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Flow Testing of Balçova Geothermal Field - Turkey

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ABSTRACT

Balçova geothermal field is located in a densely populated area which makes direct heat applications very efficient and economical. Heat produced from Balçova geothermal field is utilized for three main purposes: greenhouse heating, balneology and residential heating. Among these three applications, the latter one is the main application throughout the Balçova District Heating System. The field produces hot water from two different horizons: one shallow and one deeper zone. After had utilized for 16 years, few wellbores in the deeper zone had to be abandoned because of operational difficulties, and new wellbores were drilled in the same zone. Interference tests were carried out during flow testing at newly drilled wellbores. Analysis of pressure response at observation wellbores for production/injection practices indicated that there exists a very strong connection within the wellbores in the same zone. In addition, there exists also a hydraulic but weaker connection between shallower and deeper zones. Response of the field and the operational changes in production/injection applications are also presented.

1. INTRODUCTION

Balçova geothermal field is situated 11 km southwest of city of İzmir in western Anatolia (38.2º latitude, 27.0º longitude) (Figure 1). It is located along the E–W trending Izmir Fault Zone. The most important tectonic feature in the region is the E–W oriented Agamemnon-I Fault, which extends over 30 km. (Yılmazer, 1989; Öngür, 2001). Other than this main fault, series of E–W and S–N oriented faults and fractures can be observed in the region but the NE–SW oriented Agamennon-II Fault is the most pronounced one (Figure 2). The hot waters recharging in the Balçova region circulate through the major, about 2 km long, fracture zone associated with the Agamemnon-I Fault. Faults and fractures within the Izmir Flysch formation provide a hydrothermal system to Balçova region. The meteoric precipitations in recharge area infiltrate through faults, fractures into deeper parts of the region (deeper than 2000 m), are heated by an undefined heat source, and rise along the Agamemnon Fault (Figure 3). From this zone, the thermal water flows mainly into two permeable horizons: one in the alluvium located in the upper 100 m of the system, and the other more permeable layers of the Izmir Flysch formation between 300 and 1100 m depth (Satman *et al.*, 2001).

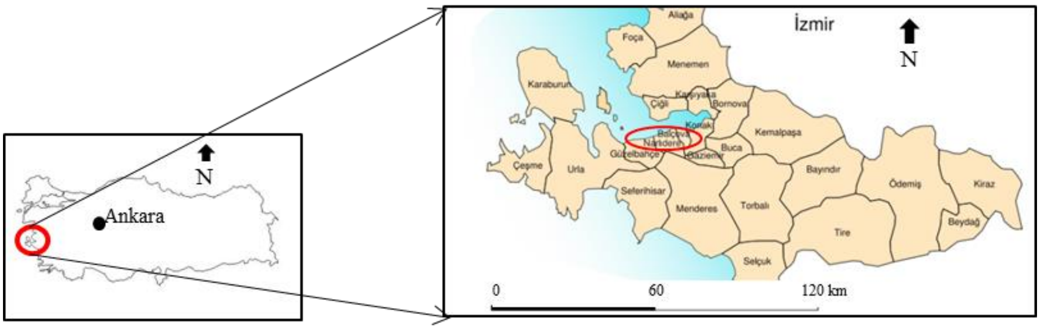

Figure 1: Location map of Balçova Geothermal Field.

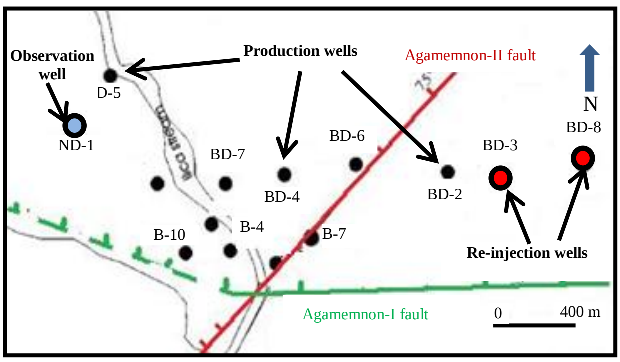

Figure 2: Location map of Agamemnon–I and Agamemnon–II faults (after Yılmazer, 1989).

There are more than 40 wells drilled in Balçova geothermal field. Some of those wells are gradient wells aiming to get information on geology as well as geothermal gradient of the region and indicated by G. The wells indicated by B or BG are shallow wells while the wells with BD are deep wells (Figure 4). The depths of shallow wells are in the range of 50–150 m while the deep wells have an average depth of 700 m. These twelve wellbores are utilized as production wells and two of them (BD-3 and BD-8) are continuously used for re-injection purposes (Table 1).The wells shaded with yellow in Table 1 (BD-10 and BD-15) are mainly used for re-injection but they were also used as producers, especially during summer time to supply the demand from swimming pools and balneology. On the other hand, gray shaded wells in Table 1 are seldom used as re-injectors during peak times. As indicated in Table 1, the maximum capacity of the production wells is over 2000 m^3/h, which was not tested yet. The producing temperatures of the wells are in the range of 97 to 140°C.

2. UTILIZATION OF THE FIELD

Balçova geothermal field is located in a densely populated area (Figure 5) which makes direct heat applications very efficient and economical. Produced heat from Balçova geothermal field is utilized for three main purposes: greenhouse heating, balneology and residential heating. Among these three applications, the latter one is the main application throughout the Balçova District Heating System (BDHS) (Figure 6). There are three main flow loops within BDHS system:

- *Geothermal water loop* in which produced geothermal fluid at an average temperature of 120 °C is sent to Heating Centers to exchange the heat energy of it to the closed loop of city water with the help of heat exchangers. Geothermal fluid after heating centers is re-injected into ground at an average temperature of 60°C.
- *City water loop:* In this loop, the city water is circulated in a distribution network between the heating centers and residences. The city water is heated to a temperature of 90°C at the Heating Centers and headed to residences in which each residence has its own heat exchanger to heat its radiator water.
- *Residences loop:* This is the loop within a single residence through which the heat energy of city water is transferred to the radiator system.

There are eight heating centers within the system to cover the residential area of Balçova - Narlıdere districts. Each heating center serves the residences to their close vicinity. Heating Centers do not serve with their full installed capacities since some of the residences do not subscribe for the BDHS. In average 80% of the installed capacity is used by subscribers (Figure 7). As seen in Figure 7, both installed capacity as well as subscription increases with time and a project is underway for an estimated subscription of 35000 RE (Residence equivalent (RE), 1 RE = 100 m^2 heated area). In addition to heating centers, BDHS has two pumping stations and more than 350 km pipeline network. Individual houses, governmental institutes and private firms such as Dokuz Eylül University Hospital, University Dormitories, Izmir Economy University Campus, one shopping center and hotel are the subscribers of BDHS. In addition to BDHS, Balçova geothermal field supplies geothermal water to two health centers-hotel for balneological purposes, namely Balçova Thermal Hotel and Kaya Hotel.

