Reinjection Management in Balcova Geothermal Field

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ABSTRACT

Balcova geothermal system, which has two concealed outflow zones at 40-100 m (shallow) and 300-700 m (deep), is a defined fracture zone system. The temperature of the production wells is changing between 100 and 140°C. A district heating system has been operating since 1996. A large scale reinjection was applied to shallow zones up to 2001. Tracer and monitoring studies showed that reinjection to shallow zones is not efficient, causing environmental problems and severe cooling at shallow zones of the field. Thus, reinjection strategy has been changed. The main principles of the new reinjection strategy are: (1) reinjection is an integral part of the geothermal reservoir management, (2) full scale reinjection is needed for producing much energy, sustaining geothermal reservoir and environment properly, (3) new reinjection wells must be placed on the margins of the Balcova field, (4) effect of the new management strategy on the field must be monitored. For two years, half of the produced water has been reinjected in well BD8, in the eastern margin of the field. A new well, named BD10, is being drilled in the western margin, with the goal of reaching full scale reinjection target in the field.

1. INTRODUCTION

The Balcova geothermal field is situated in the Izmir bay of the Aegean Coast of Turkey. Exploration of the system started in 1962 and first exploratory well was drilled in 1963, but could not be developed due to scaling problems and relatively low temperatures (124°C) encountered in the first 3 shallow wells. The Balcova field was first exploited in 1980’s for space heating of nearby governmental buildings by using shallow wells with downhole heat exchangers to overcome scaling problems. Recent developments on inhibitors encouraged city authorities to install a district heating system that was started in 1996 and reached to the heating capacity of 72 MWt by the end of 1993.

The exploitation of Balcova geothermal field started with shallow wells in 1996. Later, with increase of power demand by rising number of subscribers, heat energy requirements rose and deeper wells were drilled to discover higher temperatures (130-140°C). Until 2002, mainly shallow (%86) and partially deep (%14) reinjection was carried out. Recent modeling studies have indicated that shallow reinjection resulted in inefficient heat mining (Aksoy, 2001; Satman et al., 2002) through fractures between shallow wells. Some amount of reinjection reached to the surface due to the wrong completion of the wells, contaminating nearby agricultural fields. On the other hand, greater amount of geothermal fluids with lower temperatures had to be pumped to meet the heating requirements, and bigger amount of the disposal fluids had to be reinjected, increasing both costs and the number of reinjection wells. Moreover, since there used to be a natural flow of geothermal fluids through the shallow zone, shallow reinjection threatened northern agricultural fields due to high boron content. Consequently, shallow reinjection had to be stopped, and deep reinjection was started in 2002.

In this study, the results of tracer tests are evaluated, and the direction, velocity and the amount of reinjected fluids are estimated. The necessary distances between injection and production wells are estimated through modeling studies. The cooling time in the existing shallow and deep wells are also estimated. Total production and reinjection rates for the last 5 years are reported with increasing trend. The result of change of water levels vs. the production-reinjection differential with time in shallow and deep reservoirs is also presented. In 2003, the newly obtained data indicated that deep reinjection maintained both the pressures and temperatures in especially nearby deep wells.

