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MODELING OF KIZILDERE GEOTHERMAL RESERVOIR, TURKEY

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ABSTRACT

Kizildere field is the first and only geothermal field of Turkey producing electricity from geothermal steam. Although it produces energy since 1984, it has some operational problems such as fluid disposal and decline in reservoir pressure. The best solution for these two operational problems seems to be the re-injection of produced fluid.

A numerical modeling study was carried out to investigate the response of the field to different production/injection scenarios. While developing the model, permeability values from build-up tests and log-derived porosities were utilized. After getting a good match for the available 17 years production history, the model was applied to predict the response of the reservoir with several scenarios.

Interpretation of build-up test data indicated a double porosity behavior for Kizildere Geothermal field. History match runs resulted with a requirement of a 200 m thick bottom aquifer for pressure support.

Nine different scenarios were applied to observe the response of the field for different production / injection schemes. The performance prediction runs covered time period between January 1, 2001 and December 31, 2012. Performance prediction trial with existing wells without any re-injection resulted with a decline of 530 kPa in reservoir pressure in average.

Among several re-injection trials, re-injection of fluid from the center of the field resulted with the highest-pressure support.

KIZILDERE GEOTHERMAL FIELD

The Kizildere geothermal field was discovered in 1968. It is located in the Denizli and Aydin provinces of western Turkey (Figure 1) at the Western extreme of the Büyük Menderes graben (Figure 2). The Menderes massif was uplifted during late Pliocene and Quaternary times, and east-west grabens formed as a result of tensional forces. Magma rose under the massif and under the grabens where the earth's crust is thinner. Thus, the geothermal fields occur naturally along the grabens and the Kizildere field is an example (Simsek, 1985). The field lies on three main fault blocks, generated by two-step normal faults, running nearly parallel to the flank of the Menderes Valley. The area is rich with geothermal manifestations, including water springs at a temperature between 30 °C and 100 °C.

Kizildere geothermal field in the exploited region consists of two producing reservoirs in the intermediate block within the depths explored. The main reservoir, Igdecik formation, is sited in the metamorphic basement, and composed of crystalline limestones, which has high fracture permeability. Sazak, a limestone formation, is the minor producing zone and lies above Igdecik. Kizilburun, Kolonkaya formations and locally Sazak formation form the caprock. The maximum temperatures of Sazak and Igdecik formations are 198 °C and 209.1 °C, respectively.

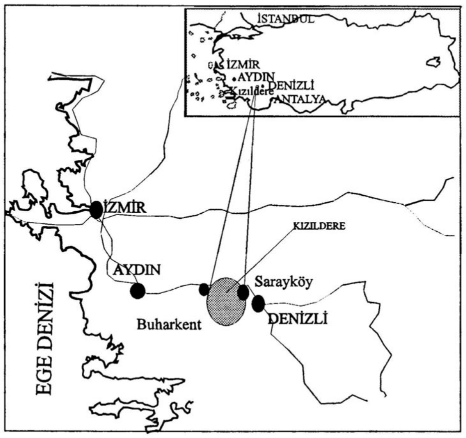

Figure 1. Location of Kizildere Geothermal Field (Aksoy, 1997).

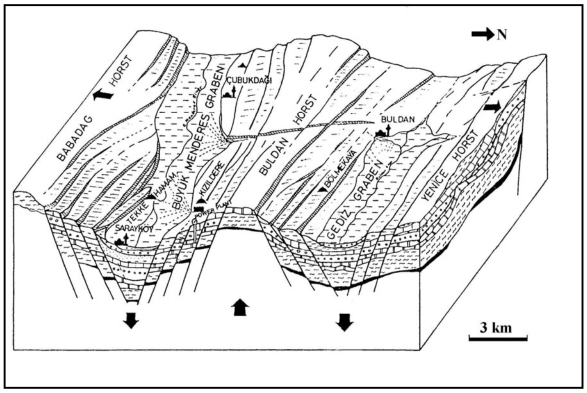

Figure 2. Horst-Graben Systems in Western Anatolia (Simsek, 1985).

