Transmissivity Distribution at The Ahuachapán-Chipilapa Geothermal Field in El Salvador

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Abstract

Through the analysis of injectivity test in 30 wells in The Ahuachapán-Chipilapa Geothermal Field a transmissivity distribution map has been constructed. The analysis was carried out by simulating injectivity tests with a radial model of 50 elements in a single layer 400 m thick. Previous to the simulation, on base on injectivity test data was calculated the sandface flow (W_{sf}) and reservoir pressure (P_r). W_{sf} was calculated considering a wellbore storage coefficient in a well with free surface and P_r was calculated considering a turbulence regimen in the boundary well-feedzone. The simulations were carried out with the TOUGH2 code changing rock permeability to fit the observed pressure (P_r) with the calculated pressure in the central element. In general, the results show a transmissivity distribution between 1 and 10 Dm in the areas of Ahuachapán and Chipilapa and an anomalous zone with transmissivities between 80 an 140 Dm southern to the Ahuachapán Field.

Introduction

The geothermal development resources in the Ahuachapán-Chipilapa geothermal area have been involved drilling activities in three main areas: Ahuachapán Geothermal Field (AGF), Chipilapa zone located about 3 km from CGF and the Agua Shuca zone (Figure 1). During the explorations stage in the period 1956-1958 were drilled 7 shallow wells in the AGF (Fritz Durr, 1960). After that, in the period 1968-1981, 32 deep wells were drilled in the AGF and a power plant of 95 MW was constructed. Looking for a new geothermal reservoir during the period 1989-1993, 7 deep wells were drilled in the Chipilapa zone. The result, showed that AGF and Chipilapa are parts of the same geothermal system and Chipilapa is a marginal part of its outflow (Aunzo A., 1988). Trying to expand the exploitation zone in the Ahuachapán Field, in order to increase the total mass steam without a fast depletion of the reservoir fluid, 7 deep wells have been drilled in Agua Shuca. Until now some wells are under thermal recovery and the other ones wait for the pipe connection to the plant.

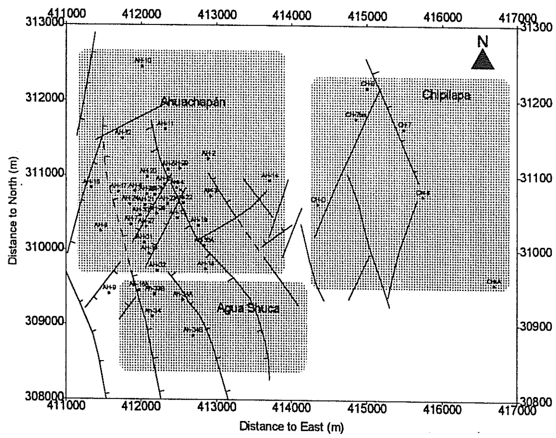

Figure 1. Ahuachapán-Chipilapa Geothermal Field. Geothermal development resources areas in chronological order, Ahuachapán, Chipilapa and Agua Shuca.

One of the most critical parameter in Reservoir Engineering assessment is the transmissivity thickness product kh (Dm). The transmissivity means how easy the fluid flow within the medium.

In order to get the transmissivity kh we can execute pressure transient test by management the wellhead flowrate in drawdown, buildup interference test. If the test is conducted in the short term (usually few hours o days) we can get near wellbore condition such as kh, storage and skin (Horne, 1995). During long term production, pressure is often controlled by production equipment requirements, and production rates and reservoir pressure are monitoring over month and years. In this case the decline analysis give information about reservoir properties, such its volume.

The general theory for well test analysis is based on Theis solution, which consider a radial liquid flow in an isotropic and isothermal porous media. Factors such, non isothermal effect, two phases effects and fractured media make difficult to apply conventional well test analysis (Gudmundur S., 1984). Trying to avoid this, the present study use as a analysis tool a radial model centered in a well using the code TOUGH2 (Tansport of unsaturated groundwater and heat) (Pruess, K., 1993).

