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2015 Reinjection Update of Salavatli Geothermal Field in Turkey

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ABSTRACT

In this study, geoscientific and reservoir engineering information on the last eight years of reinjection operations of Salavatli geothermal field will be provided, and all existing and planned reinjection systems are described. PT information from the monitoring will be presented. Finally, results of these operations will be reported.

Since modular development strategy was opted in Salavatli geothermal field, reinjection operations followed that line and were conducted in four consequent time spans in the peripheral areas of the field. Reinjection operations have been closely monitored by tracer testing, micro-seismic activities monitoring and continuous pressure and temperature surveying in the field. Detecting no adverse effect so far, the longest 100% full reinjection has increased the confidence and viability of it in the country.

1. INTRODUCTION

Salavatli geothermal field is located in one of the most promising geothermal regions, on the northern flank of B. Menderes graben of Menderes Massif (Fig.1). The field was discovered after a regional resistivity survey conducted by MTA Institute of Turkey. Two wells were drilled in 1987 and 1988 to 1500 m and 962 m, with temperatures of 169.5^{o}C and 172.5^{o}C, respectively. The geothermal fluid contains an average of 1% of CO_2 by weight, which is more or less similar to that of other geothermal fields encountered in the Büyük Menderes region. Development efforts reassumed in 2003 by drilling a third well, and installing an air cooled binary power plant with 7.35 MW_e gross power which has been generating electricity since May 2006.

Information so far provided by geophysical studies (two resistivity and CSAMT surveying) and drilling and testing the wells indicated that the volume of the Salavatli-Sultanhisar geothermal field could reach up to 56 km^3, in other words, it might be a giant structure. Menderes Geothermal Inc. owns a license with a 36 km^2 of area in the western and central part of this giant structure. A protection belt was formed by the state between these two license areas (Salavatli-Sultanhisar) to prevent interference between operations of these two areas. Recently, several wells drilled 5-8 km away from the main area to the east in Sultanhisar section, found lower temperatures (decreasing from the west to the easternmost part of about 120°C) with relatively good permeability (up to 5000 D-m), confirming the extension of the field to the east as resistivity survey indicated (Serpen and Aksoy, 2010).

After commissioning of the first power plant in 2006, a total of 25 more wells with temperatures ranging from 160°C to 212°C have been drilled for the production and reinjection, and 3 more power plants have been installed with a total additional capacity of 45 MW_e.

In this study, after a brief introduction of the Salavatli geothermal field all reinjection history and our experience for the last five years will be presented. Planning, execution and the results of operations to improve injectivity of the reinjection well will be reported. Our reinjection strategy for the full development of the Salavatli field together with our recommendations will also be reported.

2. HISTORY OF REINJECTION OPERATIONS IN SALAVATLI GEOTHERMAL FIELD

Since commissioning of Dora I power plant (7.35 MW_e) in 2006, reinjection operations have been successfully conducted to ensure sustainability for the Salavatlı geothermal system and prevent environmental pollution. A second plant, Dora II (11.1 MW_e) was introduced in 2010, and since then wastewater reinjection has been going on. Another plant, Dora IIIa (17 MW_e) was taken into line in August 2013, and its reinjection has also been carrying out. The fourth plant, Dora IIIb (17 MW_e) has just been commissioned in June 2014 and its reinjection operation has already started.

Salavatli is a middle enthalpy field (700-750 kJ/kg), and binary power plants that are installed require large amount of geofluids to be handled in reinjection operations. Therefore, prevention of cooling effect is very critical, and special care must be taken to avoid negative effects of reinjection. Several strategies (line drive, infill, peripheral area, etc.) have already been examined to conduct successful reinjection into this field. Geoscientific and reservoir engineering aspects of the field have been carefully studied and finally suitable areas which have lower pressures and temperatures on the margins of the field were selected for each reinjection operation. By this way reinjected waste waters were distributed around the field and cooling hazard was mostly mitigated.