2. HYDROGEOLOGY OF THE BALCOVA GEOTHERMAL SYSTEM

The Balcova geothermal area is situated in the extensively exposed Izmir Flysch unit of Upper Cretaceous age. The field is located at the northern margin of the Seferihisar Horst where the flysch outcrops. While to the south of the field talus breccias cover the northern flank of the Seferihisar Horst, young and recent sediments infill Izmir bay (Fig. 1) further north (Ongur, 2001). The Stratigraphic sequence of the area, in general, consists of Upper Cretaceous Izmir Flysch, Miocene sediments, Pliocene volcanics, Quaternary talus breccias and alluvium. The regionally predominant formation, Izmir Flysch, is composed of different rocks, such as sandstone, clayey schist, phylite, limestone, limestone olistoliths, granodiorite, serpentinite and diabase. Balcova area wells intersect mainly lightly metamorphosed sandstones, clays and siltstones of the Izmir Flysch sequence (Ongur, 2001 and Serpen, 2004).
Serpen (2004) defines the Balcova geothermal system as fracture zone system, which is situated in the active Izmir Fault where higher than normal heat flow (110 mW/m²) is encountered. The Balcova geothermal system can be easily driven with this high heat flow. On the other hand in the Balcova geothermal system, higher piezometric levels beneath the mountainous terrain to the south of the fracture zone (the Agamemnon Fault) are also likely to create terrain induced by forced convection. In fact, isotopic studies indicated that geothermal system is fed by high terrains about 500 m (Aksoy and Filiz, 2001; Yilmazer, 1989). With prevailing temperatures of 140°C at relatively shallow depths within the fracture zone reservoir and high temperatures estimated by geothermometers, the Balcova geothermal system is defined as “the fracture zone systems with high temperatures at sweep base” (Serpen, 2004). The two concealed outflows at 40-100 m and 300-700 m, and the steeply dipping fracture zone constitute the presently exploited reservoir, which extends up to 1.5 km away from the feeding fracture zone (Serpen, 2004). The hydrogeological model of Balcova by Aksoy, (2001) geothermal system is illustrated in Fig. 2.
3. TRACER TESTING

Since there is no steam production in the process of district heating system, it was not possible to use conservative species such as chloride for monitoring the reinjection, and therefore, tracer testing was utilized to monitor reinjected fluids. The disposal fluids were reinjected to both the shallow and relatively deep outflowing zones of the Balcova geothermal system. The tracer testing was conducted through B9 (shallow) and BD2 (deep) wells and the observation from the deep and shallow production wells took 1 to 4 months. Uranin was used as tracer element during the testing. Concentrations were measured up to 0.02 ppb by fluorometer. Fig. 3 shows the reinjection and production wells through which tracer testing was implemented. A computer code, TRINV (Arason et al., 1993) was used to simulate tracer return curves. High tracer return velocities were observed at the shallow wells. Qualitative interpretation of the resulting tracer profiles (concentration vs. time) pointed out a fractured medium (Fig. 4).
In the year 2000, the shallow reinjection of the Balcova geothermal field was carried out through B2, B9, B12 and N1 wells of which B9 absorbed 58% of the disposal fluid. The reinjection into B2 and B12 was stopped after sometime because of pollution claims from owners of nearby agriculture fields; apparently, disposal water surfaced in their fields. On the other hand, the well B9 is only 42 m deep and its location is unlikely to disturb the agricultural fields, and therefore, it was chosen for tracer testing in the shallow zone reinjection together with observation wells B4, B10 and B11. Tracer testing for deep zone reinjection was carried out between BD2 and the other deep wells. While tracer was detected in wells BD3, BD4 and BD6, no tracer was measured in wells BD7 and BTF3.
As seen from the Fig. 3, the reinjected fluids are dispersed into the shallow zone with velocities ranging from 2 m/h to 12.7 m/h and they reach shallow production wells that are 80 to 200 m far away within 20 and 60 h, respectively. As for the reinjection into deep zone (BD2), the disposal fluids move with velocities ranging between 0.6 and 3.3 m/h toward the deep production wells. The fluid velocities toward the wells BD4 and BD6, which are situated in the central production area, are higher than the velocity toward the well BD3. Table 1. summarizes reinjected fluids velocities in shallow and deep outflows.

### Table 1. Reinjected fluid velocities.

<table>
<thead>
<tr>
<th>Reinjection wells</th>
<th>Monitoring wells</th>
<th>Distance to reinjection well (m)</th>
<th>Velocity, u (m/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B4</td>
<td></td>
<td>114</td>
<td>2.6</td>
</tr>
<tr>
<td>B10</td>
<td></td>
<td>85</td>
<td>4.2</td>
</tr>
<tr>
<td>B11</td>
<td></td>
<td>160</td>
<td>7.6</td>
</tr>
<tr>
<td>BTF3</td>
<td></td>
<td>268</td>
<td>12.7</td>
</tr>
<tr>
<td>BD2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BD3</td>
<td></td>
<td>229</td>
<td>0.9</td>
</tr>
<tr>
<td>BD4</td>
<td></td>
<td>414</td>
<td>1.8</td>
</tr>
<tr>
<td>BD6</td>
<td></td>
<td>216</td>
<td>0.6</td>
</tr>
</tbody>
</table>

