THE LOS HUMEROS GEOTHERMAL RESERVOIR, A CASE OF A VERY HIGH TEMPERATURE SYSTEM

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ABSTRACT

The Los Humeros geothermal field is located in the eastern portion of the Trans-Mexican volcanic belt. At present, 7 backpressure turbogenerators of 5 MW each are in operation. The reservoir is characterized by very high temperatures at depths below 1500 m (300°C), rather low permeabiltty ($kh = 2x10^{13}$ m^3, 200 md-m) generally. The thermodynamic conditionsof the reservoir, based on the interpretation of pressure and temperature logs together with pressure transrent testing, place the reservoir in the subcooled liquid region. very close to saturation conditions (two phase). In this paper, it is discussed how these propertiesdeterminethe production mechanism of the wells, by using a wellbore simulator. Results indicate that there are high pressure losses mainly in the formation (90% on average) as fluid moves up from formation to wellhead. This typically causes the fluid to reach saturation conditions in the formation. The low porosity of the system allows a significant amount of heat transfer from the formation to the fluid, so that surface enthalpy values (2600kJ/kg) exceed of those in the reservoir (1400 kJ/kg).

INTRODUCTION

The Los Hurneros geothermal field is located in a calderic structure. in the eastern portion of the Mexican Volcanic Belt near to the Sierra Madre Oriental (Figure 1). In order to locate geothermal sites for commercial exploitation, in 1968 the Comision Federal de Electricidad (C.F.E.) began geological, geophysical, geohydrological and geochemical studies in the Los Hurneros - Derrumbadas area. In 1982 the first well was drilled in the Los Humeros Field in order to confirm the results of these studies. At present, there are 34 wells with an average depth 1500m. In 1990 the commercial exploitation started with one unit of 5 MW and at present there are 7 back pressure units of 5 MW each.

LOS HUMEROS RESERVOIR SYSTEM

Geological background.- Lithology in the wells is variable and includes sedimentary, intrusive igneous and volcanic rocks. The sedimentary rocks present diverse levels of rectystalization ranging from unaltered to fully rnetamorphized phases. Metamorphic rocks are essentially marbles, hornfels and skarns. The intrusive rocks are granites. The volcanic rocks are andesites of Miocene age (10 million years) and Quaternary Ignimbrites. In order to simplify the correlation of wells. the lithology was clustered in the following four units, from oldest to youngest (C.F.E, 1990):

- Unit 4, Prevolcanic basement: Includes sedimentary, metamorphic and intrusive igneous rocks. These are of pre-miocenic age. This unit is underlies the other ones and is considered the basement having high temperature and low permeability. The top of this unit was reached at a minimum depth of 1142 m (well H-2) and a maximum depth of 3230 m (well H-24). The bottom of the basement has not been found in any well.

- Unit 3, Precalderic vulcanism: This unit includes andesites of piroxenes and hosts the geothermal reservoir. The average thickness is 1203 m.

- Unit 2, Calderic vulcanism: This unit includes the Xáltipan and Zaragoza Ignimbrites that are the origin of the Los Humeros and Los Potreros Colapso, respectively. These rocks are between 500,000 and 100,000 years old. This unit acts *as* an aquitard and has an average thickness of 593 m.

- Unit 1, Postcalderic vulcanism: This unit includes deposits produced by the explosion of freatic craters and lava flows from volcanic centers. It is less than 100,000 years old with an average thickness of 336 m.

Figure 2 shows a local south-north cross section including only the area where wells have been drilled. In this figure the 150, 200, 250 and 300°C isotherms are indicated to give some idea about the behaviour of temperature with depth, reflecting the reservoir conditions. From petrological analysis the following minerals of alteration have been detected : Zeolites (withoutWairakite), in a temperature range between 50 - 150°C; Epidote, between 150 - 200°C; Epidote-Wairakite, between 200-300°C; And anfiboles, at temperatures greather than 300°C. Anfiboles are found in the prevolcanic basement (Unit 4). From these results and from fluid inclusion analysis it is concluded that the Los Humeros system, mainly the Colapso Central, has had higher temperatures in the past. Also in the past more than one hydrothermal alteration event has occurred with processes of autosealing and hydraulic fracturing. This indicates that there are, at present, strong thermal perturbations that are complicating the distribution of temperatures.