Actually, some 4000 ton/h of water is handled in the reinjection systems, which is a substantial amount of fluid. Eight and four years of successful 100% reinjection operations have been conducted so far in Dora I and Dora II, respectively, depended upon reliable geoscientific, reservoir engineering evaluations and continuous monitoring of the field. Every important parameter such as bottomhole and/or wellhead pressures, temperatures and gas contents was either periodically, or continuously measured and registered. In order to follow reinjected water routes, tracer tests have been conducted. Furthermore, a seismograph grid was

installed and micro-seismic monitoring was conducted. So far, pressure measurements in monitoring wells have indicated no pressure decline in the reservoir, and measurements from the production wells have not pointed out any cooling effect either.

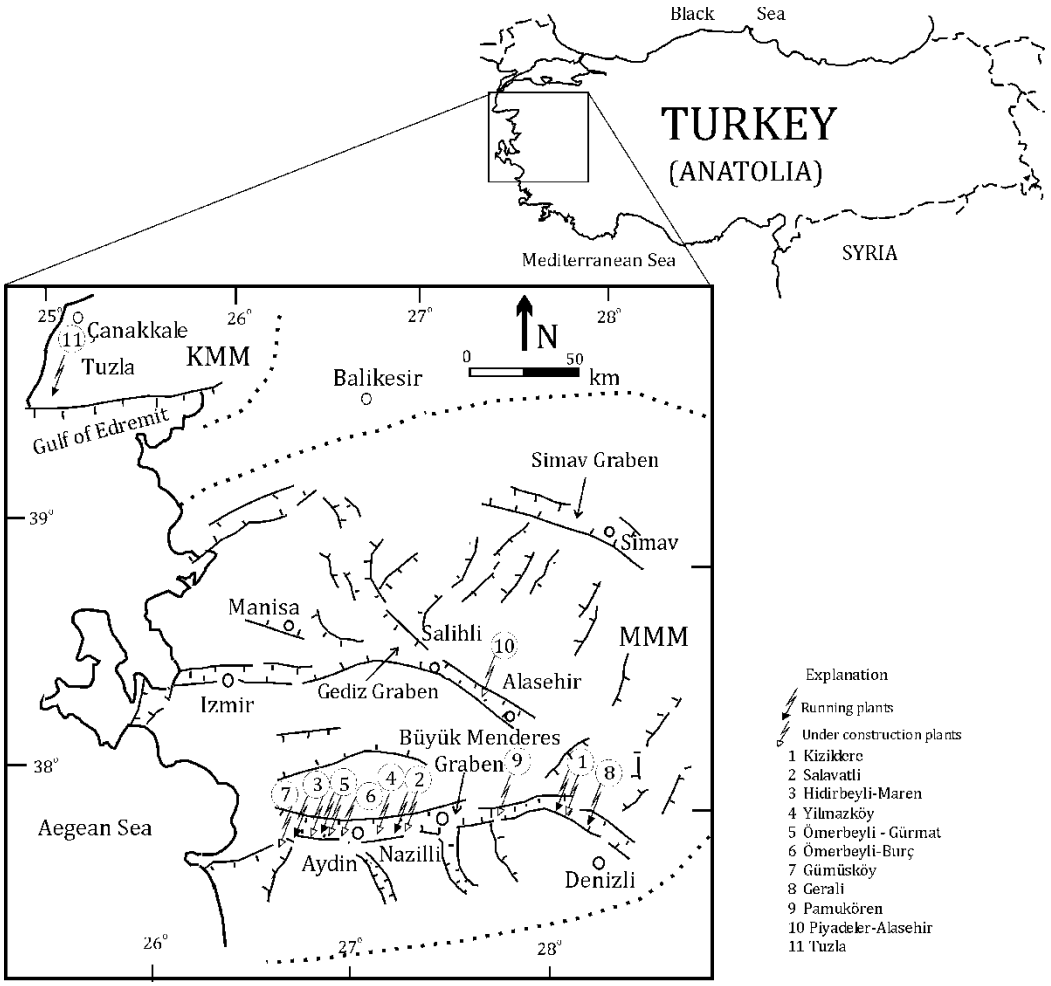

Figure 1. Location of the Salavatli-Sultanhisar field (from Aksoy, 2014).