4. COOLING OF CONCEALED OUTFLOWING ZONES OF FRACTURE ZONE SYSTEM

Daily recorded wellhead temperatures were used to monitor the effect of reinjection on production wells. A total amount of 2.0 E6 m³ water was produced and 1.1 E6 m³ were reinjected during one year observation period (2000), and 58% of disposal fluid was pumped into the well B9, in other words, mostly into the shallow zone. As seen from Fig. 5, the reinjection of disposal water into the shallow zone caused 6-7°C of temperature drop. The cooling observed in shallow production wells B4, B10 and B11 was caused by the reinjection into the well B9. Tracer material injected into the B9 broke through those production wells within 20-60 hours during the tracer testing. Fig. 6 illustrates that the cooling effect in B4 was initiated after 12 days of reinjection into B9. Similar cold front reaches B10 after 15 days. As can be observed from the Fig. 5, the temperature decline stabilizes with diminishing reinjection amount at the end of heating season, and then, begins rising again. Temperatures in B4 and B10 oscillated between 18 and 19°C during one year period, but at the end of the year a permanent temperature drop of 6-7°C rested in the shallow production wells. Permanent cooling in the well BTF3 was greater, around 15°C. Fig 6 illustrates the cooling observed in shallow wells B4, B10 and B11.

![Figure 5: Changing temperatures of shallow production wells vs reinjection rate to B9 (Aksoy, 2001).](image-url)
Fig. 6: Observing cooling effect on the shallow wells.

Fig. 7 shows the effect of the reinjection into the deep concealed outflowing zone on temperatures. The wells BD2 and partially BD5 were used for reinjection in the year 2000. As seen in Fig. 7, during the year 2000, a temperature drop of 3-4°C was observed in deep wells, which persisted also in the next year, although, no substantial amount of disposal fluid was reinjected into deep zone in 2000 and 2001. The small amount of cooling (3-4°C) observed above is attributed to shallow water recharge from the southern intake area, not to the reinjection of small amount of disposal water. The increase of Mg content which is high in surface waters and the decrease of SiO₂ content that is low in surface waters pointed out shallow water mixing (Serpen, 2004). In fact, the silica and chloride mixing models also confirmed shallow water mixing (Aksoy, 2001 and Serpen, 2004). On the other hand, the reinjection with a rate of 30-60 t/h into well BD2 during 2000 and 2001 did not seem to influence even the closest well BD3 and the reinjection into the well BD3 with a rate ranging from 150 t/h to 250 t/h between Oct/2001 and May/2002 did not affect the nearest well BD2 either.
5. MODELLING STUDIES

The model developed by Bödvarsson, (1972) for the flow through fractures was first used. In these studies, first the temperature change vs. time by a constant rate of reinjection at different distances in shallow and deep zones were investigated, and then the temperature change vs. time at a distance of 200 m with different injection rates in shallow and deep zones were studied. The results are illustrated in Fig. 8 and Fig. 9.

Since the reinjection related cooling was only observed in the shallow zone and necessary data was collected; modeling studies were directed to that zone. The natural hot water influx together with disposal fluid was taken into account at that stage of modeling. The model data matched to the field data. Cooling effects of the reinjected fluid from the well B9 were estimated in wells B4, B10 and B11. The results are shown in Fig. 10. On the other hand, from modeling study, the wells B4, B10 and B11 are estimated to produce 8%, 25% and 2.5% of reinjected fluid from B9, respectively.

Figure 8: Calculated temperatures for the different distances at 30 kg/s reinjection rate.
The reinjection from well B9 surely cools down the shallow zone. When the temperature of the produced fluid decreases to 62°C (which is also the temperature of reinjected fluid), it becomes impossible to produce energy from this shallow zone. Since no breakthrough was observed, no matching was attempted for the deep concealed zone.

