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Numerical Simulation Study of the Sabalan Geothermal Reservoir, Iran

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ABSTRACT

Simulation of geothermal fracture reservoirs is a difficult task both due to the description of the reservoirs and numeric methods. The flow rate of geothermal fluid production from a fractured reservoir is a function including several variables; size and specifications of the blocks of matrix and the saturation of the fraction system. The double porosity method assumes that the porous fractured layer can be shown by two overlapping connected systems that are called fraction and matrix. The fractured part constitutes some connected fractions together with vugs that make the primary ducts for the fluid current. The matrix is also constructed of porous spaces of stone that contains the biggest share of the supply of the reservoir.

In this field, after obtaining the conformity of the log and adjusting the reservoir parameters and completing the dynamic model, its future conditions were studied. To do so, according to the current conditions regarding the number of the wells, well testing and well logging results, separator conditions and the steam flow rate of production, different production and reinjection methods were studied aiming at determining the best production scenario.

1. INTRODUCTION

The Sabalan geothermal field is located in the Moil Valley on the north western flank of Mt Sabalan, in the Ardebil Province of NW Iran. The resource area has been previously identified by Geoscientific studies as an approximately quadrangular shaped area that covers approximately 75 km2.

The idea of power generation from the NW Sabalan geothermal field was initially proposed in 1994; thereafter emphasis has been put onto this field as the first priority. Subsequent for exploration studies, in 2002–2004, three deep wells were drilled to determine the subsurface geology and the geothermal reservoir characteristics in that area. A maximum temperature of 240 ◦C was recorded at 3197m depth. Currently there are 11 drilled wells in Sabalan Field which 7 out of 11 of them are producible. The main objectives of this study are

- Thermal and compositional modeling of NW Sabalan field
- Predicting the future behavior of this reservoir.

Regarding to the discharge test results, it can be illustrated that drilled wells in faults and fracture network areas play important role in production. For NW Sabalan reservoir modeling, Eclipse-300 software which is a reliable simulator in oil and gas industries is applied. This study helps us to estimate the capacity of power generation of the Sabalan field by different scenarios. Initially the static model was made by RMS software following by model initialization. Also, the history matching was done by the results of discharge and heat up tests for available wells.

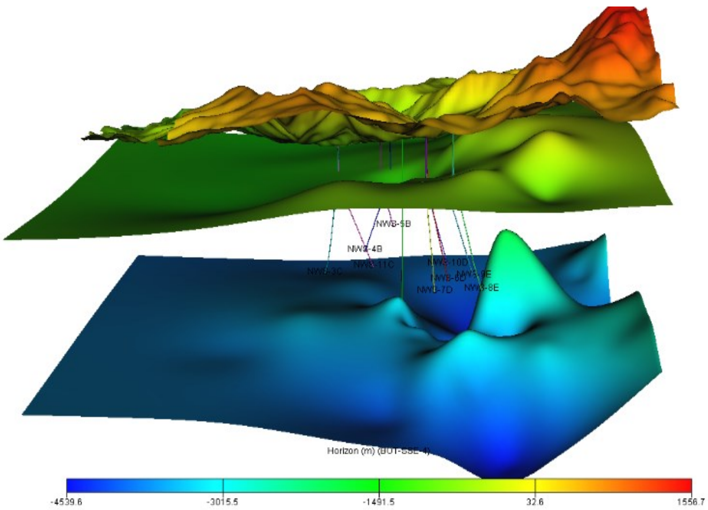

Figure 1: reservoir layer and wells location in static model

2. DYNAMIC MODEL INITIALIZATION

At the first stage of model initialization, the gridding of the Geology model was constructed by Flogrid software; according to the test results and reservoir studies the fractures and faults have significant role in production. Therefore, the gridding size of the area between main faults of reservoir was created smaller than other areas of the field. **Error! Reference source not found.**, demonstrates the reservoir layers and wells location in static model.

As the reservoir is a dual porosity model, the fracture layers should be added to the layers in Z direction. So the number of layers in Z direction would be double (2×10). The dimensions of model are as below:

NX = 17, NY = 20, NZ = 20

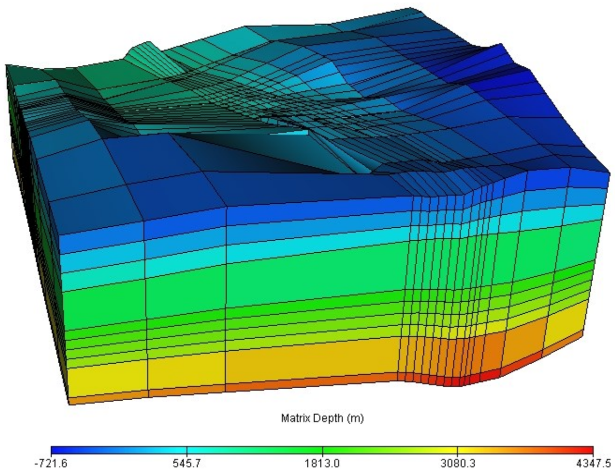

Figure 2: Sabalan Structure gridding pattern

Location of wells in reservoir model is shown in the following figure.