The first well, KD-1, drilled in 1968 to a depth of 540 m, produced a mixture of water and steam with a temperature of 198 °C in the reservoir, thus indicating the existence of a water-dominated geothermal system. Later, 17 wells more have been drilled in this field. A geothermal power plant with a capacity of 20.4 MWe was put in operation in 1984. Three additional production wells were drilled in 1986 due to the shortage of steam. The depths of the wells are between 370 m-1241 m.

Kizildere geothermal field has three main problems. These are:

- Calcite scaling in the production wells and surface connections: Geothermal fluid at Kizildere Geothermal field contains high $CaCO_3$ and 1-1.5 % dissolved CO_2 by weight (Simsek, 1985). The CO_2 partial pressure drop that takes place during the upflow of geothermal fluid causes calcite scaling. Calcite scale causes a reduction in well bore radius thus a decrease in productivity of the well bore. Because of the higher costs of scale inhibitor injection and acidizing, mechanical reaming appeared as the most economical method to remove calcite of the wells. Figure 3 shows daily production rates for the field between 1989-2000. The production rate reaches its maximum right after cleaning work, but it starts to decline immediately after a short production period due to calcite scaling

- Depletion of reservoir pressure due to production: Kizildere Geothermal power plant with an installed capacity of 20.4 MWe has been operating since 1984. The average effective capacity was 5.8 MWe between 1984 and 1987, and about 10 MWe between 1988 and 2000. About 100 million tones of water were produced at an average rate of 900-tones/h causing pressure drops in the reservoir. Reservoir pressure is continuously monitored from four observation wells KD-1A, KD-7, KD-8 and KD-9. Figure 4 shows the decline in reservoir pressure observed in wells KD-7 and KD-8. Re-injection of wastewater to underground is the only solution to prevent the depletion of reservoir pressure. A re-injection project was prepared for this purpose in 1995 and MTA drilled 3 re-injection wells during the period 1996 and 2000. One of these wells is in the Tekkehamam area, 3 km away from the Kizildere field, and the others are in the Kizildere field. The well drilled in Tekkehamam (TH-2) is not suitable for re-injection because of low injectivity. The first re-injection well drilled in Kizildere area (R-1) resulted with a high production capacity but low injectivity. It has a temperature of 243 °C and it is the best producer of Turkey. Its capacity is 6 MWe. The second well drilled in Kizildere area (R-2) showed good injectivity as well as good production capacity. It is planned to start re-injection from R-2 by the end of 2001.

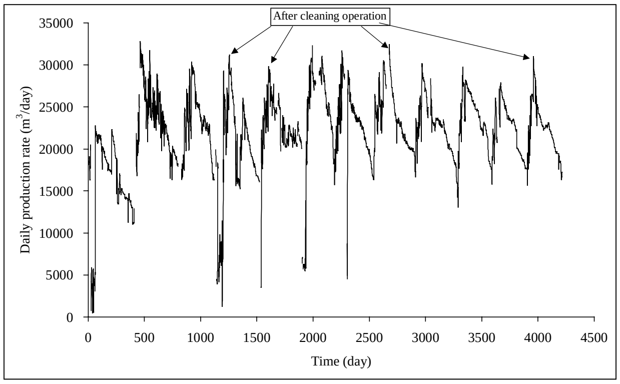

Figure 3. Daily production rate of Kizildere Geothermal Field (1988-2000).

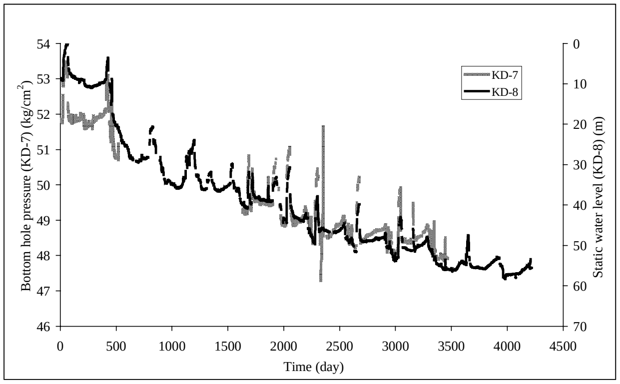

Figure 4. Pressure decline in observation wells (1988-2000).