Reservoir enaineerinq backsround.-Interpretation of temperature logs during drilling and warming-up steps has permitted the estimation of the average temperature and *feed* intervals. From the point of view of temperatures, the field is divided into two sectors: The Colapso Central with greater temperatures and Mastaloya with tower ones. There are two identifiable productive zones: The shallowest interval between 1400-1900 masl and the deeper interval below 700 masl. The reservoir temperature has been estimated at the two levels: The shallowest interval is 290°C in the Mastaloya sector and 320°C in the Colapso Central sector, and the deeper interval is 315°C in the Mastaloya sector and 330-360°C in the Colapso Central (Torres, 1993). There are very high temperatures where wells reach depths near to the prevolcanic basement (Unit 4), as is shown in Figures 3 and 4.

The average reservoir pressure was estimated from pressure logs and pressure transient testing interpretation. The former gives the pivot point and the latter gives the average reservoir pressure. A vertical profile of pressure distribution in the reservoir was constructed and is shown in Figure 5.

The fluid in the reservoir is situated in the subcooled liquid region, near to the top of the saturation curve where latent heat of evaporation is small with respect to low temperatures. A small change, (6 $bar)_{abs}$, in pressure can cause flashing in the formation.

The interpretation of pressure transient testing gives also the conductivity of the formation (permeability-thickness, kh), which for Los Humeros results in low values ($2x10^{-13}$ m^3). The Los Humeros reservoir is a low permeability and a high temperature system.

Wellbore simulation.- In order to discuss how the reservoir conditions affect the mechanism of production, wells H-1, H-7, H-8, H-9 and H-17 were chosen. Flowing conditions of these welts were simulated using Wellsim (Probst et. al., 1992) a wellbore simulator. The results of the simulations were compared with real pressure and temperature logs during flowing conditions. The Hagedorn-Brown two phase correlation was used for the simulations.

Well H-1.- Well H-l is located in the Mastaloya sector and was drilled in 1981 to a total depth of 1450 m. The feed interval is between 1158-1438 m (shallowest interval). This well exhibits one of the highest permeabilities in the field ($kh=5.2x10^{-13}$ m^3). Static temperature and pressure at the feed interval is 280°C and 98 bar_{abs}. At these conditions fluid is located in the subcooled liquid region and to reach Saturation conditions, pressure must decrease by 33 bar. Maximum flow rate is 174 t/h with 40% steam quality at atmospheric conditions. Simulation results indicate that the flashing zone is at 1048 m and from this point to the wellhead is two phase. Figure 6 shows the measured and calculated pressure profiles . As can be seen, a good agreement was obtained with the simulator. Pressure losses from formation to wellbottom are of the order of 22 bar and from bottom to wellhead are 61 bar. Lower pressure losses in the formation are due to the high permeability. Pressure drop in the formation is less that the necessary to reach saturation conditions (33 bar). Enthalpy in the reservoir is 1235 kJ/kg and at the surface is 1190 kJ/kg, then 45 kJ/kg (4%) is lost when the fluid moves up to the wellhead. Low resistance to flow in the formation prevents a high pressure drop and the onset of flashing in the formation.