Interference Tests in The Ahuachapán-Chipilapa Geothermal Field

In order to have information about the transmissivity and storativity of the Ahuachapán reservoir, several interference test were conducted in the Ahuachapán Field. The first one was carried out in the period from may 6 to August 19, 1982, in which Ah-1, Ah-4, Ah-6, Ah-17, Ah-20, Ah-21, Ah-22, Ah-23, Ah-24, Ah-26, Ah-27 and Ah-28 were used as producers wells, Ah-2, Ah-8 and Ah-29 used as injectors wells, and Ah-25 was used as an observation well. The test was analyzed with the simulator VARFLOW (EG&G and LBL, 1982), which uses the Theis solution and superposition principle. The results show transmissivity and storativity values of 25 Dm y 2.5e10-6 m/Pa respectively (Aunzo Z., 1989).

Another analysis to evaluate the transmissivity and storativity values in the reservoir between Ahuachapán and Chipilapa was carried out by Quijano in 1997. The analysis was based on the production history since 1975 to October 1997. The total extraction by year was concentrated in the well Ah-21, and the observation point in the well Ch-7bis and well Ah-14 located in the boundary between the two areas. The output of the model was fitted with the pressure decline curve observed at 200 m a.s.l. in the observation wells. The results show transmissivity and storativity values of 16 Dm y 2.5e10-6 m/Pa respectively.

Inyectivity Test, Sandface Flow and Wellbore Storativity Effect

From the Reservoir Engineering point of view after the completion well, some well test must be executed: Temperature profiles with fixed injection rates, injectivity tests and temperature profiles during recovery temperature. The step wise injectivity is an experiment with several fixed flow rate injections (10, 40, 60 kg/s etc) for more than one hour. During the test the pressure transient is measured with a gauge tool near the main feedzone.

Previous to the simulation the sandface flow must be calculated, considering the wellbore storage coefficient in a well with a free liquid level. Also we need to calculate the pressure acting on the reservoir considering the turbulent regime in the boundary well-feedzone.

The cause of the wellbore storage effect is that the sandface reservoir boundary flow rate does not necessarily have to equal to the well head flow at all times. If a well is suddenly opened, the wellbore pressure will drop, and cause expansion in boiling wells and water level depletion at first in non-boiling wells. If a well is suddenly shut in, fluid continues to pass through the sandface into the hole. Both effect result in changes of the wellbore storage volume (Kjaran S., 1983). The sand face flowrate can be calculated from the following equation.

$$(1) \qquad W_{sf} = W - \rho C \frac{dp_w}{dt}$$

where W_{sf} is the sand face mass flow, W is the surface mass flow, C is the wellbore store coefficient and P_w is the bottom hole pressure. If the well has free liquid level, the wellbore storage coefficient is given by:

$$(2) \qquad C = \frac{\pi r_w^2}{\rho g}$$

where r_w is the wellbore radius , ρ is the density of the water filling the wellbore and g is the gravity acceleration. If we combine this two equations we can correct the data from a injectivity test as follow:

$$(3) \qquad W_{sf} = \left[W\Delta t - \pi r_w^2 \frac{\Delta p_w}{g} \right] \frac{1}{\Delta t}$$

A injectivity test executed in June 24, 1997 is showed in the Figure 3.

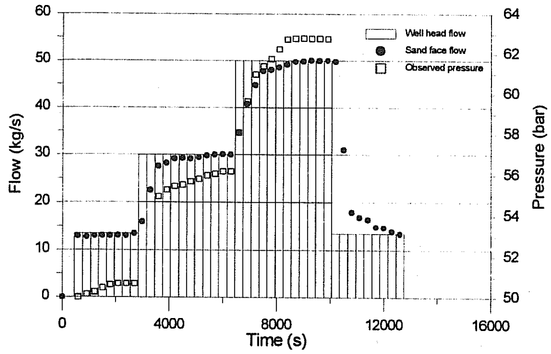

Figure 2. Pressure an flow measured during the injectivity test in the well Ah-34 on Jun-24-97. The filled circles means the estimated sandface flow.

