A preliminary interpretation of gas composition in the CP IV sector wells, Cerro Prieto geothermal field, Mexico

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Abstract

To increase the electrical generation capacity of the Cerro Prieto geothermal field from 620 MW to 720 MW, the Cerro Prieto IV (CP IV) sector of the field was developed in the NE portion of the exploited field. Fourteen new wells have been drilled there since 2000. The wells in CP IV zone produce two-phase fluids at wellhead with heterogeneous steam fraction characteristics: at the central zone and towards the NW, the wells are liquid-dominated while those towards the E and S produce a relatively high steam fraction. This work studies the gas compositions of produced fluids to obtain reservoir parameters such as temperature and steam fraction and identify different sources of fluids in the wells. A method was used based on the Fischer Tropsch reaction and H_2S equilibria with pyrite-pyrrhotite as a mineral buffer (FT-HSH3). The results for the “natural state” showed the presence of fluids with reservoir temperatures from 275 to 310° C and excess steam values from -1 to 50%. Data are aligned in a FT-HSH3 trend, suggesting that the well discharges consist of a mixture in different proportions of the two end members. One seems to be a liquid with a temperature of over 300° C with negative or negligible excess steam. The other seems to be a two-phase fluid with a temperature of about 275° C and an excess steam fraction of about 0.5. According to the data for single wells and depending on the production conditions of the wells, reservoir fluid mixtures could occur in different proportions of liquid and steam. Data for 2005 that included wells drilled after 2000 suggest the presence of a steam phase in the reservoir. The steam could be generated with the boiling of deep reservoir fluid from a pressure drop. The mixing trend obtained for the natural state was also seen for 2005 data but lower temperatures (from 265 to 295° C) were obtained compared with those for natural conditions. The entry of lower-temperature fluids descending through the H fault to the reservoir was inferred, since results for the wells affected by this process (located at the center of the CP IV area) showed small or negative excess steam values and slightly lower temperatures (265-270° C).

Keywords: Cerro Prieto, geothermal fluids, gas composition, chemical equilibrium

Interpretación preliminar de la composición gaseosa de pozos del sector CP IV del campo geotérmico de Cerro Prieto, México

Resumen

A fin de aumentar la capacidad de generación de 620 a 720 MW, se desarrolló el sector Cerro Prieto IV (CP IV) en la porción NE del campo geotérmico de Cerro Prieto, donde se perforaron catorce pozos nuevos a partir del año 2000. Los pozos de la zona de CP IV producen fluidos bifásicos con características heterogéneas en cuanto a la fracción de vapor: en la porción central y hacia el NW los pozos producen líquido dominante mientras que hacia el E y S producen una fracción de vapor relativamente alta. En este trabajo se estudia la composición gaseosa de los fluidos producidos para obtener parámetros del yacimiento tales como la temperatura y la fracción de vapor e identificar diferentes aportes de fluidos a los pozos. Se utilizó un método basado en la reacción de Fischer Tropsch y el equilibrio del H_2S con pirita-pirrotita como amortiguador (FT-HSH3). Los resultados para el estado inicial indican que existen fluidos con temperaturas de yacimiento entre 275 y 310° C así valores de exceso de vapor entre -1 y 50%. Los resultados se alinean en un patrón de mezcla FT-HSH3 que sugiere que los pozos descargan una mezcla de los dos miembros finales en diferentes proporciones. Uno de ellos parece ser un líquido con una temperatura superior a los 300° C con exceso de vapor negativo o insignificante. El otro parece ser un fluido bifásico con temperatura de unos 275° C y un exceso de fracción de vapor de aproximadamente 0.5. De acuerdo con datos de cada pozo y dependiendo de las condiciones de producción de cada uno, pueden ocurrir mezclas de fluidos con diferentes proporciones de líquido y vapor en el yacimiento. Datos de 2005 de pozos perforados después del año 2000 sugieren la presencia de una fase de vapor en el yacimiento, que podría generarse por la ebullición de fluidos profundos debido a una caída de presión. El patrón de mezcla obtenido para el estado inicial se observó también en los datos de 2005, pero se obtuvieron temperaturas menores (de 265 a 295° C) que las del estado inicial. Se infirió la entrada al yacimiento de fluidos de menor temperatura que descienden por la Falla H, ya que los resultados en los pozos afectados por este proceso (ubicados al centro del área de CP IV) presentaron valores de exceso de vapor negativos o mínimos, y temperaturas ligeramente inferiores (265 a 270° C).