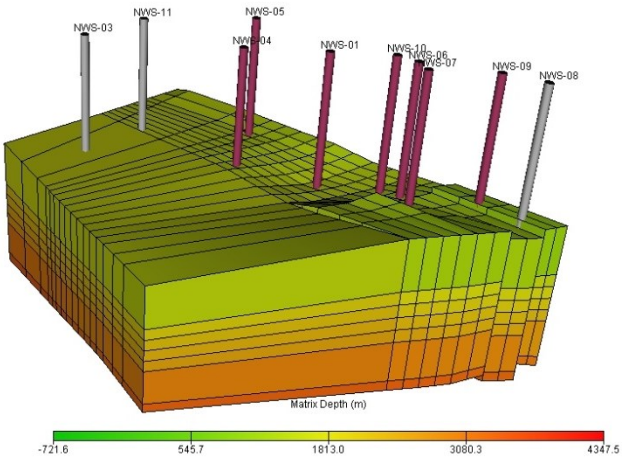

Figure 3: Wells location in reservoir model

After initialization the model was tuned by available tests such as: discharge and heat up tests results.

3. MODEL TUNING

After initialization of the simulation model data file, different reservoir and simulation parameters have been selected as the matching parameters to get a reasonable match of observed data. Thermal parameters were used to tune model temperature by heat up test results. Conduction and heat transmissibility parameters were determined by heat up test results in different depth of reservoir.

Different kinds of sensitivity analysis scenarios were run to define thermal parameters for the model. In **Error! Reference source not found.**, the results of temperature surveying in different depth of Sabalan reservoir are shown.

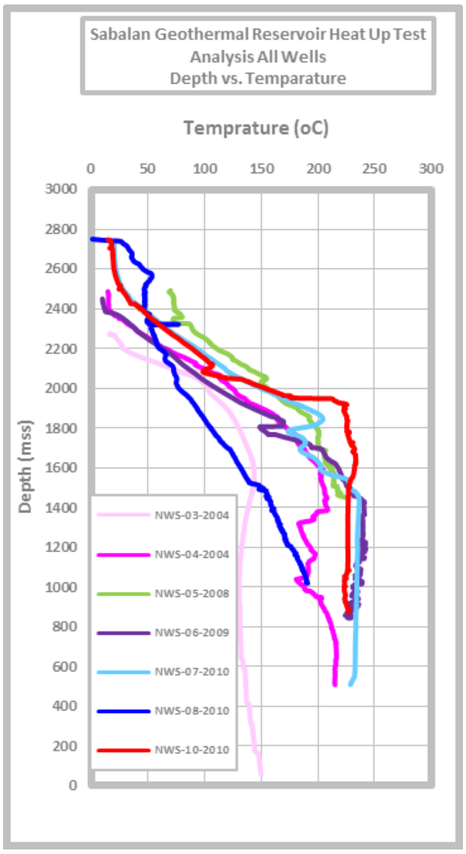

Figure 4: temperature surveying of heat up tests results

Thermal parameters were tuned by changing the rock heat capacity, heat transmissibility and thermal conduction. Comparison between simulation results and temperature surveying are shown in **Error! Reference source not found.** to Figure 10.

