PROCEEDINGS
JOINT CONVENTION BANDUNG (JCB) 2021
November 23rd – 25th 2021

Geothermal System Modeling of Roosevelt Hot Springs (RHS), Utah Using TOUGH2 Simulator

D.R.A. Gandini[1], N. Rahmawati[1], A.F. Raharja[1], D.B. Soebakir[1], M.I. Defri[1], M.D. Paratin[1], S. Widyanti[1]

[1]Department of Geophysical Engineering, Faculty of Exploration and Production Technology, Pertamina University

Abstract

Roosevelt Hot Springs (RHS) is a two-phase geothermal system located in the western side of Mineral Mountains, Utah. Previous study stated that the composition of the fluid has not changed since it was first produced in 1984, except for the effects of steam loss and injection fluid through well 14-2. To know the current condition of the geothermal system below the surface, conceptual model and reservoir simulation are made. The conceptual model is based on the results of geological, geophysical, and geochemical surveys that have been carried out in this area in previous studies. Furthermore, reservoir simulation using TOUGH2 is carried out by combining information of rock physical properties, initial conditions, boundary conditions, as well as sinks and sources to reach the natural state which is characterized by the similarity of the temperature to depth curve from the simulation results carried out with data from one exploration well and two monitoring wells. From the simulation results, it is known that the fractured granitoid reservoir is located at a shallow depth and is limited by the Opal Mound fault in the west which has low permeability. The heat source located in the eastern side of the RHS system, which is just below the Mineral Mountains, makes the fluid in the reservoir the hottest and has a temperature between 175-230°C.

Keywords: Reservoir simulation, geothermal system, TOUGH2, natural state, Roosevelt Hot Springs

Introduction

The Roosevelt Hot Springs (RHS) is a two-phase geothermal system located in Utah, United States of America. This geothermal system is located between the Mineral Mountains in the east and the central part of the Milford Valley in the west (Simmons, et al., 2018). The reservoir covering an area of about 32 km^2 is formed in fractured Precambrian gneiss and Tertiary granite by a fault intersection of the Opal Mound Fault and the Negro Mag Fault (Christensen et al., 1983; Ward et al., 1978; Moore and Nielson, 1994). The geothermal system is believed to be driven by heat from a young intrusion related to rhyolite domes emplaced beneath the Mineral Mountains, which is a 250 km^2 pluton, the largest and youngest in Utah (Lynne et al., 2005).

In 1984, fluids discharged from three production wells are used at tbe Blundell 1 flash plant which generates approximately 26 MW of electrical power (Blackett and Ross, 1992). Additional generation was installed in 2006 by commissioning of Blundell 2 binary plant which generates more 10 MW. Analysis obtained from reservoir fluid prior to production shows that fluid obtained from well 14-2 has the highest temperature and represents hydrothermal fluid in the geothermal system. However, during the production period, well 14-2 was used as an injection well. The reservoir fluid composition has likely not changed since 1984, except for the effects of steam-loss and mixing with the injection fluid (Simmons et al., 2018). This effect is the result of the pressure drop in the reservoir due to the fluid production process and the close distance between the injection well 14-2 and the reservoir. If sorted, the production wells that are most affected are wells 54-3, then wells 45-3 and 28-3. Meanwhile, production wells 13-10 are not affected even though they have been operating for years.

After the geothermal system has been producing for almost 40 years, it is very important to maintain the condition of the geothermal reservoir so that it can continue to produce. Because we cannot see its conditions below the surface with naked eyes, a reservoir modeling simulation was carried out in this study to determine the recent of the geothermal system, which was lastly carried out by Faulder (1991) and Yearsley (1994). Reservoir modeling will be carried out based on geological, geophysical, geochemical, and well data available using a software simulator named TOUGH2. This simulator will test the reservoir model based on previous conceptual model and predict the response of the geothermal system for various production scenarios.

