Numerical Modeling of Kizildere Geothermal Field, Turkey

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Abstract

A numerical modeling study was carried out to simulate Kizildere geothermal field of Turkey. Three different reservoir models were developed: isothermal, non-isothermal and non-isothermal with CO_2. While developing the reservoir models, permeability values from build-up tests that indicated a double porosity behavior and log-derived porosities were used. For the isothermal model production and pressure history match was obtained using 200 m thick bottom aquifer for pressure support. On the other hand for the non-isothermal model a good temperature, pressure and production match for the available 17 years history was obtained using a thick layer of rock strata underlying the reservoir and a bottom aquifer for pressure support. When free carbon dioxide was assumed to be present in the reservoir, the pressure response of all production wells oscillated resulting in high uncertainty. Among several re-injection trials, re-injection of produced geothermal water from the center of the field resulted with the highest-pressure support for all numerical models.

Keywords: Numerical modeling, history matching, reinjection, carbon dioxide

Introduction

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 hot water springs at a temperature between 30 °C and 100 °C.

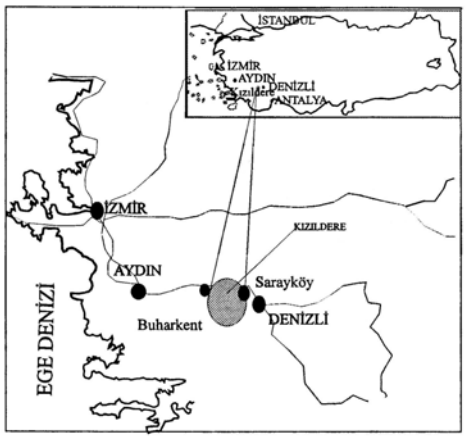


Figure 1. Location of Kizildere Geothermal Field (Aksoy, 1997).

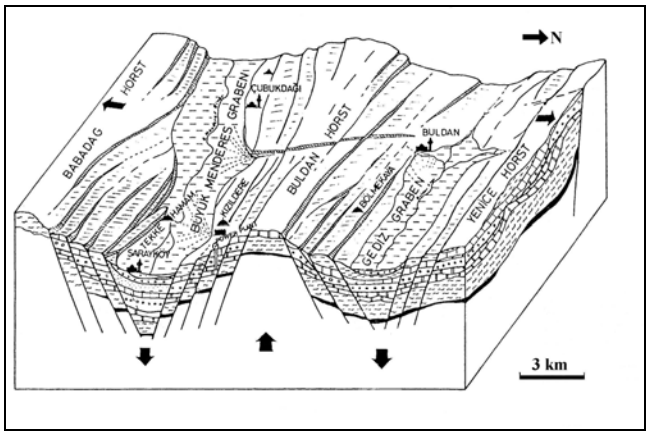


Figure 2. Horst-Graben Systems in Western Anatolia (Simsek, 1985).

Kizildere geothermal field consists of two producing reservoirs in the intermediate block within the depths explored. The main reservoir, Igdecik formation, which is composed of crystalline high fracture permeability limestones is in the metamorphic basement. Sazak, a limestone formation, is the minor producing zone and lies above Igdecik. Kizilburun, Kolonkaya formations and locally Sazak formation forms the caprock. The maximum temperatures of Sazak and Igdecik formations are 198 °C and 209.1 °C, respectively. The first well, KD-1, drilled in 1968 produced a mixture of water and steam with a temperature of 198 °C at a depth of 540 m indicating the existence of a water-dominated geothermal system. A total of 17 wells have been drilled. 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 producing wells are between 370 m-1241 m.