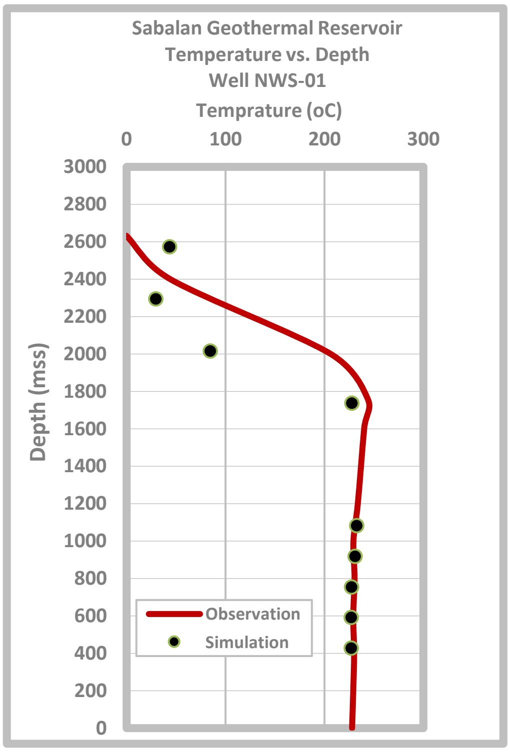

Figure 5: Heat up test matching results for Well NWS-01

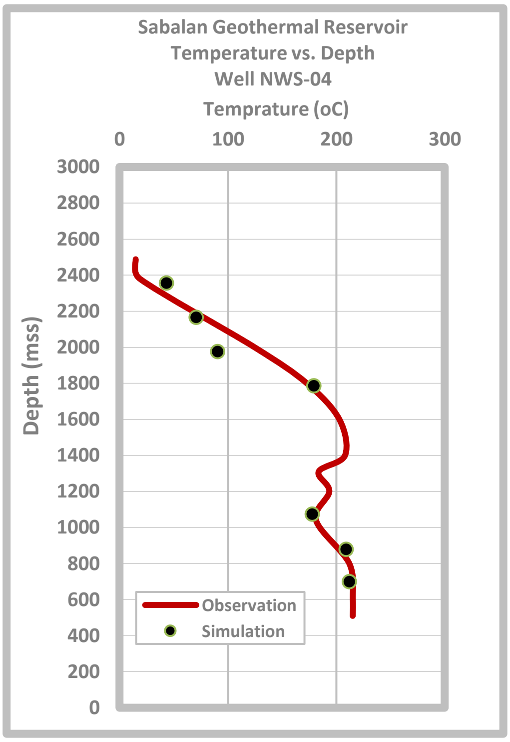

Figure 7: Heat up test matching results for Well NWS-04

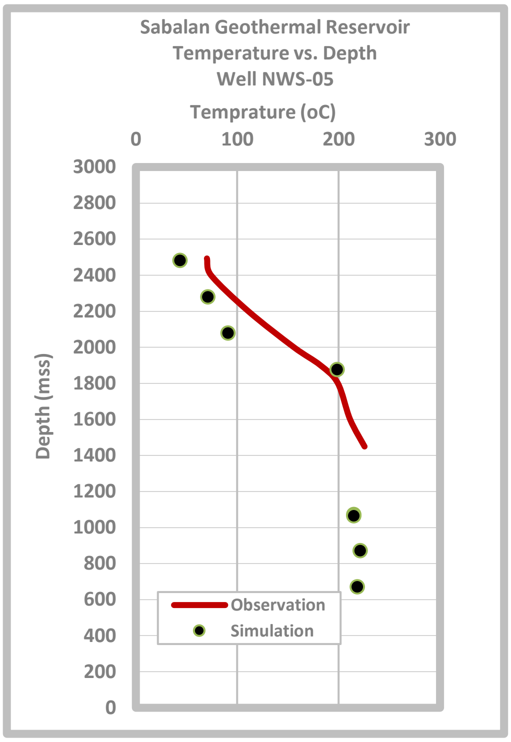

Figure 6: Heat up test matching results for Well NWS-03

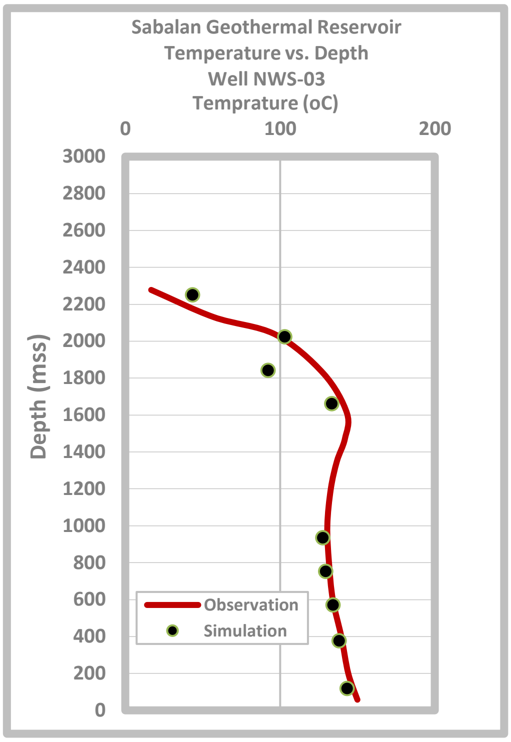

Figure 8: Heat up test matching results for Well NWS-05

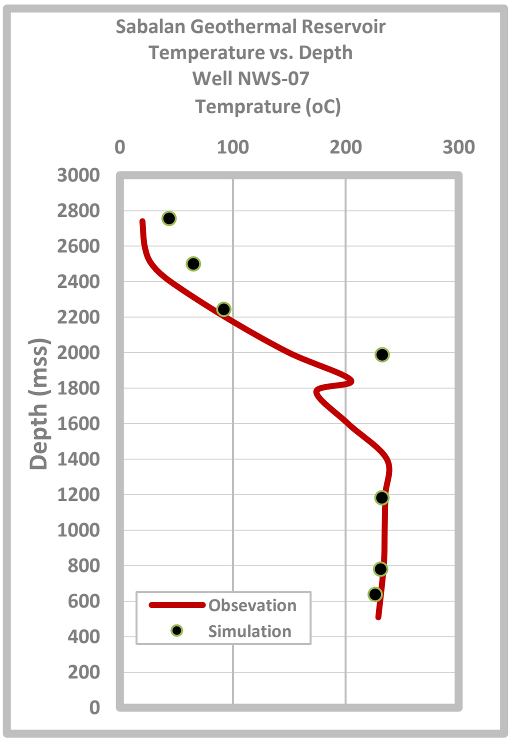

Figure 9: Heat up test matching results for Well NWS-06

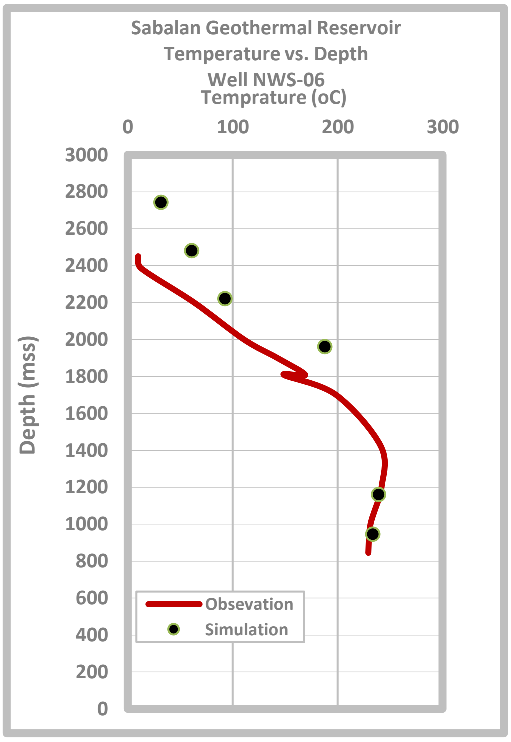