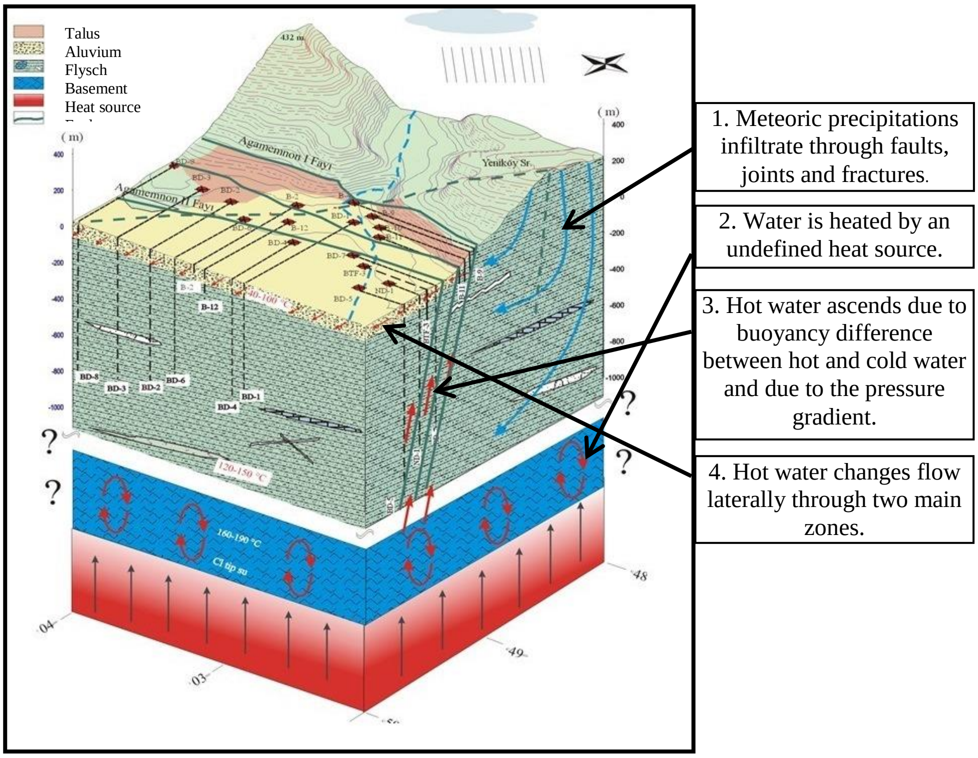

Figure 3: Hydrogeological model of Balçova geothermal field (modified after Aksoy, 2001).

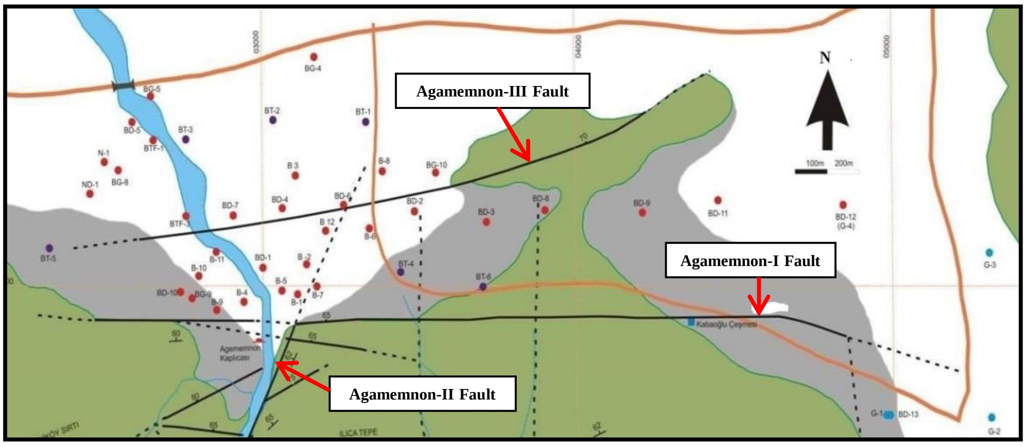

Figure 4: Well locations of Balçova geothermal field.

Table 1: List of active wells.

No	Production well	Maximum rate (m^3/h)	Injection well	Average reinjection rate (m^3/h)
1	B-5	117	BD-3	180
2	B-7	41	BD-8	800
3	B-10	220	BD-10	93
4	BD-2	130	BD-15	134
5	BD-4	209	BD-1	11
6	BD-5	55	B-4	70
7	BD-6	199	B-1	160
8	BD-7	69	B-7	12
9	BD-9	360	BH-1	10
10	BD-11	225	BTF-2	7
11	BD-12	256		
12	BD-14	125		
TOTAL RATE (m^3/h)		2006		1478

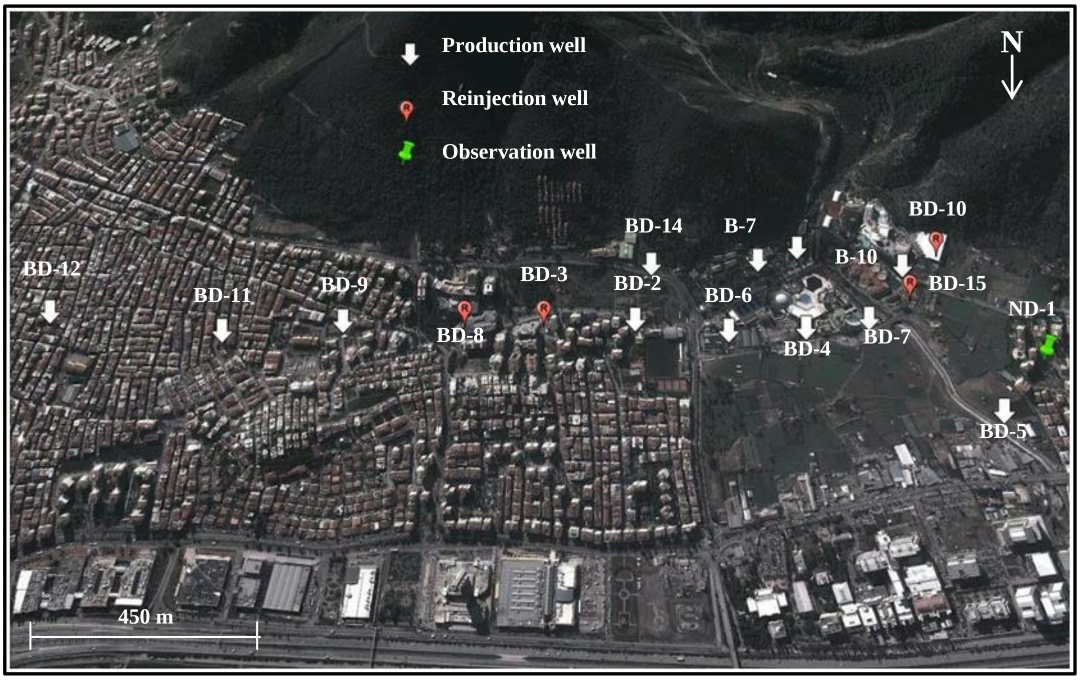

Figure 5: Residential view of Balçova District with well locations.

