PROCEEDINGS, Twenty-Seventh Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 28-30, 2002
SGP-TR-171

RESERVOIR MODELLING FOR THE BERLIN GEOTHERMAL FIELD EL SALVADOR

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ABSTRACT

The Berlin Geothermal field is located 100 km to the eastern part of the country. The field began to commercial operation in February 1992 when 2x5 Mwe Back Pressure units went on line. Later on in October 1999, 2 x 27.5 Mwe Condensing type units also went on line. At the beginning of the exploitation the reservoir yields up to 80 kg/s of total mass at 1300 kJ/kg using wells TR-2 as producer and TR-9 as injector. In 1994 the former Geothermal Division of CEL starts to drill 18 producer and injection wells in order to achieve the steam requirements for the power station and to complete the injection capacity for the brine. At the moment the Berlin field has 26 wells: 8 producer, 14 injector, 1 monitoring and 3 abandoned, the gross power production is close to 58 Mwe and there are no evidence of thermal breakthrough, and some boiling are observed in the surrounding of some producer wells.

In order to predict the reservoir behavior Lumped and 3-D numerical model have been prepared by GESAL. Three scenarios of exploitation have been used, 50 Mwe for the actual condition, 60 Mwe increasing with the back pressure operation that are already installed, 85 Mwe increasing with one additional 27 Mwe condensing type unit.

The results of the modeling for 85 Mwe scenario shows it is possible to achieve that production, the pressure drawdown of the reservoir will range 30-35 bar for 20 years forecasting. The saturation for the whole reservoir will less than 20%, and the cooling effect to the system will range 20°C. According with the results one additional 27 MWe is possible to be installed at the Berlin Geothermal Field in a sustainable way for at least 20 year.

GENERAL DESCRIPTION OF THE FIELD

The Berlín Geothermal field is located at the eastern part of the country, the exploration began in 1968 with UNDP program and well TR-1 was drilled. Unfortunately the well did not reach the hot reservoir because the drilled depth was 1500 m. Later on in the late 70 the well TR-2 was drilled in order to reach the hot geothermal reservoir. The maximum temperature measured at well TR-2 was close to 290°C and produce 80 kg/s of total mass and 20 kg/s of steam with enthalpy 1300 kJ/kg. After they were drilled TR-3, TR-4, TR-5 and TR-9 all had high temperatures and yielded hot fluids.

In 1992 went on line two back pressure units (2X5 Mwe). The well TR-2 was used as producer and TR-9 as injector. In the original plan the well TR-9 was considered as producer but due the blow out of well TR-6, the injection capacity fell close to zero.

IN 1999 two 27.5 MWe condensing type units were commissioning at the field to replace the power production of the back pressure units. The power efficiency was increase from 4.2 to 1.9 kg/s/Mwe.

In order to achieve the steam and injection capacity 18 new wells were drilled during 1997-1999, the Table No.1 shows the actual capacity of the wells. after the acid stimulation project:

Type	Wells	Total Flow rate (kg/s)	Steam Flow (kg/s)
Producer	TR-2,TR-9, TR-5,TR-5 A/B/C,TR-4, TR-4 A/B/C	480	130
Hot Injection	TR-1A/B/C, TR-14, TR-8. TR-8 A, TR-3 TR-12,TR-12A	290	
Cold Injection	TR-7, TR-11A	50	

Table 1. Wells in operation at The Berlin Field

The Figure No.1 shows the well location:

