic mechanism for the fault related low-temperature Omer-Gecek geothermal resource. Some of the thermal water flows laterally away from the fault in the unconsolidated alluvium that fills the region to the south.

PRODUCTION-REINJECTION STATE OF THE FIELD

Although the AFJET management operates the field since 1996, the available recorded production data only go back to Oct. 2001. Reinjection started in October 2003.

Considering the last four heating seasons, nearly 75% of the total production is used by AFJET, the district heating system. However, this ratio reduces to only 10% during the non-heating seasons. This is mainly caused by the high demand of the bath and thermal hotels.

The geothermal water produced from the field are being utilized by five users (AFJET, 2 baths, and 2 thermal hotels). However, no water/heat sharing scheme is valid among the users and each user behaves individually. Such operation, of course, yield to undesirable and inadequate (although expected) problems and inefficient use of the reservoir. An integrated reservoir management based on a production sharing agreement between the users is definitely required.

Based on the study of the AFJET data covering the period of the last four years, the following observations are valid:

- The maximum production rate during the heating season is 650 m^3/h (181 kg/s).
- The annual production is about $2.3x10^6$ ton which corresponds to an annual average of 73 kg/s.
- The ratio of water reinjection to production was about 75% and 50% in 2003-04 and 2004-05 heating seasons, respectively.

The production and reinjection data regarding the AFJET wells covering the period of last 4 years were available. To find the total production from the field, all the flow rate data on the water produced by the baths and thermal hotels (although not continuous) were collected and estimated if necessary.

Considering all the wells, it is estimated that:
- The maximum flow rate becomes nearly 850 m^3/h (236 kg/s) of which 650 m^3/h is from the AFJET wells and 200 m^3/h (55 kg/s) from other wells.
- The annual production from the field becomes $3.6x10^6$ ton of which $2.3x10^6$ from the AFJET wells and $1.3x10^6$ ton from other wells. The corresponding annual average rates are 114, 73, and 41 kg/s, respectively.
- AFJET reinjects about 50% of the produced water at an average temperature of 40 ^oC.

The capacity of the Omer-Gecek geothermal field can be calculated using

$$Capacity = wx\Delta Tx0.004184 \qquad (1)$$

where capacity is thermal power in MW_t, w is the flow rate in kg/s, and ΔT is the difference between the inlet temperature (or the average field production temperature) in ^oC and the outlet temperature (the waste water or reinjection temperature) in ^oC. As Eq.1 indicates capacity depends on flow rate. If the maximum flow rate is used in Eq.1 then the maximum utilization capacity of the AFJET system is determined to be 53 MW_t and the capacity of the whole field becomes 71.4 MW_t based on an average inlet temperature of 100 ^oC, the waste water temperature of 20 ^oC, and the reinjection temperature of 40 ^oC. However, if the annual average flow rate is considered then the corresponding annual utilization capacities become 21.4 MW_t and 35 MW_t, respectively. The annual utilization capacity factors are 0.40 for AFJET and 0.49 for the total field.

The water level changes are measured in several wells, some periodically and some intermittently. The water level data of the AF-1 well, is presented in Figure 9. The AF-1 well with 902 m depth is located near the southern flank of the field (see Figure 2 and Table 1) and has been used as an observation well. It has the longest duration of water level recording.

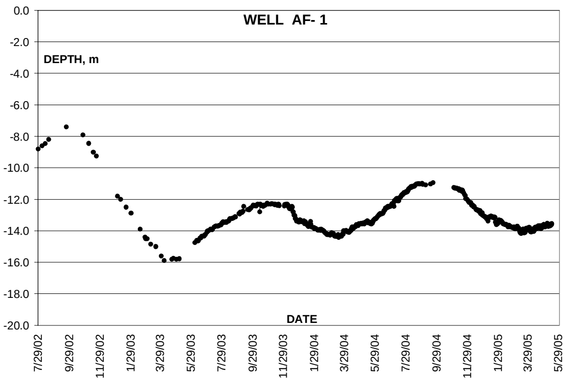


Figure 9: Water level data of AF-1.