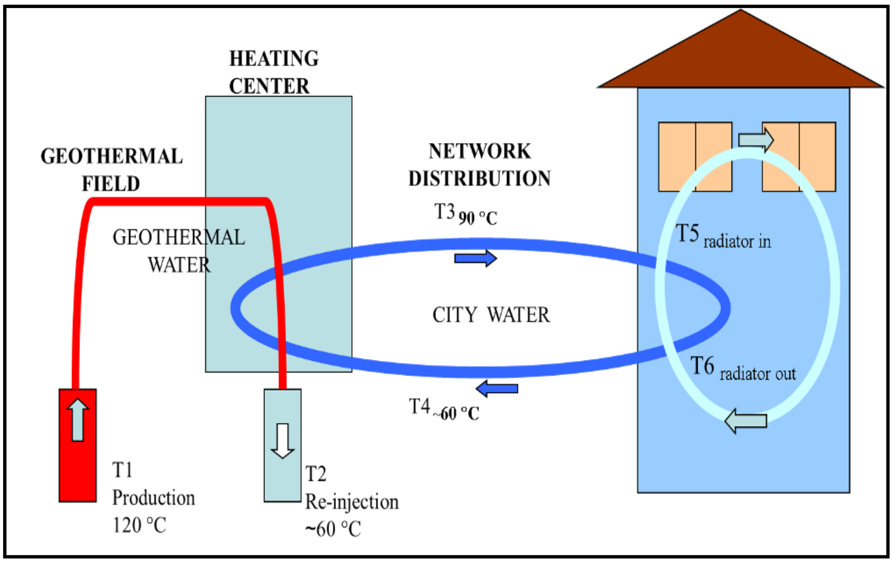

Figure 6: Schematic plan of Balçova District Heating System.

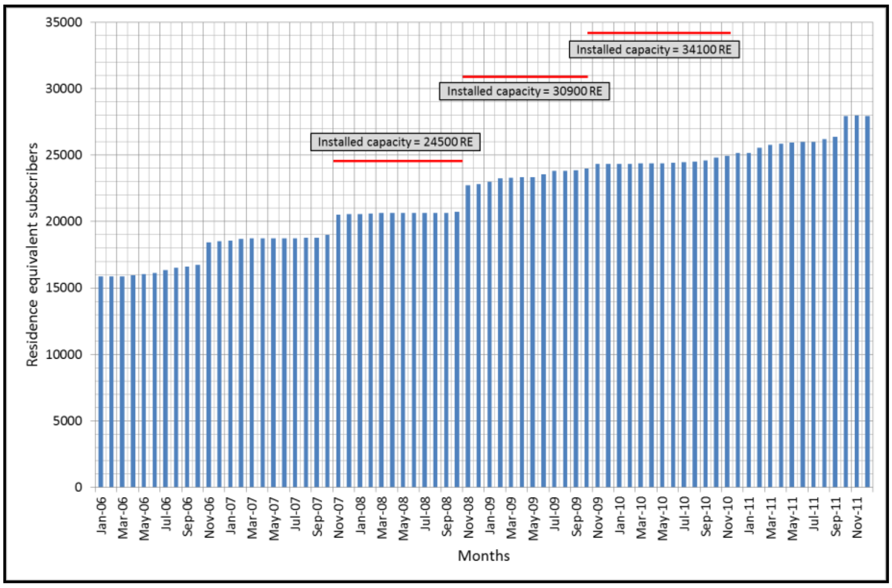

Figure 7: Installed capacity and residence equivalent subscribers of BDHS.

3. FIELD PERFORMANCE

Balçova geothermal reservoir is a water dominated hydrothermal reservoir, which is prone to relatively high pressure drop to fluid production. The main precaution for the decline in pressure within geothermal reservoirs is the re-injection of produced fluid. At the early years of operation (October 2000 – February 2002) re-injection into a shallow well (B-9) was tried but resulted with rapid decline in fluid temperatures (10–15 °C) nearby shallow wells (Figure 8) (Aksoy *et al.*, 2008).

In order to find a permanent solution to the re-injection practice of the field, a deep well, BD-8, was drilled at the eastern part of the field in 2002, which turned out to be a very powerful wellbore for re-injection (>700 m^3/h). Although the re-injection capacity of the field increased after the drilling of BD-8, addition of the produced geothermal fluid into city loop due to the leaks from the network decreased the amount of hot water available from the re-injection, and the ratio of re-injection to production continued to decrease within the period of 2000–2005 (Figure 9). This observation was interpreted as continuous pressure decline within reservoir (Figure 10). Decline in the water level at the observation well ND-1 resulted in an interpretation that the total water level decline was more than 80 m for the heating season in 2007–2008. It is fortunate that remediation of pipeline network after 2005 decreased the production rate for the same heating capacity since there was no need to add geothermal water into city loop, which was actually a permanent loss. This was caused by an increase in re-injection / production ratio (Figure 11) and an obvious recovery of reservoir pressure (Fig. 12). The decreasing trend of water level of ND-1 during 2004–2005 changed its direction to a recovery after 2006 because of the increase in re-injection/production ratio.

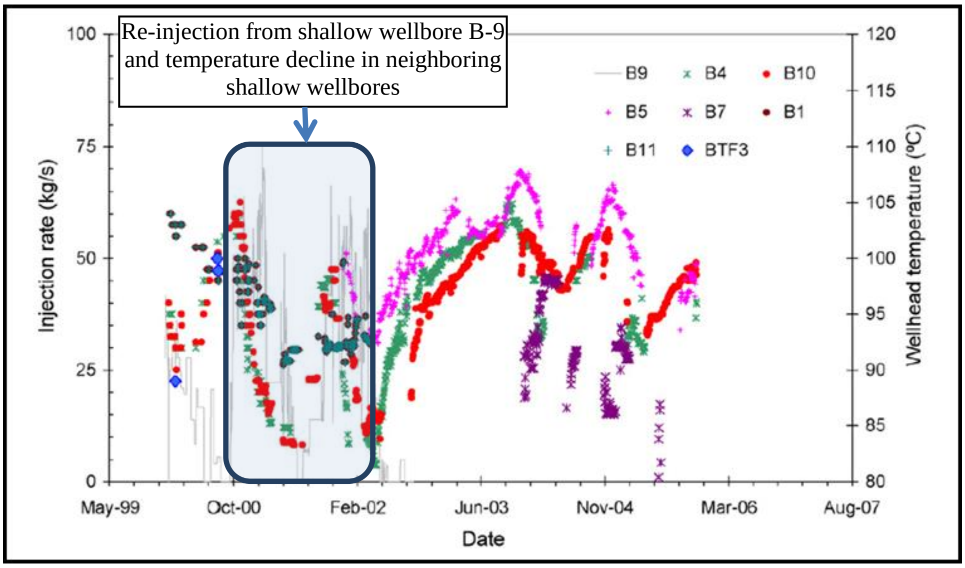

Figure 8: Re-injection trials from B-9 (Aksoy *et al.*, 2008).