Kizildere geothermal field has three main problems: calcite scaling in the production wells and surface lines, depletion of reservoir pressure due to production and the disposal of wastewater with high boron content (25-30 ppm) into B.Menderes River. The most obvious solution to the aforementioned problems is the re-injection of power plant effluent. It is aimed to understand the behavior of Kizildere geothermal field by means of numerical modeling. Reservoir characterization and modeling studies of the Kizildere geothermal field were carried out to forecast the response of Kizildere Geothermal Field using three different models (isothermal, non-isothermal, and non-isothermal with CO_2 presence) and scenarios with and without re-injection practices. A three-phase multi-component thermal and steam additive numerical simulator, STARS (CMG, 2002) was used throughout the study. Pressure build-up tests, and density - neutron logs were the data sources to estimate permeability and porosity values of the reservoir.

Results

In this study, STARS thermal simulator (CMG, 2002) was used. In both isothermal and non-isothermal models a Cartesian dual porosity simulation model was developed with the properties given in Table 1. The models were calibrated using past production, temperature and pressure data from Kizildere geothermal field, Turkey (Yeltekin et al, 2002). A rectangular grid model of 8x12 grids was used (Figure 3). All grids had equal dimensions (60x60 m) except at the corner blocks where 120x120 m was used. The depth of formation top of the blocks (Figure 4) matched the depth of the producing reservoir (Igdecik formation)

and the thickness was divided into five equal parts. For the isothermal simulation model an aquifer was placed at the bottom of the last layer to simulate the natural water discharge. On the other hand for the non-isothermal models the last z block was thick (5000 m) and was supported by a thermal aquifer at 220° C. Both of the developed simulation models were in accord with hydro-geological models (Satman and Serpen, 2000; Dominco, 1974) that consider infiltration of meteoric water into deeper sections of the Earth and up-flow of it after heating. The permeability data initially derived from well test analysis (Kappa, 2001) was modified to achieve a reasonable match for both models. It should be noted that the operating company reinjected some of the effluent at 147 °C from well KD-24 for about 6 months that was also considered during the matching process in both models.

Sample pressure and temperature history matches for wells KD-6, KD-13 and KD-20 are provided in Figures 5 through 7. It could be seen that when CO_2 presence is considered pressure oscillations could be observed. These oscillations coincide with mechanical scale reaming periods during which the well is shut for a period of about one week. It is apparent that such high oscillations are physically unrealistic. These unrealistic pressure humps are probably due to the numerical instabilities, CO_2 insulation effect and multiphase flow effects. There is also a minor pressure oscillation effect for the non-isothermal model when compared to isothermal one that could be related to the heating effect. The initial and final temperature and pressure distributions at the end of 14 years of history match for the non-isothermal model are given in Figures 7 and 8, respectively.

Table 1. Simulation model properties

Property	***Value***
Fracture spacing	20 m.
Shape factor	Gilman – Kazemi
Fracture relative permeability	Power law n = 2.8
Matrix permeability	1 md.
Fracture porosity	0.08

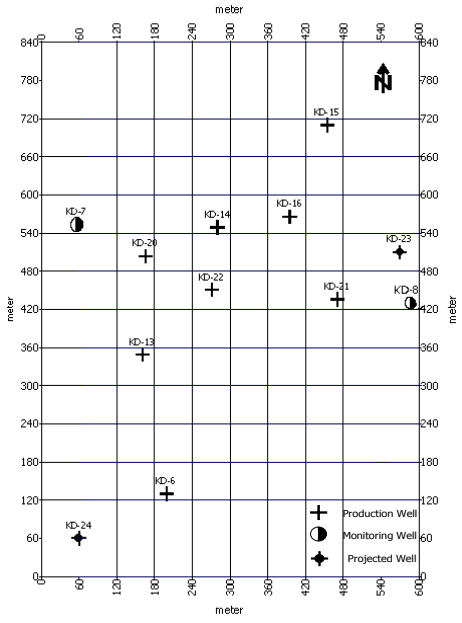


Figure 3. Well locations and model grid diagram.