Palabras clave: Cerro Prieto, fluidos geotérmicos, composición gaseosa, equilibrio químico

1. Introduction

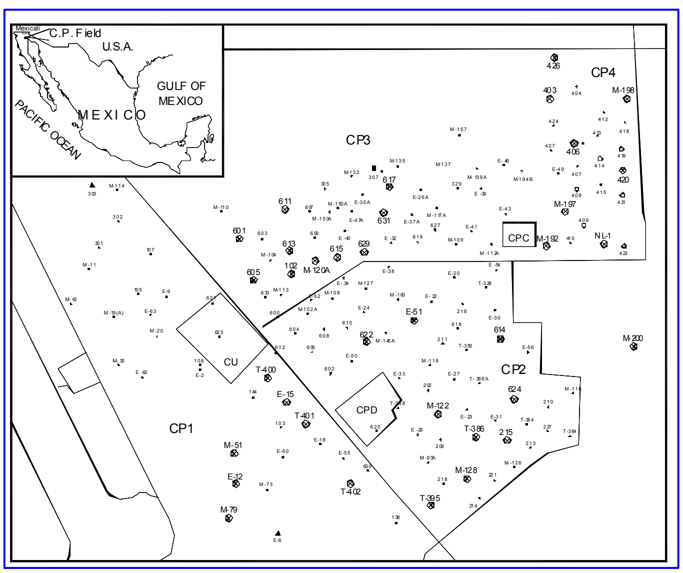

Fig. 1. Location of Cerro Prieto and the CP IV sector

To increase the electric generation capacity of the Cerro Prieto geothermal field from 620 MW to 720 MW, the Cerro Prieto IV (CP IV) sector (Figure 1) was developed (Quijano-León y Gutiérrez-Negrín, 2001). This is located at the NE portion of the exploited field, where fourteen new wells were drilled since 2000 to date. Detailed reservoir studies have been developed for CP IV area (Portugal *et al.*, 2006) to estimate the "natural state" characteristics of the reservoir and also to investigate the changes due to exploitation.

The wells in the CP IV zone produce two-phase fluids at wellhead with heterogeneous characteristics regarding steam fraction: at the central zone and towards the NW, the wells are liquid-dominated while those towards the E and S produce a relatively high steam fraction. This is seen in Figure 2 where the distribution of production enthalpy of the wells for data previous to year 2000 is shown.

According to the "natural state" geochemical characteristics, the discharged fluids showed almost the same pattern of chemical composition but dilution effects are seen in some wells, and different pH values (ranging from 5 to 8) were found. This dilution was attributed to the presence of condensate in wells where important boiling occurs and also to the entry of shallower lower temperature fluids in wells located at the center of CP IV (Portugal *et al.*, 2006). Chemical geothermometers (TCCG, TNa-K-Ca) indicated temperatures between 280-310° C. Although most of the fluids exhibited total equilibrium in a triangular Na-K-Mg diagram, few of them showed partial equilibrium. The chemical characteristics of single wells also varied with time depending on the production conditions of the wells.

As there is a high enthalpy zone in CP IV and hence production of two-phase fluids with a relatively high steam fraction located to the East, the study of the gas phase becomes important to obtain reservoir parameters. Thus the objective of this work is to identify different fluids feeding the wells by obtaining reservoir parameters (temperature and steam fraction) in the Cerro Prieto IV sector. The FT-HSH3 method based on gas composition using the Fischer Tropsch reaction and H_2S equilibria with pyrite-pyrrhotite as mineral buffer (Siega *et al.*, 1999) were used.

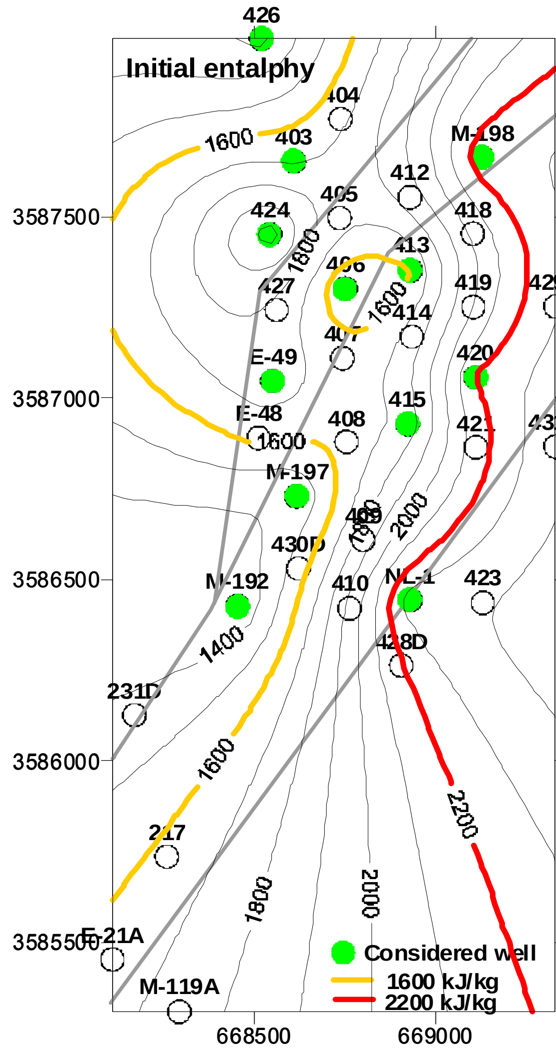

Fig. 2. Initial enthalpy values distribution of CP IV wells.