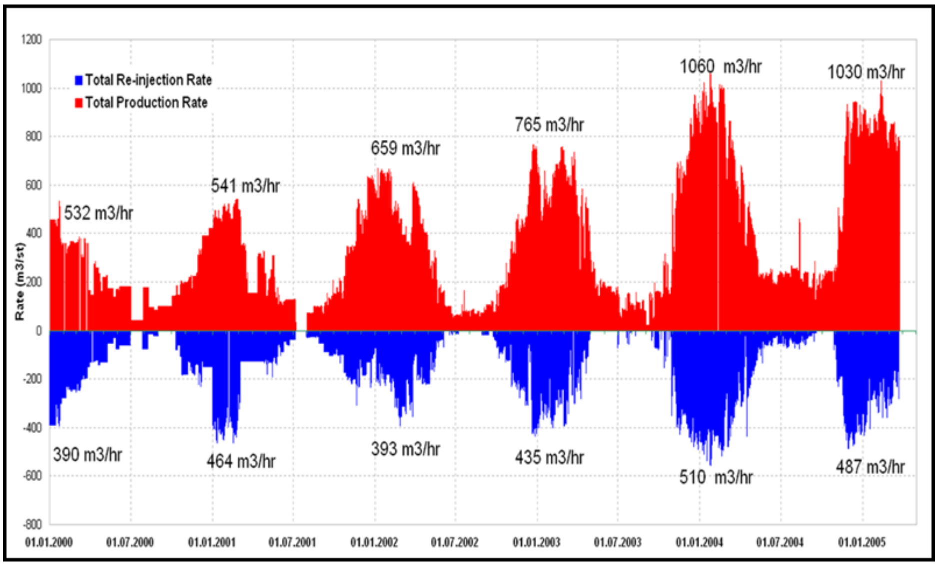

Figure 9: Production re-injection rates during 2000-2005.

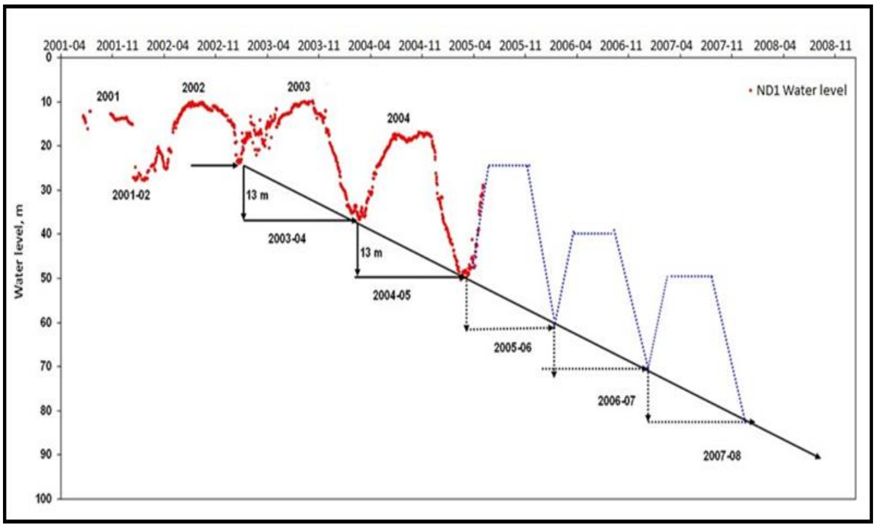

Figure 10: Forecast for reservoir pressure decline.

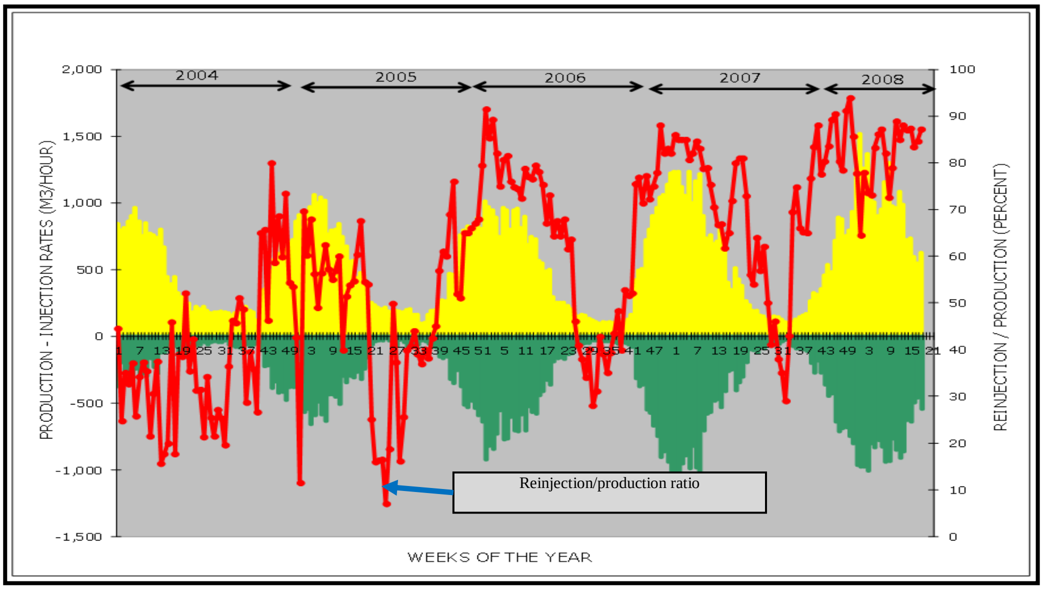

Figure 11: Production-re-injection rates and ratio during 2004–2008.

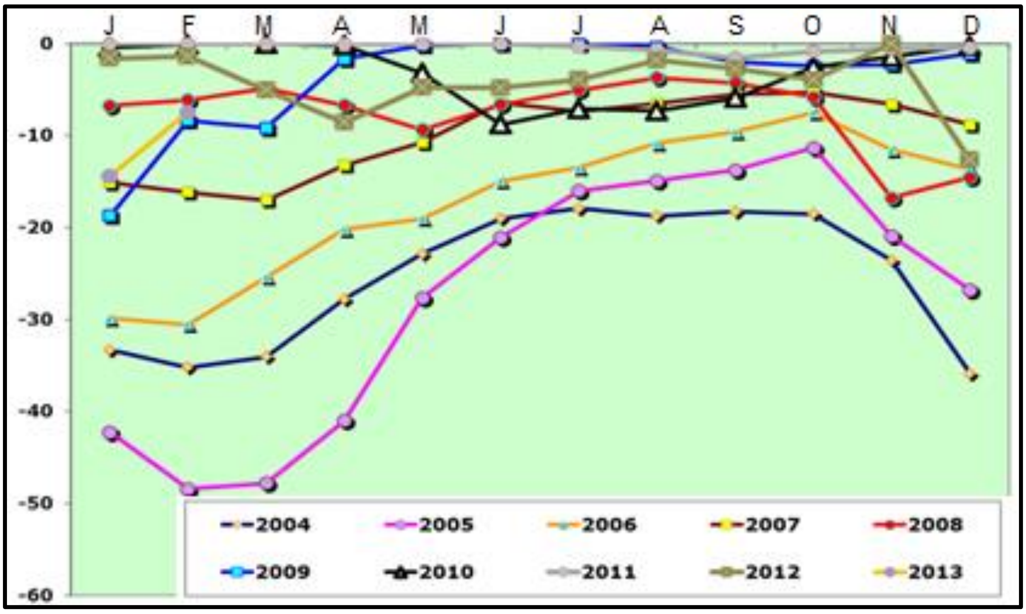

Figure 12: Water level measurements (m) at ND-1 during 2004–2013.

Operation in a district heating system for sixteen years gave the management of Izmir Geothermal Inc. experience to take necessary precautions to prevent possible problems during long-term operation. As mentioned earlier, re-injection of the geothermal fluid is crucial for the continuation of a successful operation. The key parameter for the success of re-injection operation is the site selection for re-injection wells. The previous trial to re-inject fluid into the shallow reservoir (B-9) was unsuccessful and resulted in immediate cooling nearby the shallow wells (Figure 8). Thus, this practice has not been applied except few days a year during peak times of heating (Table 1).

