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Numerical Modeling of the Balcova-Narlidere Geothermal Field, Turkey

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ABSTRACT

The Balcova-Narlidere geothermal field, located in the Izmir bay of the Aegean Coast of Turkey is a liquid-dominated system with a maximum temperature of 140°C. The geothermal water has been characterized as "fresh" underground water and used for heating of Balcova-Narlidere district. The geothermal water has been produced/reinjected through a total of 21 wells: 9 deep wells with depths ranging from 564 m to 1100 m, and 12 shallow wells with depths ranging from 48.5 m to 160 m. The net fluid production per year from the field was around 650,000 m^3, when this study was conducted.

A three-dimensional numerical simulation model of the field was developed using the simulation code TOUGH2. The numerical model was based on a conceptual model derived from geological, geophysical, geochemical data as well as data from drilling and well tests. Natural state modeling was conducted by matching the temperature and pressure data initially measured at the wells. The natural state modeling provided satisfactory matches of measured temperature data of all the wells and represented the major qualitative features of the field, that resulted in a net recharge mass rate of about 51 kg/s and a net heat recharge of about 33 MWt.

The natural state model was further calibrated to match all available production and injection data (flow rates, pressures and temperatures vs. time) of the wells. After calibrating the model to all available data, the model was then used to predict overall reservoir performance and individual well performances under existing and proposed production/injection schedules for the next 20 years. Forecasting runs showed that production could be sustained for the next 20 years in terms of bottomhole pressures and temperatures. Forecasting runs considering only deep well production and injection indicated that the reservoir could be better sustained in terms of bottomhole pressures and temperatures for the next 20 years. In addition, forecasting runs assuming two new wells drilled in the field, with injectivities similar to currently available deep wells, and 20% increase in net production rate showed that the system could also be sustained for the next 20 years.

1. INTRODUCTION

Balcova-Narlidere geothermal field, which is known as the oldest geothermal system in Turkey, is situated 10 km away from the west of Izmir (Fig. 1). The geothermal water with the temperature ranging from 80 to 140°C is produced from the wells with the depths between 48.5 m and 1100 m. The first well was drilled by General Directorate of Mineral Research and Exploration (MTA) in 1963. There are about 50 wells drilled todate and they are classified as gradient, shallow and deep wells. The field started to feed a district heating system with a capacity of approximately 5,000 residences in 1996-2001.

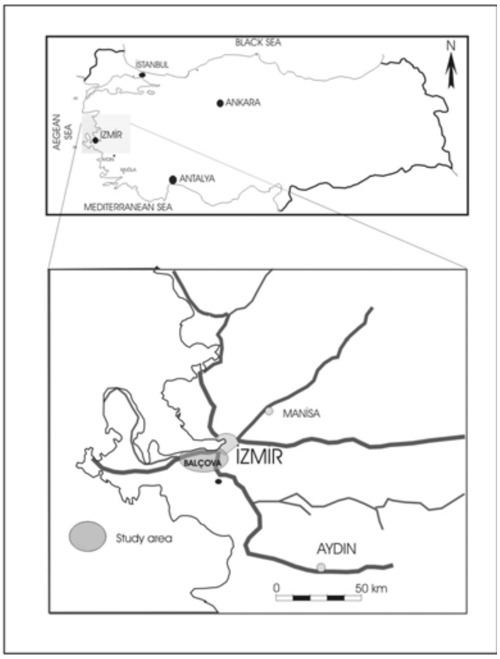


Figure 1: Location of Balcova-Narlidere geothermal field (modified from Aksoy and Filiz, 2001).

Geoscientific studies on the area around the Balcova-Narlidere geothermal field indicate that regional tectonics coupled with a major fault system has created NW-N-NE trending permeable pathways for a geothermal system, starting from a delimited intake area on the Seferihisar Horst in the south to the out-flowing area in the north (Yılmazer, 1989; Ongur, 2001). The Balcova geothermal system is a fracture zone system in which hot water ascends over an area of about 2 km^2 along a major fracture zone associated with Agamemnon Fault. The hot water discharges via two concealed horizontal flows, one in the alluvium (upper 100 m) and another deeper one in more permeable, ill-defined layers in the flysch formation between 400 and 700 m depth. Figure 2 is a structural map of Balcova-Narlidere geothermal system, including all well locations, and is based on alluvium thickness and alluvium-flysch contacts observed in wells (Ongur, 2001). The intense tectonic activity in the field has created a series of east-west and south-north oriented faults (and related fractures), as shown in Figure 2. The dips of the faults range from 60^o to 80^o (Yılmazer, 1989). The most important fault in the area is the east west oriented Izmir Fault, which is locally called as the Agamemnon Fault (AI in Figure 2) and extends over 30 km (Yılmazer, 1989 and Ongur, 2001).

