Intermittent Recharge Processes at the Los Humeros (Mexico) Geothermal Reservoir Indicated by Analysis of Gas Data

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Keywords

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ABSTRACT

Gas data from wells of the Los Humeros geothermal field were analyzed in order to investigate reservoir processes occurring as a result of fluid extraction and reinjection. Equilibrium of the gas phase with mineral buffers controlling H_2S concentration in fluids was assumed to occur according to the Fischer-Tropsch (FT) and the combined pyrite-hematite-magnetite (HSH2) reactions. At Los Humeros two reservoirs have been identified: a shallower liquid-dominated one with temperatures between 300 and 330ºC and a deeper low-liquid saturation one with temperature between 300 and 400ºC. In this work the behavior of gas data of two representative wells: H-1 that produces from the upper reservoir and H-7 from the deeper reservoir, is shown. The 1987-1995 and 2000-2005 trends observed in the FT-HSH2 diagram in most wells indicated that important recharge processes of hotter deeper fluids have occurred for such periods of time with maximum temperatures occurring in 1995 and 2005. Temperatures estimations for 1995 data were 310°C in well H-1 and 338°C in well H-7 while higher temperatures were estimated for 2005 data, 333°C (H-1) and 350°C (H-7). These results could be related to some increases in reservoir permeability due to tectonics. The analysis of data also evidenced the presence of steam phase reinjection returns in well discharges from 1995 to 2000.

Introduction

The Los Humeros geothermal field is located in the eastern part of the Mexican Volcanic Belt in the State of Puebla, (19° 40´ latitude N, 97° 25´ longitude W), at an elevation of approximately 3000 m above sea level (Figure 1). The installed capacity of the field is 35 MWe (Gutiérrez-Negrín and Quijano, 2005). Major regional faults are preferentially oriented in the NW-SE direction and within the field, the most important local fault system for the transport of geothermal fluids has N-S direction (Campos and Garduño, 1987) (Figure 2). The analysis and interpretation of reservoir engineering and geochemical data for natural state conditions, suggested the presence of two reservoirs. A shallower liquid-dominated reservoir with temperature between 300 and 330ºC and neutral pH, and a low liquid saturation deeper reservoir with temperature between 300 and 400ºC (Arellano et al., 2003). Based on oxygen-18 and CO_2 profiles at reservoir a convective process with steam separation and condensate counter-flow was proposed for the natural conditions, this agreed with the natural pressure profile.

Most of the wells at Los Humeros produce high enthalpy discharges (wellhead enthalpies compared to steam enthalpies at separating conditions) but the shallowest well H-1 produce two-phase fluids with high liquid fraction (~ 0.73 by mass) from the shallower aquifer. The geochemical characteristics of the liquid phase have been defined as low salinity and almost neutral pH, bicarbonate, sulphate or chloride-type mixed waters. Regarding the Na-K-Mg diagram (Giggenbach, 1988) the waters are partially-equilibrated or sometimes equilibrated, indicating reservoir temperatures roughly between 240-280°C.

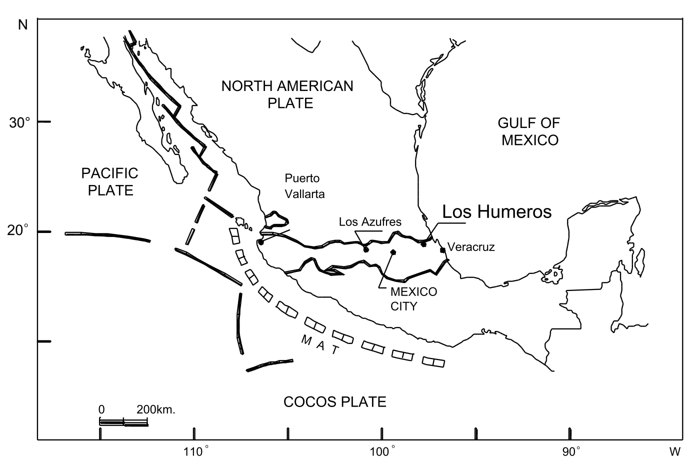

Figure 1. Location of the Los Humeros geothermal field.

Chemical variations in the liquid phase through time are observed depending on well operation conditions, because most wells produce a mixture of shallow and deeper fluids (Barragán et al., 1988; 1991). Due to the nature of the discharges in Los Humeros, gas data could provide reliable information regarding reservoir conditions.