- The disposal of wastewater with high boron content (25-30 ppm) into B.Menderes River: Since 1984, the wastewater of the Kizildere Geothermal Power plant has been flowing to B.Menderes River. The adverse effects of high boron content of wastewater on agricultural activity has put a limitation on both discharge and thus on power generation of the power plant up to a certain extent. During the arid months of spring and summer season, the flow rate in the river decreases because of the marginal water recharge and increased water withdrawal for irrigation. The effects of boron content on the environment are felt even more at this low river flow rate. Because of this, the discharge of the wastewater to B.Menderes River is restricted during arid months of the spring.

The most obvious solution to the aforementioned problems is the re-injection of power plant effluent to underground. It is aimed in this study to understand the behavior of Kizildere Geothermal Field with the help of existing production and test data. Reservoir characterization and modeling studies of the Kizildere Geothermal Field are carried out to forecast the response of Kizildere Geothermal Field under different scenarios with and without re-injection practices. A three-phase multi-component thermal and steam additive numerical simulator, STARS of CMG is used throughout the study. Pressure build-up tests, and density - neutron logs are the data sources to estimate permeability and porosity values of the reservoir.

RESULTS AND DISCUSSION

The following scheme has been applied while characterizing and modeling the Kizildere geothermal field.

- Pressure build-up tests were analyzed for the determination of permeability.
- Density and neutron logs were used to estimate reservoir porosity.
- Kriging technique was used to distribute permeability and thickness of producing zone, areally.
- A rectangular grid model 8×12×5 was created.
- Production history of the field for the period of 1984-2000 was used for history matching.
- After getting a reasonable history match, nine different scenarios were examined to predict the behavior of Kizildere geothermal field under different production/injection conditions.

Determination of permeability

A total of 30 build-up tests from 8 wells were analyzed to determine the permeability. A well test interpretation package, SAPHIR V2.30 T of KAPPA Engineering is used to interpret the tests.

Six different models have been used to interpret each pressure build-up test data. The reservoir, well bore and boundary conditions applied in these models are listed in Table 1.

Table 1. Build-up test models

Model	Reservoir Condition	Well bore Condition	Boundary Condition
1	Homogeneous	Storage Skin	Circle
2	Homogeneous	Storage Skin	Infinite
3	Double Porosity, PSS*	Storage Skin	Circle
4	Double Porosity, PSS	Storage Skin	Infinite
5	Radial Composite	Storage Skin	Circle
6	Radial Composite	Storage Skin	Infinite

* PSS: Pseudo-steady state

Estimated permeabilities for each well from well test data are tabulated in Table 2. The highest permeability estimate is 554 md obtained in well KD-13, while well KD-21 resulted with the lowest permeability of 37.2 md. These values later used to get the areal distribution of permeability by Kriging.

Table 2. Permeability of Kizildere field from build-up tests.

Well	Model	Permeability (md)
KD-6	4	185
KD-13	6	554
KD-14	4	163
KD-15	4	197
KD-16	4	233
KD-20	4	218
KD-21	4	37.2
KD-22	6	310

Determination of porosity

Since no core measured porosity data available for Kizildere field, the only data source available for the porosity determination is the well logging surveys. Available logs for porosity determinations are the density and neutron porosity logs taken from the open hole completed wells KD-13, KD-20, KD-22. Due to expansions in well radius the density logs are not reliable and only neutron logs were used in porosity determinations. Tabulated porosity readings from neutron logs are presented as histograms in Figure 5 for the wells KD-13, KD-20 and KD-22, respectively. The most frequent porosity from the histograms is 6%. This determination is in agreement with the porosity reported by Serpen and Satman (2000).

Model

There are two hydrogeological model in the literature describing the Kizildere Geothermal Field [(Dominco, 1974) (Figure 6), Serpen and Satman, 2000) (Figure 7)]. Both models consider infiltration of meteoric water into deeper sections of the Earth (about 3000 m depth) and upflow of it after heating. Therefore the drilled depths of the producing wells should not restrict the vertical extension of reservoir.
The other feature of the field extracted from the model by Dominco (1974) (Figure 6) is the two faults (Main Feeding Fault Zone and Southern Fault Zone) dividing the Kizildere Region into three blocks,

Upper Block, Middle Block and Lower Block. These two features of the field described above were utilized while developing the numerical model of this study.