Two wellbores, BD-2 and BD-7, in the field were negatively affected by long-term operation. BD-2 is a relatively old wellbore drilled in 1995. The producing temperature from this wellbore decreased from the initial temperature of 132°C to 112°C during the heating period of 2012 (20°C drop). BD-7 showed a more dramatic change in the temperature from the initial temperature of 115°C to the current temperature of 82°C (33 °C drop) (Figures 13 and 14).

The decrease in the temperature at these two wellbores can be interpreted by using results of tracer tests, which carried out in the field in 2009–2010 heating season. Two different tracers injected simultaneously into the field (NaCl from BD-10 and rhodamine from BD-8) and the arrival times of those tracers at the producing wells were observed (Figures 15 and 16). The velocities at BD-2 and BD-7 wells (indicated by green circles in Figures) obtained from tracer test data were either fast or medium. It is suggested that the temperature decrease at those two wellbores could be affected by the injected fluids.

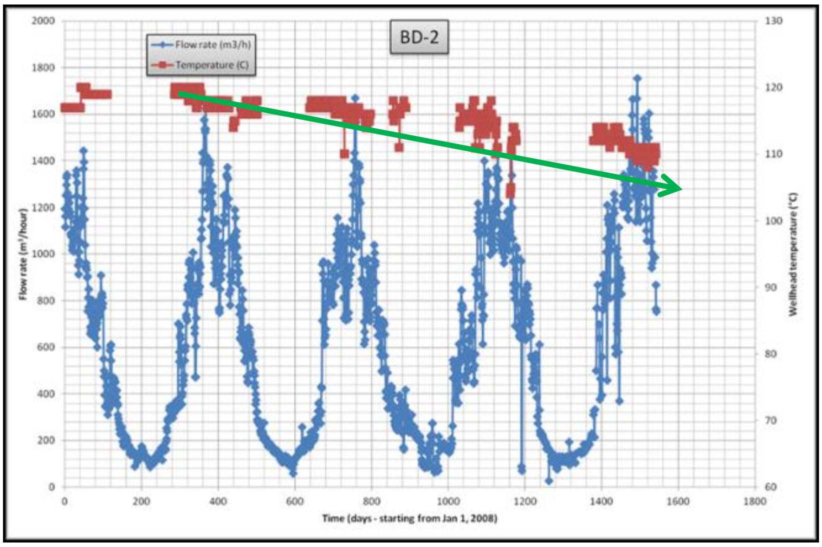

Figure 13: Flow rate and producing temperature of BD-2.

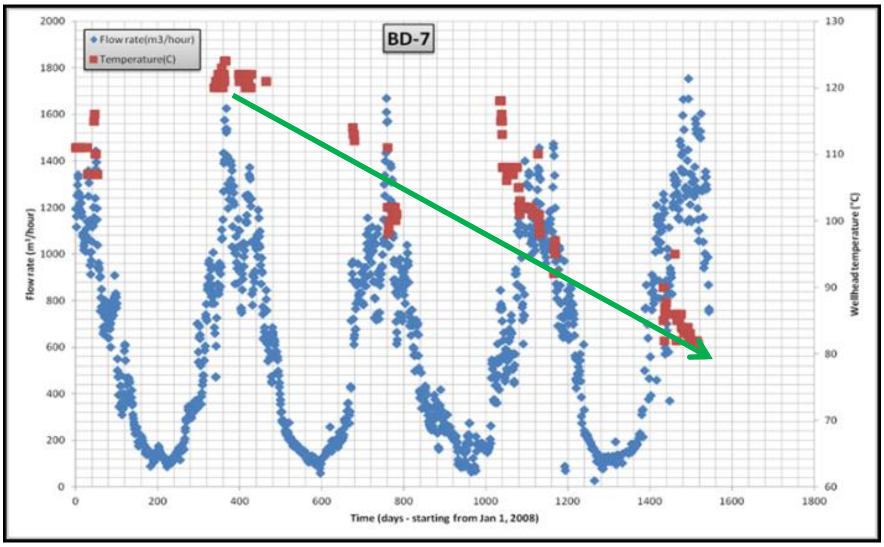

Figure 14: Flow rate and producing temperature of BD-7.

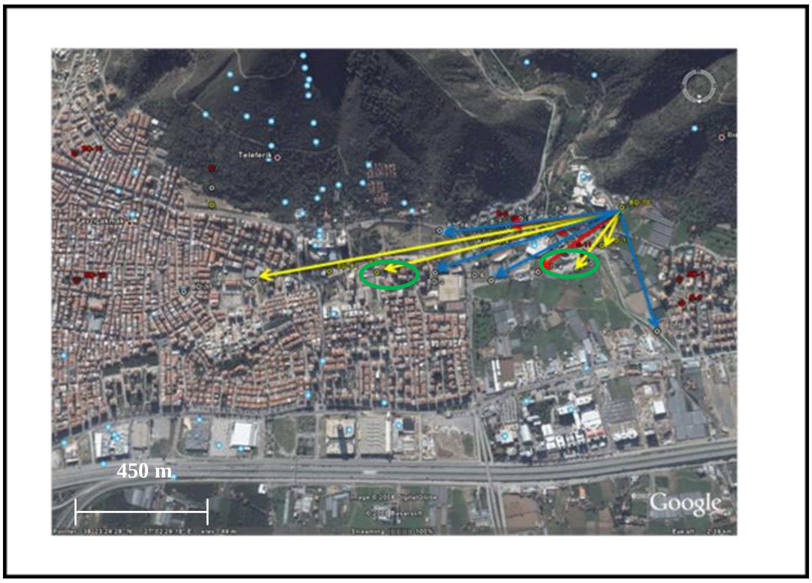

Figure 15: Velocity profiles of tracer (NaCl) injected from BD-10 (red = fast, yellow = medium, blue = slow).

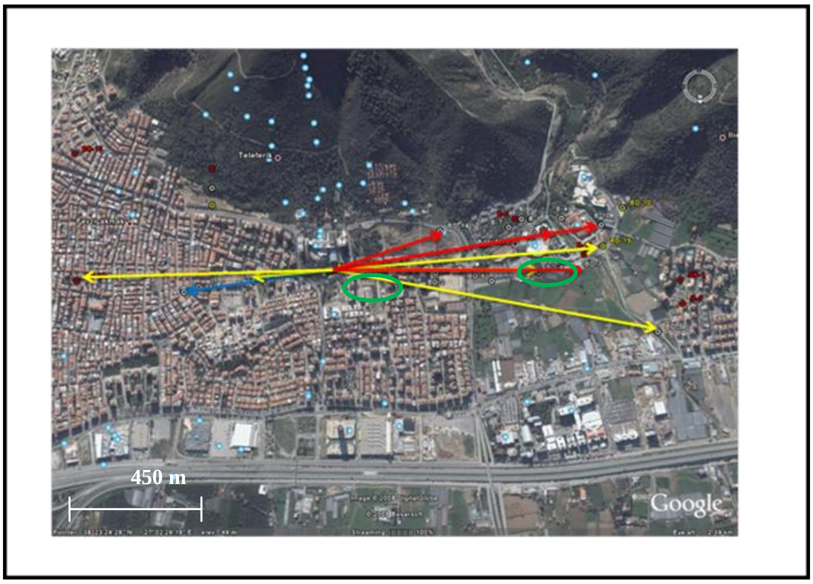

Figure 16: Velocity profiles of tracer (Rhodamine) injected from BD-8 (red = fast, yellow = medium, blue = slow).

