The Los Azufres (México) Geothermal Reservoir: Main Processes Related to Exploitation (2003-2011)

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ABSTRACT

In this work, the present-time thermodynamic conditions and the response to exploitation for 2003–2011 of the Los Azufres geothermal reservoir are given. The study was based on the analysis of geochemical and production data of 39 wells, over time. In average, due mainly to effective reservoir recharge, very moderate production declining rates were found. In the south zone, the important effects of reinjection were observed through increases in Cl in some wells (up to 8,000 mg/kg). In contrast, in wells with significant boiling Cl tends to decrease. In most of the North Zone wells, the variations in gas data indicated boiling and condensation of a highly gas-depleted brine, which seems to consist of reinjection fluids. It is suggested that this process helps to maintain the production in the zone relatively stable. In summary, the main reservoir exploitation-related processes found in Los Azufres were: (1) production of reinjection returns; for this, it was possible to distinguish (a) wells that produce liquid and steam from injection, and (b) wells that produce only steam from injection and sometimes this steam already condensed. (2) boiling; for this process, two types of boiling were identified: (a) boiling with gaining steam, and (b) boiling with steam loss.

1. INTRODUCTION

The Los Azufres geothermal field is an intensely-fractured, two-phase, volcanic hydrothermal system located in the northern portion of the Mexican Volcanic Belt, in the state of Michoacán, at an average elevation of 2,800 m.a.s.l. (Figure 1). At present, the installed capacity of the field is 188 MWe. The field was divided into two zones (North and South) because different characteristics in producing fluids were noticed in the beginning of the development stage of the field. Reservoir engineering and geochemical conceptual models of the Los Azufres system were established (Iglesias et al., 1985; Nieva et al., 1987) which constitute the reference conditions that allow characteristic changes in parameters over time to be related to exploitation. Arellano et al. (2005) studied the reservoir's response to exploitation for 1982–2002 based on a systematic analysis of chemical, isotopic, and production data from 20 representative production wells. The installed capacity of the field was 88 MWe during that time. Since 2003, four additional 25 MWe flash plants were brought on line, bringing the total installed capacity to 188 MWe. Due to this increase in power capacity that was installed at the North Zone, concerns on reservoir performance have arisen because of higher rates in fluids extraction.

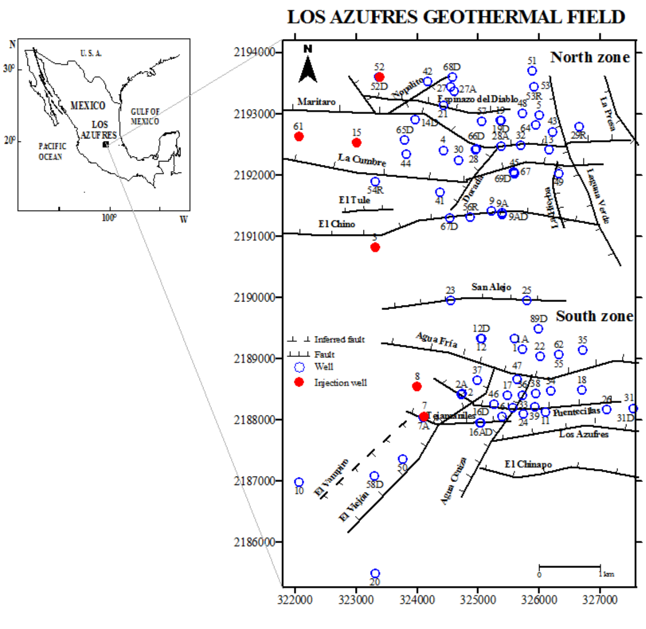

Figure 1: Location of the Los Azufres geothermal field and locations of wells.

In order to estimate the occurrence of reservoir processes induced by exploitation (fluid extraction and reinjection) for 2003–2011, the following objectives were stated (Arellano et al., 2012): (a) to identify the changes that have occurred in the Los Azufres reservoir as a consequence of exploitation, and (b) to determine the causes of these changes through the analysis of production and geochemical data of 39 wells (Figure 1) provided by the Comisión Federal de Electricidad. All of the injection wells are located on the west side of the field. Injectors Az-3, 15, 52, and 61 are in the northern production area, whereas Az-7A and 8 are located in the south (Figure 1).

