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Numerical Reservoir Simulation of Alaşehir Geothermal Field

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ABSTRACT

Use of a comprehensive reservoir simulation is essential for an effective geothermal reservoir management. TOUGH2 has become a widely used simulator for this purpose. In this study, one of the most exploited geothermal fields in Turkey, Alaşehir geothermal field has been modeled by using TOUGH2 reservoir simulator. The study includes more than 100 wells, which are operated by 7 different developers. The total installed capacity of geothermal power plants in the field is 212 MWe, but additional capacity (98 MWe) is planned to be commissioned by the end of 2020. The proximity of licensed areas and strong well interferences have made the simulation necessary for a successful reservoir management. Different data sources including pressure transient tests, reservoir monitoring and tracer test data were coupled to construct a large numerical model, which has dimensions of 18 kmx12kmx5.5km. During model calibration, good matches were obtained between model results and actual decline in the reservoir temperature, pressure and non-condensable gases (NCG) production. The effect of planned power plants on the field performance is studied by performing scenario runs using maximum possible flow rates. Model results indicated that commissioning of new power plants and additional make up wells that will compensate missing production accelerates pressure decline to more than 3 bars/year.

1. INTRODUCTION

Reservoir modeling is a powerful reservoir management tool for describing reservoir's dynamic behavior under different production scenarios. A good reservoir model should represent the actual reservoir conditions such as spatial distribution of geological formations, fault orientations, reservoir temperature and pressure, reservoir rock and fluid properties and etc. Since numerical modeling is a non-unique solution, differing history matches may be obtained using representative or non-representative models with different values of tuning parameters. Most of the time, non-representative models fail to predict the reservoir dynamics under new conditions. Thus, it is essential to understand the characteristics of geothermal reservoir. Use of variety of data from different sources is the most effective way of characterization. In this study, a comprehensive geothermal reservoir model is constructed by using TOUGH2 with PETRASIM interface. Equivalent porous medium (EPM) modeling approach was used to simulate the Alaşehir geothermal reservoir. Since, Alaşehir field produces from faults and fault associated fractures that are highly interconnected, a discrete fracture network (DFN) model was previously studied by using FracMan7.6 (Aydin and Akin, 2019). The study included a smaller reservoir volume and several fracture parameters and reservoir properties were obtained as the result of study that was limited with fracture characterization and data upscaling. Beside, each well was tested individually and the effect of other wells were not investigated. The DFN model was extended to simulate a larger reservoir volume by including more than 100 wells. Thus, Alaşehir geothermal reservoir was modeled using EPM approach by implementing the properties of grid blocks that intersect with faults that were then modified to account for the contribution of fault zones to the flow.