3. ASSESSMENT OF PAST AND ACTUAL REINJECTION OPERATIONS

Several alternatives for reinjection were considered at the beginning of exploitation stage (Serpen and Aksoy, 2010) and peripheral reinjection was selected. As seen in Figure 2 and Figure 3, reinjection wells were distributed in north, east, south boundaries of resistivity anomaly depending upon the proximity of production wells.

Disposal of water discharged from Dora I geothermal power plant has been reinjected at a rate of 550 t/h since May 2006. This successfully conducted reinjection operation has been carefully monitored by the resource management. During the first 4 year operation period no change in the performance of neither reinjection nor production wells has been observed (Serpen and Aksoy). Under normal circumstances, relatively cold reinjected disposal water is expected to move toward the area of two production wells (see Fig. 3) due to the pressure gradient formed between the production area and the reinjection point. To follow the waste brine movement, estimate disposal water velocity, and model this process, 100 kg of tracer (fluorescein) is pumped into reinjection well (AS-2), and two production wells are utilized as observation ones. During the last six years, after pumping the tracer into the reservoir, no trace element has been detected in the observation wells. No breakthrough of tracer is interpreted as the tracer being lost in a large fracture system. In Salavatli operation, because of the high rate of reinjection a successful tracing test result, with returns of the tracer, has been expected. No result in tracer testing has created a concern, such as a sudden cold water breakthrough. Failure in tracer testing has led the management to micro seismic monitoring for reinjection observation.

On the other hand, at the southern part of the field, another power plant, Dora II, started to operate in 2010. As seen in Figure 2, two producing wells (AS-3 and AS-4) have been connected to the power plant, supplying 830 ton/h geothermal brine to the ORC. After transferring the brine's heat to the ORC of the Dora II plant, waste brine is reinjected into two reinjection wells, namely ASR-4 and ASR-5, at almost equal rates (Fig. 2 and Fig.3). Since ASR-4 well is found at a fallen block its reinjection depth is very deep, at around 1900 m, while pay zones of producing wells (AS-3 and AS-4) are around 1000 to 1200 m depth. On the other hand, the other reinjection well's injection level is around 1050 m. This well is closer to the producing wells and pay zones of these wells are also at the same elevation. Consequently, it was thought that ASR-5 well might have more potential to affect the producing wells. For this reason, tracer testing was conducted between ASR-5 reinjection well and AS-3 and AS-4 producing wells. Hundred kilos of tracer (fluorescing) was pumped into the reinjection well (ASR-5) and the two production wells (AS-3- AS-4) were utilized as

observation ones. During the last four years, after pumping the tracer into the reservoir, no trace element has been detected in the observation wells.