Figure 10: Heat up test matching results for Well NWS-7

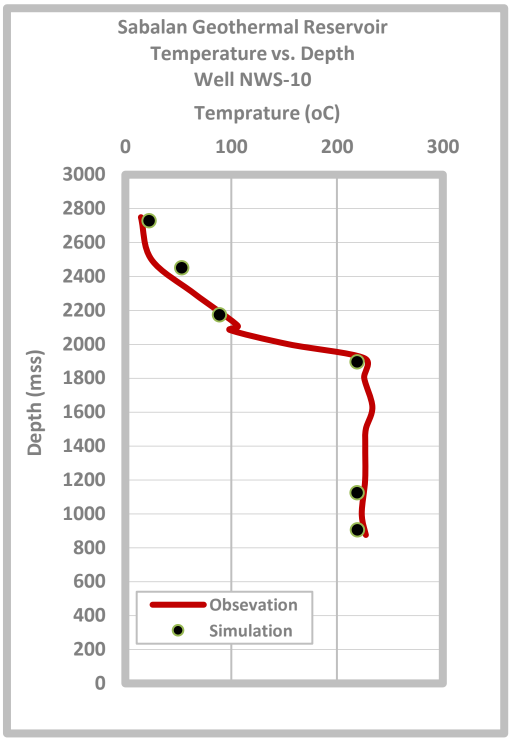

Figure 11: Heat up test matching results for Well NWS-10

In following figure the reservoir temperature in different depth of reservoir after tuning the model are shown.

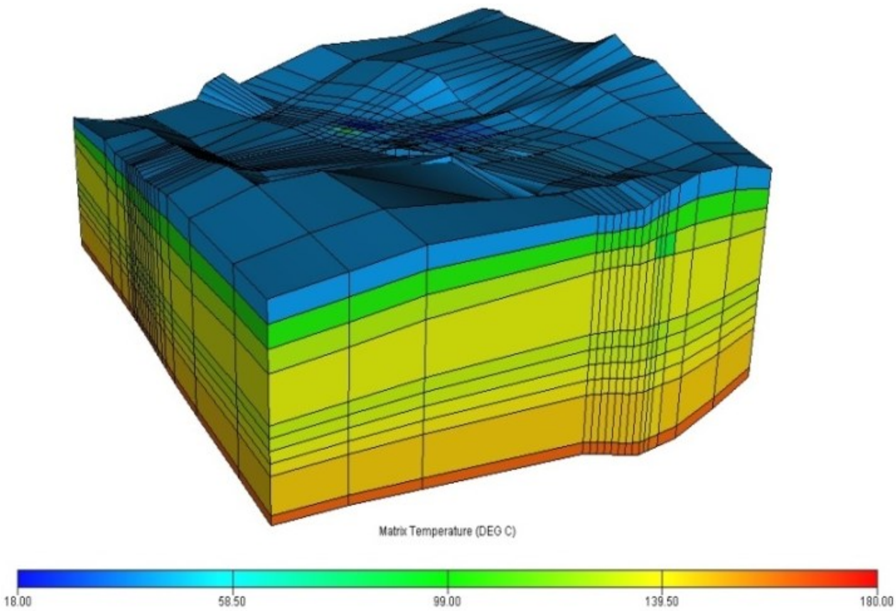

Figure 12: reservoir temperature results after tuning

By discharge tests results well head pressure, steam flow rate, water flow rate and steam water ratio was tuned. In following figures the results of well head pressure matching are shown.