Well H-7.- Well H-7 is located in the Mastaloya sector and was drilled in 1983 to a total depth of 2340 m. This well produces only from the deeper interval between 2007-2157 m. Static temperature and pressure at the feed interval is 305°C and 151 bar_{abs}. At these conditions fluid is located in the subcooled liquid region with an enthalpy of 7367 kJ/kg, and to reach saturation conditions pressure must decrease by 59 bar. Maximum flow rate is 40 t/h with 98% steam quality at atmospheric conditions. Simulation results indicate two phase flow from wellbottom to wellhead. Figure 7 shows the measured and calculated temperature profiles. A good agreement was obtained with the simulator. Pressure losses from formation to wellbottom are of the order of 99 bar and in the well are 18 bar. Pressure drop in the formation is greater than that necessary to reach saturation conditions (59 bar). The enthalpy difference between reservoir and wellbottom is 1221 kJ/kg, because additional heat is transfered to the fluid. This phenomenon is termed "excess enthalpy". When fluid moves up to wellhead 12 kJ/kg (0.5%) is lost. Higher resistance to flow in the formation causes a high pressure drop and flashing occurs in the formation.

Well H-8.- Well H-8 is located in the limits of the Mastaloya and the Colapso Central sectors It was drilled in 1985 to a total depth of 2388 m. This well exhibits two feed intervals. Between 1497-1747 m depth and between 1847-1947 m depth. Static temperatures and pressures at both intervals are 280°C and 121 bar_{abs} at the upper interval, and 300°C and 140 bar_{abs} at the deeper interval At these conditions fluid is located in the subcooled liquid region with an average enthalpy of 1288 kJ/kg. To reach saturation conditions pressure **must** decrease by 54 bar on average. Maximum flow rate is 35 t/h with an enthalpy of 2105 kJ/kg at the surface Simulation results indicate that there are two phase conditions from wellbottom to wellhead. Figure 8 shows the measured and calculated temperature profiles and a good agreement was obtained with the simulator Pressure losses from formation to wellbottom are of the order of 79 bar and in the well are 10 bar Pressure drop in the formation is greater than that necessary to reach saturation conditions (54 bar) The enthalpy difference between reservoir and wellbottom is 800 kJ/kg, therefore additional heat is transfered to the fluid. When fluid moves up to the wellhead 16 kJ/kg (1%) is lost Higher pressure drop causes flashing in the formation

Well H-9.- Welt H-9 is located in the Colapso Central sector. It was drilled in 1986 to a total depth of 2500 m. The feed interval is between 1399-1799 m. This well exhibits one of the highest permeabilities in the field. Static temperature and pressure at the feed interval are 320°C and 127 bar_{abs}. At these conditions fluid is located in the subcooled liquid region with an enthalpy of 1460 kJ/kg, reaching saturation conditions when pressure decreases 8 bar. Maximum flow rate is 90 t/h saturated steam with an enthalpy of 2660 kJ/kg at the surface. Simulation results indicate two phase flow from the wellbottom. Figure 9 shows the measured and calculated pressure profiles (Pinette, 1994). As it can be seen. a good agreement was obtained with the simulator. Pressure loss from formation to wellbottom is of the order of 69 bar and in the well is 9 bar. Pressure drop in the formation is greater than that necessary to reach saturation conditions 18 bar). Enthalpy losses from wellbottom to wellhead are of the order of 8 kJ/kg. Therefore the difference in enthalpy, 1192 kJ/kg, between reservoir and wellhead is due tu heat transfered to the fluid in the formation. High pressure drop causes flashing in the formation.

Well H-17.-Well H-17 is located in the Colapsa Central sector and was drilled in 1986 to a total depth of 2261 m. It has two feed intervals located between 1449-1899 m and 2099-2149 m depth. The well was corroded by the presence of HCI and in 7992 was deviated and completed to a depth of 1700 m. After that, only one feed zone remained, between 1450-1550 m. Static temperature and pressure at the feed interval Is 300°C and 127 bar. At these conditions fluid is located in the subcooled liquid region with an enthalpy of 1340 kJ/kg. To reach saturation conditions pressure must decreases by 41 bar. Maximum flow rate is 18 t/h with an enthalpy of 2600 kJ/kg at surface. Figure 10 shows the measured and calculated pressure profiles with the simulator. As it can be seen, a good agreement was obtained. Simulation results indicate two phase flow from the weltbottom. A change in slope is observed in the pressure profile at 1200 m depth, because the well is deviated 22°. In order to reproduce this effect with the simulator an angle of deviation was assigned to the well. Pressure losses from formation to wellbottom are 101 bar. Pressureloss in the well is 12 bar Pressure drop in the formation is 60 bar more than that necessary to reach saturation conditions (41 bar). In a similar behaviour most of the other wells the enthalpy increases in the formation ($\Delta h = 1240$ kJ/kg), because heat is transfered to *the* fluid once it has flashed. This high heat transfer is possible due to the low porosity of the rock, that results in a great heat transfer area.