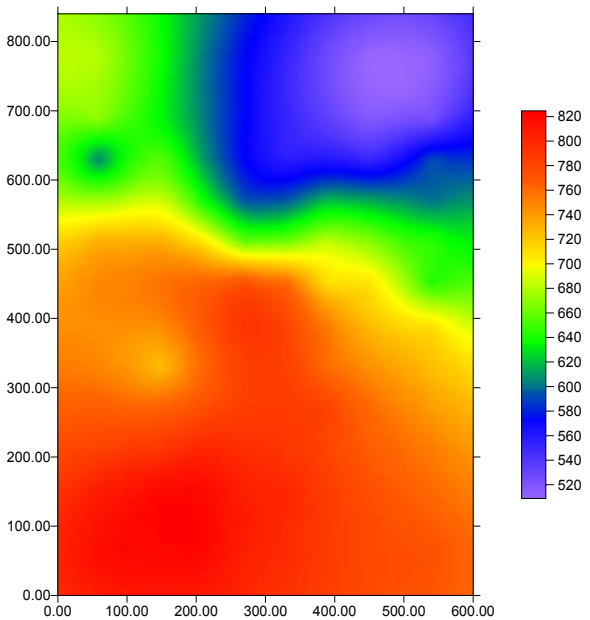


Figure 4. Grid tops (m) distribution for the producing layer.

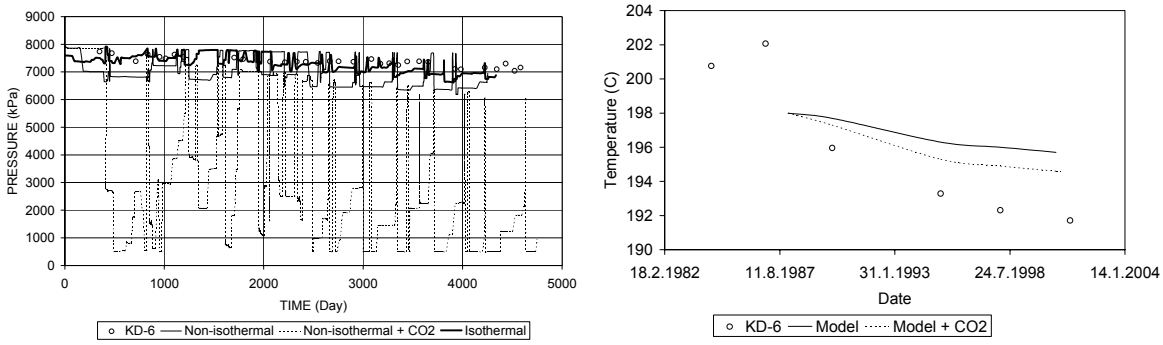


Figure 5. Pressure (left) and temperature (right) match for well KD-6.

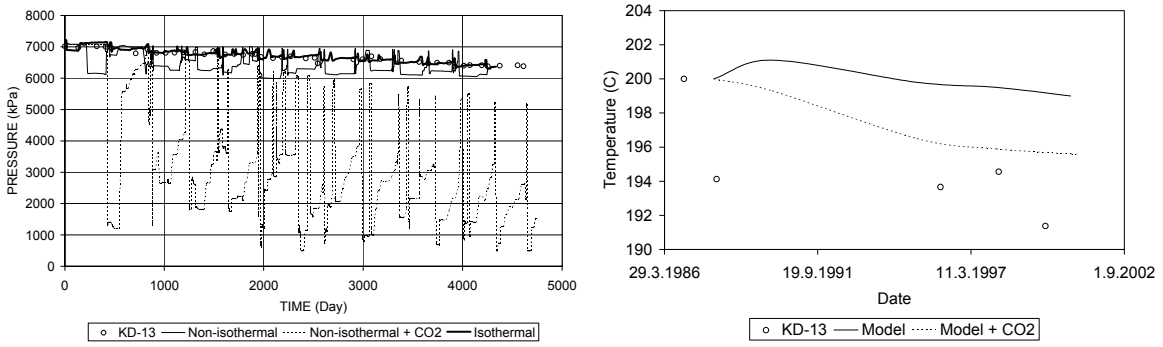


Figure 6. Pressure (left) and temperature (right) match for well KD-13.