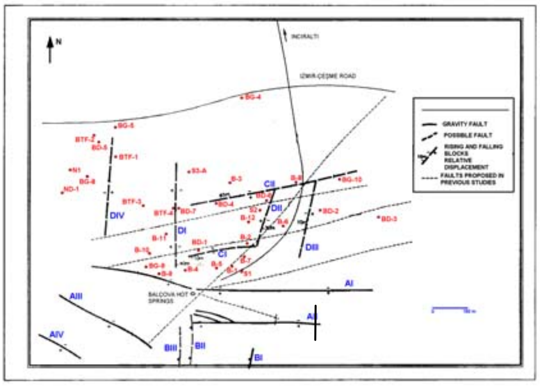


Figure 2: Structural map and well locations of Balcova-Narlidere field at seal level (Ongur, 2001).

The Balcova-Narlidere geothermal reservoir is a low-temperature liquid dominated reservoir. Geochemical studies conducted by Satman et al. (2001) indicate that the geothermal water have low total dissolved solids (approx. 1500 ppm) and very low the non condensable gas content (approx. 0.08% CO_2 by weight). Therefore, pure water flow is considered in the three-dimensional numerical model.

A total of 21 wells (9 deep and 12 shallow wells, Fig. 2) are operated since 1996. The deepest well is BD-5 with a depth of 1100 m and the shallowest well is B-9 with a depth of 48.5 m. Six deep wells, BD-2, BD-3, BD-4, BD-5, BD-6 and BD-7, and four shallow wells, B-4, B-5, B-10 and B-11 are being continuously or periodically used for production. The deep wells were produced in winter and the shallow wells were produced in summer months in general. All deep wells are producing by line shaft pumps installed at a depth of 150 m., while shallow wells are producing by line shaft pumps installed at a depth of 70 m. When the study was conducted, three shallow wells, B-2, B-9 and B-12 were used for injection. However in 2002 injection was transferred to the deep wells including a new well, BD-8, drilled in 2001.

2. DESCRIPTION OF THE MODEL

The objectives of the numerical modeling are to match the static and dynamic temperatures and pressures and to reproduce all the significant features of the conceptual model.

The numerical simulation model of Balcova-Narlidere field considered a total area of 12 km^2 a depth of 1.5 km (Figure 3). The grid refinement was focused in areas near the production and injection wells.

The model vertically extends from an average topographic surface of +400 m msl (mean sea level) to -25 m msl. It is divided into 13 layers. The layers and their thickness are shown in Figure 4. The first three layers (G1, G2 and G3) are 30 m thick each, the next three layers (C1, C2 and C3) are 50 m thick each, the next layer (C4) has a thickness of 60 m, the next four layers (R1, R2, R3 and R4) are 150 m thick each, the last two layers (R5 and R6) are 300 m thick each. A total of 5194 blocks were used in the model.

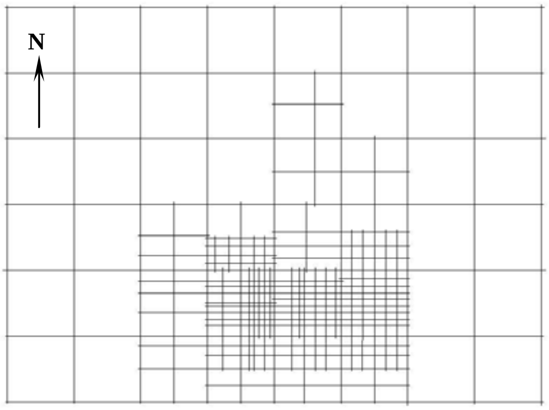


Figure 3: Grid structure of Balcova-Narlidere model.