CONCLUSIONS

A wellbore simulator was used to reproduce flowing conditions in wells of the Los Hurneros Field. A good agreement was obtained between real data and simulated results.

The reservoir is a high temperature, low permeability and low porosity system. At reservoir conditions fluid is located thermodynamically in the subcooled liquid region, very close to saturation conditions. To reach flashing conditions it is necessary for pressure in the reservoir to decrease by 45 bar average. Low permeability causes high pressure losses, of the order of 90 bar, from reservoir to the well, . When lluid moves from the formation *to* wellbottom, it reaches saturation conditions in the formation and boiling starts. When flashing occurs in the fractures the fluid temperature decreases and causes a temperature difference between the rock and the fluid. The large contact area due to the low porosity of the rock, allows a significant amount of heat transfer from the rock to the fluid and. hence, the fluid enthalpy at the surface is higher than in the reservoir.

H-1 is an example of a well which intersects high formation permeability and lower temperature fluid. Flashing occurs in the well. The behaviour of other wells *of* the field is similar to wells H-7, H-8, H-9 and H-17, all of which exhibit excess enthatpy at the surface.

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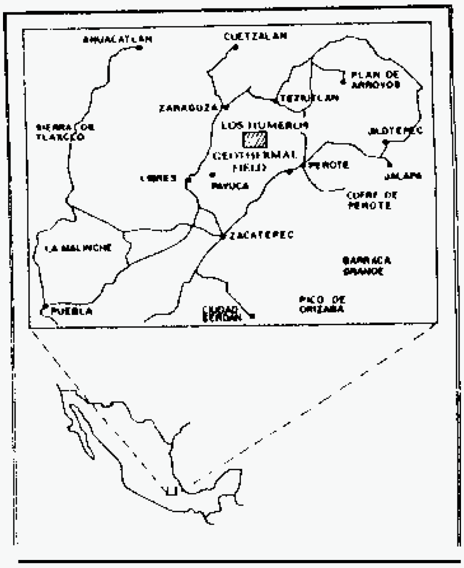

Figure 1.- The Los Hurneros Geothermal Field Location

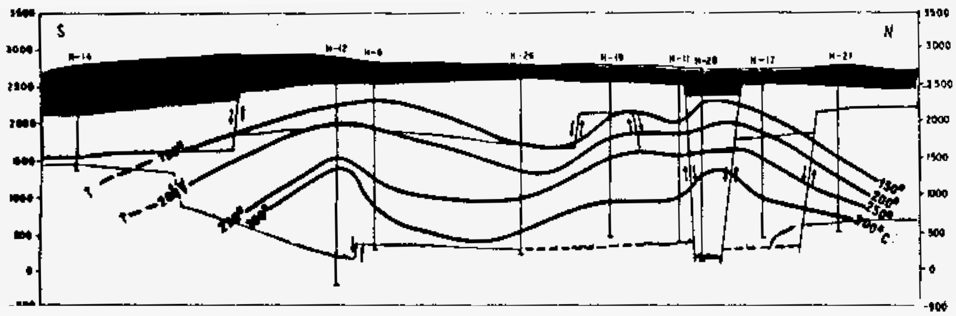

Figure 2.-Local cross section (S-N) of the Los Humeros Field.