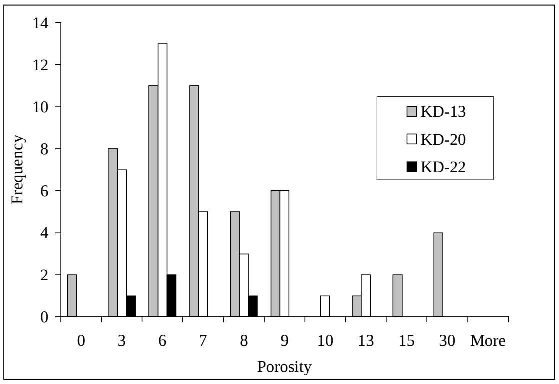

Figure 5. Porosity histograms for wells KD-13, KD-20 and KD-22.

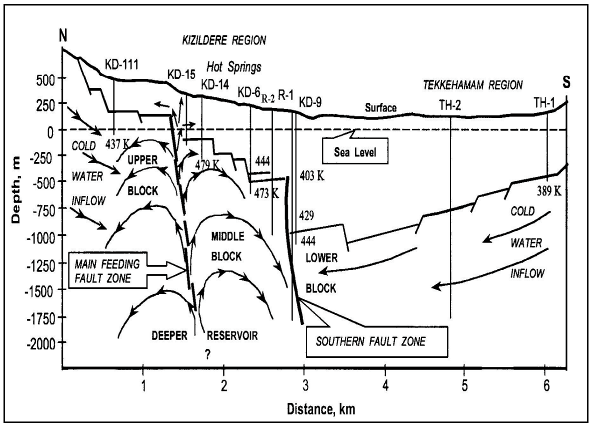

Figure 6. Kizildere Geothermal Field: Sketch of Probable Hydrothermal Conditions (Revised after Dominco, 1974).

Among the twenty-five history match runs, only the first one was tried with the vertical extent of reservoir, which is equal to the drilled thickness of Igdecik formation. This configuration did not give enough pressure support therefore the vertical extent of the model increased for the other runs. This added thickness to the drilled thickness of Igdecik formation was treated as a bottom aquifer having the same temperature with reservoir but different hydraulic properties, such as porosity and permeability.

Middle Block given in Figure 6 is taken as the areal extent of the reservoir bounded by no-flow boundaries.

Reservoir grid model given in Figure 8 is created. It is a rectangular model with number of grids as 8×12×5 in x, y and z directions, respectively. The areal extent of the model covers all of the production wells (KD-6, KD-13, KD-14, KD-15, KD-16, KD-20, KD-21, KD-22) and two monitoring wells (KD-7, KD-8). The vertical thickness of the blocks is variable. The drilled thickness of Igdecik formation of the production wells were distributed to all grids by kriging as thickness of reservoir and divided into five equal parts to form the grids in vertical direction.

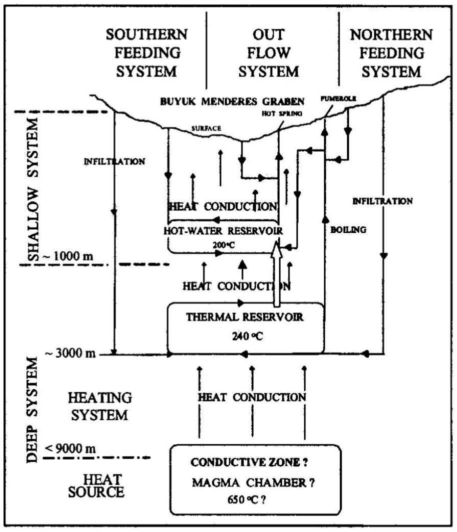

Figure 7. A model for Kizildere Geothermal system (Serpen and Satman, 2000)

Other important parameters of the model are as follows:

1. It is a fractured, dual porosity reservoir.
2. Permeability values obtained from pressure build-up tests (Table 2) distributed areally by kriging and assigned as permeability of fractures.
3. Permeability of matrix is taken as 1 md for all grids in all directions.