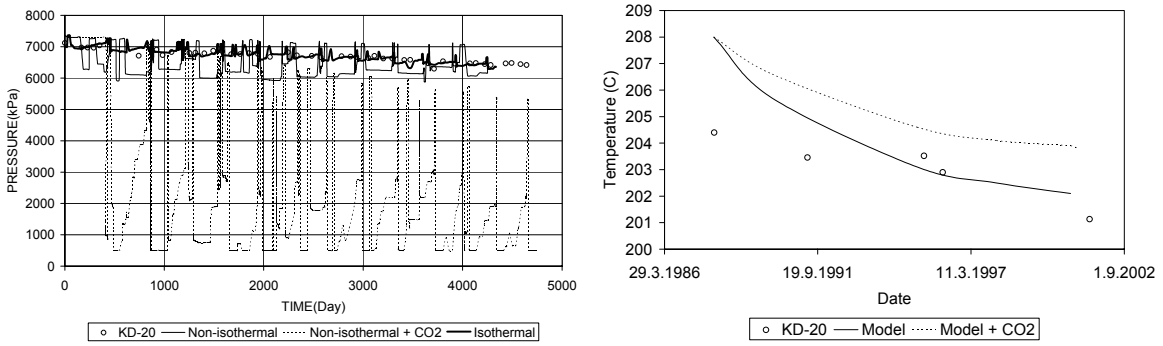


Figure 7. Pressure (left) and temperature (right) match for well KD-13.

The non-isothermal model sans CO_2 was selected due to unphysical oscillations stated above for further study. The temperature (Figure 8) and pressure distribution (Figure 9) at the beginning and the end of the simulation period is used as basis. It could be seen that the temperature of the field as of today is lower at the southwest of the reservoir compared to the other regions. On the other hand, pressure is lower mainly at northeast part of the system.

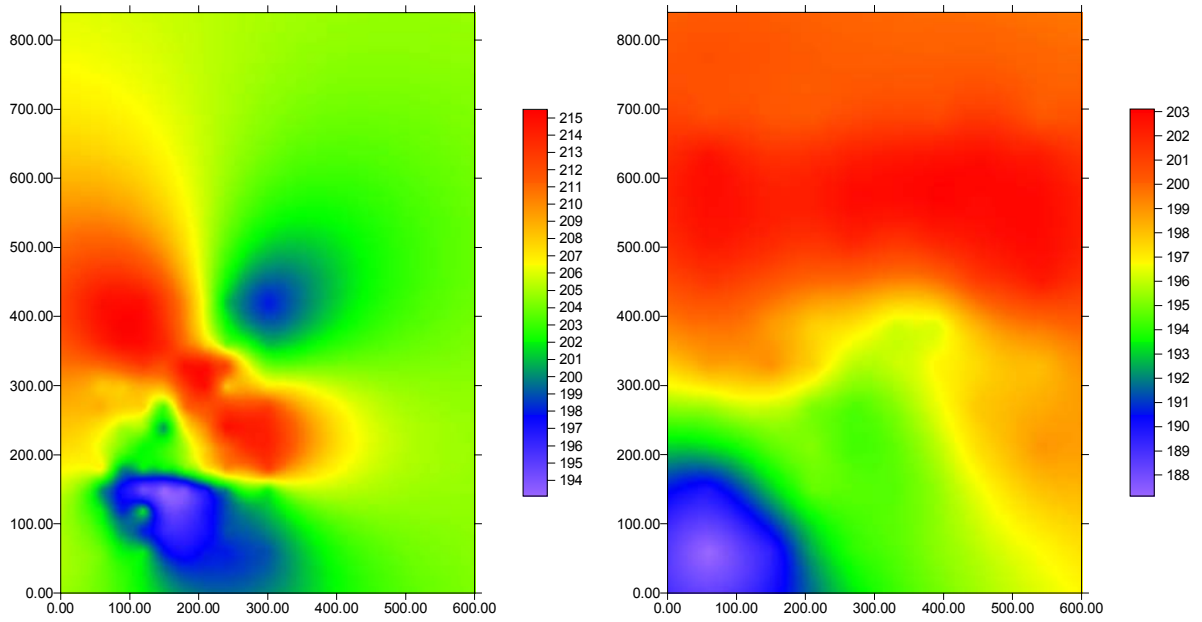


Figure 8. Temperature (°C) distribution. Initial - 01/01/1988 (left), final - 01/09/2002 (right).

