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SIMULATION OF PRESSURE CHANGES IN THE AHUACHAPAN GEOTHERMAL RESERVOIR DUE TO REINJECTION OF RESIDUAL WATER INTO THE CHIPILAPA GEOTHERMAL AREA.

Julio E. Quijano, jquijano@es.com.sv
Departamento Ingenieria de Reservorios
Comision Ejecutiva Hidroelectrica del Rio Lempa (CEL)
Km 11½ Carretera a La Libertad, Santa Tecla, El Salvador

ABSTRACT

An estimate of the pressure changes in the Ahuachapan geothermal reservoir by the reinjection of residual water from the well field into the Chipilapa area has been simulated through a 3-D model of the geothermal system. The residual water from the current 15 producer wells will be injected by gravity through a pipeline 5.5 km long into 3 wells of the Chipilapa area. Two modes of injection have been simulated: First, an injection of 260 kg/s related with the equilibrium pressure in the reservoir, and second, the injection of the total flow capacity for the reinjection wells (420 kg/s). The simulation results after 12 years of continuous exploitation show a recovery pressure in the main exploitation zone of 2.2 bars using the second mode.

INTRODUCTION

The geothermal system of Ahuachaphn has been exploited for electrical generation since 1975 through a double flash system. The energy conversion is carried out by three units: U1, U2, and U3 of 30, 30 and 35 MW respectively. Since the beginning of the exploitation until now, 360 Mtons of brine have been extracted and 38.5 Mtons of residual water have been reinjected. This has produced a pressure drop from 36.0 to 19.5 bar equivalent to a decrease in the water level of 180 m (Quijano J., 1996).

In 1993, 32 wells had been drilled in the Ahuachapan Geothermal Area (AGA) and 9 wells in the Chipilapa Geothermal Area (CGA). From all the wells in the AGA, only 15 wells are productive with a total capacity of 750 kg/s. The approximate power developed by the geothermal plant with this flow is 83 MW and represents 88% of the installed capacity. In the long term, is not possible to manage this power because the productive wells are located in an area of 1 km^2 (Figure 1) and this causes drastic pressure drops in the reservoir. The experience in field operation and "Lumped" modeling of the geothermal system gives an equilibrium in the reservoir pressure with a mass extraction of 410 kg/s (Quijano J., 1994). Currently, the field is operated with values around 410 kg/s mantaining the pressure near 19.5 bar. This limits the power to 59 MW and the installed capacity utilization to 62 %.

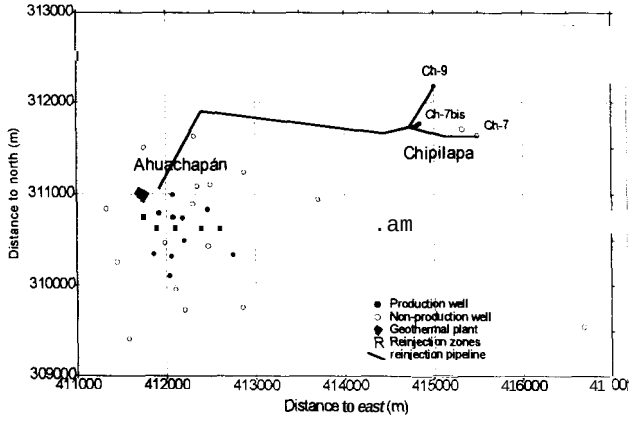

Figure 1. Location of the reinjection line and reinjector wells in the Chipilapa area.

In order to use the total installed capacity in the Ahuachaphn Power Plant, CEL is carrying out the project "Stabilization of the Ahuachaphn Geothermal Field" which consists of the following:

1. Total reinjection of residual water in the CGA to minimize the environmental impact of geothermal water discharged into the Pacific Ocean and also induce an artificial recharge in the Ahuachapan reservoir.

2. Rehabilitation of the power plant and carrying system equipment to increase the energy conversion efficiency.

3. 9 wells that will be drilled in the southern part of the Ahuachapán field to expand the extraction zone.

At this moment, 6 new wells have been drilled in the southern part of the Ahuachapdn field, and are currently under thermal recovery. With respect to the reinjection of the residual water, this year CEL plans to build the pipeline to connect the double flash units with the wells Ch-7, Ch-7bis, and Ch-9 in Chipilapa (Figure 1).

This work estimates the pressure changes in the reservoir pressure through reinjection of residual water at 110 "C into the Chipilapa area, with a 3-D model of the geothermal system. The simulations are executed using the TOUGH2 simulator (Pruess, K., 1989) for several extraction-reinjection modes.