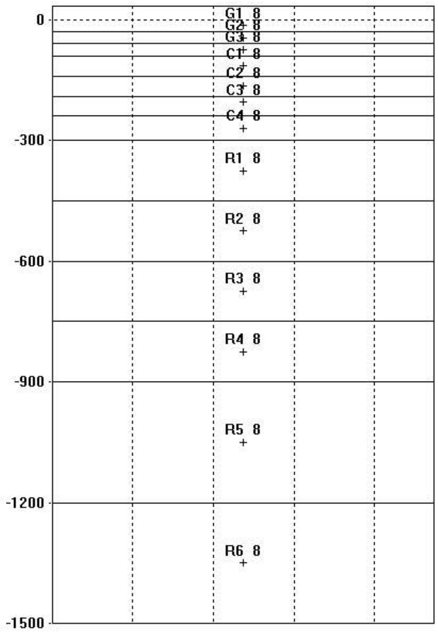


Figure 4: The depths of the vertical layers used in modeling.

In the modeling process, it is assumed that the hot geothermal water which is ascending through the Agamemnon Fault changes flow laterally (through R2 and R3 layers) to the north.

Since the fracture geometry (such as the fracture length, the fracture opening and the number of fractures) was not initially known, the reservoir system was treated to behave as a porous medium. Initial block permeabilities were assigned based on the well test data and the injectivity index of the wells (Onur et al., 2002). For blocks with no well test data, background permeability was assumed. The rock porosity for each layer was considered to be uniform and constant at a value of 5% which was determined from logs and core analysis (Satman et al., 2002). This assumption appears to be adequate since porosity has minor effects on the natural state temperature profiles. The rock density used is 2650 kg/m^3, which was determined from available logs of the wells. The heat transfer coefficient is assumed to be 2.5 W/(m^2-°C), and the specific thermal capacity to be 1000 J/(kg-°C). These values are typical parameters recommended for natural state modeling (O'Sullivan and McKibbin, 1989; O'Sullivan et al., 2001).

The numerical model was constructed using the numerical simulator TOUGH2, developed by Lawrence Berkeley National Laboratory (Pruess et al., 1999). The numerical model was calibrated in two stages, first by matching the natural state of the reservoir and second by matching the production history of the field.

3. NATURAL STATE MODELING RESULTS

For the natural state modeling, adjustments were made to the heat and mass flux. Simulation results suggest that the up-flowing source fluid has a total rate of 51 kg/sec which consists of 40 kg/sec for the deep system and 11 kg/sec for the shallow system. The total heat flux in the system is determined as 33 MW_t.

The permeability distribution in the model was constantly adjusted until the calculated temperatures reasonably matched the measured temperatures. As a result, the permeability of flysch formation is predicted as 3.5 mD. Moreover, the permeabilities of the Agamemnon Fault and the rocks connected to the Agamemnon Fault are forecasted in the range of 10-1000 mD.

Although not shown here, pressure vs. depth data predicted for each layer as result of natural state modeling was in good agreement for expected values for the field. Figures 5 and 6 compare the calculated and measured temperature profiles of two wells, BD-3 and B-4 located in the deep and shallow parts of the field, respectively. In both sectors of the field the temperature matches were generally good.

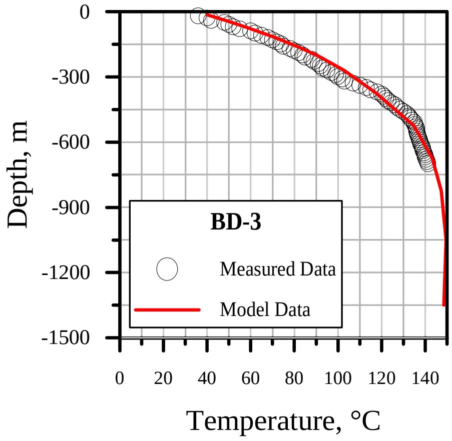


Figure 5: Temperature vs. depth profiles for the deep well BD-3.

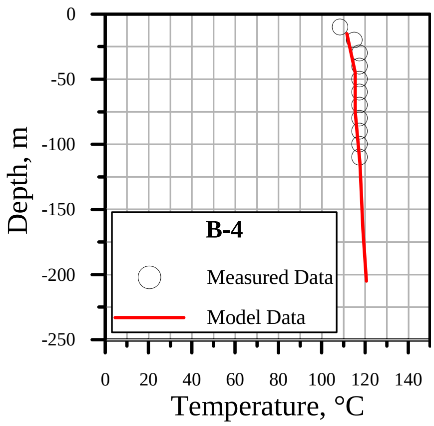
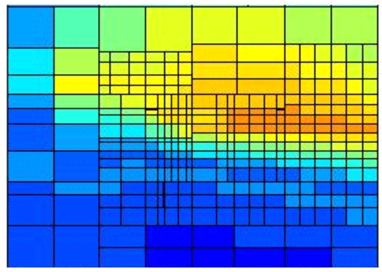
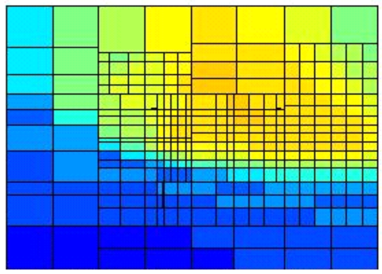