The objective of this work is to investigate the occurrence of recharge processes in the Los Humeros reservoir by the analysis of gas data through FT-HSH2 equilibria from representative wells. In Figure 2 the location of wells in the field is given. Data for this study were provided by Comisión Federal de Electricidad.

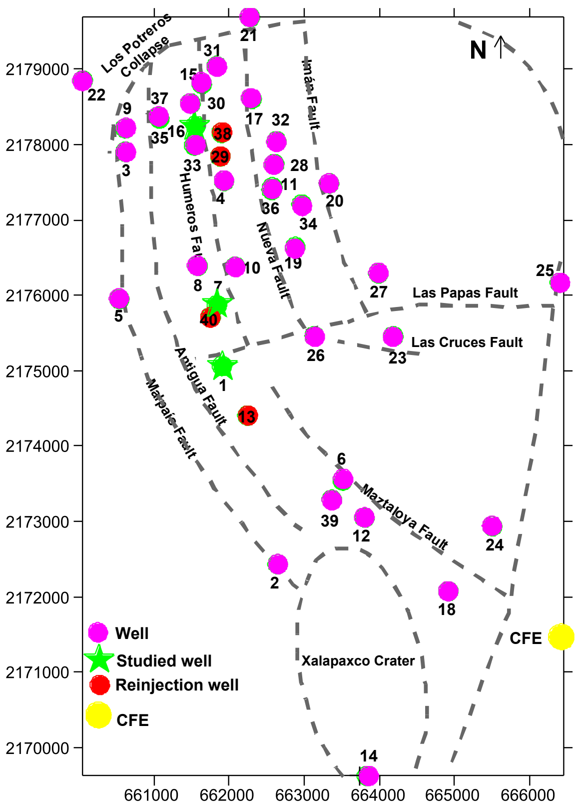

Figure 2. Location of wells at Los Humeros geothermal field.

2. Methodology

The FT and HSH2 parameters are obtained from the gas composition of wells according to the following equations (D'Amore, 1998), where concentrations of gas are taken in the total fluid:

$$FT = 4 \log (H_2/H_2O) + \log (CO_2/H_2O) - \log (CH_4/H_2O)$$

$$HSH2 = 3 \log (H_2S/H_2O) - 5/4 \log (H_2/H_2O)$$

The following trends and interpretations of FT-HSH diagram (which are the same to be used to interpret FT-HSH2 diagrams) were given by D'Amore and Truesdell, (1995); where y is the vapor fraction or "excess steam":

(a) Increase T, decrease *y*: contribution of fluid from a hotter and deeper source with high liquid saturation.

(b) Increase T, increase *y*: apparent increase in T and y due to lateral source of steam, with practically zero liquid saturation and with a strong local accumulation of gas.

(c) Decrease T, decrease *y*: local source of pure and low temperature water with no gas content as in the case of reinjection fluids or fast meteoric recharge.

(d) Decrease T, increase *y*: caused by either recharge from peripheral fluids rich in gas; or sulfides precipitation caused by local over-production with blockage of main fractures.

Limitations of this method apply when the gas phase produced by the well comes from different sources. Thus, when a deep hot zone of the reservoir located below the exploited reservoir rich in reactive gas species and CO_2 becomes an important fraction of the total produced gas, an overestimation of temperature and steam fraction values could be obtained (D'Amore, 1998). This seems to be the case for the Los Humeros gas data, however regarding reservoir temperature estimations the results obtained by the FT-HSH2 method compared well with measured temperatures for static conditions of the wells (Arellano et al. 2006). At Los Humeros very high temperatures (> 400°C) have been recorded, (Truesdell, 1991).