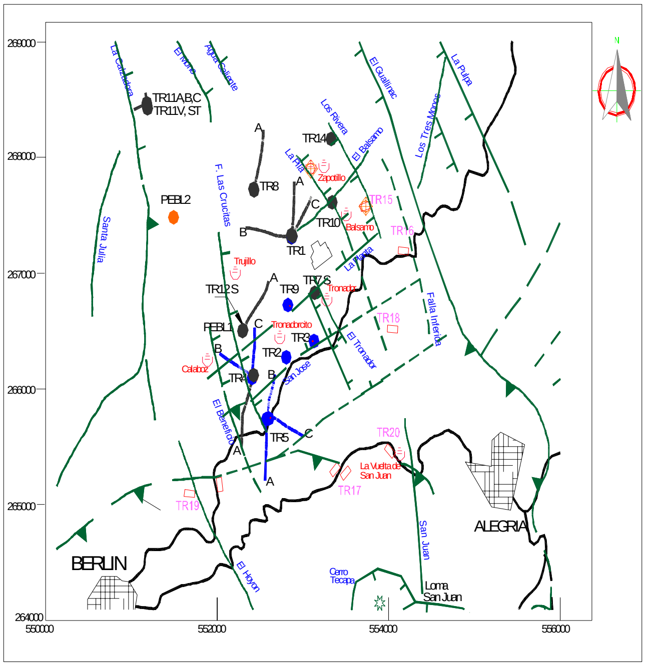

Figure 1. Well location for the Berlin Field.

At the Berlin Field the injection area is located at the north of the power plant, but some injection wells are in the center of the field. The steam field is located to the south. There are two injection temperatures: the hot injection is at separation pressure (180°C) and the cold injection is at atmospheric temperature (35 °C).

CONCEPTUAL MODEL

According with the information the conceptual model for the Berlín field, the heat source is located under the Tecapa volcanic chain, the up flow is coming from the south inside the caldera and the hot fluid is moving towards to the north along the graven structures.

At the Berlín, there are two geothermal aquifers, the shallow one is located at sea level and indicate 150-200 °C of temperature but the permeability is quite low. The geothermal reservoir temperature is close to 300°C and It is located around –1000 m.a..s.l.

The Figure 2 shows the conceptual model for the field., in the figure it is possible to observe the limits or the boundaries of the field

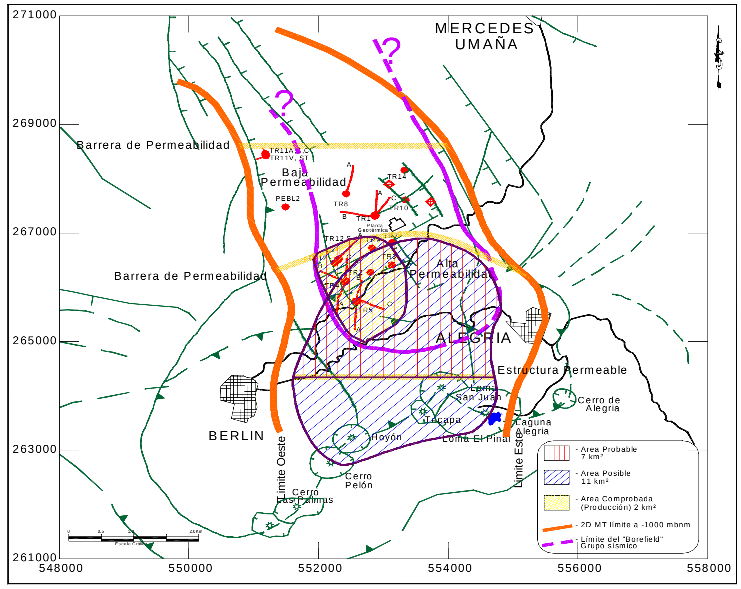

Figure 2. Conceptual model for the Berlín field

The Figure 3 shows the lateral structure of the conceptual model.