Change in wellhead fluid temperatures at the three important producers (BD-4, BD-9 and B-10) of the field are presented in Figures 17 – 19. Two plots are given for each wellbore: one includes the cumulative production and injection data and wellhead temperature at the wellbore as functions of time, while the other gives the same data but on a narrow scale of temperature to see the details. All three wellbores are discussed separately:

- Well BD-9: As seen from Figure 17 that the cumulative production and injection rates show a sinusoidal behavior because of the variable heating demand throughout the year as a function of ambient temperature. Among the 4 heating periods whose data are presented, the cumulative production and re-injection flow rates of the heating period of 2011 – 2012 were the highest while the following two heating periods exhibited lower rates (Figure 17a). The effect of the magnitude of cumulative production and injection rates are obvious in Figure 17b. First of the wellhead temperature at well BD-9 declined for the given heating period. The wellhead temperature was high at the beginning of heating period, declined by time in the given year, but recovered back during summer time where there was very limited production from the field. The red line on Figure 17b is drawn as a reference to identify the effect of cumulative production and injection rates. The highest decline in temperature occurred in the heating period of 2011 – 2012 where the rates were the highest. On the other hand, the wellhead temperature for the following years recovered to its original value. This is a good sign for the sustainability of the wellbore as far as the same production-injection strategy is followed.
- Well B-10: The wellbore is one of the most productive wellbores in the field, which has longer production period in a given year than any other producers. It is actually the only wellbore that produces from the shallow reservoir of the field and that serves to the hotels, spas and swimming pools during summer. A decline in temperature was also shown for a given heating period but was not recovered back by the next heating period since the well was not closed long enough to recover. As a result, its wellhead temperature decreased from 102 °C in November of 2010 to 92 °C in April of 2012 (Figure 18). The lower cumulative production and injection during the heating period of 2012 – 2013 helped the well B-10 to recover up to 97 °C. The wellbore did not produce for nine months prior to the year of 2013 – 2014 and started to produce water at temperature of 97 °C in December of 2013. Those observations indicate that if well B-10 is heavily used, there is a danger of losing the wellbore within few years.
- Well BD-4: The plots for this wellbore do not include the cumulative production and injection data of the field but the flow rate of the wellbore itself. The production rate of the well was highest in the heating period of 2010 – 2011 but lower in the following three heating periods (Figure 19a). If the wellhead temperatures recorded from 2010 to 2011 is taken as reference (red line in Figure 19b), there exists a distinct increase in the wellhead temperature of BD-4. This observation can be interpreted that BD-4 produced water at almost constant temperature for a given average flow rate but its value was affected by the flow rate (higher flow rate means lower average wellhead temperature).

As mentioned earlier, some wells of the field had to be abandoned because of the decrease in their production temperatures or the mechanical failures. Thus, three wellbores were drilled BD-4A, BD-6A and B-10A in 2013 in order to replace BD-4, BD-6 and B-10, respectively. In addition, a new re-injection well, BT-1, was drilled to increase the re-injection capacity of the field. Two interference tests were carried out in the field during the flow testing of BD-4A and BT-1. Four observation wells, BD-1, BD-7, B-10 and ND-1 were equipped with downhole pressure-temperature sensors to record the response of the field to production/re-injection practices from BD-4A and BT-1 (Figure 20). Table 2 lists the depths and distances between observation wells and the active wells (BD-4A and BT-1) used in the interference tests.

<u>Interference test with BD-4A</u>: Changes in downhole pressures of observation wells during the flow testing of BD-4A are presented in Figure 21. B-10 was the only observation wellbore completed in the shallow reservoir level of the field, while three others were completed in the deeper reservoir. If the responses of all four wellbores are interpreted together:

- All wellbores showed responses from BD-4A but B-10 had lower pressure drop than others.

- Existence of pressure drop in B-10, which lied in a different level from the other producers lied in, indicates that a hydraulic connection between two reservoir levels exists but is weaker than the connections between the wellbores on the same level.
- Closing the production well BD-15 caused a drastic change in the downhole pressure of all observation wells. Since BD-15 is a deeper level producer B-10 is less affected than other observation wells.
- All three-observation wells completed in the deeper level showed the same pressure drop indicating a strong hydraulic communication in the reservoir.

Interference test with BT-1: This wellbore was drilled as a candidate of an injector and resulted in being a good injector. First, production was tested and then re-injection was conducted to record its dynamic pressure-temperature profiles. The response of observation wells are presented in Figures 22 and 23.

- All three deep observation wellbores showed similar but slightly different responses of the production and the re-injection tests at BT-1. ND-1 was affected less since it was relatively far compared to the other two. BD-1 and BD-7 had almost same responses from the BT-1 operations. Their starting pressures were different but the responses were parallel (Figure 22).
- The response of shallow observation well, B-10 did not show any resemblance to the response of the deep observation wells (Figure 23). This indicates that either there was no direct connection between BT1- and B-10 or that the time was not long enough to obtain the response.
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Table 2: Depth of observation wells and distances between active and observation wells.

Observation well	Depth (m)	Distance from observation well (m)	
		BT-1	BD-4
B-10	125	692	323
BD-1	564	504	172
BD-7	700	498	152
ND-1	750	855	564

CONCLUSION

Balçova geothermal field is a successful example of a direct heating application of geothermal energy with integrated use of its energy for space heating (residential and greenhouse) and balneological use. The 16-years operation proved that there exists a strong need for the reinjection of produced water after its energy is utilized. A sharp decline in the temperature of shallow producers was experienced when the reinjection was done into a shallow wellbore. On the other hand, reinjection into the deep wellbores helped to stop the decline in reservoir pressure but resulted in decline in temperature at the few deep wells closer to the reinjection sites.

Another important observation from the long-term monitoring was that the field has been recovering to its original temperature although the temperature dropped few degrees during heating season.

A recent interference test indicated that both reservoir levels (shallow and deep) were affected by the production-reinjection practices within the deeper zone although the effect was less pronounced by the shallower wellbores.