REINJECTION HISTORY IN AHUACHAPAN

Because the Ahuachaphn Geothermal Field is located in a hydrological region which discharges into the Paz River (a boundary between Guatemala and El Salvador) and is also located inside a coffee plantation zone, the discharges of residual water have been a significant problem in its development. The problem was partly solved by building a concrete channel 75 km long to discharge the residual water into the Pacific Ocean. Also, in order to solve this problem, reinjection of the waste water has been attempted. The following experiments were carried out before and after the exploitation:

1. The first experiment was carried out before the exploitation in 1975, injecting the separated water from wells Ah-1 and Ah-6 into the well Ah-5. This experiment showed that the reinjection could be a solution for the disposal of the residual water.

2. When the exploitation began, a reinjection project was conducted from March '76 **to** October '82. Approximately 30 *Yo* of the residual water (150 "C) was reinjected into the wells Ah-2, Ah-17, Ah-19 and Ah-29 (Witherspoon P., 1979), and the rest was discharged into the Paz River (Table 1).

Reinjection stopped due to continuous rise in the wellhead pressures of the reinjection wells and also because the channel was constructed. At the end of the reinjection period in 1982, a total of 38.5 Mton of separated water had been reinjected (Table 2), leading to a cooling of the reservoir around wells Ah-5, Ah-25 and Ah-29 (LBL, 1989). Currently, only well Ah-2 is used for reinjection.

Table 1: Injected water into the Ahuachapan reservoir during the period 1975-1982.

Well	Injection period	Injection (Mton)
Ah-2	Mar'76-Mar'93	13.3
Ah-8	Jun'76-May'82	7.3
Ah-17	Oct'76-Jun'78	5.4
Ah-29	May'76-Oct'82	12.0
Ah-19	July'80-Mar'81	0.5

REINJECTION OF RESIDUAL WATER INTO THE CHIPILAPA GEOTHERMAL AREA

The Ahuachaphn Geothermal Field (AGF) has 15 productive wells with average wellhead pressure of 6.2 bar-a. The total flow capacity is 750 kg/s from which 180 kg/s of vapor feeds the units U1, U2, U3. The carrying system has a double flash unit at 1.6 bar-a where steam is produced for the double pressure unit u3.

The residual water at 110°C from the double flash unit will be injected into the Chipilapa area into the wells C'h-7, Ch-7bis, and Ch-9 through a pipeline 5.5 km long (Figure 1). The pressure drop simulations along the pipeline with a water flow of 300 kg/s give wellhead pressure values of I.78 bar for Ah-7, 4.05 bar for Ch-7bis and 2.45 bar for Ah-9 (CEL 1997). Since the water level of the reinjection wells is known, an estimate of the maximum flow capacity can be calculated as follows:

$$MaxFlow = (whp + \rho g h) * Injectivity$$

Where: h is the depth of the water level.
g is the acceleration gravity.
ρ is the water density.

The total capacity for the reinjection well is 420 kg/s (Table 2). To produce this amount of residual water, we need to extract 618 kg/s of mass using 12 of the 15 productive wells.

Table 2. Some characteristics of the reinjection wells in the Chipilapa area:

Well	WHP (bar-a)	Depth water level (m)	*Injectivity* (lt/s/bar)	*MaxFlow Capacity* (kg/s)
Ch-7	1.78	280	10	268
Ch-7bis	4.05	250	3	82
Ch-9	2.45	220	3	70

As seen above, lumped simulations of the Ahuachapán geothermal system results in an extraction value of 410 kg/s to reach the equilibrium of the reservoir pressure.

This restricts the operation of the 15 productive wells to 9, producing 285 kg/s of residual water.

Thus, we have two reinjection possibilities: the first one, using the maximum capacity of the reinjection wells **(420** kg/s) and the second one, using the extraction for the equilibrium of the reservoir pressure (285 kg/s) (Table **3).**

Table 3. Estimated values for the injection flow in the Chipilapa area.

Well	Whp (bar-g)	Reinjection Max. (kg/s)	Reinjection Eq. (kg/s)
Ch-7	1.78	255	156
Ch-7bis	2.45	85	52
Ch-9	1.78	85	52

SIMULATION OF THE AHUACHAPAN RESERVOIR PRESSURE BY REINJECTION INTO THE CHIPILAPA AREA

Before the current study, two previous studies were carried out on the changes in the Ahuachaph pressure by the reinjection in Chipilapa. The first one was carried out in October 1993 using the GEMMA simulator (CEL, 1993). In this study, an injection of 300 kgls into the wells Ch-7, Ch-7bis, and Ch-9 was simulated. The results after 10 year of continuous exploitations give a recovery reservoir pressure of 2 bar in the well Ah-1 (Figure 2).