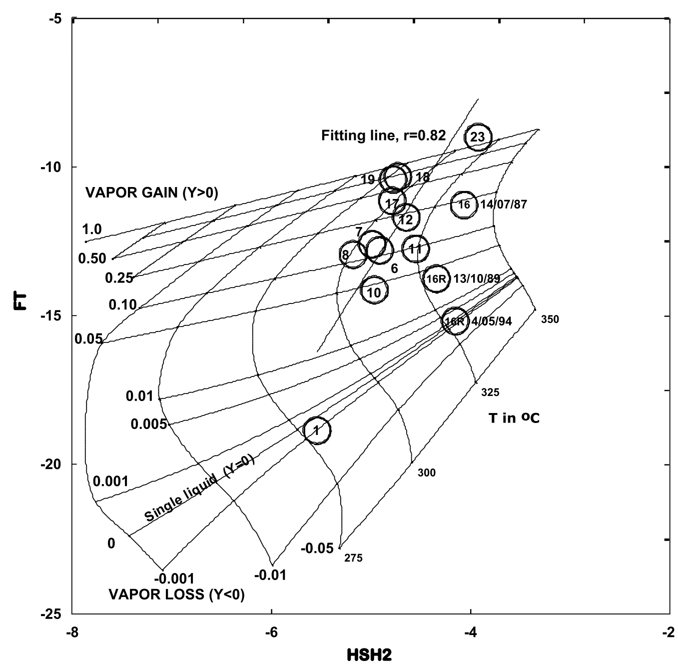

Figure 3. FT-HSH2 diagram for pre-exploitation data.

3. Gas Behavior for Pre-Exploitation Conditions

Figure 3 shows the FT-HSH2 results according to gas data collected in 1987, (Barragán et al., 1988; Arellano et al., 2003). As it is seen, the location of the well H-1 in the diagram indicates no reservoir excess steam and reservoir temperature of 278°C, which is close to results from estimations based on liquid phase geothermometers. In contrast, well H-23 which is a deeper well (2620 m) seems to be fed by a fluid with negligible liquid saturation and a temperature of ~320°C. Well

H-23 had a short production time, it was drilled in 1987 and closed in 1988. Without considering data for well H-16 in the diagram, all the other points show a lineal tendency (r = 0.82) that suggests a mixing process between two end members, being probably those the compositions of the wells H-1 and 23. Then the gas compositions of the wells result of the mixing of basically two fluids. The data of well H-16 as collected in 1987 seem to fit the linear trend but showing a relatively higher reservoir temperature (> 330°C) and a moderate reservoir steam (20%). The well H-16 was first drilled to a depth of 2048 m and produced fluids from both reservoirs depending on the operating conditions. In 1988 the well was cemented to a depth of 1383 m because of corrosion and scaling occurred due to the entry of deep acid fluids (Barragán et al., 1989; Truesdell, 1991). The points corresponding to the repaired well (H-16R) show significant less reservoir steam but still the same very high temperature. The sample collected in 1994 shows that it was fed by an equilibrated reservoir liquid phase. The profile of CO_2 in the reservoir liquid is given in Figure 4, as it is seen this profile indicates the occurrence of steam separation and partial condensation with counter-flows which concentrates the volatile species in the shallow levels of the reservoir. This convective process seems to discharge the highly acidic condensate toward the zone where well H-16R is located, (previously called "Central Collapse") since CO_2 concentration is much higher in H-16R than it is in well H-1. These results suggested that the acidity observed in some wells in the past was probably due to the convective process occurring at reservoir and the preferential condensate flow direction toward the previously called "Central Collapse" zone. The oxygen-18 profile seemed to confirm such a hypothesis (Barragán et al., 2003). Well H-16R was closed in 2005 due to the entry of shallower fluids.

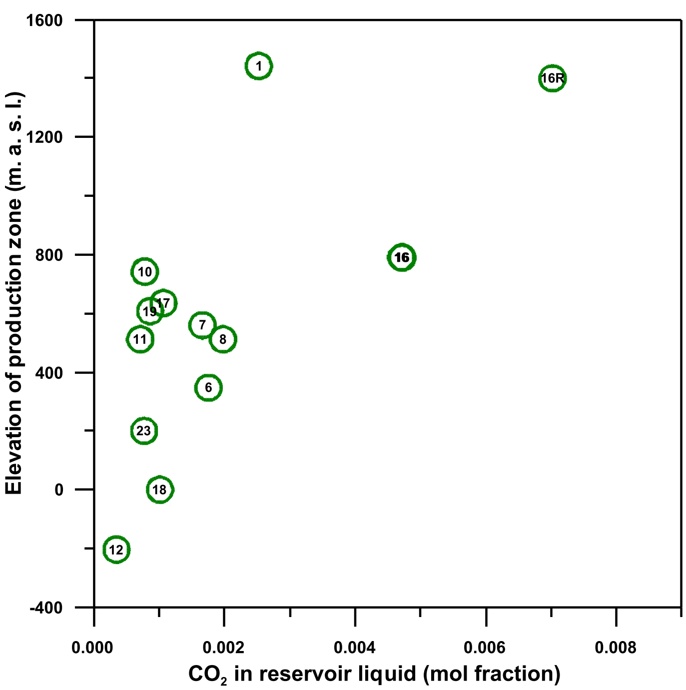

Figure 4. Profile of CO_2 in reservoir liquid.