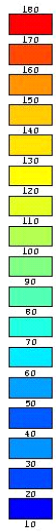
Figure 6: Temperature vs. depth profiles for the shallow well B-4.

Figure 7 shows the areal temperature profiles obtained for the layers of R6, R2, C2, and G3. These profiles provided good agreement quantitatively and qualitatively with the measured temperature profiles of the wells. The deep eastern part of the system (such as R2 and R6 layers in Figure 7) has the highest temperature and is about 20°C greater than the northwest part of the system.

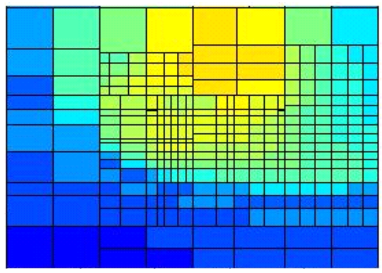


R6 Layer

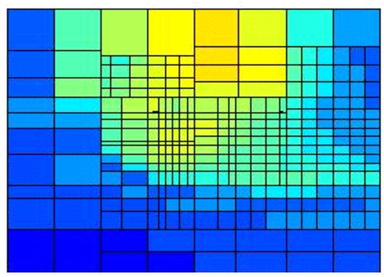




R2 Layer



C2 Layer



G3 Layer

Figure 7: The areal temperature profiles for R6, R2, C2 and G3 layers.

4. HISTORY MATCHING

The resulting initial state model was further calibrated by matching the production/injection history of field for five years (1996-2001). The production/injection history for each well (not shown here) is accounted in the simulation. The permeability structure was also further adjusted. The model results were compared with the measured temperatures and wellbore water levels.

The production and injection layers of the wells are presented in Table 1. Figures 8 and 9 show a comparison of the simulated bottomhole temperatures of deep (BD-3) and shallow (B-4) wells and measured wellhead temperatures. By considering that bottomhole temperature is generally a few degrees greater than wellhead temperature, it can be stated that the model temperatures reasonably matched the measured temperatures.

Table 1: The production/injection layers and feed zones for the wells.

WELLS	PRODUCTION/ REINJECTION LAYERS	FEED ZONES, m
BD-1	R1	300-450
BD-2	R2	450-600
BD-3	R2	450-600
BD-4	R2	450-600
BD-5	R3	600-750
BD-6	R2	450-600
BD-7	R2	450-600
BD-8	R2	450-600
BD-9	R2	450-600
ND-1	R3	600-750
B-2	G3	60-90
B-4	G3	60-90
B-9	G2	30-60
B-10	G3	60-90
B-11	G3	60-90
B-12	G3	60-90

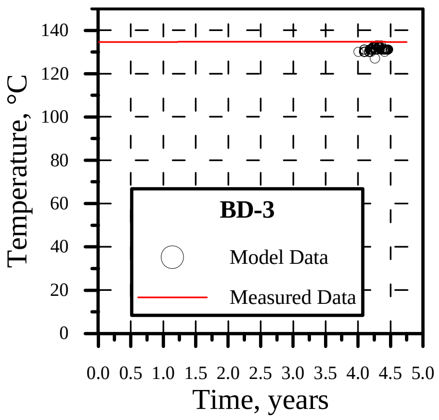


Figure 8: A comparison of the simulated bottomhole and measured wellhead temperatures for well BD-3.

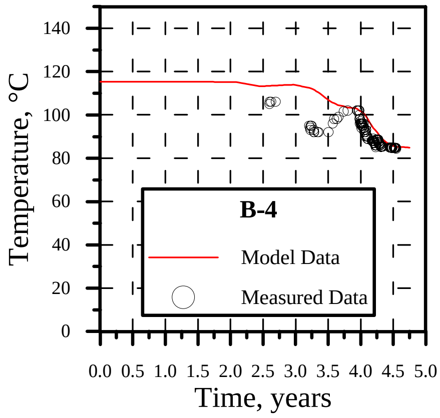


Figure 9: A comparison of the simulated bottomhole and measured wellhead temperatures for well B-4.