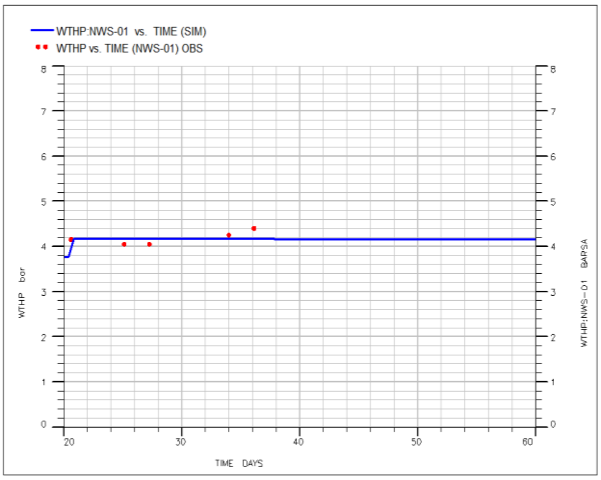

Figure 13: WHP matching results for well NWS-01

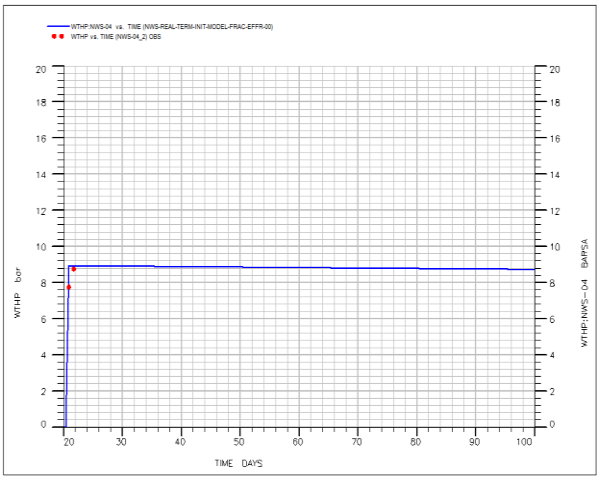

Figure 14: WHP matching results for well NWS-04

As it has been shown in Figure 13 to **Error! Reference source not found.**, acceptable matches between simulation and test results were obtained.