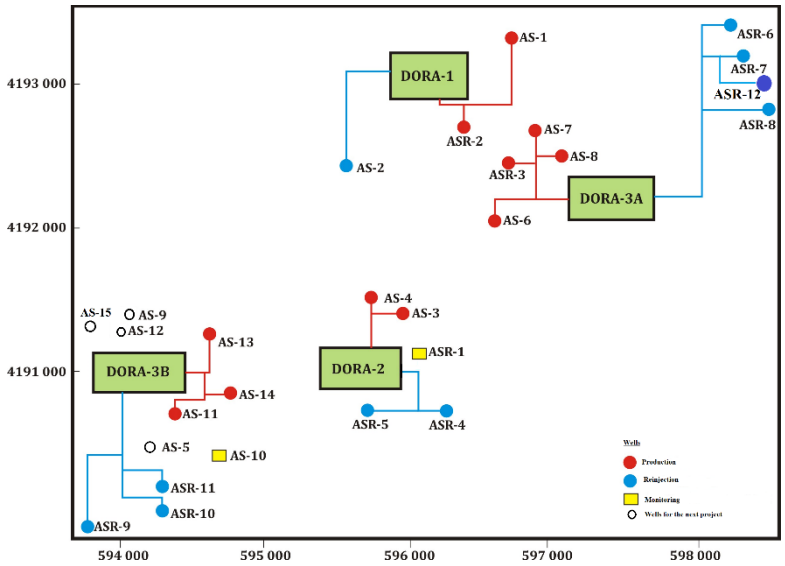

Figure 2. Reinjection and production wells together with power plants in Salavatli field.

Serpen and Aksoy, (2010) suggested seismic monitoring after the tracer test yielded no conclusions. A seismic network with 7 seismographs was immediately installed. At first a cluster of events was observed in the west and north-west of the AS-2 reinjection well. It was concluded that the seismicity was due to contraction cracking associated with cooling and circulating reinjected water. When we plot only the events with good signal to noise ratio, we have found dense clustering in the same region (Fig. 4). In 27th of June 2010 reinjection into AS-2 well stopped and 2 days later restarted. Just after the reinjection period we observed earthquakes close to the well, lasting four days (Gurbuz, et al. 2011).

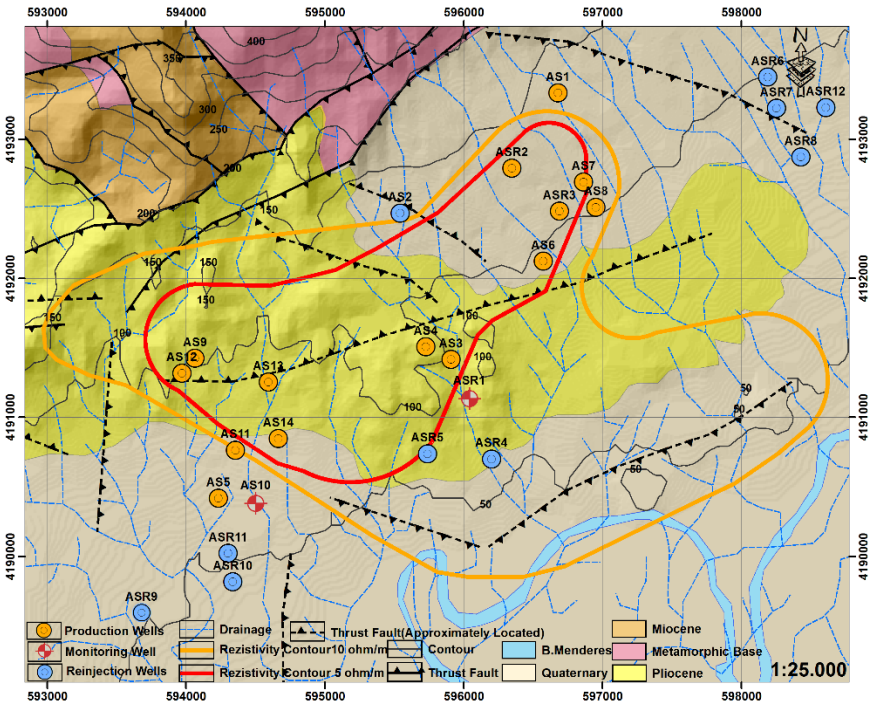

Figure 3. Geological map and location of wells of Salavatli field.

Most of the earthquakes are accumulated at a depth range of 0–2 km. This indicates that the reservoir might be extending to these depths or that dense cold disposal water is going deeper into other sections of the system. The production wells are located in the east of the AS-2 reinjection well, and the injected water does not seem to flow towards the production wells (AS-1 and ASR-2). It may indicate that fractures exist in the western and northwestern part of the AS-2 reinjection well. Previously conducted interference test between AS-1 and AS-2 wells that lasted 45 days did also not indicated any clear connection.