Since the bottomhole pressures were not measured for wells, the bottomhole pressures predicted by the model were compared with the wellbore water levels, qualitatively at observation wells. A comparison of the measured water levels at one deep well (BD-5) and one shallow well (B-12) with the corresponding simulated pressure behaviors are presented in Figures 10 and 11. Again the model pressure responses reasonably agreed with the water level changes.

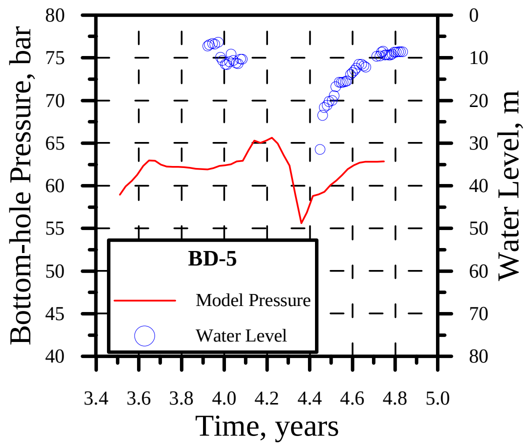


Figure 10: A comparison of the simulated bottomhole pressure and measured water level changes at well BD-5.

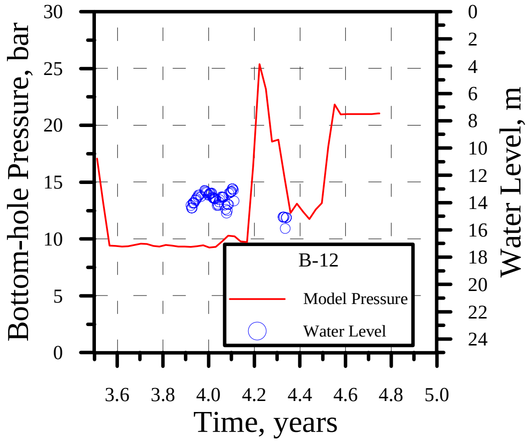


Figure 11: A comparison of the simulated bottomhole pressure and measured water level changes at well B-4.

5. PERFORMANCE PREDICTIONS

After successfully completing history matching, the simulation model was used to predict the future performance of the field for three different production/injection scenarios. The forecasting run covered a period of 20 years for each scenario.

5.1 Scenario-I Results

In Scenario-I, it is assumed that the production and injection history for the whole field, valid for the period of Jan.08 2000 to Dec.07 2001 is to be maintained for the next 20 years. Table 2 presents the monthly production and injection rates for one year. It is worth noting that production rate given in Table 2 provides sufficient heat for about 5709 residences. For all injection wells, temperature of injected water is assumed to be 65°C.

Figures 12 and 13 show the simulated bottomhole temperature and pressure responses for the shallow well B-10. It can be noted that the temperature could not reach its original value at the end of each year (Figure 12). The main reason is the injection of 65°C "cold" water into shallow wells. On the other hand, the pressure declines to about 2-4 bar in winter (when production is high) and the pressure recovers to its original bottomhole pressure in summer due to natural recharge (Figure 13).

As a next step, temperature and pressure behavior at deep wells are investigated. Figures 14 and 15 present the simulated bottomhole temperature and pressure data for well BD-6. As seen from Figure 14, the temperature does not change significantly. Similar to the shallow wells pressure behavior, the deep wells (Figure 15) pressures declines in winter (the maximum pressure drop is about 5-8 bar) due to production and reaches its original value in summer due to recharge.

The results based on the production/injection history considered in Scenario-I indicate that the Balcova-Narlidere geothermal system is sustainable in terms of heat and hydraulic balance for the next 20 years by considering pump depths at wells.

Table 2: The production/injection rate data for scenario-I.