Reservoir Modeling and Natural State Simulation

Reservoir modeling and simulation combine the information of rock physical properties, initial conditions, boundary conditions, as well as sinks and sources to reach the natural state. Initial condition is a state before the geothermal system is formed. While boundary condition is a special condition created around the simulation model of the geothermal system, especially around the reservoir, to keep fluid or heat accumulating in the geothermal system. For this reason, this boundary condition is set by using a constant pressure and temperature. To prevent the fluid or heat escaping the reservoir model, it is also assumed that the area around the reservoir is low permeability rock. Sinks and sources are other information needed in the simulation. Sink is a fluid that enters the geothermal system, such as natural recharge or reinjection wells. While the source is the fluid or heat that comes out of the geothermal system, such as manifestations or production wells. Natural state is a natural condition in a geothermal reservoir where no production or injection has been carried out which disrupts the reservoir state. In reservoir simulation, to know whether this condition is reached, it is necessary to do a curve matching by looking at the similarity of the temperature and pressure data with depth based on the reservoir simulation result and well data.

Data and Method

Based on the conceptual model of Simmons, et al. (2018), the subsurface conditions in the study area consist of three main rock types, namely Precambrian gneiss, Tertiary pluton, and basins containing sedimentary deposits. The temperature rise at the shallow depth of the well data indicates the upper part of the reservoir. The main meteoric recharge comes from rainfall on the summit and west side of the Mineral Mountains. The extensive fracture coupled with the complex east-west graben associated with the Negro Mag fault allows meteoric water to circulate to depths controlled by the presence of an open fracture. The intersection of the Opal Mound and Negro Mag faults produces a naturally fractured and intensive geothermal reservoir for thermal fluids. The outflow of the hot springs occurs over the Opal Mound horst and is centered at the confluence of the Opal Mound and Negro Mag faults. The hot fluid then mixes and dilutes with cold water in the shallow aquifer as it flows down a hydrological gradient into the Milford Valley (Faulder, 1991).

The simulation carried out using TOUGH2 requires an initial model based on a conceptual model which is then divided into several blocks/grids. Each grid has rock physical parameter information from geological data. The coordinate limits used are adjusted to the area of the geothermal system as contained in the conceptual model and reservoir simulation that has been carried out by previous studies. The simulation model used has a size of 10 x 10 x 6 km^3 in total, consisting of 1000 blocks with a size of 1 x 1 x 0.6 km^3.

The initial model used in this study was made based on geological, geophysical, and well data from previous studies. This model consists of 10 layers with the same thickness and a total depth of 6000 m. The first layer is assumed to be the top boundary with initial conditions such as a pressure of 1.26 Pa and a temperature of 100°C. The surroundings of the model are assumed to be the side boundaries which have the same initial conditions as the top boundary. The pressure and temperature values will increase with depth so that the lowest layer which is assumed to be the bottom layer has the highest value of initial condition.

In addition, rock parameters for simulation models such as porosity, density, permeability, thermal conductivity, and specific heat capacity are also required. Then, the latest well data in the research area from previous studies also needs to be used. Production wells 54-3, 28-3, 13-10, and 45-3 are known to produce fluids with a total of 240-290 kg/s. Meanwhile, injection wells 14-2, 12-35, and 82-33 injected a total of 244 kg/s and an enthalpy of 400 kJ/kg of which 25-40% was injected by well 14-2.

Result and Discussion

Reservoir simulation performed on the initial model were carried out for 35,000 years. This number is determined based on the estimated time the first time this geothermal system was formed. The simulation results obtained are the distribution of the current pressure and temperature values. The distribution of temperature values from the simulation results shows a quite good and logical condition for this geothermal system in Figure 2. It is also known that the temperature near the surface is quite high, indicating a convective heat transfer or reservoir zone. The simulated temperature gradient is 73°C/km with a reservoir temperature around 175-230°C.

After the simulation is run, curve matching is performed to see whether the temperature and pressure curves to depth from the simulation results are in accordance with the available well data or not. Due to the absence of temperature and pressure data from production or injection wells, curve matching is only performed with data from exploration and monitoring wells in the geothermal system area. Well 52-21 is an exploration well located in the southern side of the RHS geothermal system. The OH-1 well is a monitoring well located in the western side of the RHS geothermal system and the Opal Mound fault. The OH-7 well is a monitoring well located in the northeast side of the RHS geothermal system. If the distance between the three wells and the reservoir of the RHS geothermal system is compared, well OH-1 is the closest while well 52-21 is the farthest.