2. METHODOLOGY

In order to obtain the thermodynamic characteristics of reservoir fluids and to investigate the dominant processes occurring with exploitation, a method based on the analysis of the following patterns of behavior was used (Arellano et al., 2005): (a) well mass flow-rate, well-bottom pressure, enthalpy, and temperature, (b) chloride concentration in separated water and total discharge fluid, (c) the comparison of the total discharge enthalpy and those corresponding to the reservoir temperature estimated by both the "slow-response" cationic (Nieva and Nieva, 1987) and the "fast-response" silica (Fournier and Potter II, 1982) geothermometers (Truesdell et al., 1995), (d) fraction of steam entering the well, (e) total discharge and reservoir chlorides, (f) total discharge and reservoir CO_2 (g) liquid saturation, and (h) $\delta^{18}O$ and δD in total discharge. Well-bottom thermodynamic conditions were obtained through WELFLO simulator (Goyal et al., 1980). Input data consisted of wellhead production data and well geometry. Chemical, isotopic and production data were provided by the Residencia Los Azufres, CFE. The study included 39 wells (Figure 1): Az-4, 5, 9, 9A, 9AD, 13, 19, 28, 28A, 30, 32, 41, 43, 45, 48, 51, 56R, 65D, 66D, 67, and 69D corresponding to the North Zone of the field, and Az-1A, 2A, 6, 16AD, 17, 18, 22, 23, 25, 26, 33, 34, 35, 36, 37, 38, 46, and 62 corresponding to the South Zone.

3. FLUID PRODUCTION/INJECTION

Fluid production and injection rates have varied with the operation of the generating units over time. Figure 2 shows the production and injection data as a function of time for the field. Fluid extraction started in 1978 (Figure 2) and 441,744,661 tons of fluids were produced by December 2011. Of these, 254,376,326 tons (57.6 %) corresponded to the south, and 187,368,335 tons (42.4 %) to the North zone. Between 1982–2011, 132,016,271 tons (30 %) of produced fluids had been re-injected. Production increased in the South Zone in 1987, when the 50 MW power plant came on line (Arellano et al, 2005). In 2003, fluid production in the North Zone increased due to installation of an additional capacity of 100 MW.

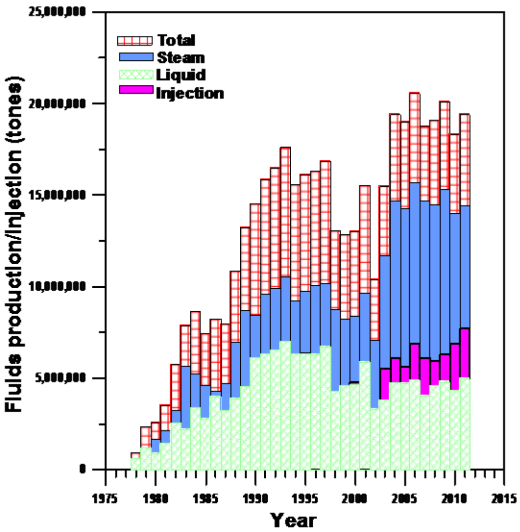

Figure 2: Production and reinjection fluids in Los Azufres geothermal field.

4. RESULTS

The results obtained allowed identification of the main processes that have occurred and are currently occurring in different zones of the Los Azufres reservoir. Two main processes were identified: (1) production of reinjection returns. In this process two sub-processes were identified: (1.1) wells that receive liquid and steam from reinjection, and (1.2) wells that receive steam originated from the boiling of reinjection fluids and/or wells that receive condensed steam originated from boiling of reinjection fluids; and (2) boiling. In this process two sub-processes were identified: (2.1) boiling with steam gain and (2.2) boiling with steam loss.

4.1 Reservoir Processes

In order to study the evolution of the well bottom pressures and enthalpies, production data for each well was simulated using the WELFLO (Goyal et al., 1980) simulator. WELFLO is a well simulator that considers multiphase, one-dimension, and steady state conditions and is suitable for vertical wells with variable diameter. Input data consists of geometry of the well, mass flow rates, and wellhead pressures and enthalpies. Reservoir temperatures were estimated by WELFLO simulations and also by a cationic geothermometer (Nieva and Nieva, 1987) for two-phase wells and by the FT-HSH2 gas equilibrium method (Siega et al., 1999; Barragán et al, 2013) for the steam wells.