	PRODUCTION, m^3/hr							
	BD-3	BD-4	BD-6	BD-7	B-4	B-10	B-11	Σ
Jan.	48	89	52	35	43	91	36	393
Feb.	50	92	75	47	43	84	23	413
March	59	102	43	24	26	67	36	357
April	30	0	32	24	22	44	19	171
May	0	0	25	28	12	75	20	158
June	0	0	0	0	0	75	28	103
July	0	0	0	0	0	67	26	93
Aug.	0	0	0	0	10	67	24	101
Sep.	0	0	0	0	0	85	0	85
Oct.	0	0	0	0	18	70	41	129
Nov.	0	24	0	0	38	78	41	181
Dec.	59	20	12	0	41	80	41	252

	REINJECTION, m^3/hr					
	BD-2	BD-5	B-2	B-9	B-12	Σ
Jan.	-26	-23	-169	-147	-28	-392
Feb.	-27	-17	-123	-185	-14	-365
March	-23	0	-31	-146	-17	-217
April	-15	0	-24	-23	0	-62
May	0	0	-17	-80	0	-97
June	0	0	0	-44	0	-44
July	0	0	0	-21	0	-21
Aug.	0	0	0	-34	0	-34
Sep.	0	0	0	0	0	0
Oct.	0	0	0	-38	0	-38
Nov.	0	0	0	-100	0	-100
Dec.	-12	-23	0	-155	0	-190

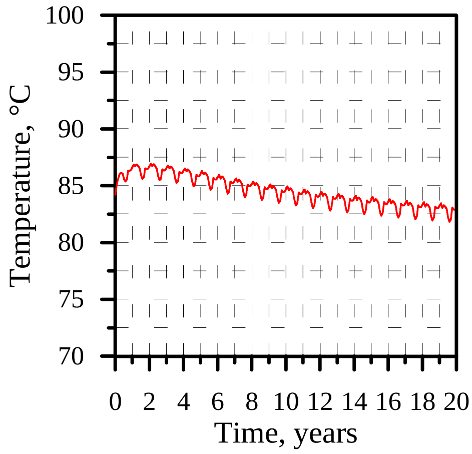


Figure 12: Simulated bottomhole temperature profile of well B-4 (Scenario-I).

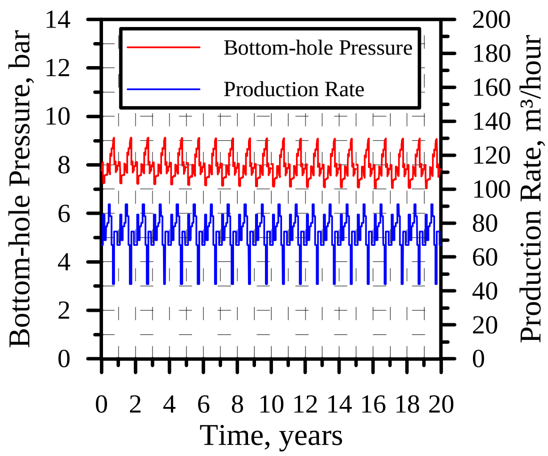


Figure 13: Simulated bottomhole pressure profile of well B-4 (Scenario-I).

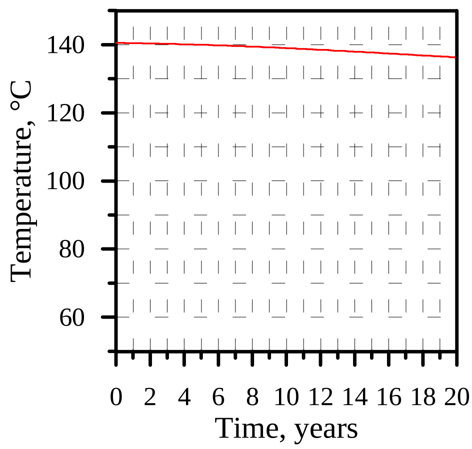


Figure 14: Simulated bottomhole temperature profile of well BD-6 (Scenario-I).

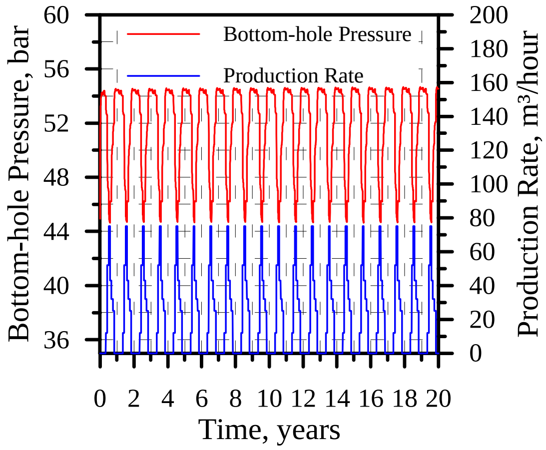


Figure 15: Simulated bottomhole pressure profile of well BD-6 (Scenario-I).