In the curve matching, the blue dots represent the simulated temperature values while the orange dots represent the values from the well data. All of the temperature curve matching from the simulation show an increase in the temperature value with depth which is quite compatible with the well data. Although curve matching cannot be done with pressure data because it is not available, the fit of this temperature curve is enough to prove that the simulation model has reached the natural state.

Conclusions

The RHS geothermal system has a reservoir formed by the fault intersection of the Opal Mound and Negro Mag faults. The Opal Mound fault also acts as a hot fluid flow path to the surface. The heat source zone is in the eastern side of the RHS geothermal system, at the bottom of the Mineral Mountains. In the RHS geothermal system, there are high temperatures at shallow depths which can be interpreted as convection heat transfer zone. The simulation results of reservoir modeling and curve matching show a good curve match even though it is only using the temperature data. This is enough to tell that the reservoir simulation model for the RHS geothermal system have reached the natural state condition. To continue, history matching can be done for the next study.

References

Blackett, R. E., and Ross, H. P., 1992, Utah Geological Association Publication, **21**, 261-280.

Christensen, O. D., Capuano, R. M., and Moore, J. N., 1983, Journal of Volcanology and Geothermal Research, **16**, 99-129.

Energy and Geoscience Institute at the University of Utah, 2018, Utah FORGE: Rock Properties [data set]. Retrieved from https://dx.doi.org/10.15121/1452765.

Energy and Geoscience Institute at the University of Utah, 2019, Utah FORGE: Earth Model Native State Simulation Results [data set]. Retrieved from https://dx.doi.org/10.15121/1557419.

Faulder, D. D., 1991, PROCEEDINGS 16th Workshop on Geothermal Reservoir Engineering, **SGP-TR-134**, 131-142.

Idaho National Laboratory, 2020, Utah FORGE: Data for 3-D Model Development - Lithology, Temperature, Pressure, and Stress [data set]. Retrieved from https://dx.doi.org/10.15121/1605155.

Lynne, B. Y., Campbell, K. A., Moore, J. N., and Browne, P. R. L., 2005, Sedimentary Geology, **179**, 249-278.

Moore, J. M., and Nielson, D. L., 1994, Utah Geological Association Publication, **23**, 25-36.

Simmons, S. F., Kirby, S., Allis, R., Moore, J., and Fischer, T., 2018, PROCEEDINGS 43th Workshop on Geothermal Reservoir Engineering, **SGP-TR-213**, 1-7.

Ward, S. H., Parry, W. T., Nash, W. P., Sill, W. R., Cook, K. L., Smith, R. B., Chapman, D. S., Brown, F. H., Whelan, J. A., and Bowman, J. R., 1978, Geophysics, **43**, 1515–1542.

Yearsley, E., 1994, Geothermal Resource Council TRANSACTIONS, **18**, 617-622.