2. Methodology

Gas equilibria considering the Fischer-Tropsch (FT) ($CH_4 + 2H_2O = 4H_2 + CO_2$) reaction together with the pyrite-pyrrhotite (HSH3) ($FeS_2 + H_2 = FeS + H_2S$) (Siega *et al.*, 1999) combined reactions were used. This mineral buffer seems to control the H_2S in the fluids at CP IV. The presence of the proposed mineral buffer at reservoir and the fact that reservoir temperatures estimated by the FT-HSH3 diagram compare well with results from geothermometers based on liquid phase composition, were the basis to select the FT-HSH3 method. The FT-HSH method was used before to obtain reservoir temperature and excess steam for Cerro Prieto data (D'Amore and Truesdell, 1985), but for CP IV wells rather low temperatures compared with results from FT-HSH3 method were obtained.

Another approach (FT-HSH2) (D'Amore, 1998; Barragán *et al.*, 2006) that considers more oxidizing conditions at reservoir, which implies high H_2S but low H_2 concentrations, was considered not suitable for the CP IV data since relatively high H_2 concentrations were found. The reservoir temperature and the reservoir excess steam (*y*) are provided as results in a graphical form and the trends observed for the data on the grids were interpreted.

3. Results

3.1 Initial conditions

Figure 3 shows the results obtained for the wells at initial conditions (up to year 2000) in a FT-HSH3 diagram. The location of the data points suggests that different fluids enter the wells at CP IV following an approximate lineal trend indicating possible mixing of fluids. Data of Figure 3 were fitted in order to find the main characteristics of the two hypothetical end members corresponding to the fluids entering the wells.

The regression had a significant correlation coefficient (0.93) suggesting that the wells produce mixtures in different proportions of two main components. The end members basically are as follows: a liquid phase of about 310° C characterized by the fluid produced by well 426, and a two-phase fluid with a reservoir steam fraction of almost 0.5 and a temperature of about 275° C, characterized by the well NL-1. These FT-HSH3 results suggested the presence of a steam phase at Cerro Prieto IV that could be originated by boiling of deep liquid. Then, if phase segregation occurs, preferential flow of steam to the wells will produce high values of excess steam (Truesdell *et al.*, 1992). By means of gas data, Nieva *et al.* (1982) also evidenced the pre-existence of steam at Cerro Prieto I, and among other studies that indicated the occurrence of two-phase fluids at reservoir, the mixing of fluids with steam was found at Cerro Prieto by Stallard *et al.* (1987).