The numerical simulator, STARS of CMG, was used to model the Kizildere Geothermal field. Although it is capable to handle non-isothermal flow, numerical instabilities occurred during the four trials as non-isothermal application. Therefore, in most cases the reservoir was assumed as an isothermal one. Although there exists decline in temperature of all production wells within the production period of 1984-2000, the extent of decline is considered as small enough (in most cases, less than 4 °C) to assume isothermal flow condition. Temperature of the reservoir and aquifer is taken as 200 °C throughout this study. Details of the model can be found in Yeltekin (2001).

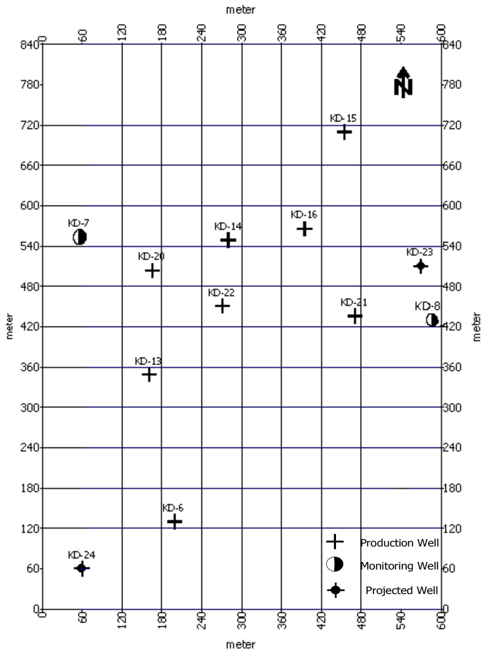

Figure 8. Top view of reservoir model grid diagram.

Performance prediction

A twelve years period, from January 1, 2001 to December 31, 2012 was chosen for the performance prediction of Kizildere Geothermal field. Production history of Kizildere Geothermal Field from February 1989 to December 31, 2000 was duplicated to supply the production data to already existing well bores during performance prediction period.

Nine different scenarios have been studied to observe the effects of adding new producers and re-injection. Table 3 lists the scenarios studied. Results of each prediction run will be discussed separately.

Performance prediction Run-1

In this prediction run, already existing wellbores (KD-6, KD-13, KD-14, KD-15, KD-16, KD-20, KD-21, KD-22) produced 12 years more with their production history between February 1989 and December 31, 2000. No re-injection has been done.
In total, 92,052,244 m^3 fluid was produced in the prediction period.

Figure 9 shows the pressure decline contour map of the Kizildere Geothermal field for the performance prediction period. As observed, the maximum decline in pressure is observed at the centre of the field where most of the wellbores are located. The average decline in reservoir pressure is about 530 kPa (5.3 bar).

Table 3. Prediction Run list

Run Number	Scenario
1	No Re-injection, No new production Well
2	Adding one producer well to grid 8*8*5 (KD-23)
3	Adding one producer well to grid 1*1*5 (KD-24)
4	KD-7 is Injector, Injection rate is 2500 m^3/day
5	KD-7 is Injector, With 9000 kPa constant BHP
6	KD-22 is Injector, Injection rate is 4500 m^3/day
7	KD-22 is Injector, With 9000 kPa constant BHP
8	KD-24 is Injector, Injection rate is 4500 m^3/day
9	KD-24 is Injector, With 9000 kPa constant BHP

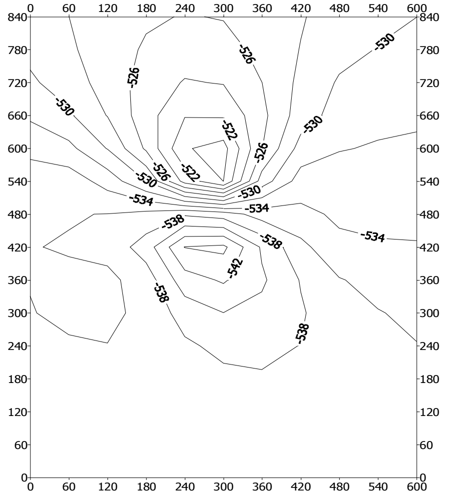

Figure 9. Pressure decline contour map of prediction Run-1

Performance prediction Run-2

At this scenario a production well (KD-23) on the NE of the field was added (Figure 8). The reason of adding this well as a new production well is the common belief of MTA geological department that the further expansion of the field should be in the NE direction of the field. KD-23 well produced 11,789,950 m^3 fluid in the performance prediction period and 1166 kPa decline in pressure was monitored. The pressure declines at the bottom of the other production wells were more than performance prediction Run-1 (without adding any producer and injector). 103,851,808 m^3 fluid produced in this simulation period.