2. DATA COLLECTION

The model was populated with variety of data from different sources. Outcrop data, well logs, drilling cuttings, drilling mud loss data, seismic interpretations, pressure transient tests, tracer test and reservoir monitoring were the main data sources that were used in Alaşehir model. Some of these data were collected from the literature but most of the data were gathered from field studies. Gurel (2016) developed a fractal model to determine fracture properties of the reservoir rock such as fracture permeability, porosity and aperture. He noted that porosity ranged between 3 % and 12% and permeability changed between 0.3 Darcy and 1.5 Darcy. Çiftci (2007) studied the geology and tectonics of the field. He reported that high angle normal faults and low angle North dipping detachment faults form the major conduits in the South of the graben. He noted that low angle (0-20°) North dipping detachment faults bound the southern margin of the graben and they constitute the contact between Menderes metamorphic and sedimentary overlain rocks. Akin (2013) incorporated drilling mud loss data into an artificial neural network model to determine fracture flow properties. Aydin et al. (2018) monitored geochemical and CO_2 production data to understand well interconnectivity in Alaşehir field. They determined that all the wells are interconnected through conductive faults. Aydin and Akin (2019) interpreted pressure buildup and fall off tests conducted at different wells of Alaşehir field. They reported spatial distribution of transmissivity and porosity. Obtaining well location and geology data was one of the main challenges throughout this study. Google Earth analysis was conducted to determine the well locations. By physically analyzing infrastructure of well pads, a well is selected as an injection or production well. All of the used wells are assumed to be active. The depth and producing intervals of the wells are estimated by using the fault dip angle and available information of some wells. The net electricity generation of 12 power plants are retrieved from Turkish Energy Transparency Platform (EPIAS, 2020). The net electricity was first converted to gross production by assuming internal consumption of power plants. After that, total fluid production for each plant was estimated based on reservoir enthalpy for a particular production area. It was found that based on enthalpy variation in the reservoir, 40 ton per hour to 60 ton per hour total fluid production (geothermal brine + steam + NCG) is needed to generate 1 megawatt power in Alaşehir field. There are 12 binary type plants and a double flash combined binary power plant in the field. It was assumed that in binary type power plants reinjection is 99 % and 1% NCG is released to the atmosphere. In the combination type plant, 16 % of total fluid is released to the atmosphere in the form of steam and NCG. Based on these assumptions, the total production rate of Alaşehir geothermal field was found 12600 ton per hour and reinjection rate was calculated as 12050 ton per hour. Total production and injection rate calculated for each geothermal power plant is divided by the number of production and injection wells obtained using the aforementioned Google Earth identification procedure. It was assumed that each well contributed to production or injection equally.

3. ALAŞEHIR FIELD

The stratigraphy of the Alaşehir geothermal reservoir is mainly represented by metamorphic rocks of the Menderes Massif and synextensional Salihli Granitoid as basement rocks, which are tectonically overlain by Neogene-Quaternary aged sedimentary rocks. These rocks are cut by detachment faults, which are also cut by younger various high angle normal faults (Iztan et al, 1991; Seyitoğlu et al, 1994; Seyitoğlu and Scott, 1996; Yazman, 1995; Yazman et al, 1998; Yılmaz and Gelişli, 2003). Basement is composed of Menderes Massif rocks overlain by younger carbonates that are highly fractured and karstified so that they are important to be possible geothermal aquifer. Menderes massif rocks are schists, quartzite, phyllites and marbles (Akin, 2017). The high temperature (> 190°C) geothermal reservoir in the upper section of the Paleozoic basement feeds from zones in the carbonaceous metamorphics at approximately 1150 m and 1600 m depths (Figure-2). The reservoir has good permeability-thickness probably from intersecting fractures. The southern part of the reservoir is liquid dominated with 2% to 4% CO_2 by weight. Well depths reach to more than 3000 m near the center of the graben. In this part, the highest recorded bottom hole temperature is 251°C at a depth of 3011 m. The average flow rate is 300 ton/hr suggesting a similar permeability-thickness that has been observed in the southern part (Akin, 2017). The location of the field and geothermal power plants operated by developers are given in Figure 1.