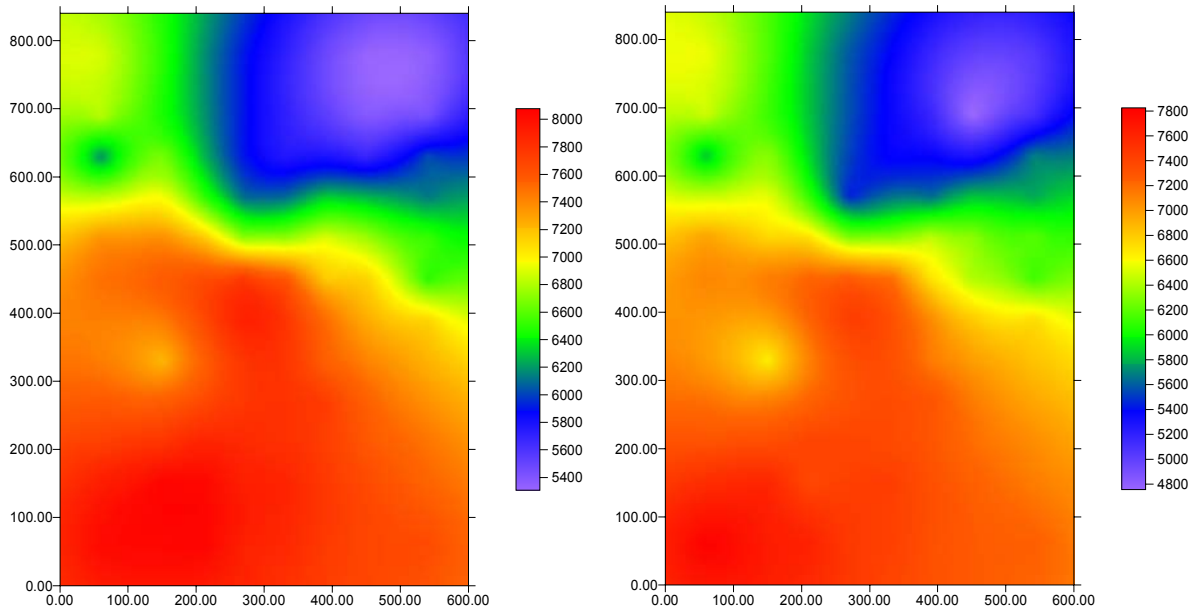


Figure 9. Pressure (kPa) distribution. Initial-01/01/1988 (left), final-01/09/2002 (right).

Several reinjection locations were used to evaluate the reinjection possibilities. The locations considered were center of the field, corners of the field and finally sides of the field. Several different injection rates from 2500 m^3/day to maximum rate of 4911 m^3/day (limited due to presently available pumps) were also considered. For all simulations the injection temperature was 147 °C simulating the present case. As a general observation for high injection rate (4911 m^3/day) overall temperature decrease was less pronounced (usually less than 4°C per grid block) with corner injections (Figure 10); however, pressure drop was the highest (more than 130 kPa per grid block (Figure 11)). On the other hand, injections near the center of the field resulted in better pressure support (less than 117 kPa per grid block) but cooling was somewhat more (about 5 and 6 °C per grid block). These observations were valid also for the lower injection rates; however, the magnitudes of the pressure drop were

somewhat different. When two extreme injection rates are considered, high injection rate results in better pressure support especially at the southeast of the reservoir. The overall pressure decrease is considerably less than that of the low injection rate. On the other hand, when low injection rate is preferred, the reservoir cools slower If maximum enthalpy is the overall objective, then lower injection rates need to be selected. In all cases southeast of the reservoir seems to be the ideal location for reinjection. This location also hosts a fault named as southern fault zone and connects to another geothermal reservoir namely Tekkehamam region located approximately 4 km from the nearest well in the area.