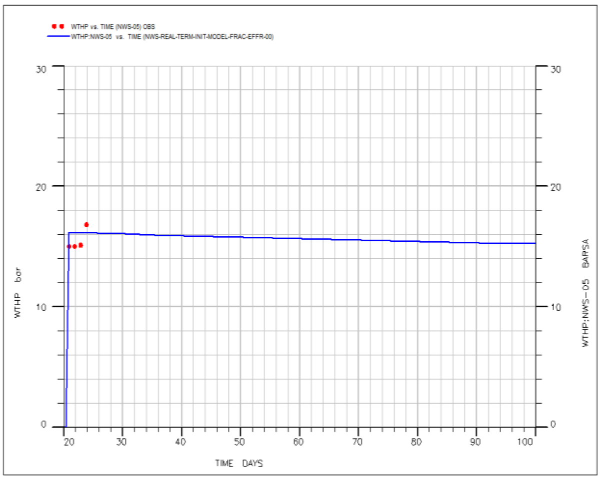

Figure 15: WHP matching results for well NWS-05

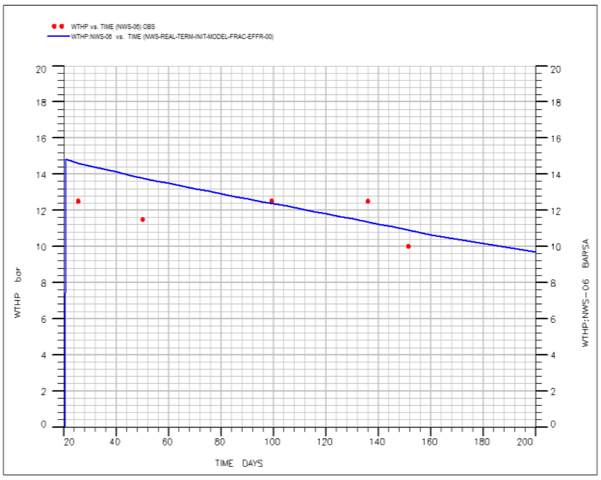

Figure 16: WHP matching results for well NWS-06

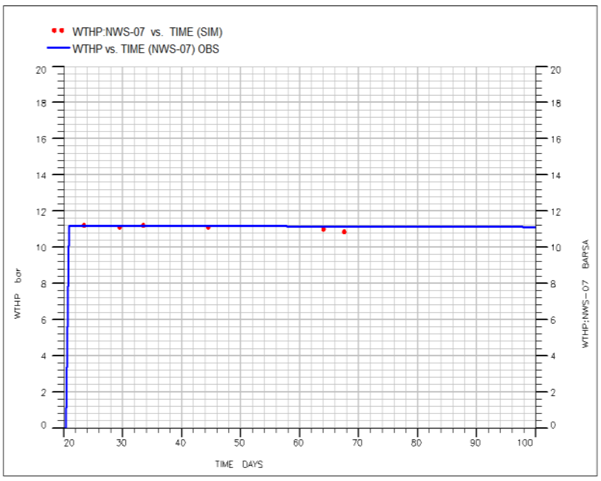

Figure 17: WHP matching results for well NWS-07

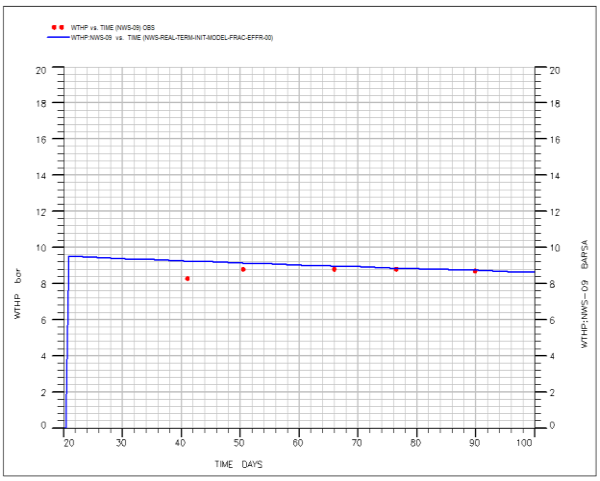

Figure 5: WHP matching results for well NWS-09

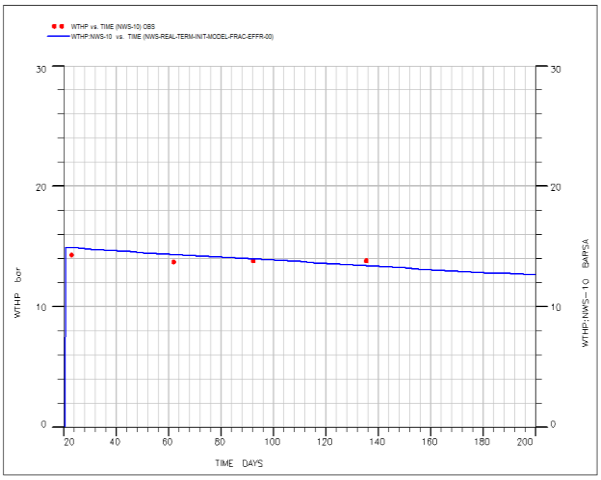

Figure 19: WHP matching results for well NWS-10

After tuning the model by heat up and discharge test results following rock and heat parameters were obtained.

Table 1: Rock parameters after tuning

Rock Properties	All of the Reservoir		Between Faults	
	Matrix	Fracture	Matrix	Fracture
Permeability (md)	138	1100	275	1650
Porosity	0.044	0.0006	0.055	0.001
Dz Matrix (m)	0.05			
SGMAV (1/m2)	0.45			

Table 2: Thermal parameters after tuning

Heat Property	Value	Unit
Thermal Conduction of Heat in the Reservoir	1000	KJ/M/D /C
Rock Heat Capacity	2500	KJ/M3/K
HEATER	100	KJ/D
HEATTX	1.00E+09	KJ/D /C
HEATTY	5.00E+08	KJ/D /C
HEATTZ	1.00E+05	KJ/D /C

4. PREDICTION

After model tuning different kinds of prediction scenarios were run. According to the discharge test results the maximum producible steam production rate from existing wells were estimated and 10% lower than these values is considered as well production rate in the model. In following table maximum production rate of each well is shown.

Table 3: Thermal parameters after tuning

Well Name	Maximum Rate		10% lower than Max.Rate	
	Steam Mass Rate (Kg/s)	Steam Flow Rate (m3/d)	Steam Mass Rate (Kg/s)	Steam Flow Rate (m3/d)
NWS-01	7	190788.6	6.3	171000
NWS-04	6.5	177160.9	5.85	160000
NWS-05	14	381577.3	12.6	343000
NWS-06	20.5	558738.2	18.45	503000
NWS-07	15	408832.8	13.5	368000
NWS-09	9.5	258927.4	8.55	233000
NWS-10	13	354321.8	11.7	319000

4.1. Pilot scenarios

First of all, a pilot scenario was run for estimating the minimum electrical power potential of Sabalan reservoir. According to the discharge test Results, maximum producible steam rate from the well NWS-06 is around 20.5 kg/s which 20% lower than this value considered as well limiting rate. The simulation represents that the minimum achievable electrical power of this reservoir is about 8.5 Mwe and well NWS-06 can produce for 30 years. In following figures the simulation results are shown.

Table 4: Pilot scenario constraint in the model

Scenario Groups	Electrical Power (Mwe)	Steam Mass production Rate (kg/s)	Steam production Rate (m3/s)	Steam production Rate (m3/d)	Prod. Wells No.	Inj. Wells No.	Production wells Location	Injection Wells Location
Pilot	8.5	16.58	5.23	447000	1	1	Pad D	Pad A