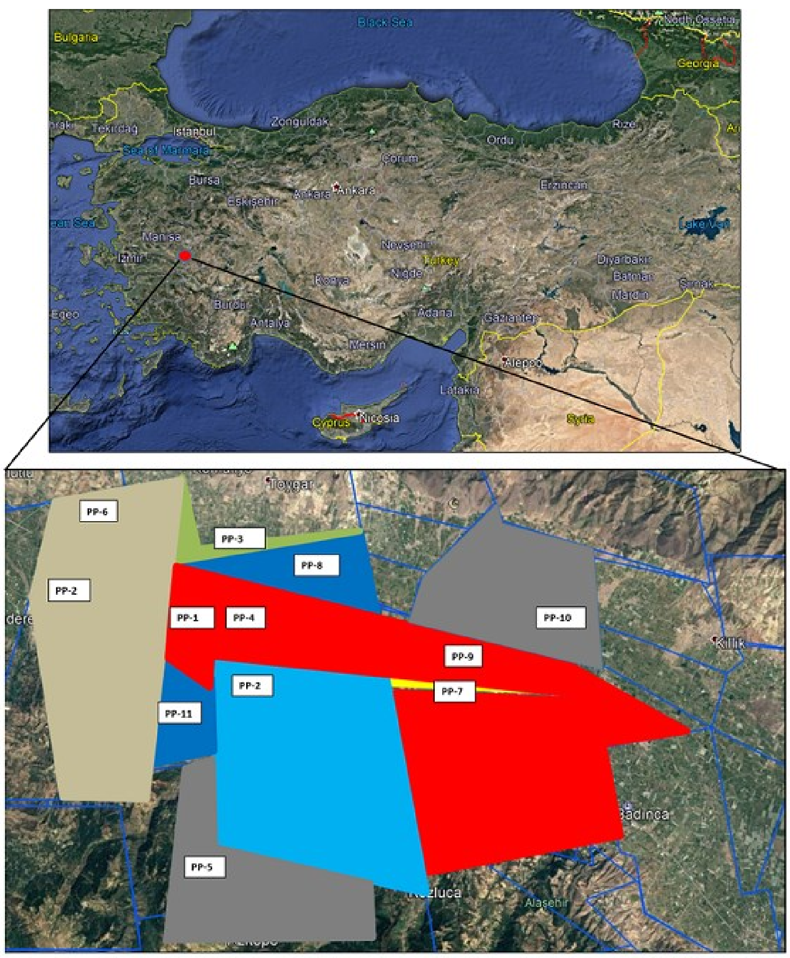

Figure 1: Licensed areas and location of power plants in Alaşehir Geothermal Field

4. CONCEPTUAL MODEL CONSTRUCTION

Conceptual model of Alaşehir field was developed by (Ciftci and Bozkurt, 2009). According to this conceptual model, geothermal fluid is of meteoric origin and there are conductive faults, which have connection between surface and subsurface. Meteoric water and spring water travel along conductive faults to the reservoir rock (Figure 2). The reservoir rock consists of fractured schist, quartz and marble sections. The reservoir rock is overlaid by sedimentary rocks and alluviums which act as cap rock of the system. A large reservoir volume is modeled by using stratigraphic and seismic information. Model area covers 18 km x 12 km with a maximum depth of 5.5 km. For simplicity all sedimentary units are treated as one single unit and the reservoir rock is considered as another unit (Figure 3).

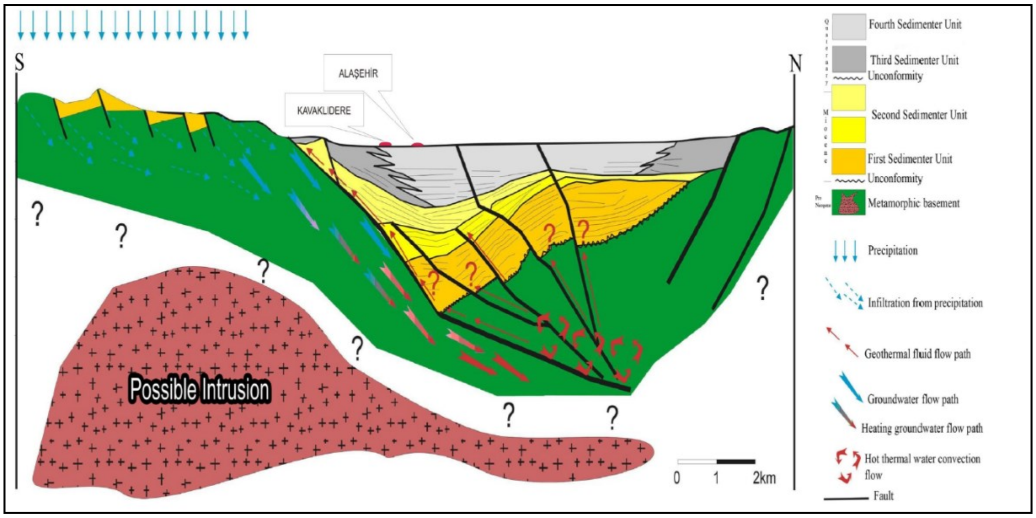

Figure 2: Stratigraphic units and static (Ciftci and Bozkurt, 2009).

