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Gas geochemistry for the Los Azufres (Michoacán) geothermal reservoir, México

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Abstract. Gas data of the Los Azufres geothermal field were analyzed by using the FT-HSH2 method based on equilibrium of the Fischer-Tropsch reaction and on the combined pyrite-hematite and pyrite-magnetite reactions. Reservoir temperature and reservoir excess steam were estimated for initial and present conditions in some representative wells. This method was very useful in estimating reservoir temperatures in vapor producing wells. It was found that as the well produces a smaller fraction of water, the reservoir temperature estimation agrees qualitatively with results from the cationic composition geothermometer. For wells dominated by liquid it is seen that reservoir temperatures estimations agree with well simulator temperatures. Results indicate a decrease in reservoir temperatures in the south zone of the field where intensive reinjection takes place.

1 Introduction

Gas equilibria in geothermal reservoirs is a useful tool to estimate reservoir temperatures and reservoir excess steam. D'Amore and Truesdell (1985) proposed a grid method named FT-HSH which is suitable to data with a relatively low content of non condensable gases. A method based on equilibria for the Fischer-Tropsch reaction and on the combined expressions for pyrite-magnetite and pyrite-hematite (FT-HSH2) was developed (D'Amore, 1998). This considers more local oxidant conditions at reservoir implying the occurrence of high concentration of H_2S and relatively low concentration of H_2 and NH_3 in the fluid. FT-HSH2 method was suitable to gas data from the Los Azufres and Los Humeros geothermal systems in order to understand the dynamics of the reservoir at initial and present conditions (Arellano et al., 1998; Barragán et al., 1999, 2000).

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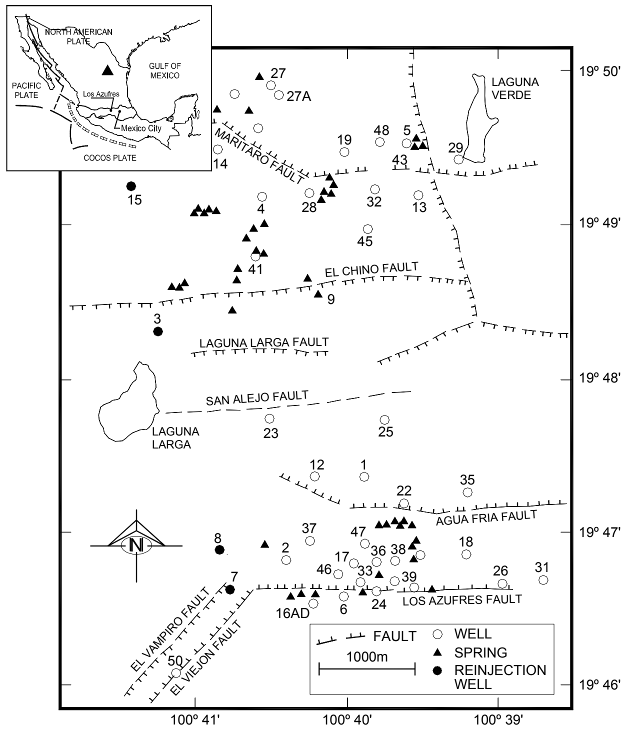

Fig. 1. Location of the Los Azufres geothermal field and location of wells.

2 The Los Azufres geothermal field

The Los Azufres geothermal field is an intensely fractured, two-phase, volcanic hydrothermal system located in the northern portion of the Mexican Volcanic Axis, in the state of Michoacán at an average elevation of 2800 masl, (Fig. 1). At present it is the second in the country generating more than 150 MWe (Sandoval, 2003). The field was divided in two zones the north and the south with different characteristics in producing fluids at starting conditions: wells of the were steam dominated while wells in the north zone produce

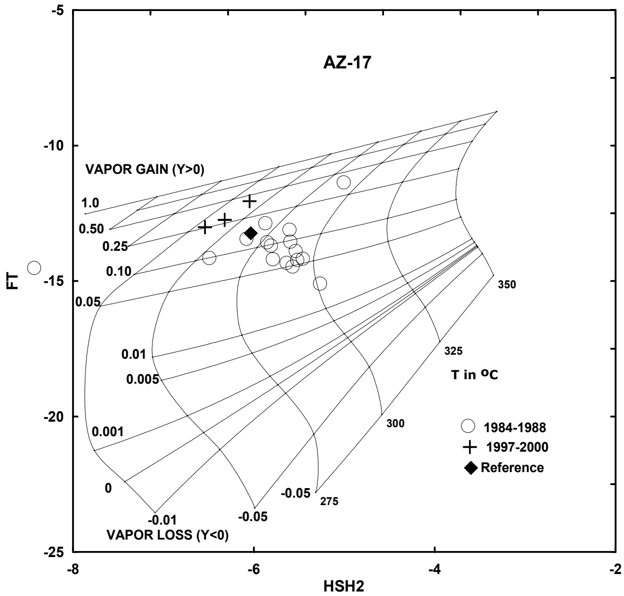

Fig. 2. FT-HSH2 grid for well AZ-17.