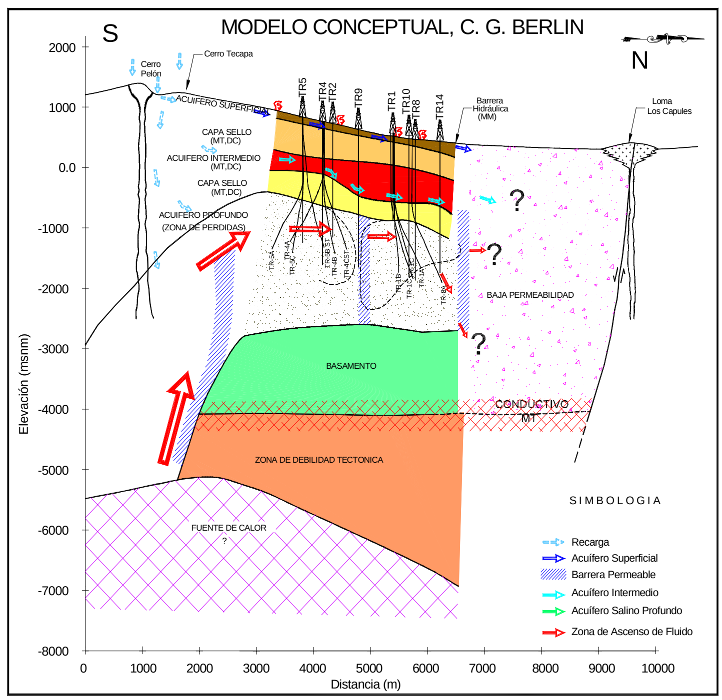

Figure.3. Lateral structure for the conceptual model

NUMERICAL MODEL

This numerical model was developed by M. Monterrosa (1993). The numerical model is a 3-D mesh, well by well block and includes nodes for fumaroles, hot spring, etc. The mesh was built with MESHMAKER software. The mesh file (segmt, in, elemen) were joint to prepare the input file for TOUGH II geothermal simulator.

The model is formed by 7 layers according to geological setting and 78 nodes by layer, and covers 100 km2 from Easting 546,000 to 556,000 and Northing 262,000 to 272,000. The following table shows the layer and some characteristics:

Layer	Name	Thickness (m.a.s.l)	Description
1	GRD	Surface to +150	Groundwater, used as boundary condition
2	BAR	+150 a +100	Cap rock of shallow aquifer, geological layer Unit I
3	SHA	+100 a –100	Layer to simulate the shallow aquifer, geological layer Unit II
4	CAP	-100 a –700	Cap rock of the reservoir, geological layer Unit III
5	REG	-700 a –1300	Geothermal productive reservoir, geological layer Unit IV and V
6	LFO	-1300 a –1500	Layer to simulate the out flow
7	BAS	-1500 a –1900	Basement of the system

Table 2. Layers of the model

According to the conceptual model and the well results, the permeability is getting down to the north/east from TR-1 and TR-8. In order to simulate this feature in the numerical model the flow path is confined to less area than the previous model.

The figure No.2 shows the plot for the permeability distribution for the reservoir layer have been used in the model, the rocks used were RESER (orange), WELLF (red), BOUND (cyan).

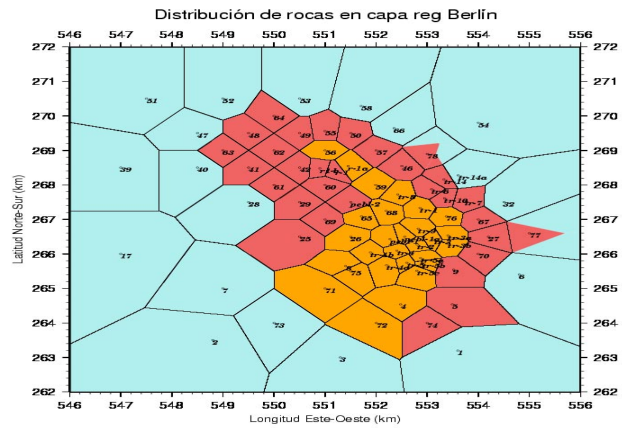

Figure.4. Permeability distribution

The main physical parameters for the 8 rocks used in the model are :