The production, reinjection, and net production data for the AFJET wells for a period from 2001 to 2005 are shown in Fig. 10. The net production is defined as the difference between the amount of water produced and reinjected..

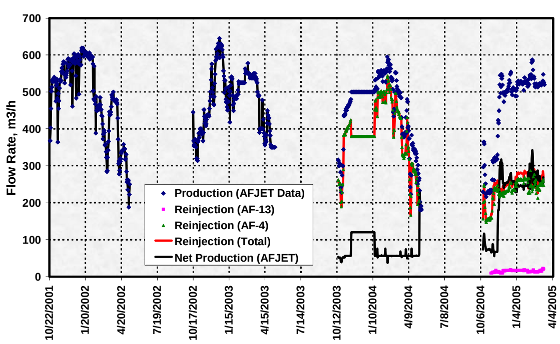


Figure 10: Production history of AFJET wells.

Lumped-Parameter Model Results

The Omer-Gecek geothermal system formed a low-temperature water reservoir and hence it is known that it contains compressed water within a partly confined reservoir. By assuming that the pressure is active in flow and temperature change in flow can be neglected (an isothermal medium), a lumped-parameter model is established and volumetric balance is investigated.

A simple lumped parameter model (Sarak et al., 2005) was applied by using the net production (production-reinjection) data of the whole field and the measured water level values of the observation wells with the measured water level data including the wells AF-1, AF-17, AF-18, AF-19, AF-20, and R-260.

The well AF-1 has the longest period of measured water level data. The lumped parameter model matched the AF-1 behavior satisfactorily. Figure 11 shows the match between the observed and simulated water level in the AF-1 well. The data of the AF-1 well matched model results with the assumption that the static water level behavior of the AF-1 well is thought to represent the geothermal reservoir behavior. The fit between the observed and simulated data is quite good as shown in Fig. 11.

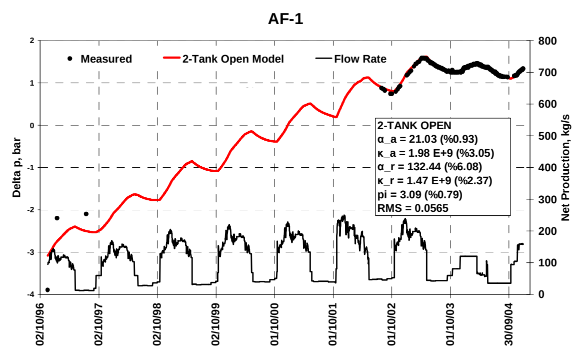


Figure 11: Simulation result of AF-1.

According to the results obtained from the lumped-parameter model, the parameters determining reservoir performance seem to be production, reinjection and natural recharge. Since it is not possible to change the natural recharge, production and reinjection 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.

Water level predictions

The lumped parameter model was then used to estimate the production potential of the Omer-Gecek geothermal reservoir, by calculating water level forecasts for several production scenarios, since the production response of the reservoir is mainly manifested as water level drawdown. Our lumped parameter model simulates the water level decline in the Omer-Gecek reservoir quite accurately as discussed earlier. The details of the prediction study are given in Satman et al. (2005).

Figure 12 shows the water level changes predicted by the model. The following two prediction scenarios are modeled:

Scenario 5.1: AFJET's net production grows 20% each year with respect to 2004-05, and 50% of the AFJET's production is reinjected.

Scenario 5.2: Field is operated by a central authority, AFJET's production grows 20% each year with respect to 2004-05, and 50% of the field production is reinjected.

In both scenarios, the AFJET production grows by 200% at the end of 10 year-projection period. In Scenario 5.1 users operate their wells individually. However, in Scenario 5.2 a central authority is assumed to handle the field operation such that 50% of the field production is reinjected while the AFJET's production still grows at 20% annually.