### 6. INJECTION TESTING

Injection testing was conducted in BD2, BD5, BD8 and BD9. Since the reinjected fluids were surfaced behind the 9-5/8" production casing during injection tests, BD2 well was discarded as reinjection well. Two reinjection tests have been conducted in BD5 with an interval of 2 years and their injectivity indexes were calculated: 0.0097 (kg/s)/kPa and 0.0051 (kg/s)/kPa, respectively. The drop in the injectivity had been already observed during reinjection operations between 2000 and 2001. BD5 was abandoned as reinjection well due to its poor injection performance. On the other hand, injectivity indexes of BD8 and BD9 wells were calculated: 0.19 (kg/s)/kPa and 3.23 (kg/s)/kPa, respectively. The injectivity of the well BD8 is 17 times higher than the one of BD9. Fig. 11 shows the comparison of injection performances of BD5, BD8 and BD9. The transmissivities of BD8 and BD9 were estimated from the injection tests. While it was not possible to calculate the transmissivity of BD8 due to its rapid pressure recovery and low sensitivity of pressure gauge, the transmissivity of BD9 was calculated by conventional well test analysis of fall-off data as 23 D-m.
7. REINJECTION MANAGEMENT

Rapid decline of produced fluid temperatures in the shallow zone was due to disposal fluid injection. The results of modeling studies and increased pumping cost have led the management to quit the reinjection in that zone in 2001 (Fig. 5). It was an inefficient heat mining that was supplying heat to the district heating system with increasing amount of fluid. The increasing amount of the fluid produced at lower temperatures from the shallow zone had to be reinjected in the shallow zone or elsewhere creating a vicious cycle. Although no reinjection in the shallow zone was carried out during last 2 years, the area had been cooled down so intensely that a recent small scale reinjection attempt (30 t/h) into B9 prevented boiling within the well causing cooling immediately in the nearby production wells. In the previous years average reinjection rate of 300 t/h had been used for this well.

On the other hand, all shallow wells were designed for the downhole heat exchangers, and therefore, the alluvial section of the well near surface is completely open. As a result, the reinjected fluid flows through the alluvium to the north Inciralti lowland, which is due to favorable local hydrological conditions (Yilmazer, 1989 and Serpen, 2004). As seen from the hydrological model (Fig. 2) rising geothermal fluids through the fracture zone flow into the alluvium, in the natural state of Balcova geothermal system. The effects of this natural lateral flow were observed in Inciralti plain with high boron content (1-3 ppm) in the water of irrigation wells (Yilmazer, 1989 and Serpen, 2004). Reinjection into the shallow zone would create an extra pressure gradient and increase flow of geothermal fluids through the alluvium, which in turn increase boron levels in the plain.

As for the effects of deep zone reinjection, the strategy followed was to choose peripheral wells. First, deep zone reinjection was carried out through well BD2 in the past six month and no cooling effect was observed in nearby wells. It was an exception because the well is situated close to the outflowing zone without a cap rock (Serpen, 2004). Small scale reinjection was conducted into BD5, which is far away to the north and drilled into a still deeper zone, but it was quickly quit due to its low injectivity, and now it is being used as production well. Then, for a year, BD3 was used as reinjection well, which could be considered also a peripheral well at that time, and no cooling was observed in other wells. Finally, the reinjection has been conducted through only BD8 well, which is also a peripheral well. Though no cooling front breakthrough has been observed, the temperature decline in some deep wells was sort of controlled; and no further decline of temperatures was observed in last two heating seasons. As can be seen on Fig.7, dropped temperatures in previous years were recovering to their original values. Fig. 12 shows water level and production-reinjection difference change with time. Reinjection into deep zone started in July 2002, and the seasonal pressure drop in the next heating season was noticeably lower although liquid extraction was more or less the same. On the other hand, a steep seasonal decline in water level is due to high liquid extraction from the deep zone in the last season and local reservoir characteristics.