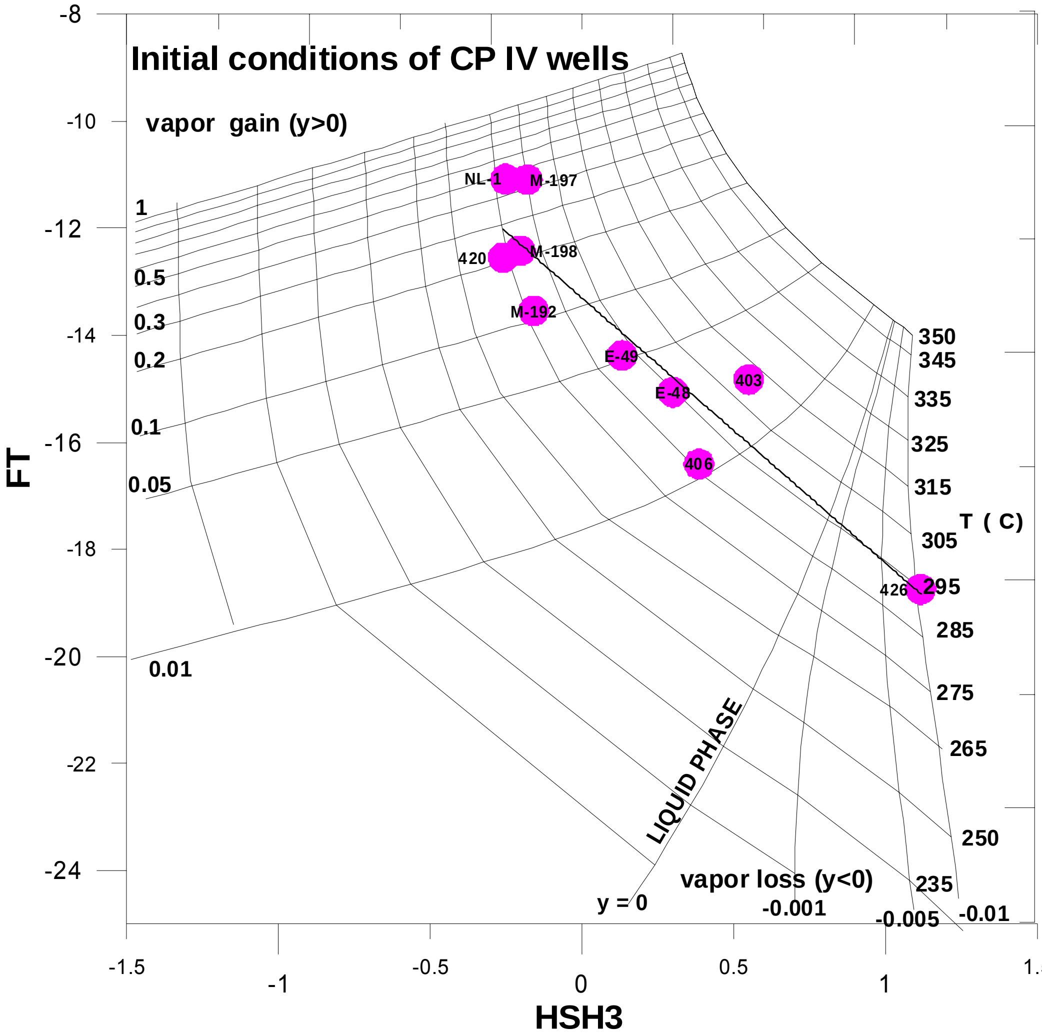

Fig. 3. FT-HSH3 diagram for data of CP IV wells for initial operating conditions.

3.2 Single wells behavior

The behavior of the CP IV gas data for single wells in the FT-HSH3 diagrams also shows the mixing pattern seen previously. As an example, in Figure 4 the FT-HSH3 diagram for the well NL-1 is given. This well is located toward the relatively high enthalpy area, its enthalpy for initial conditions was 2300 kJ/kg (see Figure 2). Data are aligned indicating the well produces mixtures in different proportions of liquid and steam end member fluids occurring at the reservoir.

According to the FT-HSH3 method, a very high temperature (335° C) liquid (with a deficit of reservoir steam) entered the well in point number 5 and was produced in 1997 when the well registered a production enthalpy of 1900 kJ/kg. In contrast, the other extreme of the mixing line represents a fluid with a lower temperature, of about 275° C, and a reservoir steam of about 70%. This fluid was produced in 1995-1996.