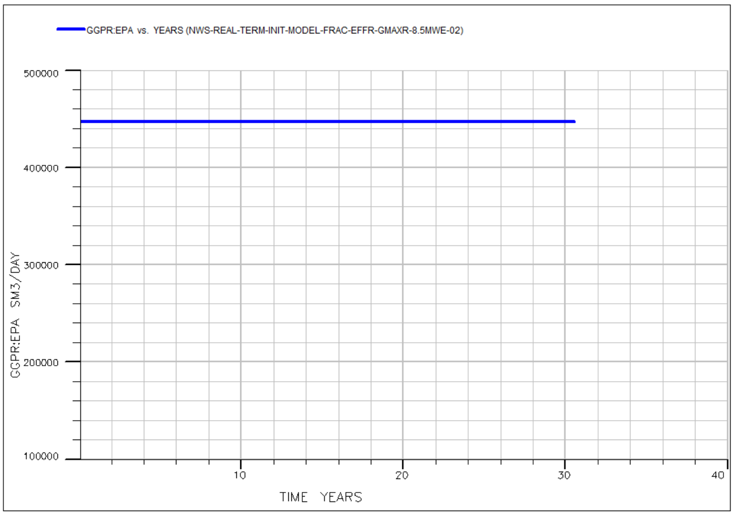

Figure 6: Steam production rate from wells NWS-06

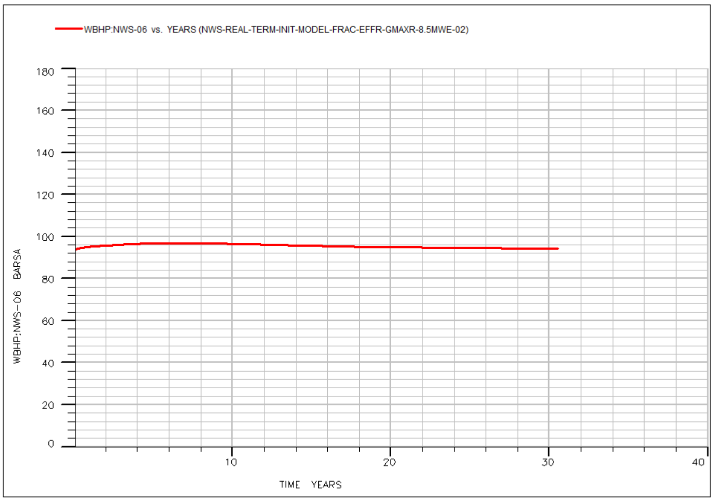

Figure 7: NWS-06 well bottom hole pressure

4.2. Existing wells

This scenario was defined for predicting the current condition of the reservoir, Between 7 existing wells of the field, 5 wells are changed to production wells and 2 Wells (NWS-04 and NWS-05) are changed to injection wells. According to the discharge test Results, 10% lower than the maximum wells steam rate considered as limiting rate and 90% of all liquid produced rate was injected to reservoir.

Table 5: Existing wells scenario constraints in the model

Scenario Groups	Electrical Power (Mwe)	Steam Mass production Rate (kg/s)	Steam production Rate (m3/s)	Steam production Rate (m3/d)	Prod. Wells No.	Inj. Wells No.	Production wells Location	Injection Wells Location

Existing Wells	27.00	52.76	16.64	1435000	5	3	Pad A,B,D	Pad B

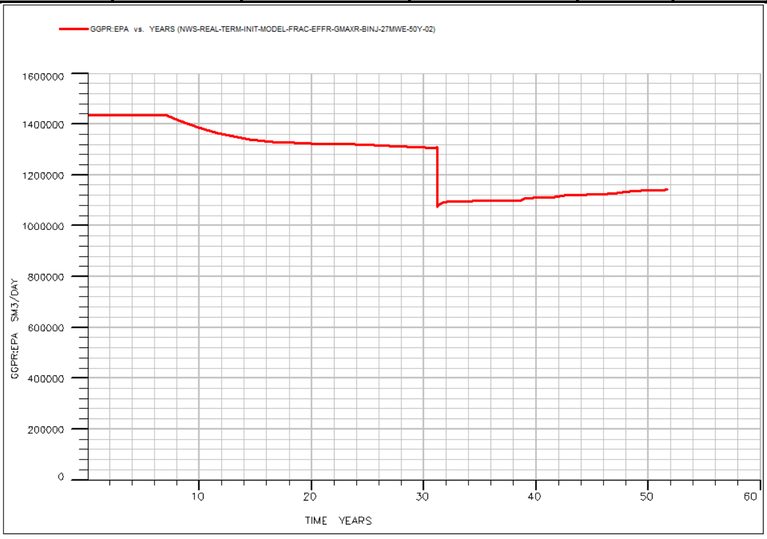

Figure 8: Steam production rate for the field in existing wells scenarios

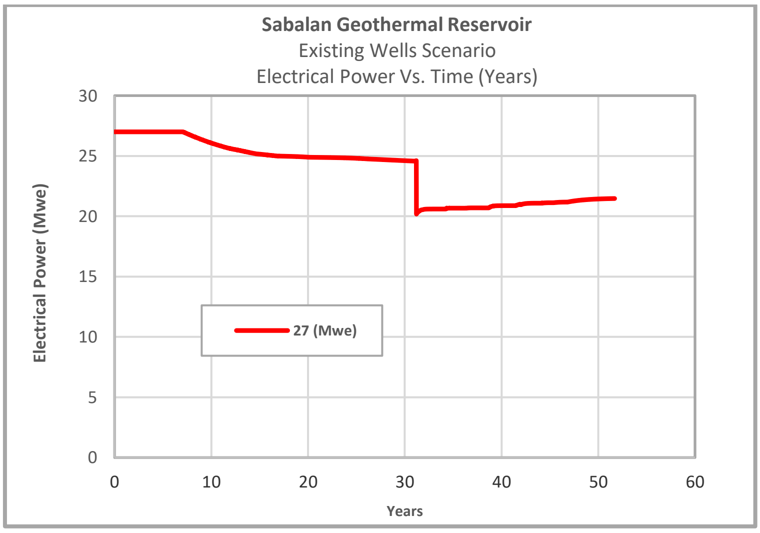

Figure 9: Achievable electrical power in existing wells scenarios

According to the simulation results from current wells just for 11 years the 27 MWe electrical power will be producible and due to declining the well-head pressures well rates will be decreased.

4.3. Existing wells and cellars

In existing wells and cellars scenario three different types of reservoir potential were estimated and four new injection wells were defined. Results of 35 MWe Scenario demonstrate that with existing wells and cellars the plateau will be maintained for 9 years and after that due to declining the well head pressure, the plateau will be decreased. But 30 and 20 MWe Scenarios will be maintaining the plateau for 30 years of simulation predicting time.