Pressure decline contour map of the Kizildere Geothermal field for this run is given in Figure 10. As observed, addition of a new production well caused a higher-pressure decline in the NE corner of the field. The pressure decline in monitoring well KD-8 was 534 kPa in Run-1, but with the addition of KD-23 as a production well it increased and became 600 kPa. The response of the other part of the field to the new production well is in the direction of increasing in pressure decline but not as much as in the NE corner.

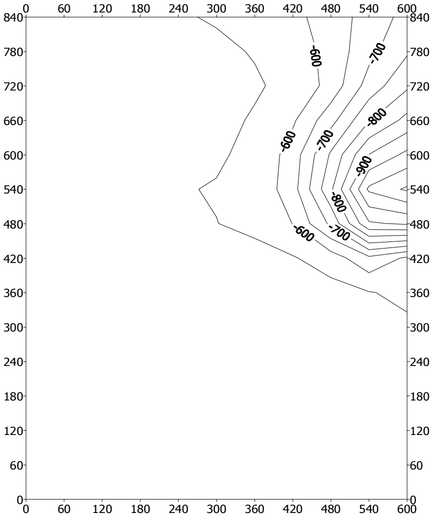

Figure 10. Pressure decline contour map of prediction Run-2

Performance prediction Run-3

At this scenario a new production well (KD-24) at the SW corner of the field was added (Figure 8). The purpose of putting a new wellbore into this location is the existence of an already drilled wellbore (R-2) nearby. It is aimed with KD-24 to observe the possible effect of R-2 beforehand. Well KD-24 produced 14,628,749 m^3 fluid in the prediction period and decline in pressure is 1552 kPa. The pressure declines of the other production wells were more than Run-1. 106,659,107 m^3 fluid produced in this simulation period

SW corner of the field responded to well KD-24 with an increase in pressure decline compared to decline in Run-1 (Figure 11.).

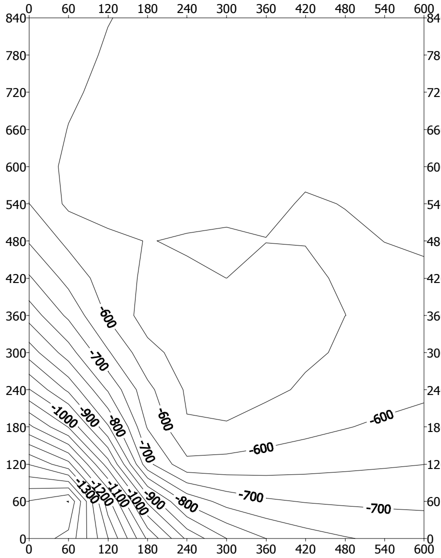

Figure 11. Pressure decline contour map of prediction Run-3

Performance prediction Run-4

In this run, the monitoring well KD-7 was converted to a re-injection well. The reason of the use of KD-7 as an injection well bore is the previous re-injection attempts tried in this well bore. The re-injection rate of the fluid is 2500 m^3/day and a continuous re-injection is done during the prediction period. The effect of the re-injection to the reservoir pressure was monitored. The total produced fluid is 92,052,244 m^3 while 10,957,500 m^3 of fluid was re-injected. The amount of fluid re-injected corresponds to 12 % of the total produced fluid during performance prediction period.

Re-injection of fluid caused lower pressure decline in the field compared to decline observed in Run-1, the decline in pressure continues (Figure 12).