Results of the seismic monitoring of reinjection at the northern part of Salavatli Geothermal Field show some clear trends of the fluid motion. Most visible pattern is the western and northwestern distribution of the micro seismic events (Fig.4). These have occurred especially at depth range of 0-2 km (Gurbuz, et al. 2011).

Monitoring micro seismic activities has continued for the last 4 years. So far, no flow was observed from Dora II reinjection wells (specifically ASR-5) to the production wells (AS-3 and AS-4). No micro seismic activity was observed from the reinjection operations of Dora IIIa power plant that started in August 2013 although 1200 ton/h wastewater is reinjected into ASR-6, ASR-7 and ASR-8 wells in the easternmost margins of the license area.

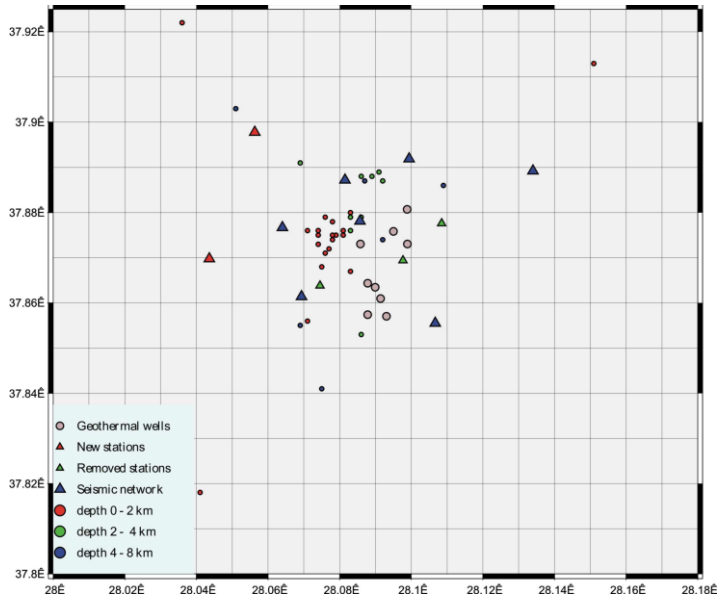

Figure 4. Location of events registered in Salavatli field.

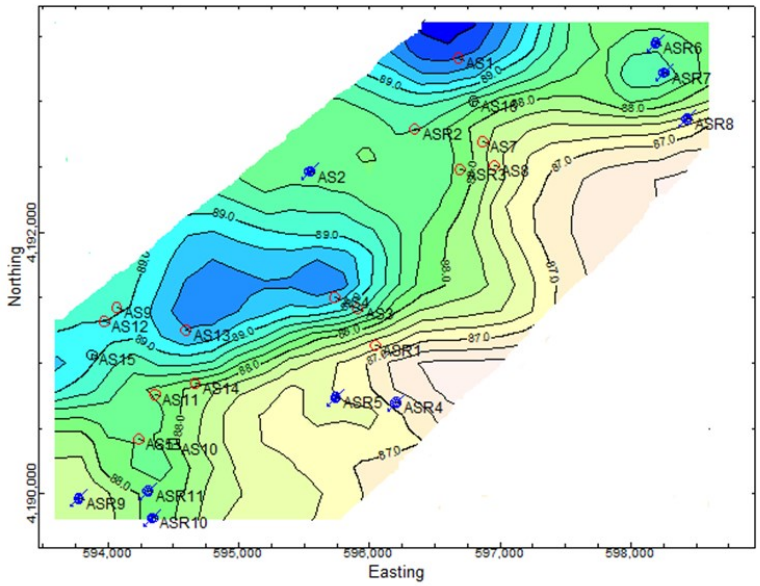

Figure 5. Pressure distribution in Salavatli geothermal field.