Table 6: Existing wells and cellars scenario constraints in the model

Scenario Groups	Electrical Power (Mwe)	Steam Mass production Rate (kg/s)	Steam production Rate (m3/s)	Steam production Rate (m3/d)	Prod. Wells No.	Inj. Wells No.	Production wells Location	Injection Wells Location
Existing Wells and Cellars	35	68.39	21.57	1860000	7	5	Pad A,B,D	Pad B
	30	58.62	18.49	1595000	7	5	Pad A,B,D	Pad B
	20	39.08	12.33	1060000	7	5	Pad A,B,D	Pad B

Scenario Groups	Electrical Power (Mwe)	Steam Mass production Rate (kg/s)	Steam production Rate (m3/s)	Steam production Rate (m3/d)	Prod. Wells No.	Inj. Wells No.	Production wells Location	Injection Wells Location

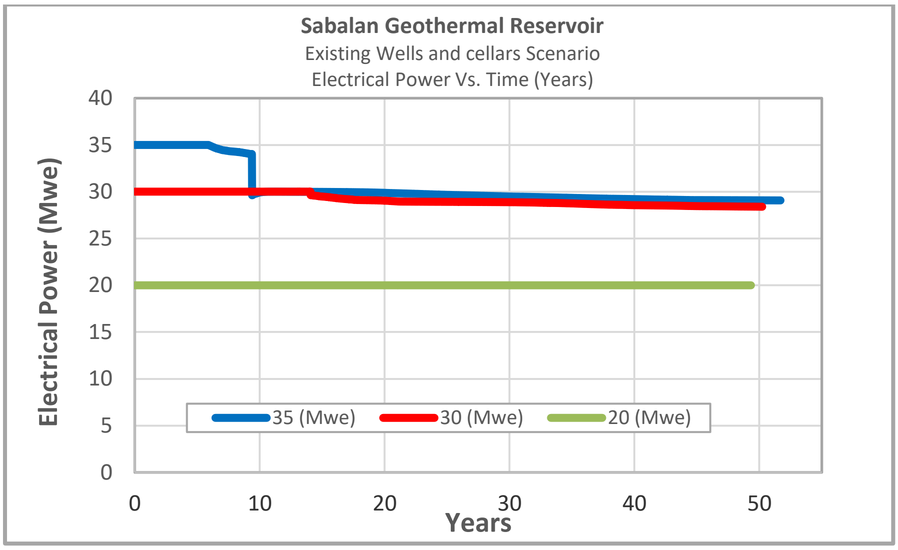

Figure 10: Comparison between 35, 30 and 20 MWe

According to the economical value of producing with the plateau rate of 35 MWe Scenario from the wells, it was decided to define a new scenario that maintains this plateau for longer time. The results of simulation show that after producing for 9 years with existing wells this plateau will be maintained with drilling of two new wells for 30 years. In Figure 11 the comparison between the two of 35 MWe Scenarios by existing wells and with drilling new wells is shown.

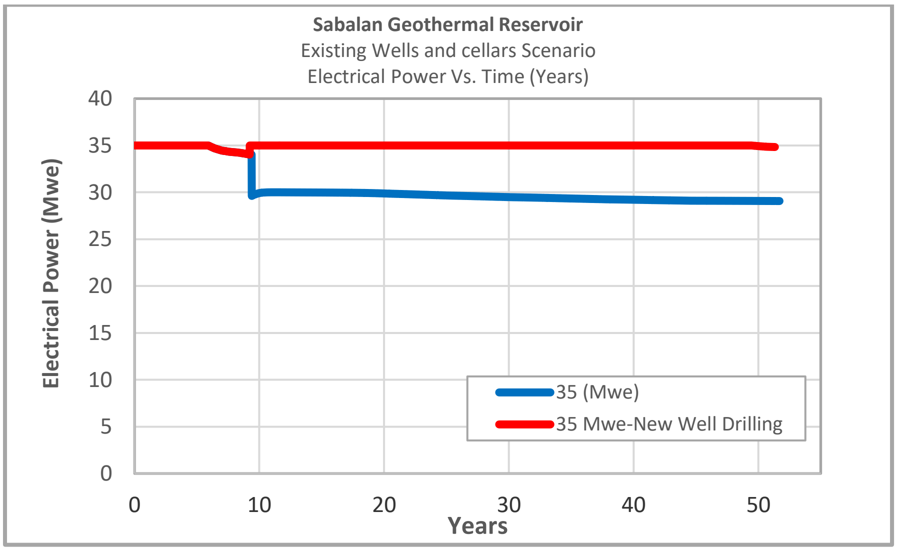

Figure 11: Comparison between 35MWe scenarios and maintaining this plateau with new well drilling

5. CONCLUSION

- The simulation represents that the minimum achievable electrical power of this reservoir is about 8.5 MWe.
- Simulation results demonstrate that Sabalan reservoir will be able to produce 27 MWe of electrical power for 11 years and the production rate declined because of decreasing well head pressure.
- In 35 MWe Scenario with 7 production wells and 5 injection wells, the wells will be maintained the plateau for 9 years
- According to the modeling results with drilling of two new wells after 9 years of producing 35 MWe of electrical power with existing wells drilling to new wells help to maintain this plateau for 30 years.
- Sabalan geothermal reservoir will be able to produce 30 and 20 MWe of electrical power for 30 years.