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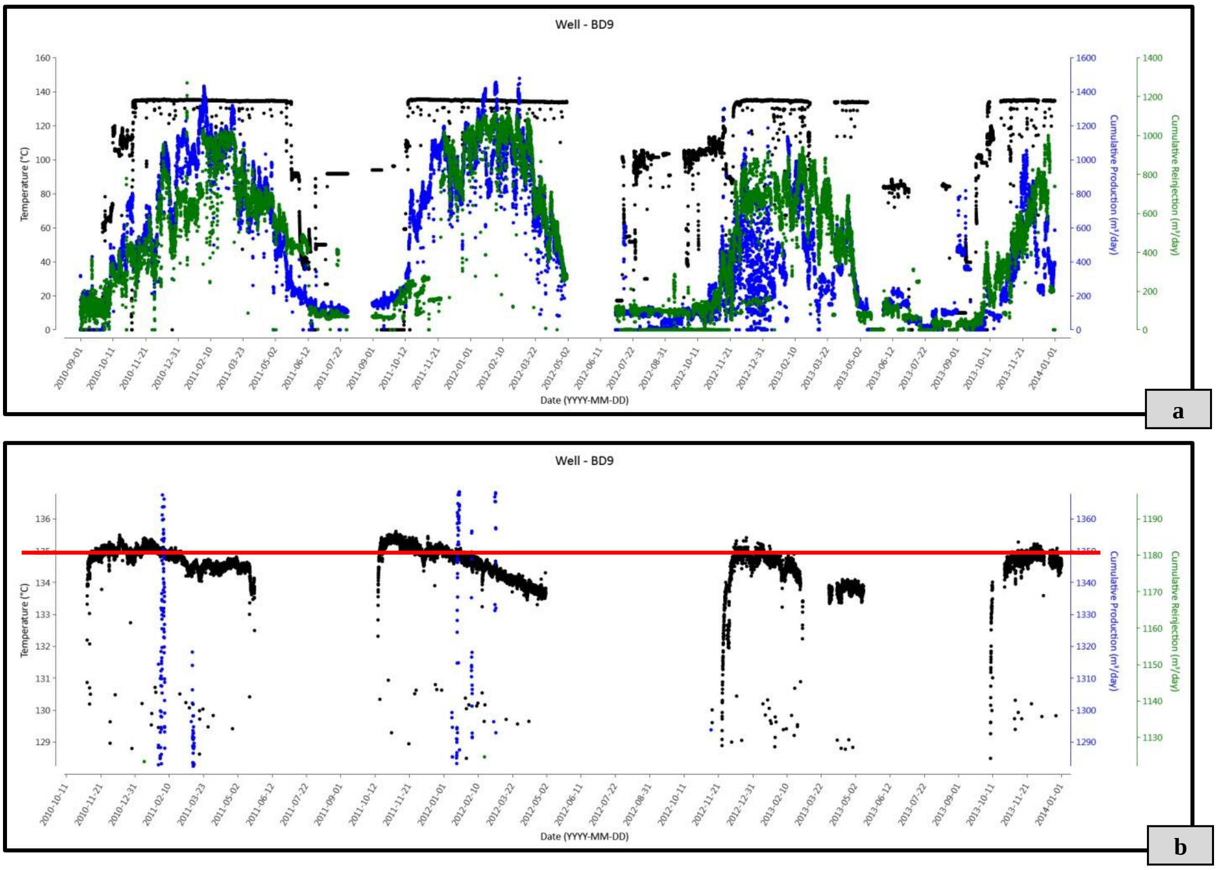

Figure 17: Field production-injection rates and wellhead temperature of BD-9 (a: Full temperature scale, b: narrow temperature scale).

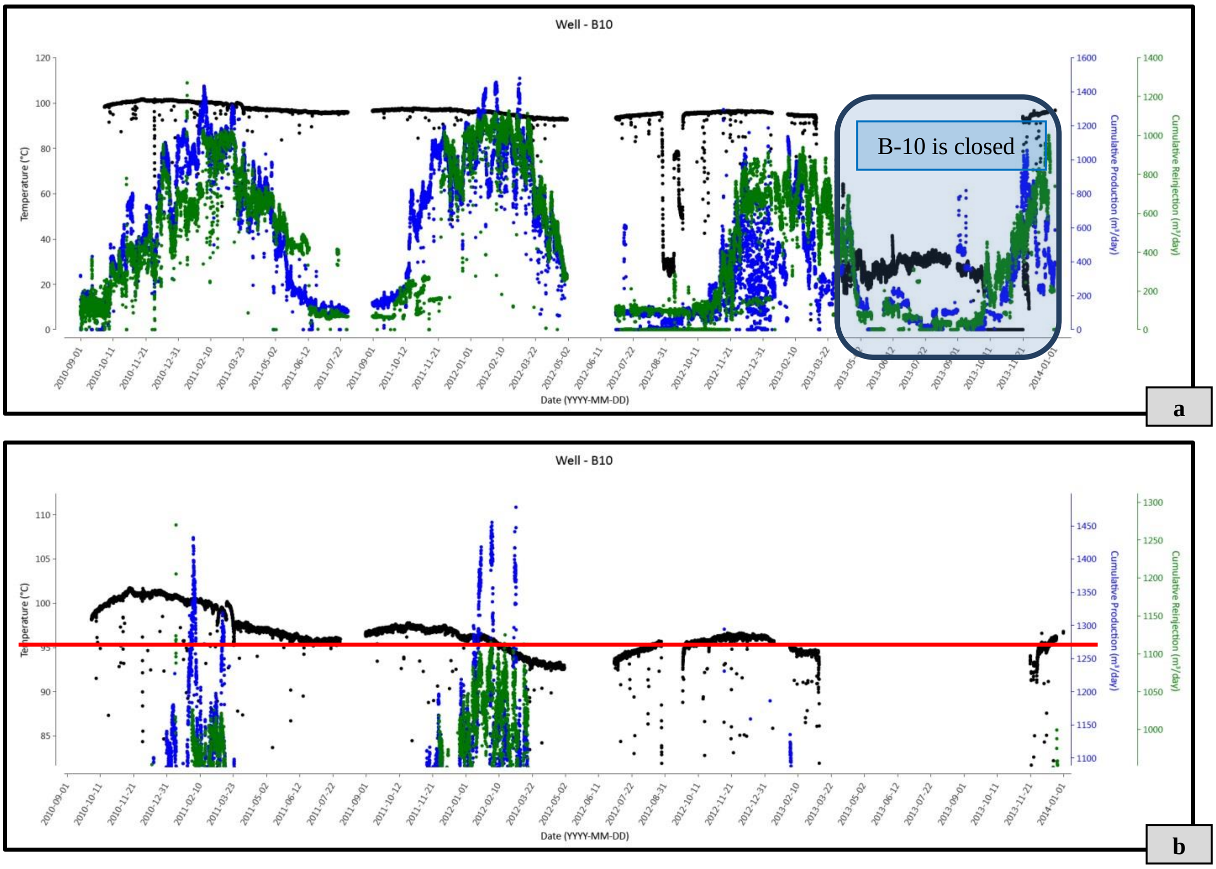

Figure 18: Field production-injection rates and wellhead temperature of B-10 (a: Full temperature scale, b: narrow temperature scale).