4.1.1 Production of Reinjection Returns

In order to illustrate the process of production of injection returns, the case of the well Az-33 that receives injection returns in liquid phase is shown. In Figure 3 time series of mass flow rates, well bottom pressure, well bottom enthalpy, chlorides, wellhead pressure, comparison of total discharge enthalpy and enthalpy estimations by geothermometers, CO_2, and reservoir liquid saturation for the well Az-33 are given. This well is 683 m deep, with 81 m of slotted liner (602–683 m). As seen in Figure 3, the mass flow rate and pressure decrease, whereas enthalpy total chloride discharge, and CO_2 increase. The pattern for the enthalpy comparison shows mixing of equilibrated liquid with steam produced by boiling away the well (Figure 3F). Figure 4A shows that well Az-33 has received reinjection fluids in some years through the increase in chlorides and the behavior of the well shows intermittent changes as the injection rates are not constant over time (Figures 3A–H and 4A, B). In Figure 4A, the enthalpy-chloride data of well Az-33 are found to the right hand side of the characteristic boiling line which constitutes the reference for the field (Arellano et al., 2005). This is due to the chloride enrichment of discharged fluids because of production of reinjection returns. Chloride and other solutes are highly concentrated in injection fluids since they are evaporated at ambient conditions before injection. Well Az-33 and other wells show important recovery in liquid saturation since 2004–2005 (Figure 3H), which can be related to the operation of the injection well Az-7AR that replaced the original injection well Az-7R. Well Az-33 produced two-phase fluids but became a steam producer when the injector well Az-7R was closed in 2003. In 2007, Az-33 started intermittent liquid production (Figure 3A). Results from tracer tests (Iglesias et al., 2011) indicate that part of the fluids injected in well Az-8R was recovered as both liquid and steam in well Az-33. However, well Az-33 develops a moderate and sometimes important boiling process depending on reinjection rates, which can be seen through the enthalpy variations in Figures 3C and F.