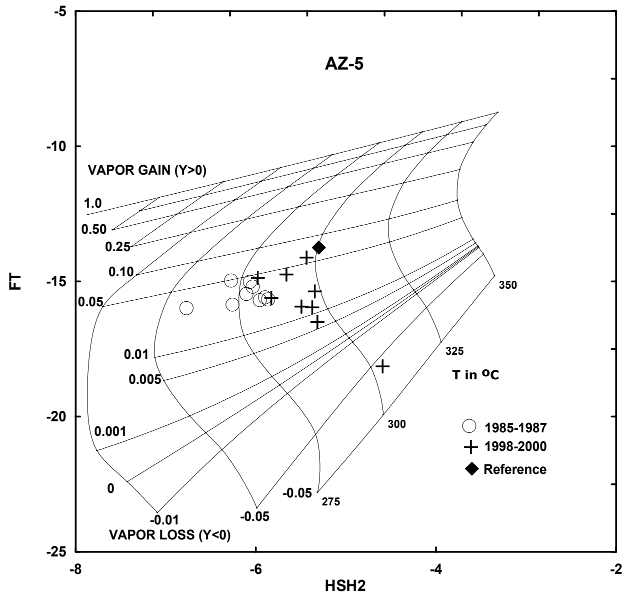

Fig. 3. FT-HSH2 grid for well AZ-5.

two-phase fluids.

3 Gas equilibria

FT-HSH2 grid method (D'Amore, 1998) is based on equilibrium of the Fischer-Tropsch reaction and another chemical reaction for the H_2S-H_2. The pyrite-hematite equilibrium was combined with the original pyrite-magnetite equilibriu*m (from FT-HSH) to obtain a equilibrium expression named HSH2. This method was fully described by D'Amore (1998); Arellano et al., (1998); Siega et al., (1999); Barragán et al., (1999; 2000a).

The FT-HSH2 grid is generated by the graphic solution of Eqs. (1) and (2):

$$\mathrm{FT} = \log \mathrm{K_{FT}} + 4 \log \mathrm{A_{H2}} + \log \mathrm{A_{CO2}} - \log \mathrm{A_{CH4}} - 2 \log \mathrm{P_{H2O}} \quad (1)$$

$$\mathrm{HSH2} = \log \mathrm{K_{HSH2}} + 3 \log \mathrm{A_{H2S}} - 5/4 \log \mathrm{A_{H2}} \quad (2)$$

Where K is the equilibrium constant and the A coefficient for every species is defined by:
If $y \geq 0 : A_i = y + (1 - y)/B_i$ and If $y < 0 : A_i = 1/(B_i(1 + y - yB_i))$
Where "y" is the reservoir excess steam and B_i is the distribution coefficient for every gas as a function of temperature (D'Amore, 1992). The expressions for the equilibrium constants ($\log \mathrm{K_{FT}}$ and $\log \mathrm{K_{HSH2}}$) are functions of absolute temperature (K) and are given by:

$$\log \mathrm{K_{FT}} = -4.33 - (8048/T) + 4.635 \log(T)$$

$$\log \mathrm{K_{HSH2}} = 7.609 - (6087/T) - 0.412 \log(T)$$

$$\log \mathrm{P_{H2O}} = 5.51 - (2048/T)$$

The parameters FT and HSH2 are obtained from the gas composition according to Eqs. (3) and (4), where concentrations of gas species are taken in the total fluid.

$$\mathrm{FT} = 4 \log(H_2/H_2O) + \log(CO_2/H_2O) - \log(CH_4/H_2O) \quad (3)$$

$$\mathrm{HSH2} = 3 \log(H_2S/H_2O) - 5/4 \log(H_2/H_2O) \quad (4)$$

4 Results

4.1 AZ-17 south zone

Figure 2 shows the FT-HSH2 diagram for the steam well AZ-17. In the diagram, the dark marks correspond to the initial reference points proposed by Nieva et al. (1987) calculated by equilibrium of FT reaction for the measured reservoir temperature. It is seen that the FT-HSH2 method overestimates the reservoir temperature for 1983–1988 data, which probably indicates the source temperature of the steam. The anomalous point with high "y" value corresponds to a sample taken one week before the September 1985 earthquake. For 1997–2000 data, a drop in temperature due to the drop in reservoir pressure and an increase in "y" values were obtained. Those effects are due to exploitation.

4.2 AZ-5 north zone

Figure 3 shows the FT-HSH2 grid for well AZ-5. This well produces two-phase fluids with an average steam fraction at separating conditions of 0.73. In the figure, the points corresponding to 1985–1987 indicate reservoir temperatures lower than the reference temperature of 300°C (obtained by CCG) and lower y values than that calculated for the reference. As an explanation it could be stated that in the past, there was a steam "cap" in the field that was not at full equilibrium with the reservoir liquid phase. With exploitation, it seems that equilibrium was attained, since data for 1998–2000 indicate an average reservoir temperature of 288°C while 284°C is the value obtained by TCCG, geothermometer (Nieva and Nieva, 1987) which is based on the liquid phase composition. Reservoir steam values range between 0.5 and 5%.

5 Conclusions

Two representative wells were studied using the FT-HSH2 method. For the south zone where reinjection is important, the well AZ-17 showed a decrease of about 15°C in temperature regarding initial conditions. In well AZ-5 (north zone) reservoir temperatures provided by FT-HSH2 method are close to TCCG estimations which indicates fluid equilibrium at present time. For other wells such as the AZ-9 (north zone) FT-HSH2 temperatures approach the values obtained by WELFLO well simulator then for those wells the last equilibrium for the gas phase occurs in the entrance of the well. This method was very useful in studying data from dry steam wells where no liquid phase is available to estimate reservoir temperatures. It was noticed that as the wells have a high steam fraction FT-HSH2 method provides better estimations.

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