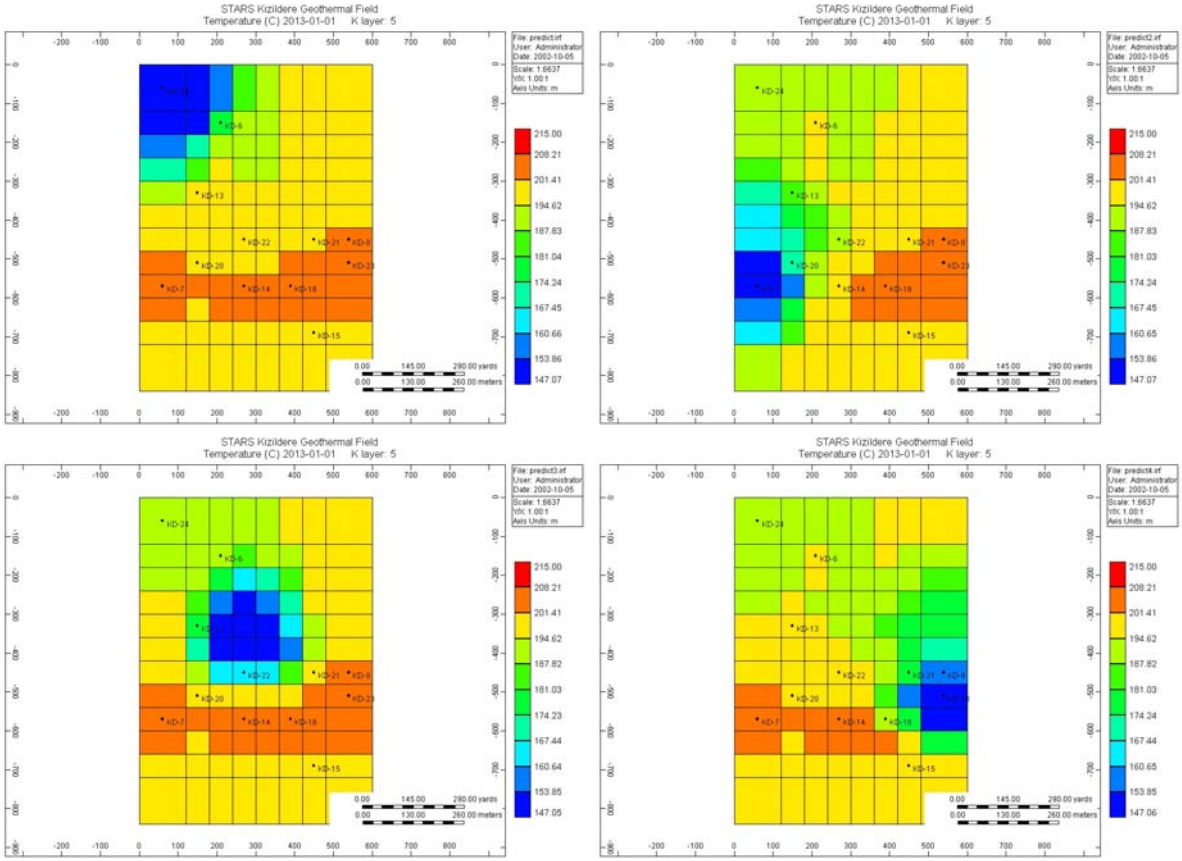
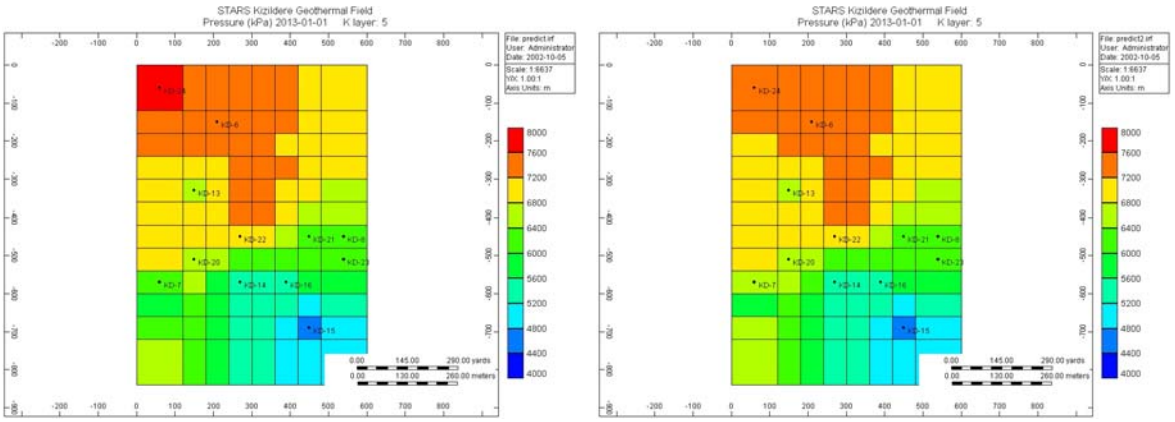