Rock	Kx (mD)	Ky (mD)	Kz (mD)	φ (%)	Density (kg/m3)	T.Con W/m °C	Heat capacit (J/kg °C
Surfa	10	10	10	20	2600	2	850
Ignim	0.01	0.01	0.01	0.05	2600	2	850
Andes	0.1	0.1	0.1	10	2600	2	850
Shall	1.0	1.0	1.0	15	2600	2	850
Shaqu	10	10	10	20	2600	2	850
Wellf	40	40	40	15	2600	2	850
Reser	60	60	60	10	2600	2	850
Bound	0.1	0.1	0.1	0.05	2600	2	850

Table 3. Rocks parameters

The natural state model was achieved with the rock parameter indicated in table No.1. Figure No.5 shows the steady state condition of the model after 60,000 years of simulation, Figure No.6 shows the adjustment for the formation temperature of the wells and the simulated temperature of the layers. The matching is pretty good and behaves close as observed data.

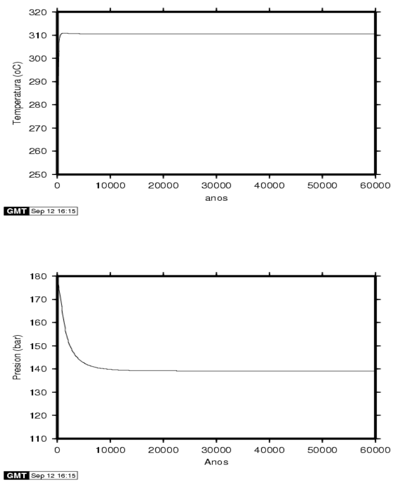

Figure 5. Steady state condition of the model

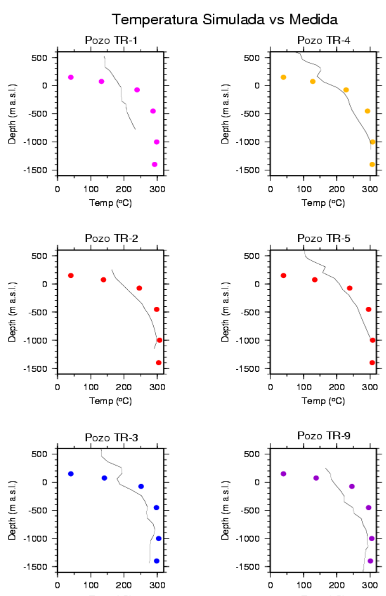

Figure 6. Formation temperature calibration

The pressure monitoring at the well TR-4 was used as reservoir pressure in order to calibrate the production model. The pressure is monitoring at sea level (corrected to reservoir depth) with capillary system.

The mass extraction and injection history has been adjusted in order to reduce short-term period of shut or opening of the well. We are considering period of weeks or moths in the simulation instead of days or hours.

According to the behave of the reservoir there are any evidence or effects of boiling in the whole reservoir or well field area, also the cooling effect due to the injection does not looks to be a problem at the moment. In the report Modelo Geoquímico del CGB 1999 (F Montalvo), is revised all the chemical and production data and the main conclusion is there are no evidence of boiling in the reservoir but some localized boiling occur at the surrounding zone to the wells.

In the Figure No.7 we observe the best fit of the model and the measured pressure in well TR-4., the results are pretty good adjust.

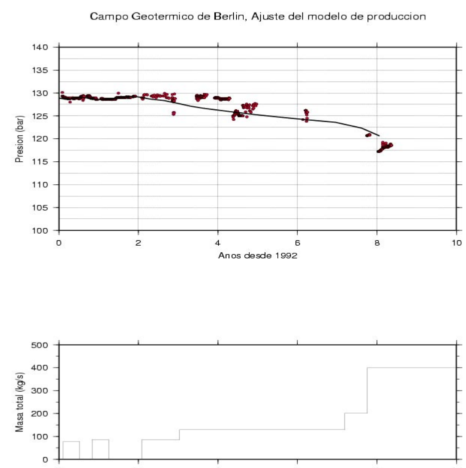

Figure 7. Production model adjust

With the production model it is possible to observe:

1- There are no evidence of large or significant changes in the main parameter of the reservoir (thermodynamic, chemical, etc.) in the wells, no large pressure drawdown is observed.
2- There are no significant effects due to injection, no thermal breakthrough is observed.
3- The reservoir is still in liquid dominated condition.