5.2 Scenario-II Results

In this scenario, it is also assumed that the production and injection history for the whole field valid for the period of Jan.08 2000 to Dec.07 2001 is to be maintained for the next 20 years. However, in this scenario, only the deep wells are used for production and injection purposes, while the shallow wells are not utilized for production or injection at all. Table 3 shows the monthly production and injection rates used in forecasting. Wells BD-2, BD-3 BD-4, BD-6 and BD-7 are used for production and wells BD-5, ND-1 and two new wells BD-8 and BD-9 (they are assumed to be drilled) are used for injection purposes.

The simulated bottomhole temperature and pressure responses for deep well BD-6 are plotted in Figures 16 and 17. As clearly seen from Figures 16 and 17, temperature and pressure responses are similar to those obtained for Scenario-I. The bottomhole temperature stays almost constant (Figure 16), and the bottomhole pressure oscillates periodically (Figure 17). The maximum pressure drop (about 7-10 bar) occurs in winter and natural recharge replenishes the well in summer. These results also indicate that the Balcova-Narlidere geothermal system is sustainable in terms of heat and hydraulic balance for the next 20 years by considering pump depths at wells.

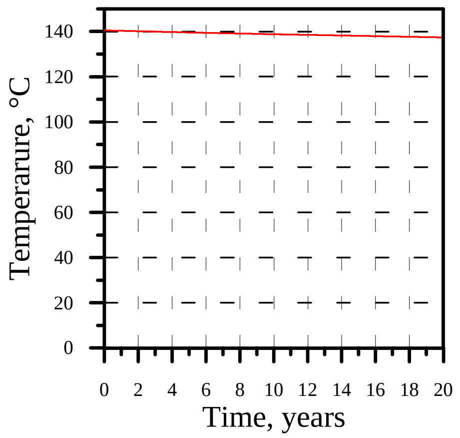


Figure 16: Simulated bottomhole temperature profile of well BD-6 (Scenario-II).

Table 3: The production/injection rate data for scenario-II.

	PRODUCTION, m^3/hr					
	BD-2	**BD-3**	**BD-4**	**BD-6**	**BD-7**	**Σ**
Jan.	82	55	106	62	42	347
Feb.	70	58	107	88	58	381
March	51	59	81	70	65	326
April	51	59	81	70	65	326
May	38	0	0	51	54	143
June	0	0	0	46	0	46
July	0	0	40	0	0	40
Aug.	0	0	40	0	0	40
Sep.	0	0	0	50	0	50
Oct.	69	0	0	0	35	104
Nov.	35	51	32	38	35	191
Dec.	40	60	68	46	35	249

	REINJECTION, m^3/hr				
	BD-5	**ND-1**	**BD-8**	**BD-9**	**Σ**
Jan.	-48	-30	-100	-100	-278
Feb.	-50	-35	-110	-110	-305
March	-41	-20	-100	-100	-261
April	-41	-20	-100	-100	-261
May	0	0	-57	-57	-114
June	0	0	0	-37	-37
July	0	0	-32	0	-32
Aug.	0	0	-32	0	-32
Sep.	0	0	0	-40	-40
Oct.	0	0	0	-83	-83
Nov.	0	0	-78	-75	-153
Dec.	0	0	-100	-99	-199

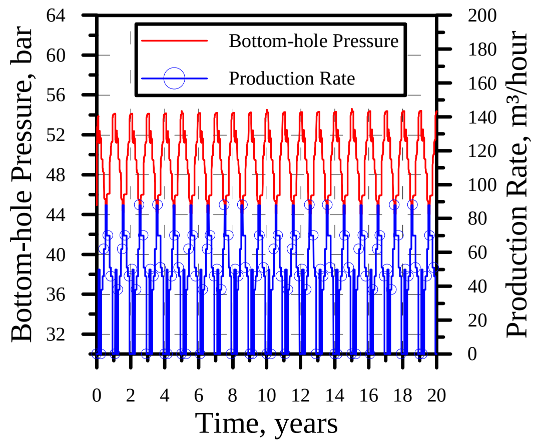


Figure 17: Simulated bottomhole pressure profile of well BD-6 (Scenario-II).