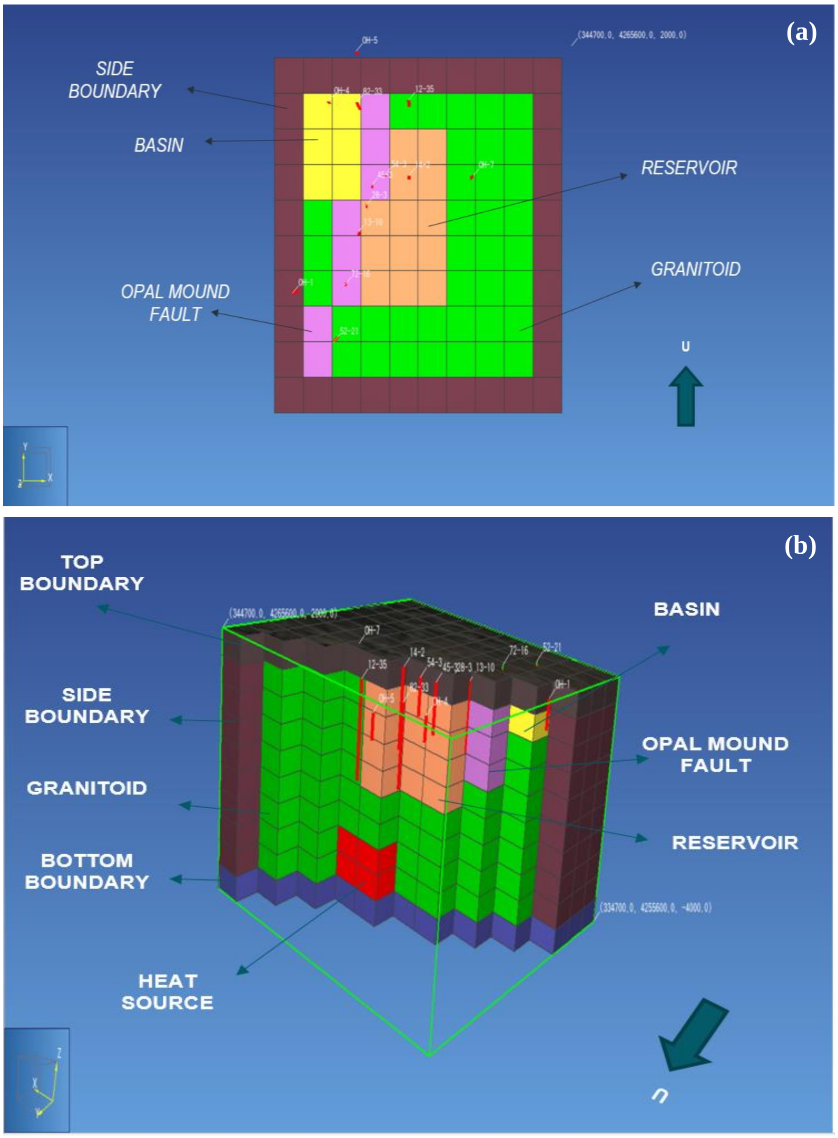


Figure 1: Map view (a) and cross section (b) of the RHS geothermal system simulation model. The model is made based on Simmons et al. (2018) conceptual model with production, injection, exploration, and monitoring wells located in the study area.

Tabel 1: Physical rock parameters used in the reservoir modeling

Rock Type	Density (Kg/m^3)	Porosity	Permeability (m^3)			Thermal Conductivity (W/m.K)	Specific Heat Capacity (J/Kg.K)
			X	Y	Z		
Top Boundary	2500	$1.0e^{-7}$	$1.0e^{-21}$	$1.0e^{-21}$	$1.0e^{-21}$	2.0	1000
Side Boundary	2500	$1.0e^{-7}$	$1.0e^{-18}$	$1.0e^{-18}$	$1.0e^{-18}$	2.0	1000
Bottom Boundary	2500	$1.0e^{-7}$	$1.0e^{-20}$	$1.0e^{-20}$	$1.0e^{-20}$	2.0	1000
Granitoid	2750	0.0118	$1.2e^{-16}$	$1.2e^{-16}$	$1.2e^{-16}$	3.05	790
Basin	2500	0.12	$1.7e^{-14}$	$1.7e^{-14}$	$1.7e^{-14}$	2.0	830
Reservoir	2750	0.13	$1.2e^{-13}$	$1.2e^{-13}$	$1.2e^{-13}$	3.05	790
Opal Mound Fault	2750	0.12	$1.2e^{-14}$	$1.2e^{-14}$	$1.2e^{-14}$	2.0	790
Heat Source	2750	$3.0e^{-1}$	$1.2e^{-14}$	$1.2e^{-14}$	$1.2e^{-14}$	3.05	1000