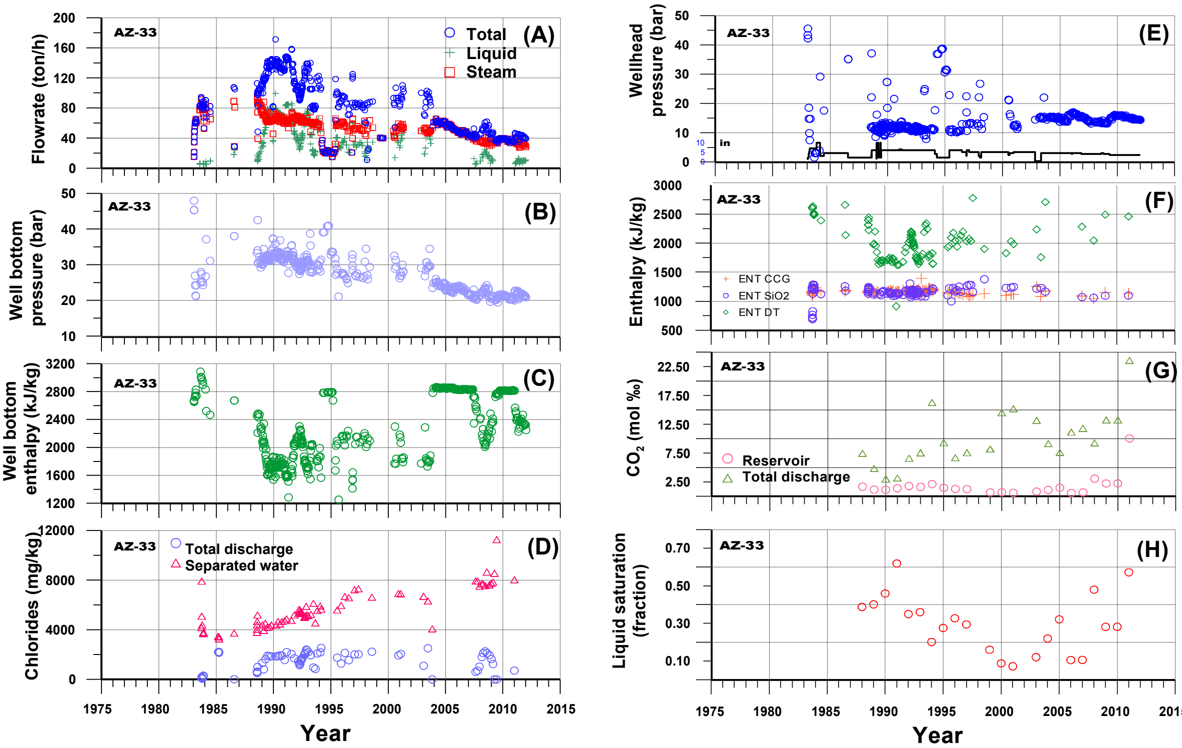

Figure 3: Time series of (A) mass flow rates, (B) well bottom pressure, (C) well bottom enthalpy, (D) chlorides, (E) wellhead pressure, (F) comparison of total discharge enthalpy and enthalpy estimations by geothermometers, (G) CO_2, and (H) reservoir liquid saturation of well Az-33, taken as representative of production of reinjection returns.

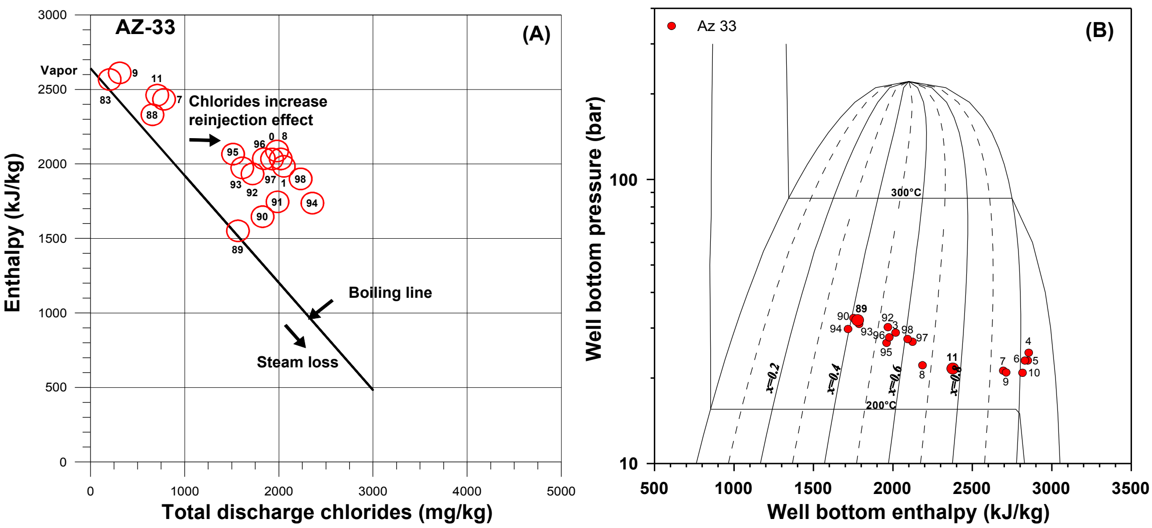

Figure 4: (A) Enthalpy versus chlorides and (B) well bottom pressure versus well bottom enthalpy for well Az-33.

The production of injection returns is shown only by some wells from the South Zone, where injection plays an important role, such as in Az-1A, 2, 2A, 16D, 36, and 46. Among these, wells Az-36 and 46 became steam producers since well Az-7R was closed. In wells that receive reinjection returns in liquid phase, chloride concentrations in separated water range between 5,500–8,000 mg/kg, whereas concentrations range between 2,500 and 4,000 mg/kg in wells with no reinjection interference.

The production of steam from the boiling of reinjection returns and sometimes condensed steam from the boiling of injection fluids, was also identified to occur in some wells of the field. When injection fluids consist of recycled produced fluids, the effects of reinjection in two-phase production wells is routinely depend on the salt increase in the discharged liquid (Arnórsson, 2000; Arnórsson and D'Amore, 2000; Arellano et al., 2005; Barragán et al., 2005 and 2010) as was illustrated for well Az-33. However, injected fluids in contact with reservoir rocks were heated and eventually evaporated by boiling. Then reinjection fluids either as steam or as condensed steam flew to the production zones of wells. These types of reinjection returns could not be recognized in production wells by the increase in the salinity of the liquid discharged, since condensed steam is depleted in terms of salt and isotopes. Thus, in two-phase wells that produce such types of reinjection returns, the effect in the discharged liquid sometimes include the decrease in salinity. In this case, identification of the effects of injection returns consisting of steam or condensed steam from boiling of reinjection fluids in production wells, gas, and isotope data analysis is suggested. Following characteristics are particularly observed in the produced fluids, when production of steam from reinjection occurs: (a) N_2/Ar molar ratios lower than that of air-saturated water (38), (b) low gas and CO_2 (<5 ‰) concentrations, and (c) relative depletions in δD and δ^{18}O.