5.3 Scenario-III Results

In this scenario, it is assumed that the production and reinjection history for the whole field valid for the period of Jan.08 2000 to Dec.07 2001 is to be increased by 20% each year for the next 20 years. Similar to Scenario-II, only the deep wells are used for production and injection purposes and the shallow wells are not utilized for production or injection at all.

Table 4 shows the monthly production and reinjection rates used in forecasting. Figures 18 and 19 show the modeled bottomhole temperature and pressure responses for well BD-6. Based on the results of Figures 18 and 19, again it can be concluded that the Balcova-Narlidere geothermal system is sustained in terms of bottomhole pressures and temperatures for the next 20 years.

Table 4: The production/injection rate data for scenario-III.

	PRODUCTION, m³/hr					
	BD-2	BD-3	BD-4	BD-6	BD-7	Σ
Jan.	98	66	127	74	50	416
Feb.	84	70	128	106	70	457
March	61	71	97	84	78	391
April	61	71	97	84	78	391
May	46	0	0	61	65	172
June	0	0	0	55	0	55
July	0	0	48	0	0	48
Aug.	0	0	48	0	0	48
Sep.	0	0	0	60	0	60
Oct.	83	0	0	0	42	125
Nov.	42	61	38	46	42	229
Dec.	48	72	82	55	42	299
	REINJECTION, m³/hr					
	BD-5	ND-1	BD-8	BD-9	Σ	
Jan.	-58	-36	-120	-120	-333	
Feb.	-60	-42	-132	-132	-366	
March	-49	-24	-120	-120	-313	
April	-49	-24	-120	-120	-313	
May	0	0	-68	-68	-137	
June	0	0	0	-44	-44	
July	0	0	-38	0	-38	
Aug.	0	0	-38	0	-38	
Sep.	0	0	0	-48	-48	
Oct.	0	0	0	-100	-100	
Nov.	0	0	-94	-90	-183	
Dec.	0	0	-120	-119	-239	

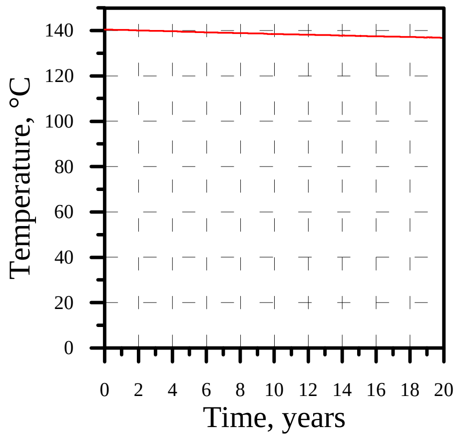


Figure 18: Simulated bottomhole temperature profile of well BD-6 (Scenario-III).

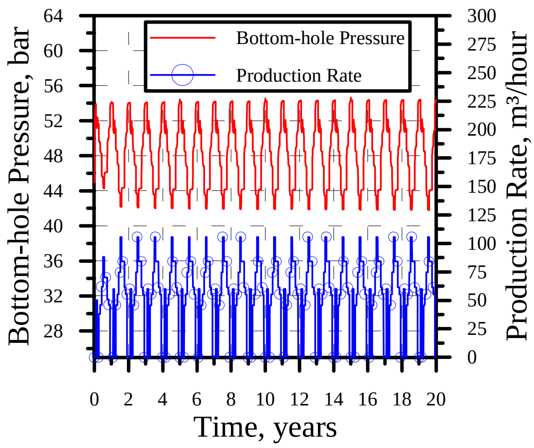


Figure 19: Simulated bottomhole pressure profile of well BD-6 (Scenario-III).

6. CONCLUSIONS

The natural state modeling of the Balcova-Narlidere field reasonably matches the temperature profiles of all wells. Thus, the obtained numerical model provides a good representation of the geothermal system.

The numerical model was calibrated against the available production/injection data with reasonable matches being obtained to the bottomhole temperature and pressure response. After successfully calibrating the model, it was used to predict the future field performance under three different scenarios.

Results indicate that the injection should be made into the deep wells to prevent the temperature decline in the system. Two additional deep wells are suggested to be drilled as injection wells.

Forecasting runs indicated that the system could be sustained in terms of bottomhole pressures and temperatures for the next 20 year for the three different scenarios considered in this work.

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