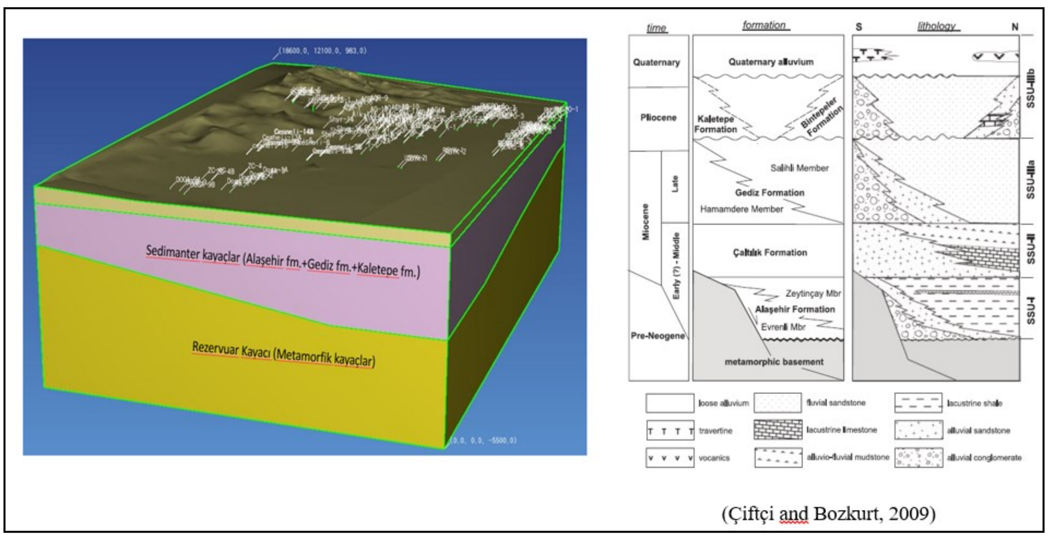

Figure 3: Stratigraphic units and static model construction

5. NATURAL STATE SIMULATION

Once the conceptual model is constructed, the study proceed with gridding process. Grid dimensions of the model changed between 250 m, 1000 m and 1500 m (Figure 4). Well field was kept smaller (250 m) while other parts of the field were divided into larger blocks. There are two up flow zones in the field. To represents these up flow zones, two sources are defined from the bottom of the reservoir: deep source located at 5500 meter depth with 13 km^2 area, 0.4 kg/sn liquid rate, 0.3 j/s*m^2 heat flux, 1000 kj/kg enthalpy and 2% NCG; a shallower source located at 700 m to represent cold recharge influx with 13 km^2 area, 0.4 kg/sn liquid, 750 kj/kg, without NCG. The surface of the model was conditioned as fixed state with 1barg and 20 °C temperature. Surrounding boundary of the model was assumed to provide 0.1 kg/sec constant flow rate (Figure 5). The model was run for 700000 years and it was found that after 100000 years the model reach to steady state conditions (Figure 6). Good matches were obtained between actual static PT profiles and simulated wells' profile (Figure 7).