4. Results

The wells selected for this study were H-1 which is representative of the shallower reservoir and well H-7 that produces mostly from the deeper reservoir. The original well H-1 was drilled in 1981 to a depth of 1458 m, it was operating until July 1995 when because of scaling was deviated. After being repaired, the well H-1D reached a depth of 1850 m and started operation in November 1995. The well H-7 was drilled in 1983 to a depth of 2340 m and started operation in 1984 since then up to now it has been in production.

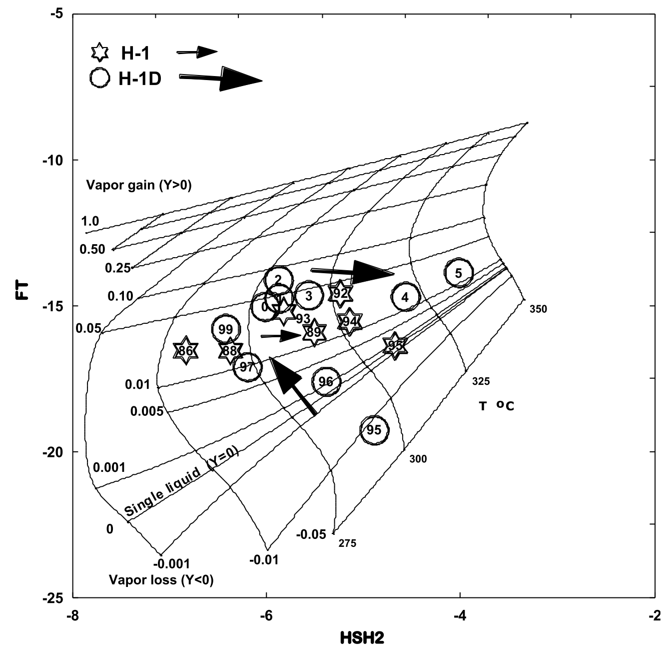

Figure 5. FT-HSH2 diagram for well H-1 data.

4.1 Wells H-1, H-1D

Figure 5 shows the FT-HSH2 diagram for the wells H-1 and H-1D, the points represent average values for the years considered. For the well H-1 (see thin arrow) the points indicate a small reservoir steam (less than 5%) since 1986 and a negligible value in 1995 just before the well was repaired. At the same time important increases in temperature with time, from 260°C in 1986 to about 310°C in 1995, are seen. The fact that for 1995 data equilibrated and hotter (compared to 1986-1989 data), liquid reached the production zone of the well, could be an indication of the income of fluids from the deeper reservoir due to a possible pressure decrease in the upper reservoir because of exploitation. However, according to the conceptual model of the reservoir, the temperature of the shallower reservoir was estimated between 300 and 330°C, thus data for 1995 is contained in that interval. The points of the repaired well, H-1D, show two tendencies, one with increase in reservoir steam and decrease in temperature, from the end of 1995 (when the well started operation) to 1999. The point for 1995 indicates that the well produced boiled liquid after loosing some steam, at about 290°C. The mentioned tendency is caused by either recharge from peripheral fluids rich in gas; or sulfides precipitation caused by local overproduction with blockage of the main fractures (D'Amore and Truesdell, 1995) and, in steam wells of Los Azufres, this tendency was related to the presence of steam phase reinjection returns in the discharges (Barragán et al., 2006). As reinjection started in 1995 at Los Humeros, the possibility of steam reinjection returns could not be discarded, although according to analysis of production data, the amount of such returns would be rather small since the enthalpy and the production of the well are not affected (Arellano et al., 2006). At Los Humeros, as in the case of Los Azufres, a water-air mixture is reinjected to the reservoir, hence the "peripheral fluids" identified in the FT-HSH2 diagram, are constituted by the air injected, which is highly diffusive and reaches the production zones of wells. This characteristic makes the injected air act as a qualitative gas phase tracer at reservoir. The other tendency shows an increase in temperature and decrease in reservoir steam and occurs from 2000 to 2005. This trend is interpreted as the income of hotter deeper recharge to the well. Very high temperatures were obtained for 2004 and 2005 data; 320 and 333°C respectively, this is probably due to the increase in H_2S concentration that occurred not only in well H-1 but also in other wells. Still such high temperatures are contained in the range proposed for the shallower reservoir, however there are other evidences supporting the input of fluids from the deeper reservoir, such as increase in production in this well from 2001 to 2005 (Arellano et al., 2006) as a result of increase in permeability, which could be due to tectonics (Lermo et al., 2002).