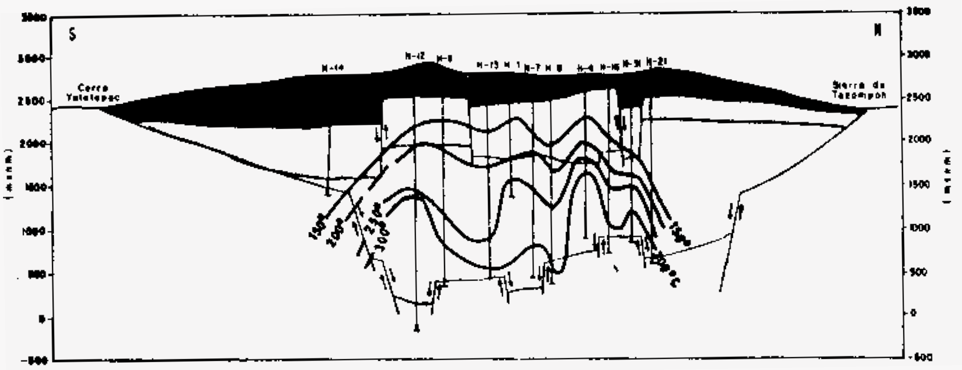

Figure 3.-Regional cross section (S-N) of the Los Humeros Field.

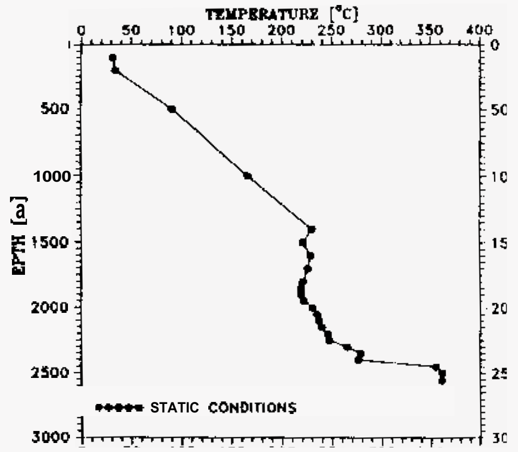

Figure 4.- Temperature profile in the well H-28.

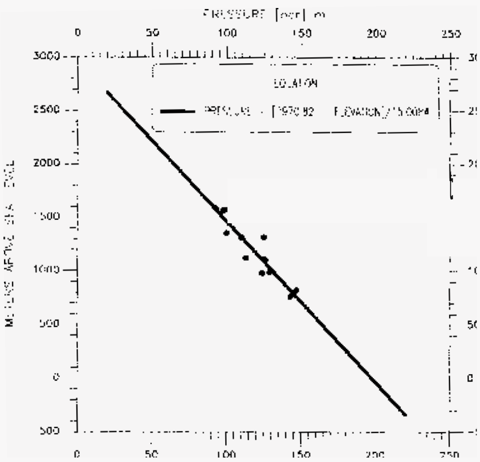

Figure 5.- Vertical profile of pressure distribution in Los *Humeros.*

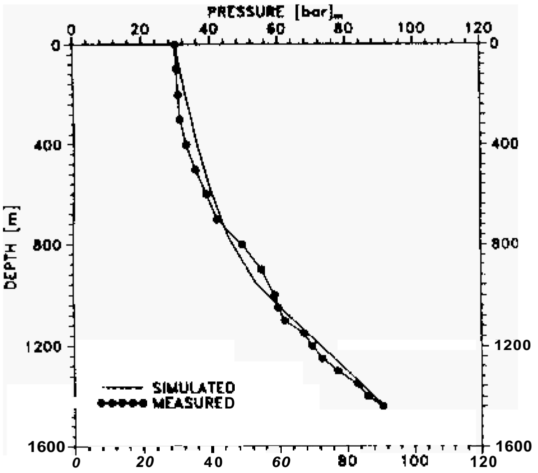

Figure 6.- Pressure profile measured and simulated in well H-1.