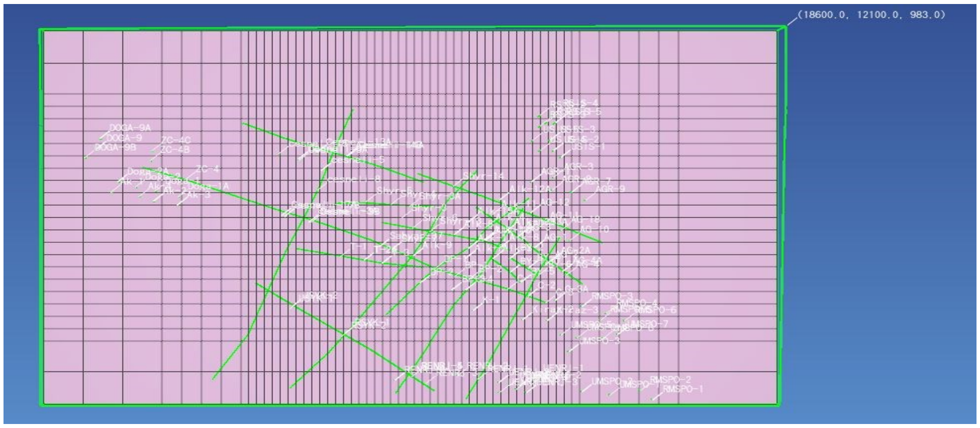

Figure 4: Gridding process

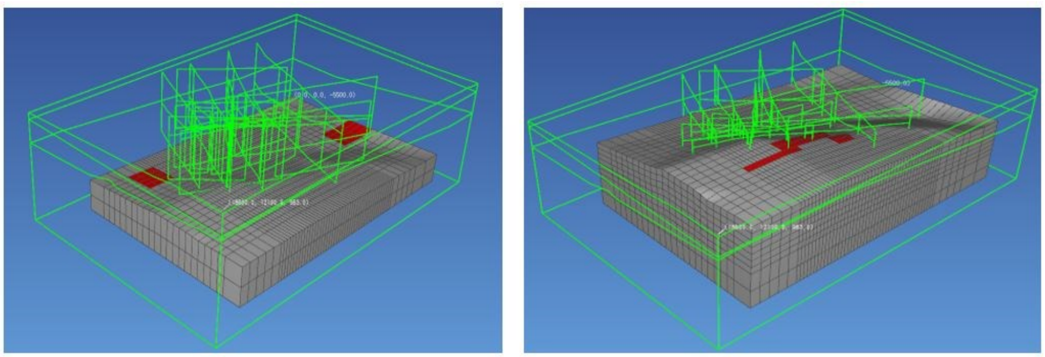

Figure 5: Deep and shallower sources

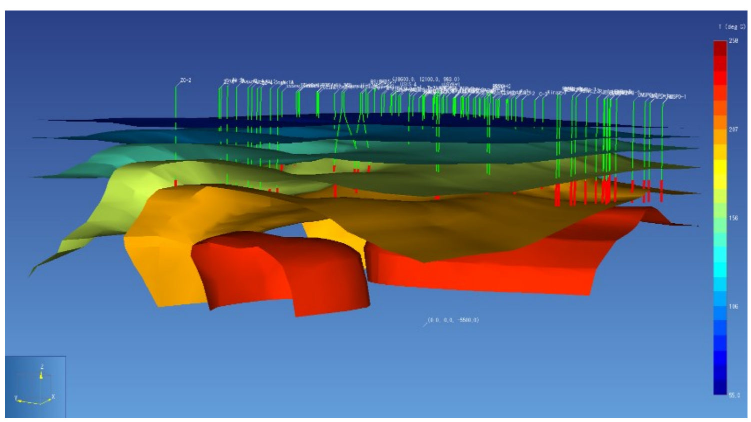

Figure 6: Isosurfaces of simulated temperatures

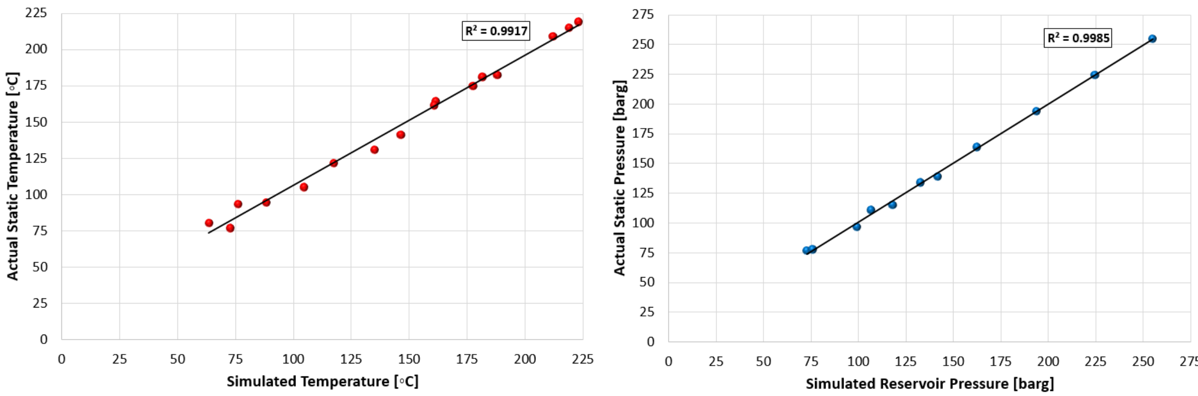

Figure 7: Matches verification

6. HISTORY MATCHES

History matching was carried out by changing some model parameters to obtain good matches with actual observation data. In Alaşehir geothermal field, significant local pressure drops, temperature reduction and NCG decline occurred in some wells. Moment analysis of tracer data was carried to obtain reservoir volume between injection and production wells. By changing volume factor in the numerical model the same fracture pore volume in between corresponding wells throughout fault zones was obtained that resulted excellent temperature and pressure matches (Figure 8). Permeability factor was mainly used in a similar fashion to obtain matches of NCG and pressure declines (Figure 9).