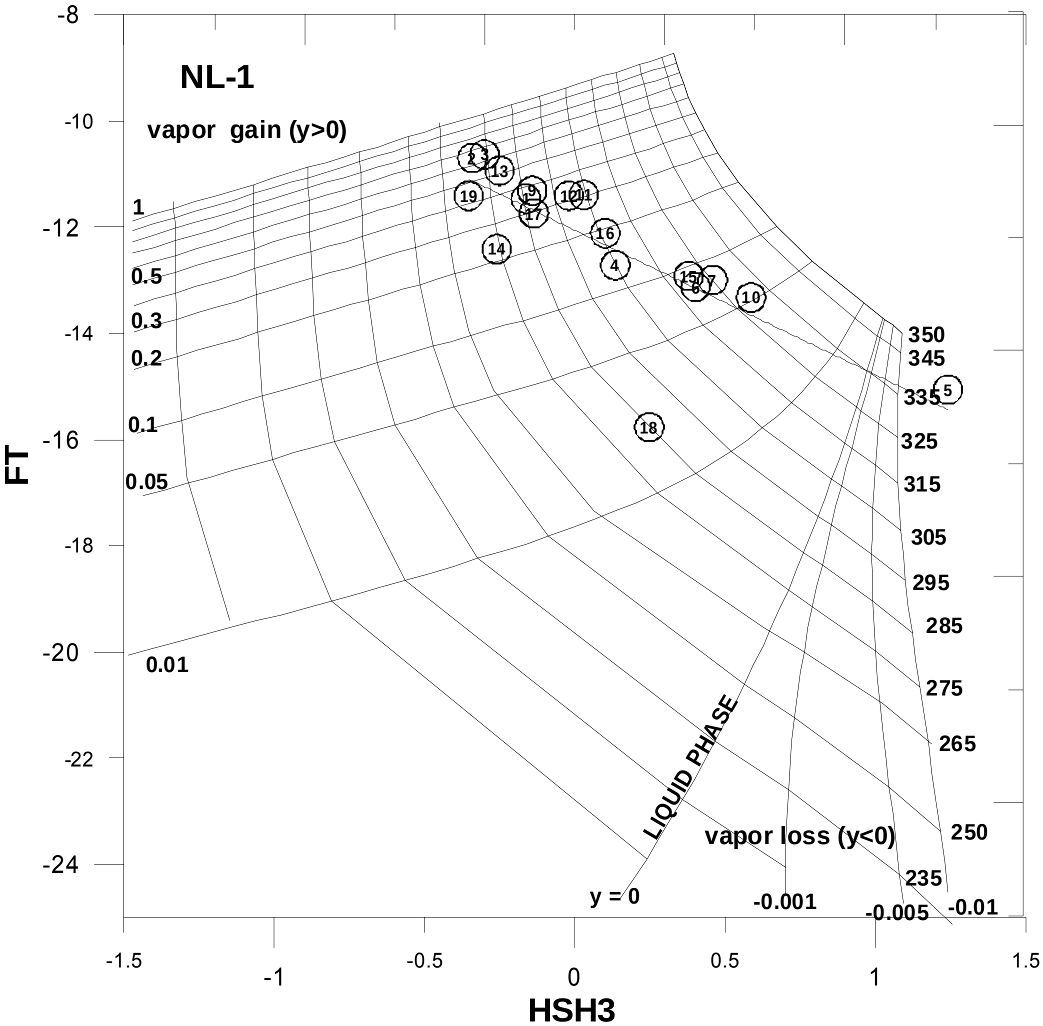

Fig. 4. FT-HSH3 diagram for data of well NL-1 located at the high enthalpy area of CP IV.

Other example is given for well 407 which is located at the center of the CP IV area in a low enthalpy zone (see Figure 2), where influence of the H Fault is evident because of the production of liquid dominated fluids. Figure 5 shows the FT-HSH3 diagram for well 407. The data points are almost aligned showing that the well produces a mixture of steam dominated two phase fluid and a liquid phase (with a deficit of reservoir steam). At the beginning (point number 1) the well produced a 275° C fluid with a reservoir steam 20% but at other times (points number 2 and 6) the well produced liquid phase at about 285° C. The last point (number 7) indicates production of a fluid of about 270° C and a negligible excess reservoir steam (1%). The lower temperature and the negligible reservoir steam obtained for the point number 7 agree with other evidences that indicate the input of shallower lower temperature waters to the reservoir through the H Fault.

The behavior shown by wells NL-1 and 407 is representative of practically all the other wells at CP IV and it was interpreted in terms of mixing of basically two end members. It seems that depending on the production conditions, pre-existent reservoir steam enters the wells in different proportions.

3.3 Present conditions

The FT-HSH3 diagram for the wells according to 2005 gas data (September 2005) is shown in Figure 6 (point for the well NL-1 corresponds to November data). The trend observed indicates that the mixing process is important in the CP IV area since the points are aligned in a trend showing that the wells fluids consist of different proportions of the end member fluids identified before.