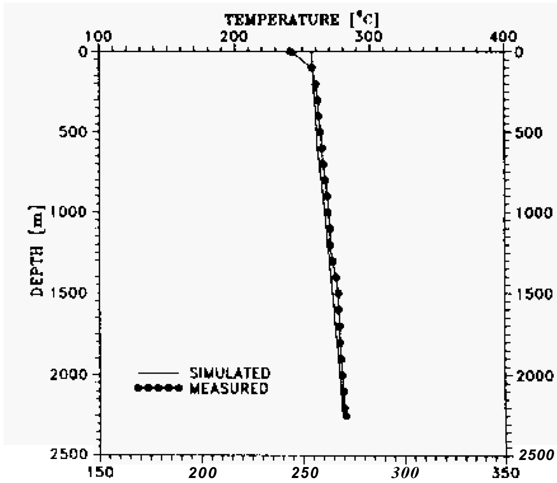

Figure 7.- Temperature profile measured and simulated in well H-7.

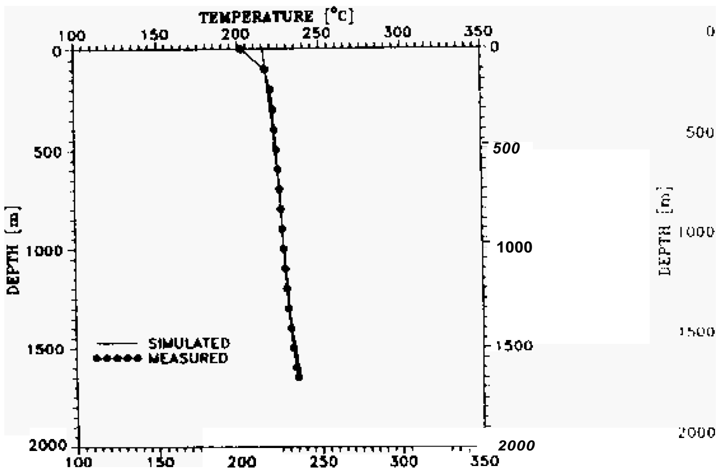

Figure 8.- Temperature profile measured and simulated in well H-8.

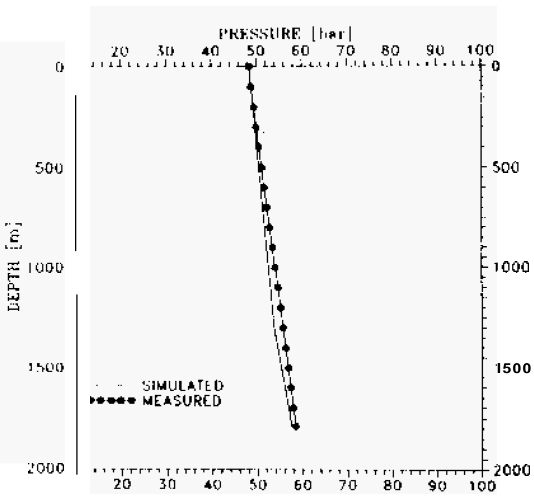

Figure 9.- Pressure profile measured and simulated in well H-9.

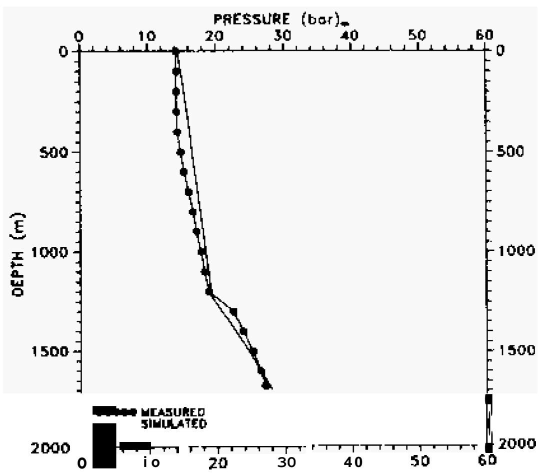

Figure 10.- Pressure profile measured and simulated in well H-17