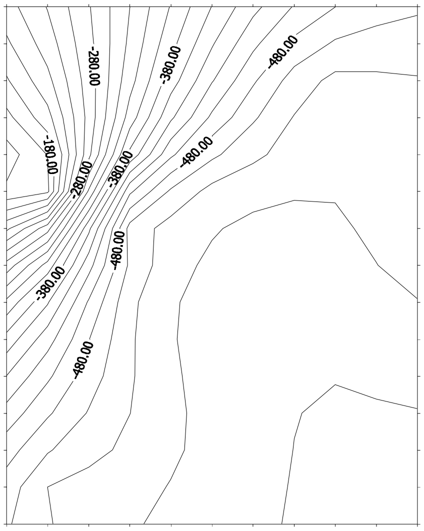

Figure 12. Pressure decline contour map of prediction Run-4

Performance prediction Run-5

In this run, again well KD-7 was converted to a re-injection well, but instead of fixing re-injection rate bottom hole pressure (BHP) of the well was fixed at 9000 kPa. The amount of fluid re-injected was determined by the simulator to achieve this goal. Total fluid re-injected is 79,620,425 m^3. Figure 13 shows the results of this run. Since the amount of fluid re-injected is very close to the total fluid produced (92,052,244 m^3) there exists lower decline in pressure in all wells and some of the wells experienced an increase in their BHP values. To be able to keep the BHP of the well KD-7 at 9000 kPa, a pressure increase of 2830 kPa was required which should be supplied by pump pressure. The amount of fluid to be reinjected is too high to be realized from a single wellbore.

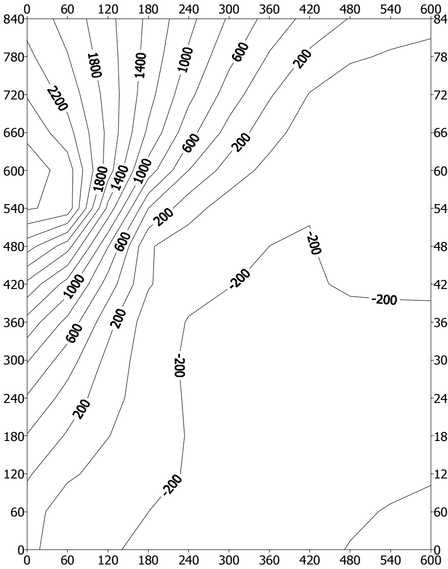

Figure 13. Pressure decline contour map of prediction Run-5

Performance prediction Run-6

Within this scenario KD-22 was used as a re-injection well with a rate of 4500 m^3/day. The fluid was re-injected without any interruption throughout the performance prediction period; therefore the total amount of re-injected fluid is 19,723,500 m^3. Since KD-22 was converted from a production to a re-injection well, the total fluid produced from the field decreased to 81,273,288 m^3. The proportion of re-injection to production is 24.2 %. The pressure depletion at the bottom of the wells decreased but no increase in pressure was observed in any well, except KD-22. (Figure 14).

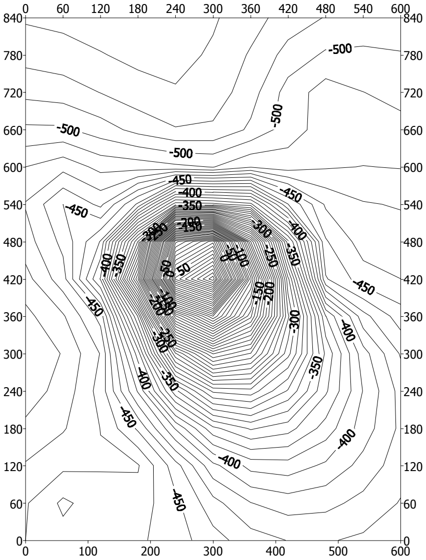

Figure 14. Pressure decline contour map of prediction Run-6

Performance prediction Run-7

At this scenario, the fluid was re-injected from KD-22 with 9000 kPa pressure at the bottom of the well (BHP was increased from 6187 kPa to 9000 kPa). The reason of the selection of KD-22 as a re-injection well is to observe the response of the field to the fluid reinjection from the center of the field. The total produced and injected fluids are 81,273,288 m^3, 79,129,344 m^3, respectively. Since production and re-injection amounts are very close to each other, bottom of pressures of most wells increased and the rest had very low decline in pressure (Figure 15).