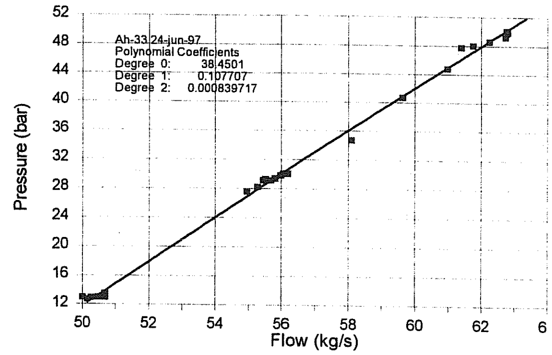

Figure 3. Polynomial fit for a observed pressure versus sandface flow plot for the injectivity test in the well Ah-34 on Jun-24-97.

Correction of pressure by turbulence effect

When a stepwise injectivity test is carried out, in the boundary well-feedzone could be formed a turbulent regime. This phenomenon cause a pressure drop and could masked the real pressure acting on the reservoir. To correct this, the calculation of the turbulence coefficient is necessary, considering the sandface coefficient pointed before. Then in a turbulent regime, the pressure at depth is given by the following equation (Todd, 1980):

(4) $$P = P_o + aW_{sf} + bW_{sf}^{\,2}$$

Where W_{sf} is the sand face flow, Po is the static bottomhole pressure and P is the pressure measured by the pressure gauge tool during the injection test. By plotting P versus W_{sf} and fitting it with a second order polynomial equation, we can get the turbulence coefficient b (Figure 3). Then, the measured pressure can be corrected with the following equation.

(5) $$P_{res} = P - bW_{sf}^{\,2}$$

As an example, the corrected pressure observed during the injectivity test in the well Ah-34 Jun-24-97 is the following: From the Figure 3 the turbulence coefficient b = 8.397×10^{-4}, and if it is considered the maximum measured pressure of 50 bar related to a sandface flow of 62.5 kg/s, using the equation 5 we have a corrected pressure of 46.7 bar.

Numerical Model

To simulate the stepwise injection a numerical model with radial geometry was used. The model consists of 50 elements in a single layer of 400 m thick. The first 10 elements of the model have a constant incremental radius of 1 m and the others ones increase logarithmically until 2000 m.

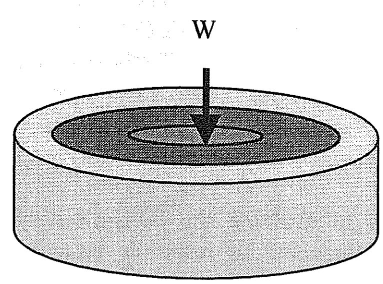

Figure 4. Reservoir model concentrically to the well.

To check the results from the injectivity test two model with 300 and 400 m thick were used, getting similar results. For example, with both models 300 and 400 m, we get transmissivity values of 4.36 and 4.16 Dm respectively.

During the fitting process of calculated and observed pressure the permeability values in the numerical model was changed in a range of 1 to 150 mD. By other side, the simulation result in the Ah-34 also show a cooling effect of 100 °C in the near well formation by the injection of water at 25 °C.

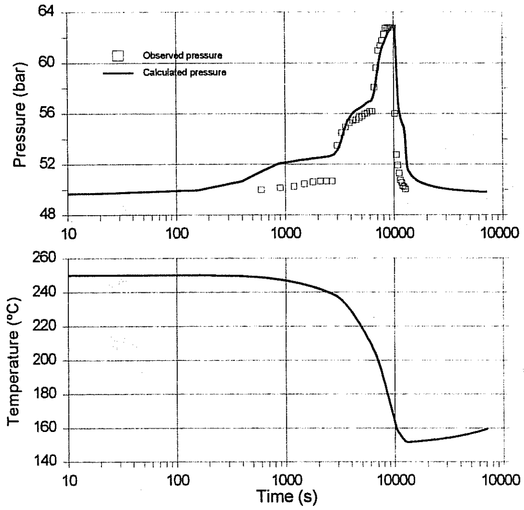

Figure 5. Simulation results of the stepwise injection in the well Ah-34 on Jun-24-97. The top figure show the best fit between observed and calculated pressure and the bottom figure show the cooling effect of 100 °C in the central element.