Source: Utah FORGE data set, 2018, 2019, 2020

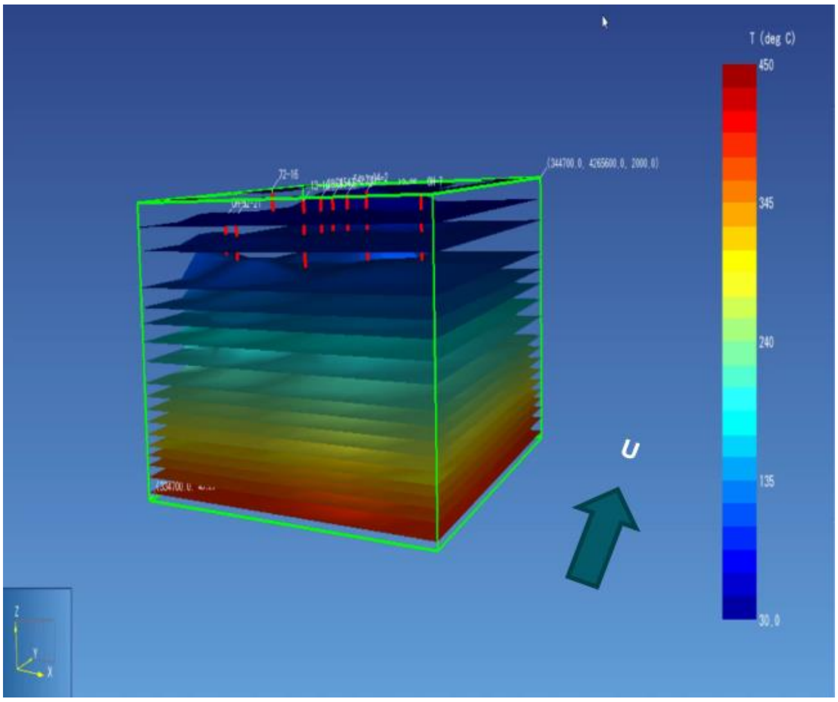
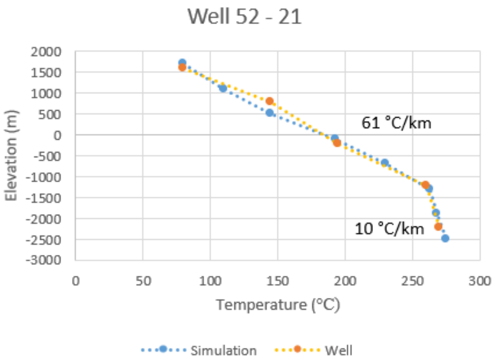
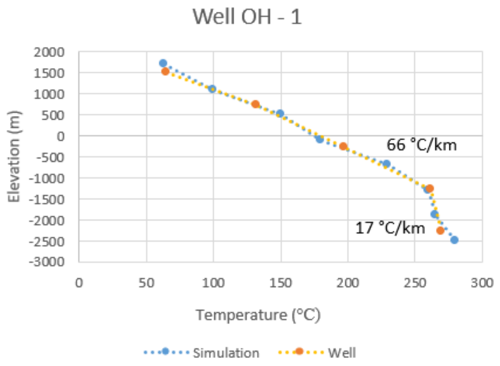


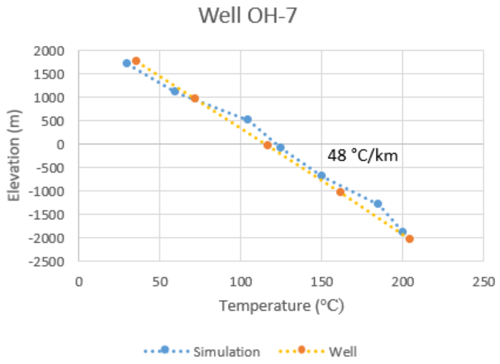
Figure 2: Temperature distribution of the simulation result shows the condition of RHS geothermal system



(a)



(b)



(c)

Figure 3: Curve matching for well 52-21 (a), OH-1 (b), and OH-7 (c). Blue dots represent the simulated temperature values while orange dots represent the values from well data. The temperature gradiens for each curve are shown near the curve.