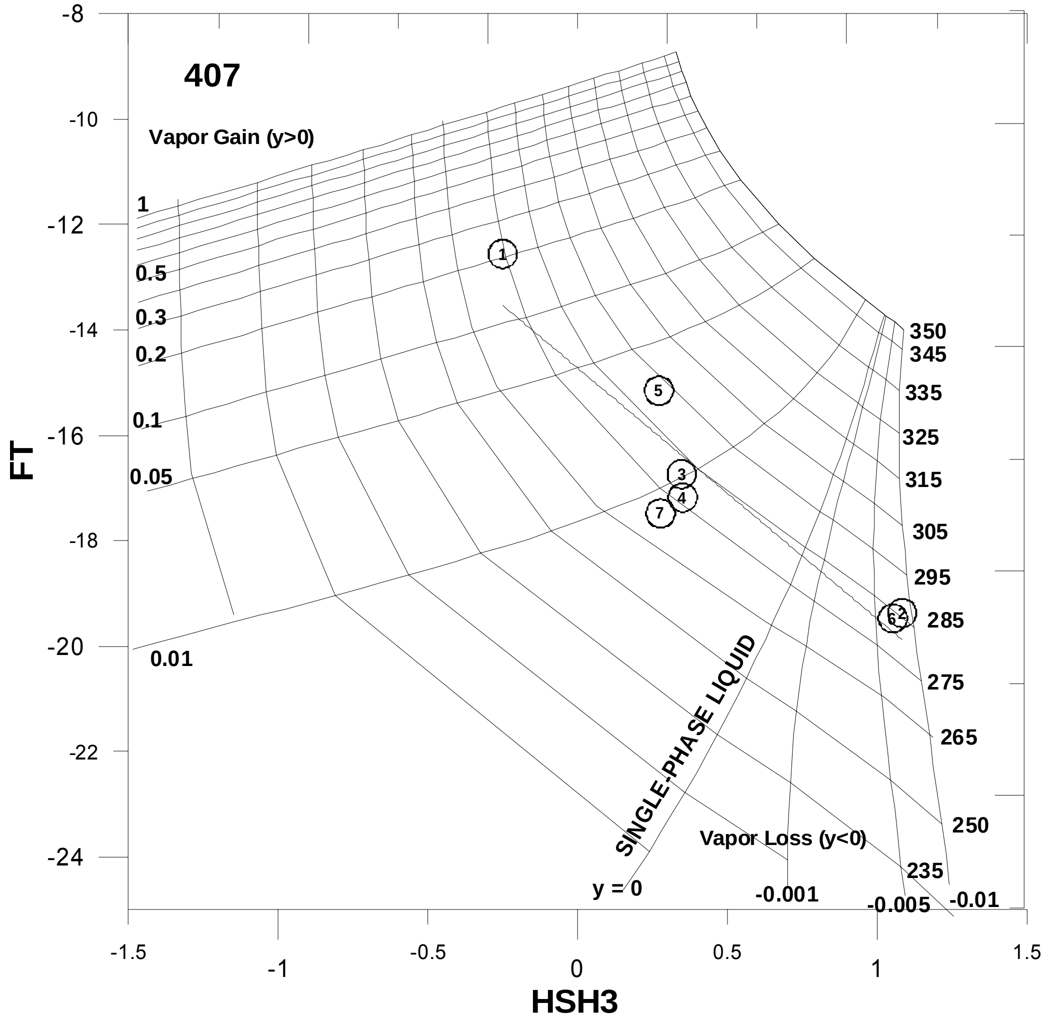

Fig. 5. FT-HSH3 diagram for data of well 407 located at the lower enthalpy area of CP IV.

In Figure 6 the point of the well 425 which started operating in 2005, is interpreted as constituted by practically reservoir steam phase. In contrast, the fluid produced by the wells 406, 407, and 230D comes from a liquid phase with negligible reservoir steam (1%), with a temperature of about 275° C. As mentioned, according to detailed reservoir studies (Portugal *et al.*, 2006), this fluid is descending to the reservoir from a shallower aquifer through the H Fault, because of pressure drop due to exploitation.

In Figure 7 the deuterium-oxygen-18 composition of the fluids for 2005 data is given. As shown in Figure 7, the deuterium content of high enthalpy fluids is higher than that for low enthalpy fluids, which is due to the fact that deuterium is slightly partitioned to the steam phase at reservoir temperatures. The relatively light isotopic composition of the fluids from wells 406 and 407 compared to that of the other CP IV wells is probably due to the entry of such lower temperature water descending through Fault H to the production zone of the wells. In contrast, towards the East, where high enthalpy wells are located, it seems that a steam phase originated by boiling of deep fluids is present. This steam contains a relatively high gas proportion, which could be related to the up-flow of magmatic gases that according to Truesdell *et al.* (2003) occurs not far from CP IV.