Figure 5 shows pressure distribution of Salavatli reservoir at 900 m depth where most of the feed zones have been encountered. Two major upflow zones are located in the north and middle parts of the reservoir. Pressures decline towards east, south and southeastern directions. On the other hand, temperature distributions indicate the same trend confirming upflow and downflow regions of the field. As seen in Figure 5 reinjection wells are located accordingly.

Since reservoir pressures are slightly lower in these zones, wellhead reinjection pressures are around moderate 12-15 bars. And, with time wellhead reinjection pressures have a declining trend. They are reducing 2-3 bars. No increasing reinjection pressures are encountered during the 2006-2014 period. Reinjection temperatures have always been kept around 75-80°C to mitigate silica scaling in the reinjection wells.

Reinjection into Salavatli field started with AS-2 well when there were only two other wells drilled. After drilling several wells and being able to obtain pressure distribution in the reservoir, it seemed that AS-2 well remained in the upflow area of the field. In order to avoid counter pressure in the upflow zone it was decided to move this reinjection well to the eastern part where Dora IIIa reinjection wells are located and for that purpose the ASR-12 well was drilled.

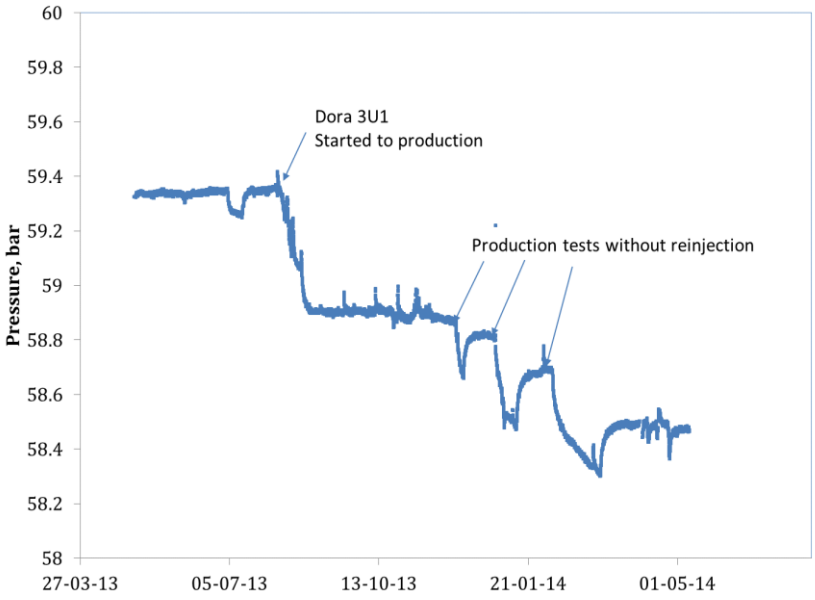

Figure 6. Observed pressure from the monitoring well.

Serpen and Aksoy, (2010) stated that there were no pressure drops within the reservoir as observations in monitoring wells have pointed out. On the other hand, reservoir pressures are very sensitive to the reinjection. In some cases when reinjection is interrupted and wastewater is discharged to the surface, response of the reservoir pressure shows a quick small decline. Otherwise, reservoir pressure is kept constant with reinjection (Fig. 6).

4. CONCLUSIONS

Eight years of progressively increasing production and corresponding 100% reinjection successfully has given enough confidence and enabled geothermal resource management to investigate and study the resource thoroughly using geoscientific, reservoir engineering methods, and continuous monitoring of geothermal field performance.

This approach is the key element of sustainable modular development of Salavatli geothermal field.

In the light of above mentioned, the following elements have been found vital for successful reinjection operations:

- Continuous monitoring of pressures and temperatures.
- Occasional tracer testing.
- Micro-seismic activity monitoring.
- Engineered selection of reinjection areas.

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