Figure 10. Temperature (℃) distribution for different reinjection scenarios: top row left, north west injection; right, center west injection; bottom row left, center injection; right, center east injection.



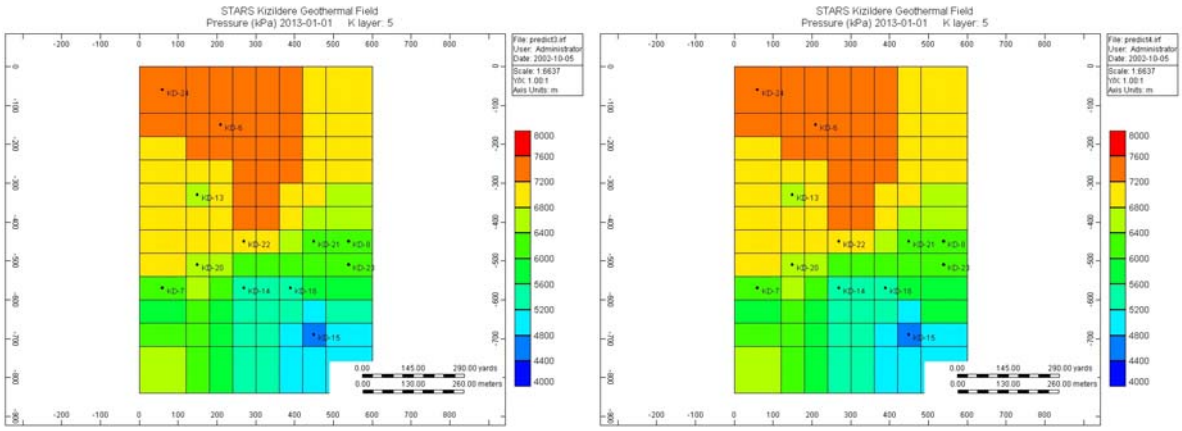


Figure 11. Pressure (kPa) distribution for different reinjection scenarios: top row left, north west injection; right, center west injection; bottom row left, center injection; right, center east injection.

Conclusions

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

1. For high injection rate (4911 m^3/day) overall temperature decrease was less pronounced with corner injections; however, pressure drop was the highest (more than 130 kPa per grid block.
2. Injections near the center of the field resulted in better pressure support but cooling was somewhat more.
3. High injection rate results in better pressure support especially at the southeast of the reservoir.
4. For high injection rates, the reservoir cools faster.
5. Southeast of the reservoir seems to be the ideal location for reinjection.

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