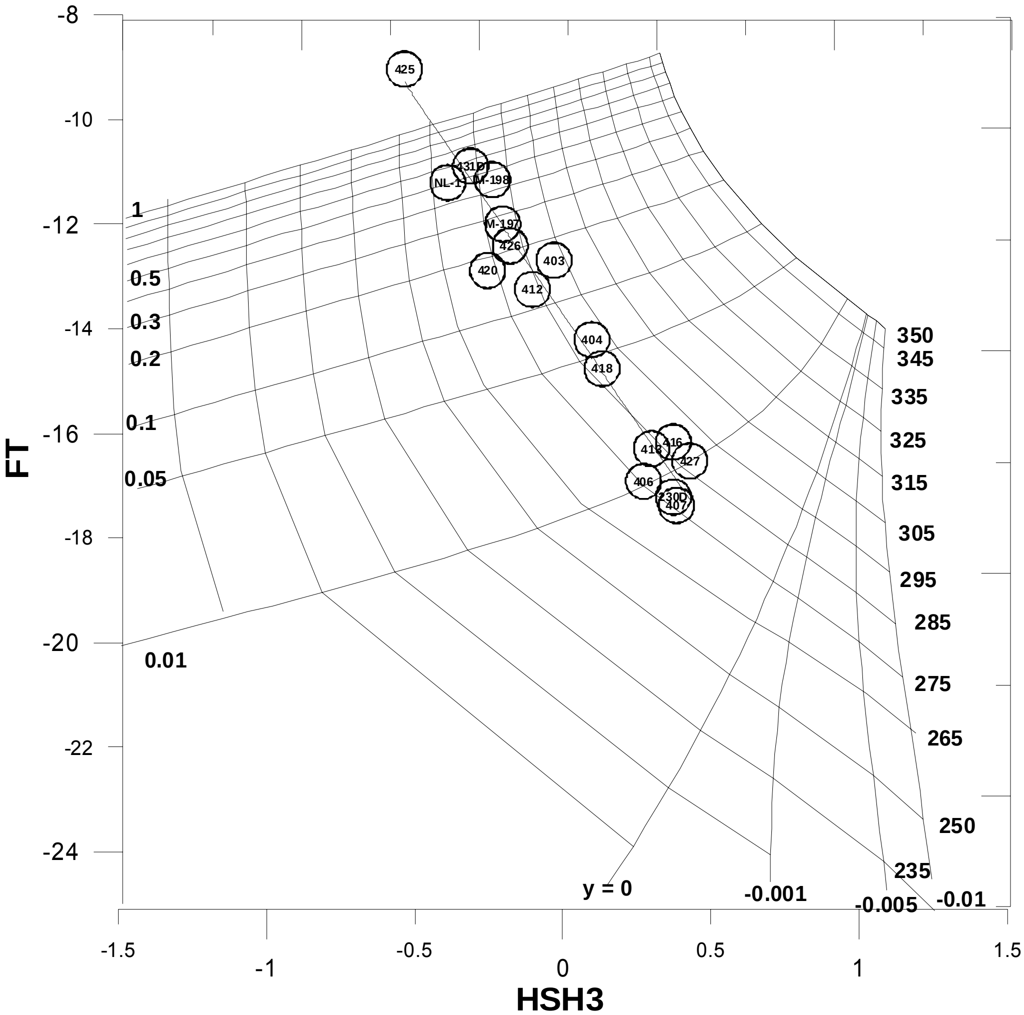

Fig. 6. FT-HSH3 diagram for CP IV gas data, according to 2005 conditions.

4. Conclusions

Gas data from the CP IV zone of the Cerro Prieto geothermal field was studied by using the FT-HSH3 method, and a mixing process was inferred to occur in well discharges that implies the pre-existence of steam at reservoir. One end member consists of liquid phase with temperature higher than 300° C. The other consists of steam phase that was produced by boiling of deeper fluids at reservoir and could be enriched in gases since the gases up-flow probably occurs near to CP IV. Income of lower temperature fluids descending through the Fault H to the reservoir was also observed in the FT-HSH3 diagrams. This occurs mainly in wells located at the center of the CP IV sector, where the wells 406 and 407 are located.

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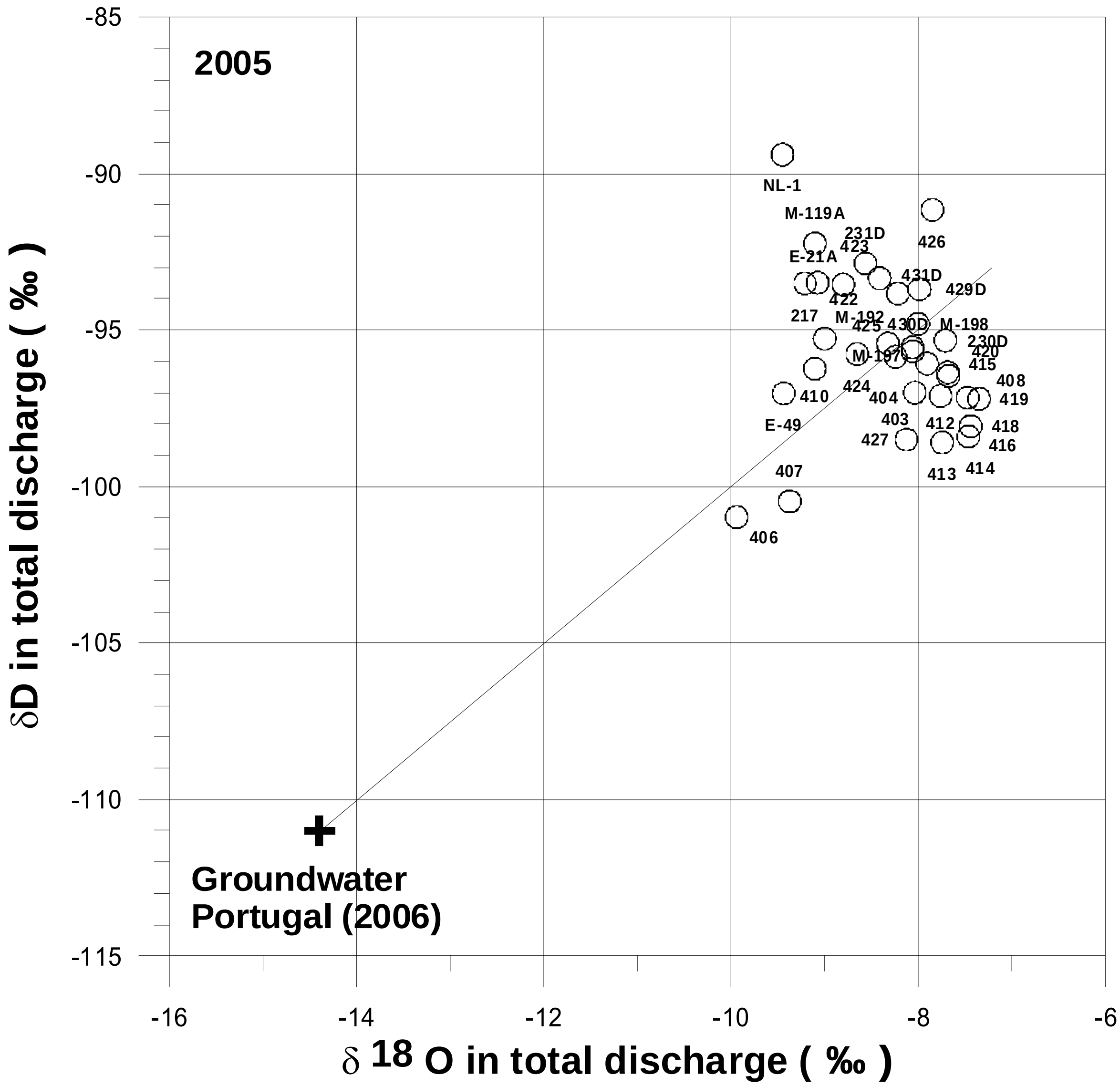