In the South Zone, due to reinjection rates, this process seems to occur constantly in wells Az-1A, 23 and 25, and intermittently in Az-22, 35, and 62. In contrast, many of the wells in the North Zone (e.g., Az-4, 9, 19, 28, 28A, 45, 51, 57, 66D, 67 and 69D and Az-5, 13, 32, 42 and 48) that constantly produce steam or condensed steam from the boiling of reinjection fluids began to produce in an intermittent way after 2005. In Figure 5, the N_2-He-Ar ternary diagrams for wells Az-9 (two-phase) and Az-35 (steam) are given. Both wells receive steam or condensed steam from the boiling of injection fluids in the years when data plot below the He corner-meteoric line. As seen in Figure 5A, well Az-9 has received condensed steam from the boiling of reinjection fluids almost constantly, which explains the production of slightly lighter fluids (δ ^{18}O: -3.5‰, δD: -63.5‰) in 2010 (Figure 6A; Barragán et al., 2010) relative to the reference isotopic composition (δ^{18}O: -2.4‰, δD: -61‰; Nieva et al., 1987). Well Az-28 has also become isotopically lighter compared to its reference composition (δ^{18}O: -2.51‰, δD: -61.8‰) due to production of condensed steam from boiling of reinjection fluids. This can be seen in Figure 6A, where 2010 data plots closely to the lighter end of the fitting line (Barragán et al., 2011). In contrast, steam well Az-35 (South Zone) intermittently received steam produced by boiling of reinjection fluids in 2010 and 2011 (Figure 5B). This probably causes deuterium enrichment in well Az-35 relative to the fitting line in Figure 6B, considering that deuterium partitions preferably in steam at temperatures above 220°C. As a result, isotopic compositions of two-phase wells Az-1A, 23 and 25, which constantly produce condensed steam from reinjection fluids, are more depleted in the South Zone (Figure 6B).

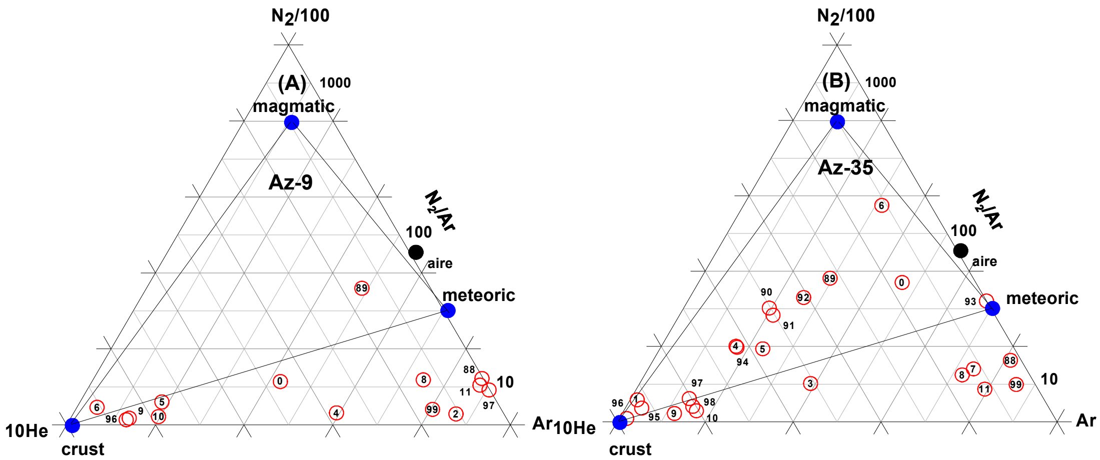

Figure 5: He-N_2-Ar relative compositions of (A) well Az-9 (North Zone) and (B) well Az-35 (South Zone).