4.2 Well H-7

Figure 6 shows the FT-HSH2 diagram for data of well H-7. This well produces high enthalpy fluids at wellhead with fraction of steam of more than 90%. In the diagram two trends

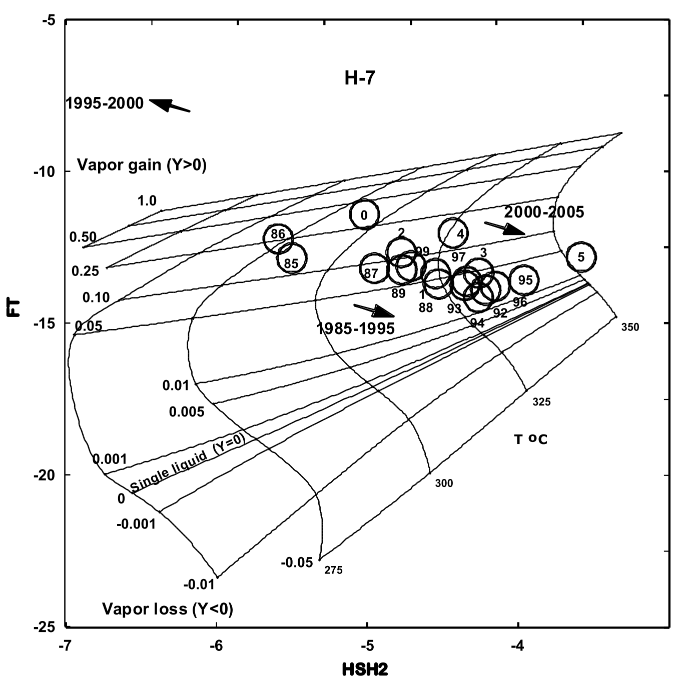

Figure 6. FT-HSH2 diagram for well H-7 data.

are observed, one of them indicates temperature increase and reservoir steam decrease and occurs for 1985-1995 and 2000-2005 data. Recharge of hotter deeper fluids with high liquid saturation entry the well during such periods of time. From 2002 to 2005 the decrease in steam fraction was from 0.15 to 0.02 while the increase in temperature was noticeable from 315 to 350°C which, as explained for well H-1, is probably due to the increase in H_2S concentration. Also from 2002 to 2005 a small increase in well bottom pressure was recorded (Arellano et al., 2006) supporting the income of such recharge. The other trend shows temperature decrease and steam fraction increase and occurs for 1995-2000 data, as in the case of well H-1, this trend could be related to the income of steam reinjection returns. In this well an increase in steam production (for a constant orifice plate diameter) was observed to occur from 1995 to 2000, the steam mass flow rate changed from ~ 42 to 52 tons/hr (Arellano et al., 2006) and subsequently decreased because of a reduction in the orifice plate diameter. Since reinjection started in the field in 1995, the variations observed in the FT-HSH2 diagram for 1995-2000 data and the increase in steam production could be related to the presence of steam returns from reinjection. Also, a very small increase in liquid production was noticed (~1 ton/hr) from 1998-1999 which did not affect the enthalpy of the well.

5. Conclusions

FT-HSH2 method was used to study the changes in gas composition of wells from the Los Humeros geothermal field and the occurrence of intermittent recharge processes was identified. Two wells were given as example H-1 representative of the upper reservoir and H-7 representative of the deep reservoir. According to the trends observed, the input of deeper hotter fluids has occurred during specific periods of time in both wells. For well H-1 the overall trends found for 1986-1995 and from 2000 to 2005 data indicated the entry of hotter recharge and specially in 2005 very high temperature was estimated (333°C) for the reservoir fluid. For well H-7 the trends found for 1985-1995 and 2000-2005 indicated the inflow of hotter fluids. In this case the temperature estimated for 2005 was 350°C. Such important increases in temperature were due to the increase of H_2S concentration in the discharges. The approach has limitations and the reservoir temperatures could be overestimated, however the tendencies of the data points with time found in the FT-HSH2 diagrams are useful to qualitatively assess the reservoir characteristics with exploitation. At the same time, there were other evidences suggesting increase in reservoir permeability and were attributed to tectonics. For both studied wells a decrease in temperature and increase in reservoir steam fraction were observed to occur from 1995-2000 data. This tendency was interpreted as a result of the presence of steam phase reinjection returns in well discharges, since reinjection in the field started in 1995.

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