Fig. 7. δD vs δ^{18} O for fluids of CP IV area

References

Barragán, R.M., V.M. Arellano, E. Portugal, F. Sandoval, and N. Segovia (2006). Changes in gas composition of the Los Azufres (Mexico) geothermal fluids related to exploitation. *Transactions* of the Geothermal Resources Council, Vol. 30, pp. 9-14.

D'Amore, F., and A.H. Truesdell (1985). Calculation of reservoir temperatures and steam fraction from gas compositions. *Transactions* of the Geothermal Resources Council, Vol. 9, Part 1, pp. 305-310.

D'Amore, F. (1998). *Time evolution of chemical and physical parameters of the reservoir fluid in Ahuachapan geothermal field (El Salvador)*, Report for the IAEA, 210 p.

Nieva , D., J.J. Fausto, J. González and F. Garibaldi (1982). Flow of vapor into the feeding zone of Cerro Prieto I wells. *Fourth Symp. on the Cerro Prieto Geothermal Field*, Baja California, Mexico, Guadalajara, Jal., Mexico, August 10-12, 1982.

Portugal, E., V.M. Arellano, A. Aragón, R.M. Barragán, G. Izquierdo, y J. Torres (2006). Estudios geocientíficos del Polígono Hidalgo del campo geotérmico de Cerro Prieto. Internal Report IIE/11/12875. Unpublished.

Siega, F. L., N.D. Salonga, and F. D'Amore (1999). Gas equilibria controlling H_2S in different Philippine geothermal fields. *Proc. 20th Annual PNOC-EDC Geothermal Conference*, Manila, Philippines, pp. 29-35.

Stallard, M. L., T.L. Winnett, A.H. Truesdell, T.B. Coplen, C. Kendall, L.D. White, C.J. Janik, and J.M. Thompson (1987). Patterns of change in water isotopes from the Cerro Prieto geothermal field, Baja California, Mexico: 1977-1986. *Transactions* of the Geothermal Resources Council, Vol. 11, pp. 203-210.

Quijano-León, J. L., and L.C.A. Gutiérrez-Negrín (2001). Geothermal production in Mexico in the year 2000. *Transactions* of the Geothermal Resources Council, Vol. 25, pp. 593-596.

Truesdell, A., A. Mañón, L. Quijano, T. Coplen, and M. Lippmann (1992). Boiling and condensation processes in the Cerro Prieto Beta reservoir under exploitation. *Proc. Seventeenth Workshop on Geoth. Res. Eng.*, Stanford CA., SPG-TR-141, pp. 205-214.

Truesdell, A. H., M.J. Lippmann, M.H. Rodríguez, and A. Pérez (2003). Influence of reservoir processes on gas in Cerro Prieto steam. *Transactions* of the Geothermal Resources Council, Vol. 27, pp. 335-340.