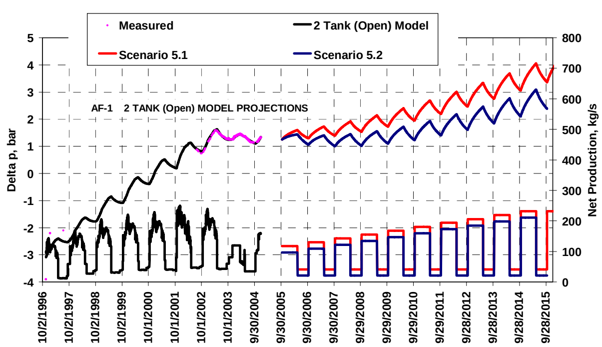


Figure 12: Projections for the Omer-Gecek field.

The projections are valid for next 10 years. The prediction results for the two scenarios are given for comparison purposes in Fig. 12. The prediction result for Scenario 5.2 yields lower pressure drops than Scenario 5.1 gives. Scenario 5.2 results in a further drop of 17 m in liquid level reaching to 31 m whereas Scenario 5.1 results in 27 m drop to 41 m. Thus, operation of the field by an central authority helps to maintain the reservoir pressure at a higher level.

The projection study indicates the importance of reservoir management. Operating a geothermal field as a whole yields more efficient use of thermal energy and increases the sustainability of the field.

To keep the water level low is very crucial for the operation of such a low temperature geothermal field containing even low amount of CO_2 dissolved in geothermal water. Further drops in pressure or water level result in flashing points occurring in greater depths which means that two phase flow occurs at greater depths. In such cases, the wells require continuous gas injection to sustain the production. Of course, sustaining production through pumping is possible. However, since the existing wells are relatively shallow and have small casing radii, installation of pumps is limited and new wells with greater depths have to be drilled. Besides, greater flashing depths become an important constraint in installation of pumps in those shallow wells.

CONCLUSIONS AND RECOMMENDATIONS

A production and reservoir engineering study was carried out within the context of Omer-Gecek 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. The lack of geoscientific information and production-reservoir engineering data during the exploitation stage were identified; and for complementing those, in addition to the geological, geophysical and well testing works the necessary methods were developed to establish data base by monitoring the field. Moreover, modeling studies whose results are partially presented in this paper were conducted to identify better the geothermal system and the reservoir. Finally, strategies were developed for the future developments of the field.

On the basis of this work, we state that:

1. Monitoring is an essential part for better understanding and modeling of production and reservoir performance of the Omer-Gecek geothermal field. This aspect requires significant improvement in Omer-Gecek, particularly in view of foreseeable increase in production during the coming years.
2. The deeper part of the reservoir should be investigated and possibly targeted for production and reinjection purposes.
3. The higher and field wide reinjection into the reservoir should be preferred and is vital to the sustainable management of the field.
4. All of the production and reinjection wells should be controlled and coordinated by a central authority.

In summary: in operation of the Omer-Gecek field, heat recovery rather than thermal water production should be maximized, the reservoir water should be conserved to maintain the reservoir pressure, the hotter wells should be used in production, and finally by emphasizing and increasing the reinjection the net production should be minimized. All of these seem to be required for the sustainable management of the field. Increasing the capacity of the field should be best accomplished by drilling new deep wells, increasing the reinjection ratio as well as controlling and operating the field by a central authority.

ACKNOWLEDGEMENTS

We gratefully acknowledge support of governor Muzaffer Dilek and mayor Abdullah Kaptan of the Afyon city. We also express our gratitude to the manager of AFJET A.Ş. Cahit Serteser and assistant manager Erhan Özşakacı. We also thank to Namık Çağatay, Ö. İnanç Türeyen, Hulya Sarak and Eylem Kaya for their contributions at successful accomplishment of the project. Information provided by MTA is also appreciated.

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