FORECASTING MODEL

Several scenarios have been simulated, in this report we are presenting only the 85 MWe. This scenario consider the operation of the actual condensing unit for at least two year to the maximum capacity 60

Mwe and to install a new one 27 Mwe condensing unit in the year 5 to totals 85 MWe.

For this scenario will be necessary to drill at least 13 additional well, 4 producer well in TR-20 pad and 9 injection well at TR-15,16 and 17 pad. This scenario also consider the commissioning of the third 27 MWe condensing type unit. The back pressure units were not considered in this report.

The Figure No. 8 shows the pressure behavior for scenario No.3, also it is include the 50 Mwe ELC forecast (Estudio de Factibilidad). With this figure it is possible to observe the forecast for the reservoir pressure still higher than the 50 MWe ELC forecast, we are confident that the reservoir is able to produce steam and fluid to operate 85 Mwe for 25 year.

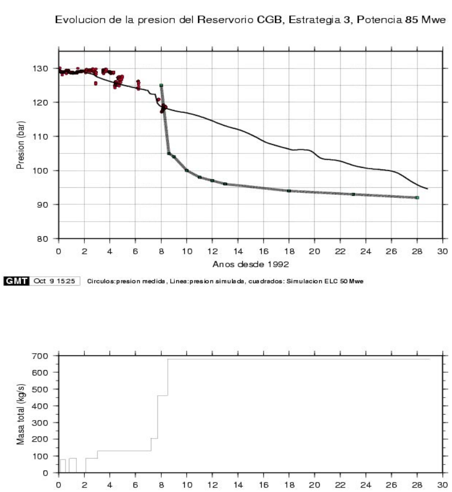

Figure 8. Reservoir pressure forecast

The effect of the pressure drawdown should be observed that could reach less than 90 bar, this value in some places is very close to the minimum pressure for the operation of the wells. This situation reinforces the recommendation of executing an analysis to know the minimum pressure to operate the actual power units. This situation can be reduced if in the system increase the two-phase condition, according to the model results in the reservoir is observed an increment of boiling up to 25% in the fraction of vapor inside the reservoir.

CONCLUSIONS

1- A new and actualized reservoir assessment for the Berlin Geothermal Field has been carried out where incorporated the last gathered information of the field.
2- The presented numerical model was adjusted with data measured in most of the wells drilled until now, and with the production history of almost 10 year, its results presents pretty good matching with the real data.
3- The results of the simulation indicate that it is possible to increase the generation capacity up to 85 Mwe for next 20 years. Some important changes could be presented in the behavior of the reservoir. Those situations can be handle opportune and efficiently through a RESERVOIR AND FIELD MANAGEMENT, which will be useful to increase the continuos operation of the resource in a sustainable way.
4- The Berlin reservoir is still in liquid phase although 10 years of commercial operation according of thermodynamic data, despite this some wells presents lightly excess enthalpy, this situation could be due mainly to the resolution characteristic of the method used for the measurement or due to very localize boiling effects in the surrounding area to the well.
5- If the boiling expands in the reservoir, the pressure drawdown will reduce and the inflow of hot liquid water will increase conducting to reduce the cold injection effects. Although these effects some collateral problems could be add to the field management like scaling due to formation flashing.
6- The presented numerical model have to be good shape and acceptable size, however a more vertical layers should be included inside the reservoir layer in order to simulate the steam cap.

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