Analysis of the Results

With respect to the quality an quantity of the injectivity tests collected, going back in time it is more difficult to analyze. The injectivity tests collected from the last wells in Agua Shuca, have a good quality, and sandface flow and corrected pressure was estimated. The results are showed in the table 1.

Table 1. Injectivity index and transmissivity values from the wells in Agua Shuca.

Well	kh (Dm)	Well	kh (Dm)
Ah-4bis	9.5	Ch-7	3.5
Ah-16a	140.0	Ch-7bis	4.2
Ah-32st	6.5	Ch-8	3.2
Ah-33a	1.2	Ch-9	3.6
Ah-33b	85.0	Ch-D	4.1
Ah-34	6.2	Ch-A	--
Ah-34a	5.2	Ch-Abis	--
Ah-34b	5.6	--	--

The analysis of the injectivity tests carried out in the Chipilapa area, also have a good quality, and easy to interpret. But, the analysis of the injectivity test in the first 32 wells drilled in the Ahuachapán Field was difficult to interpreted. This data was analyzed by Campos in 1980, who calculated the injectivity index (kg/s/bar) with the following equation:

$$(4) \qquad I = \frac{\Delta q}{\Delta t} = \frac{q_m}{P_{qm} - P_o}$$

where Po is the initial static pressure at measured depth, q_m is the maximum injection flow and P_{qm} is the pressure associated with maximum flow during the test.

After the completion well in the first 32 wells in Ahuachapán, were performed injection test with steps of 20, 30, 40 y 50 lt/s during 10-15 min each one. The reported pressure by step is a unique value, making difficult to know if that pressure correspond to a stabilized pressure.

This data, also was reinterpreted by LBL in 1989 using conventional well test analysis by computing the transmissivity Kh/μ (m^3/Pa/s). Because of poor information, the present study analyze this injectivity tests without the corrections by storage effect and turbulence regime. The results are presented in the following table:

Table 2. Injectivity index and transmissivity at the Ahuachapán-Chipilapa Geothermal Field

Well	Inj. index kg/s/bar	Kh/μ (10^{-8}) m^3/Pa/s	Kh Dm
Ah-2	3.0	2.2	3.49
Ah-14	2.0	2.2	2.82
Ah-16	8.0	6.2	8.30
Ah-17	8.0	5.5	7.29
Ah-18	2.0	1.1	1.61
Ah-19	6.0	4.4	5.67
Ah-21	12.0	6.6	11.36
Ah-23	8.0	4.0	9.17
Ah-24	6.7	5.1	6.80
Ah-28	7.0	5.1	6.23
Ah-29	4.0	2.2	3.16
Ah-30	4.5	2.6	3.56

The results from the injectivity test give a injectivity index in the range of 1-10 lt/s/bar and transmissivity values in the range of 1e-8 to 7e-8 m3/Pa-s (Aunzo Z., 1988). The results after modelling in the present study, also present transmissivity values in the range of 1-10 Dm. We can observe that good production wells such Ah-21, Ah-27 and Ah-28 have good injectivity index and good transmissivity and non production wells such Ah-14, Ah-18 have low injectivity index and low transmissivity.