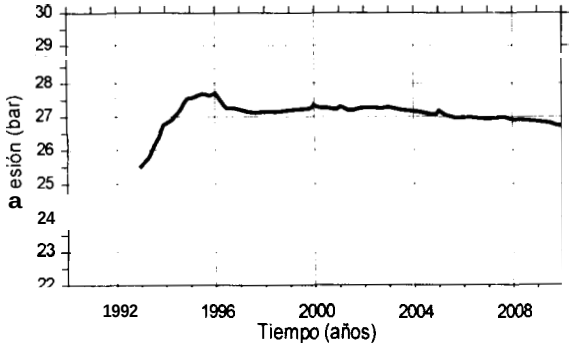

Figure 2. Recovery pressure in the well Ah-1 at 150 m a.s.l. due to the reinjection of 300 kgls into the Chipilapa Geothermal Area (from CEL, 1993).

The second study was carried out in October 1996 using the VARFLOW (EG&G, 1982) code. Injections of 288 kg/s and 460 kgls into the reinjection wells Ch-7, Ch-7bis and Ch-9 were simulated. The results using this method show a recovery pressure of 4 bar with the injection of 460 **kgls,** and 2 bars with the injection of 288 kgls. A disadvantage of this method is that it does not consider the extraction and temperature distribution into the reservoir, only the pressure distribution in a homogeneous medium for extraction or reinjection (Figure **3).**

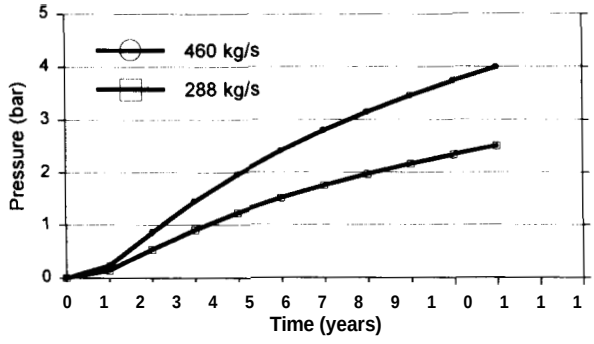

Figure 3. Recovery pressure in the well Ah-21 by the reinjection of 460 and 288 kgls into the Chipilapa Geothermal Area using VARFLOW.

In the current study, a 3-D model of 6 layer with 71 elements each for the simulation of the reinjections of the residual water into the Chipilapa area, has been used. The model is operated through the TOUGH2 simulator. The model was previously calibrated with natural and production state data. The pressure and temperature formation of the reservoir (Quijano J., 1994) was used for the natural state. The historical data for the productive and reinjection wells was used for the production state. The predictions were simulated over 12 years using the following three extraction-reinjection modes:

1. Current conditions: an extraction of 410 kgls (extraction for the equilibrium of the reservoir pressure) producing 260 kgls of residual water. This water is sent to the ocean through the channel.

2. Same as above, but now the residual water is reinjected into the reinjection wells Ch-7, Ch-7bis, and Ch-9.

3. An extraction of 618 kgls that produce 420 kgls of residual water, which is the maximum capacity for the reinjection wells Ch-7, Ch-7bis, and Ch-9.

The simulation results with mode 3 show a recovery pressure in the Ahuachapán reservoir of 2.3 bar after 12 years of continuous exploitation (Figure 4).

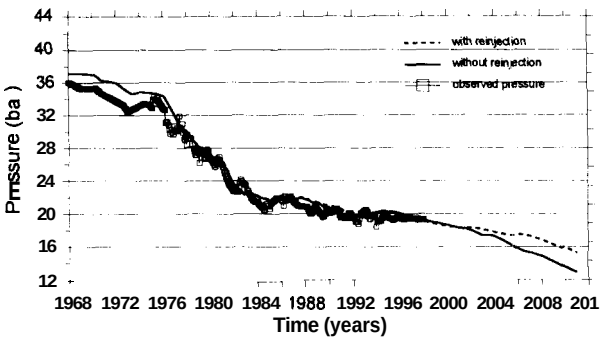

Figure 4. Prediction for the pressure at 200 m a.s.l. in well Ah-25, extracting 618 kgls from the Ahuachapan field and reinjecting 420 kgls into the Chipilapa area. The comparison between the pressure with and without reinjection gives a recovery pressure of 2.3 bar.

CONCLUSIONS

Using a 3-D model of the Ahuachaphn Geothermal System with the TOUGH2 simulator, the predictions of the pressure changes in the Ahuachapán reservoir with an extraction of 618 kg/s and a reinjection of 420 kgls in Chipilapa during 12 year of continuous operations, give a recovery reservoir pressure of 2.3 bar.

The simulation results with the GEMMA, VARFLOW and TOUGH2 simulators regarding the pressure changes the Ahuachaph reservoir due ***to*** the reinjection of residual water in the Chipilapa area, suggest a recovery pressure of at least 2 bar if it is reinjected 300 kg/s over a period of 10 years.

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