Figure 11: Injection performances of BD5, BD8 and BD9 wells.
Figure 12: Water level changes in well ND1

Recently, a secondary district heating system was introduced in the western site of the field, namely Narlidere. Therefore, some of the produced fluids were directed to that station for heat exchanging and heat distribution in that area. Since the location of reinjection well BD8 is situated in the eastern part of the field, which is 1.5 km away and at a higher elevation, pumping costs of the disposal fluid are considerably high. On the other hand, only approximately 50% of the produced fluid are being recently reinjected. Therefore, new reinjection sites were proposed. BD9 had been already drilled at the easternmost of the field in 2003, but it was not brought into reinjection line yet. Even if it is connected, fluid transportation costs would be prohibitive. Consequently, two reinjection well locations were proposed in the opposite direction; one just in the south of Agamemnon Fault and Balcova Hot Springs, another in west of well B9, which is being drilled.

For the time being, the management considers to utilize well BD9 as a production well to supply heat for the extension of Balcova district heating system to the east. In that case, another reinjection well will be necessary in the easternmost of the field in order to reinject the disposal water from the well BD9.

8. DISCUSSION AND CONCLUSIONS

The reinjection into the shallow zone was wrong from production engineering point of view. The more power is produced with lower amount of disposal water from the hotter and deeper zone which meets the heating requirements; and in turn decreases the amount of disposal fluids to reinject. On the other hand, it was also wrong from the environmental point of view, since that threatened Inciralti lowlands with boron pollution.

The decision to inject the disposal fluids into the deeper zone was the correct one. It enabled rising of disposal fluids to be heated in a hotter medium. Moreover, the strategy of reinjection through peripheral wells is logical and has not created any problem so far. Furthermore, the reinjection well, BD8 is situated more than 500 m from the main production area. The well BD9 drilled to explore further east of the field (approx. 175 m away from the BD8) can also be used for reinjection. Another well has also been planned further east to test the field limits, and there is substantial possibility that the planned well could also strike permeable and hot horizons since BD9 has good permeability and high temperature (135°C) for this field.

In the end, this area covering the planned well BD9 and BD8 could be used for reinjection site, and the deep concealed outflowing zone could be utilized for production site. This approach is logical in the sense that this area is also on the main feeding zone of the field. The fluids rising through the fracture zone, namely Agamemnon Fault, are feeding the field mostly from this southeastern zone (Serpen, 2004). Another approach is to use above mentioned main feeding zone as production site and to reinject the disposal fluids into the deep concealed fracture zone (actual production site). Both approaches have negative and positive aspects. The indicated main feeding zone is completely inhabited. The wells BD8, BD9 were drilled in unoccupied lands and there are no more such lands to be used for location site. This would prevent the development of the indicated area as production site. Even though this problem can be overcome by drilling directional wells, possible subsidence in the future, due to reservoir pressure and temperature drop, might create serious social problems. On the other hand, the actual production site could not be extended much more since it has almost reached its natural limits. Even if some more production could be extracted from the actual outflowing region, massive reinjection of disposal fluids to the inhabited area would induce seismic tremors creating a social problem. Reservoir simulation studies on each approach are needed to determine the best one.

The proposed reinjection well location in the south of the Agamemnon fault is important since fracture zones might have lateral concealed flows in both sides, as stated by Hochstein, (1989). Only northern part of fracture zone system in Balcova was developed because actual manifestations of the system were clearly observed in the lower part of the system where hydraulic conditions are
favorable. On the other hand, hydrothermal alterations at other fracture zones were also discovered by Ongur (2001) in the south of the Agamemnon Fault favoring the presence of hot zones in that part of the fracture zone.

In the light of the above mentioned, the following conclusions are reached:

- Inefficient and costly reinjection that threatened the lowlands with potential boron contamination was quit.
- So far, deep reinjection in area far from the production area helped the temperature recovery in deep wells in a paradoxical way. Some pressure recovery was also observed in 2003.
- In the extension of existing district heating system, besides reservoir engineering studies, environmental (subsidence, tremors) problems should also be taken into account.

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