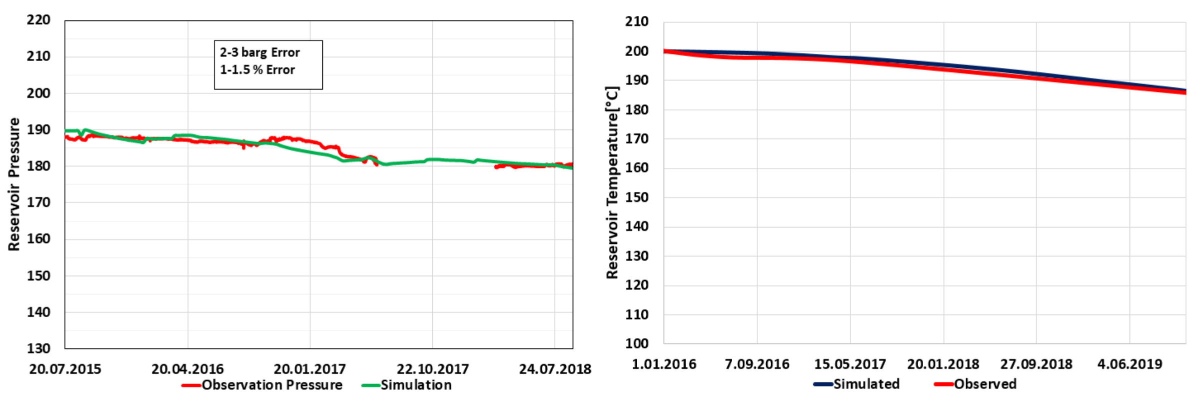

Figure 8: History matches of temperature and reservoir pressure

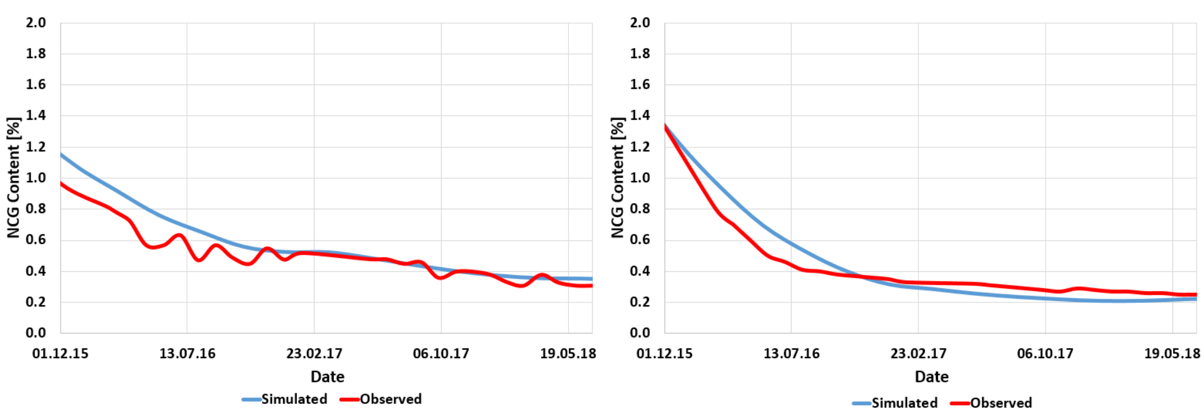

Figure 9: Calibration of NCG decline for two different production wells

7. PRODUCTION FORECASTING

The current production scenario of the field can be defined as aggressive since most of the wells are operated at their maximum allowable rates. High local pressure drops are observed in some parts of the field where most of the production occurs. In other parts of the field, strong hydraulic connectivity between injectors and producers that accelerates temperature and NCG decline was observed. By keeping the current production and injection rates, the average reservoir pressure decline was found as 3 bars per year. However, it should be noted that average reservoir pressure covers the whole system. Thus, local pressure drops can be larger than average reservoir pressure decline. NCG decline of some wells reached to negligible levels, which means that in Alaşehir field, some part of the field will produce almost no emissions within few years. In some parts of the field, temperature decline is also found to be significant. Thus, to compensate power reduction there will be a need for larger flow rates.

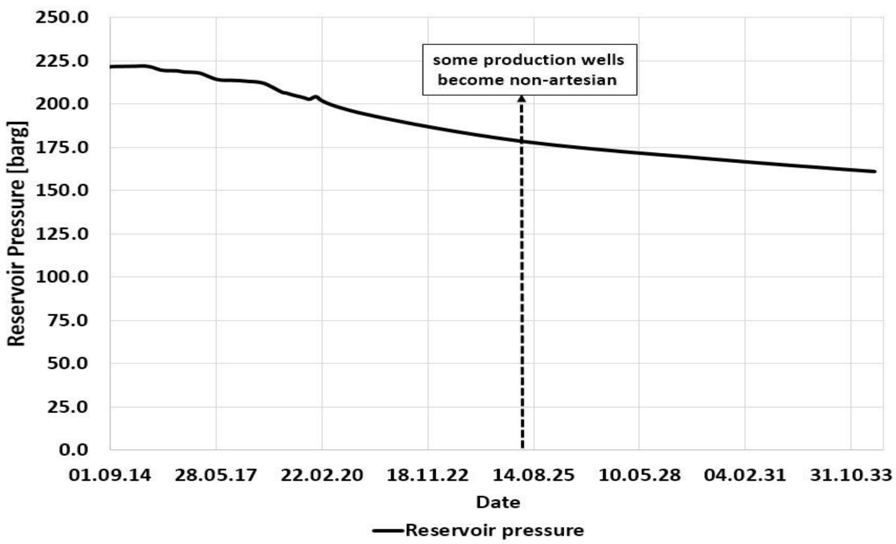

Figure 10: Decline of reservoir pressure at 2000 m depth

8. CONCLUSION

A comprehensive numerical model of Alaşehir geothermal field that simulates more than 100 wells operated by 7 different operators has been developed using TOUGH2. The model was populated with a variety of data sources including geology, geophysical and actual well data as well as publicly available power production data. Currently it is believed to be the one of the largest geothermal reservoir simulation models ever build in Turkey. The following conclusions were drawn using the model runs.

1. With the current aggressive production scenario, it has been observed that most of the wells will suffer from high local pressure drops by the end of 2024.
2. Significant NCG and temperature declines will be observed in several locations due to high hydraulic connectivity between injectors and producers.
3. Average pressure decline of the field is calculated as 3 bar/year; however, local pressure drops that are larger than this value can occur.
4. All these problems show that, there is a need for unitized reservoir management.
5. It is possible to maintain production with make-up wells in the short term; however artificial downhole pumps may be needed to operate existing power plants at their nominal capacity.

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