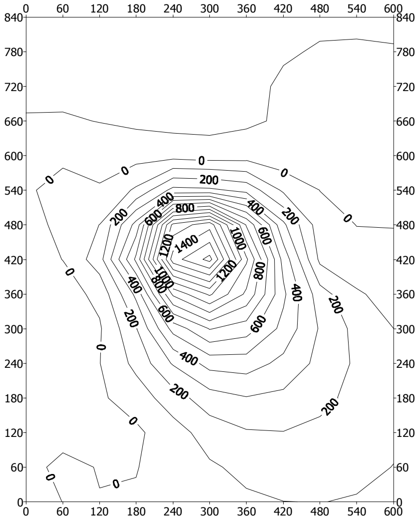

Figure 15. Pressure decline contour map of prediction Run-7

Performance prediction Run-8

At this scenario 4500 m^3/day fluid was re-injected from KD-24 without any extra pump pressure. 92,253,947 m^3 fluid was produced in this prediction period. Amount of fluid re-injected was 19,723,500 m^3 which is 21.4% of total fluid produced. The extent of pressure decline in whole reservoir decreased but no increase in pressure in any well (Figure 16). The location of this well is very close to the location of the re-injection well, R-2, drilled by MTA.

Performance prediction Run-9

At this scenario KD-24 was an injector with 9000 kPa constant pressure. In order to achieve this 36,095,112 m^3 fluid was re-injected from the wellbore. Total fluid production is 92,253,947 m^3 and the injected to produced fluid ratio is 39.13 %. Although there exists decrease in the extent of pressure decline in reservoir, no increase in bottom hole pressure of any well was observed (Figure 17).

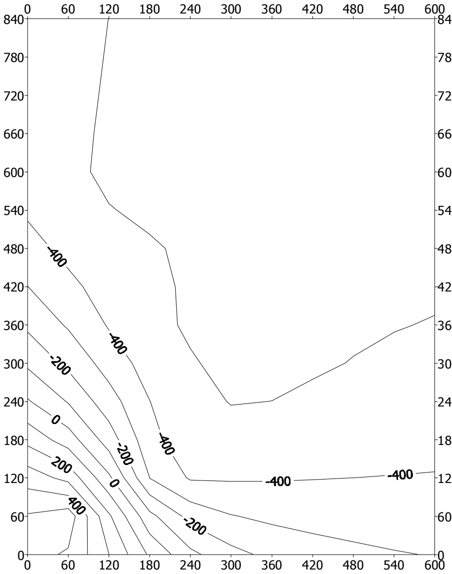

Figure 16. Pressure decline contour map of prediction Run-8.

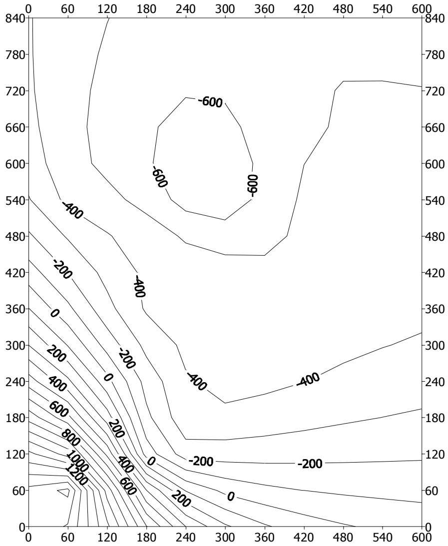

Figure 17 Pressure decline contour map of prediction Run-9.

CONCLUSION

The following conclusions can be drawn from the analysis of the results of this study:

1. Interpretation of pressure build-up test data of Kizildere Geothermal field modeled with dual porosity behavior.
2. Simulation of Kizildere Geothermal Field with a producing zone thickness of drilled Igdecik formation could not match the pressure history of the field. As a result, a bottom aquifer with a thickness of 200 m taken as the fluid recharge and pressure support of the system.
3. Performance prediction trial of the field with existing wells without re-injection gave an average pressure decline of 530 kPa after a period of twelve years production. Necessity and importance of re-injection becomes more obvious from this result.
4. Among the nine performance prediction runs (between 2001 and 2012), re-injection application from the center of the field (KD-22) resulted with full pressure support with increase in bottom hole pressures.
5. Re-injection trials from the sides (SW or NE) of the field resulted with lower pressure support compared to the re-injection from the center of the field.
6. Re-injection of the fluid with a constant bottom hole pressure of 9000 kPa resulted with the highest-pressure support, but the amount of fluid to be re-injected for this purpose is too high to be injected from a single well.

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