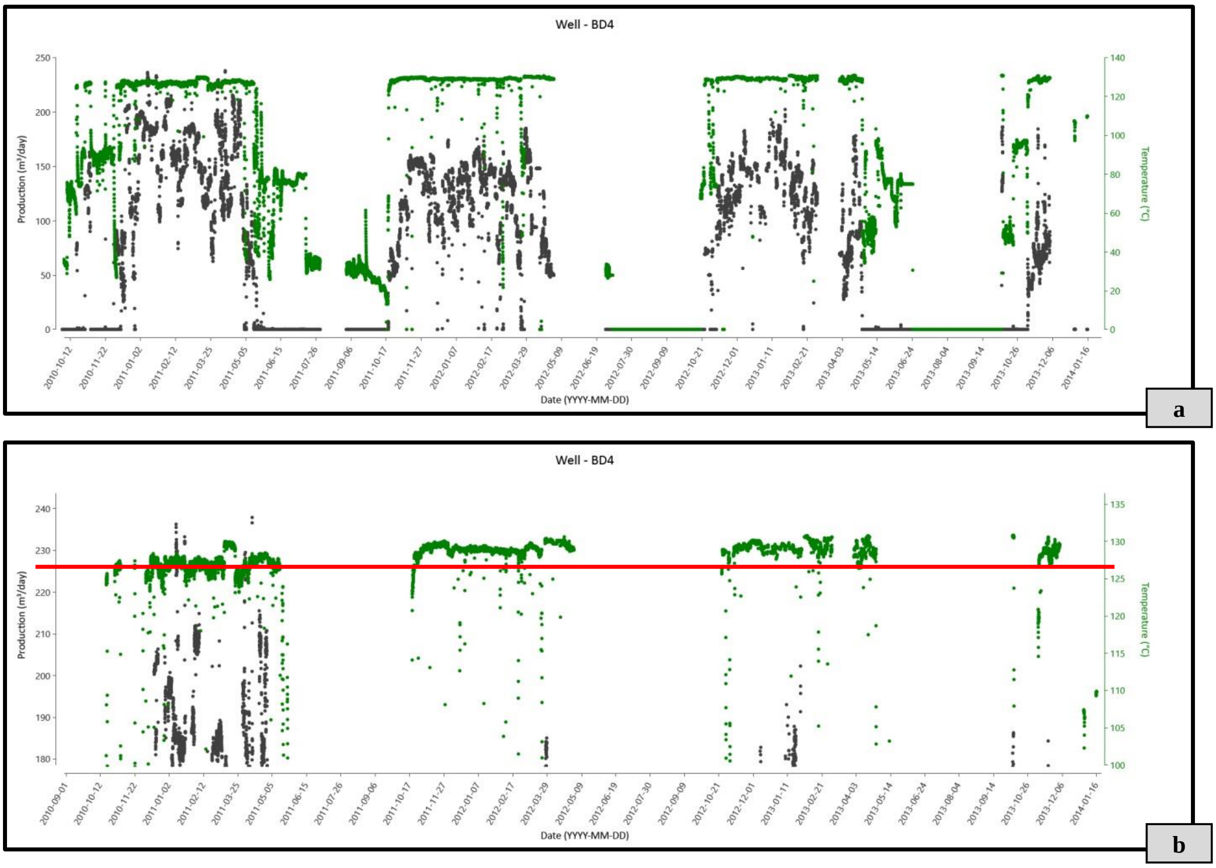

Figure 19: Production rate and wellhead temperature of BD-4 (a: Full temperature scale, b: narrow temperature scale).

Figure 20: Locations of wellbores.

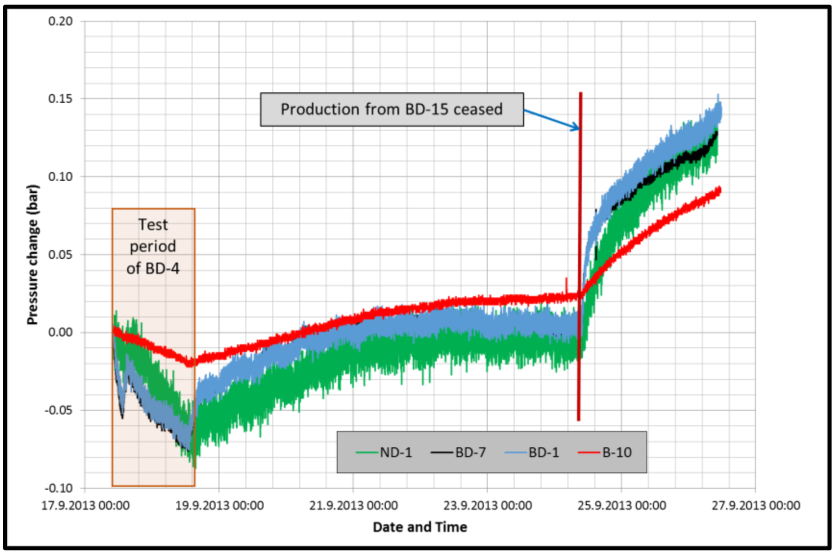

Figure 21: Response of observation wells BD-1, BD-7, ND-1 and B-10 to the production of BD-4A.

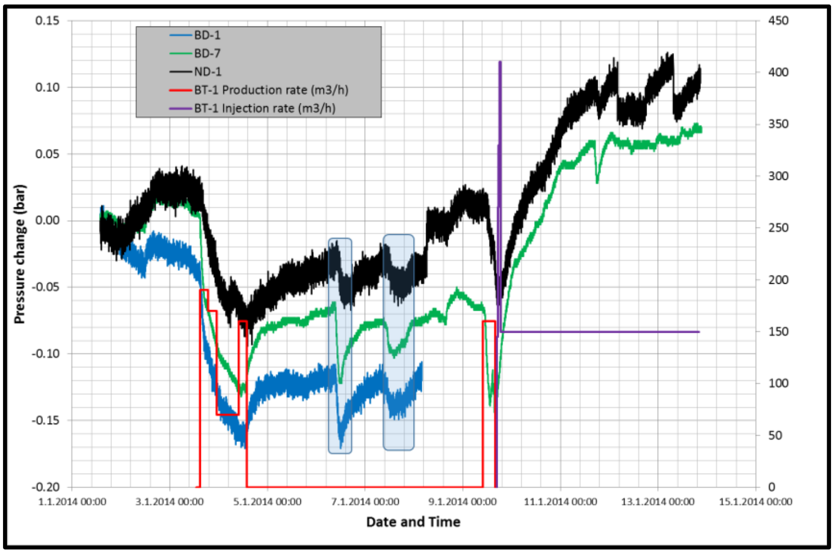

Figure 22: Response of observation wells BD-1, BD-7 and ND-1 to the production/re-injection of BT-1.

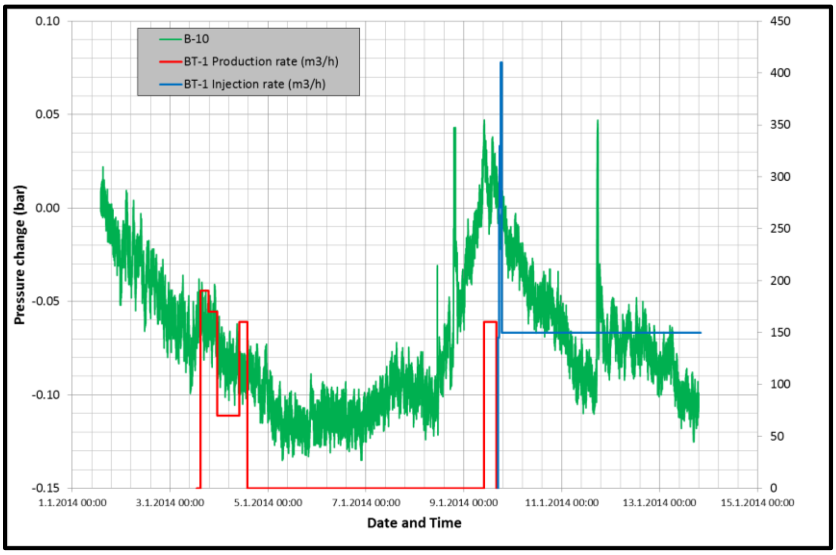

Figure 23: Response of observation wells B-10 to the production/re-injection of BT-1.