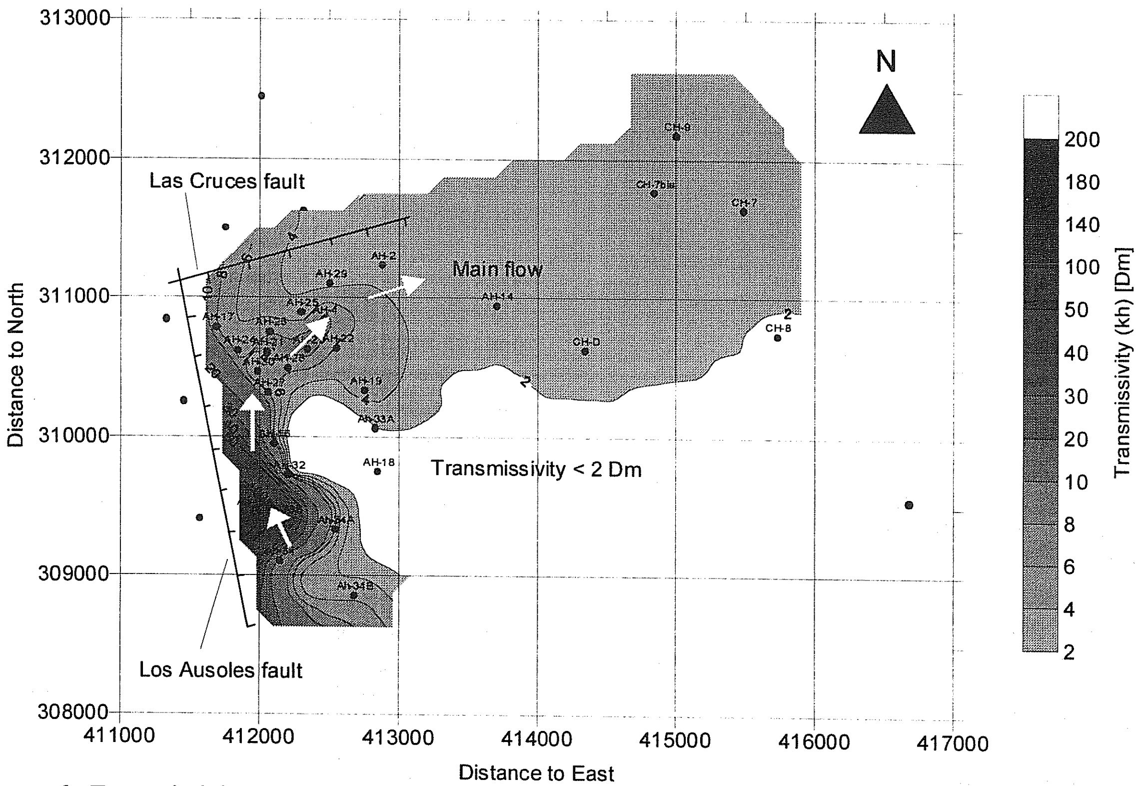

Figure 6. Transmissivity distribution at the Ahuachapán-Chipilapa Geothermal field.

The transmissivity values from simulating with the radial model are mapped in the Figure 6. We can observe that the transmissivity distribution suggest a flow movement in north direction from the upflow zone at the south to The Ahuachapán Field as is indicated by arrows. The main flow movements is governed by Los Ausoles and Las Cruces faults, acting as barriers because the wells outside the mapped zone are completely dry and its lithology does not present the stratum andesitas of Ahuachapán where the reservoir is located.

Conclusions

The transmissivity values obtained from the injetivity test in the Ahuachapán wells are lower than the transmissivity values obtained from the interference test. This is probably due to near well transmissivities determine the pressure response in the well during short duration injection test, whereas interference tests measure global reservoir transmissivities.

Proportionality is observed between the injectivity index and transmissivity values. The calculations show well injectivities in the order of 1-10 l/s-bar and transmissivities in the order of 1 to 10 Dm. The results are generally consistent with the well productiveness, good producers have relatively high transmissivity (~10 Dm), while low transmissivities are found in the poor producers (~ 1 Dm).

The transmissivity distribution in the Ahuachapán-Chipilapa Geothermal Field suggest an entrance of geothermal fluids from the south (near the well Ah-34), into the Ahuachapán reservoir. The fluid primarily feeds the actual exploitation zone in Ahuachapán (kh ~ 6-10 Dm), after that it goes to the east and feeds the Chipilapa Geothermal Field (kh ~ 3-4 Dm). Finally, the flow goes to the north to the discharge zone in the El Salitre Area.

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