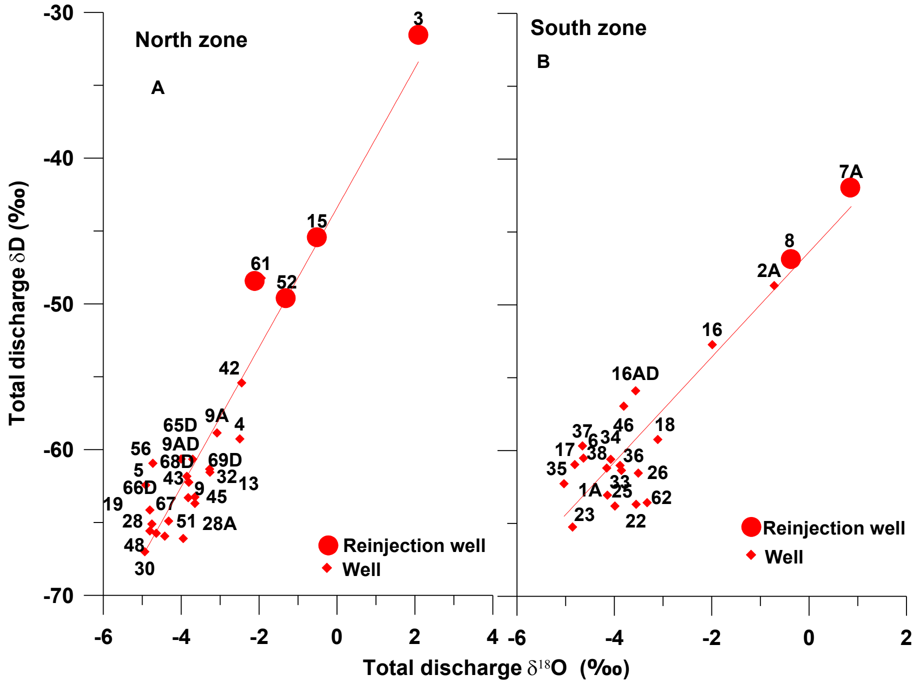

Figure 6: δD versus δ^{18}O compositions of (A) North Zone and (B) South Zone wells according to 2010 data (Barragán et al., 2010).

4.1.2 Boiling

Boiling occurs in wells due to pressure drops induced by fluids extraction during exploitation. Boiling may occur in a well either by steam gain or by steam loss.

Boiling by steam gain was identified in some wells of Los Azufres such as wells Az-5 and 13 from the North Zone and Az-18 and 26 from the South Zone (Arellano et al., 2005). From these wells, Az-5, 13, and 18 dried after being first two-phase producers. Well Az-26 is taken as a representative to illustrate the process through the analysis of chemical and production data. Time series of mass flow rates, well bottom pressure, well bottom enthalpy, chlorides, wellhead pressure, comparison of total discharge enthalpy and enthalpy estimations by geothermometers, CO_2, and reservoir liquid saturation of well Az-26 are given in Figure 7.

Well Az-26 produced two-phase fluids with high liquid/steam ratio until 1995 (Figure 7). During 1996–2003, it produced lower but constant amounts of liquid until production decreased drastically between 2003 and 2005. From 2008 to date, a decreasing trend in liquid production is observed due to the boiling with limited recharge. Following a relatively stable period, the well bottom pressure started to decline 2009 (Figure 7B) and enthalpy increased to values that reach the vapor enthalpy (Figure 7C). Well shows an decreasing enthalpy trend during 2007–2008, corresponding to a small recovery in liquid production, which could be due to low recharge coincident with a peak in injection rates in wells Az-7AR and Az-8R. Figure 7D shows that total chloride discharge decreases due to very small liquid fraction that is calculated for very high total discharge enthalpies. The pattern of enthalpy comparisons in Figure 7F indicates boiling in the well, but high-temperature condensation is inferred in the well and in the reservoir since 2010. There is an increasing trend in CO_2 (Figure 7G) due to boiling, while the reservoir liquid saturation has significantly decreased, with the exception of 2007 data by which time some recharge might have reached the well (Figure 7H). The boiling process can also be identified through the pressure-enthalpy plot in Figure 8A, in which the data trend over time has a direction toward higher enthalpies. In this case, the well has reached to a steam fraction of 0.9 in 2011 because of high enthalpy. In an enthalpy-chloride diagram (Figure 8B), data from well Az-26 plot on the boiling line (enthalpy increases as chloride decreases), trending towards the enthalpy of vapor. Az-18 and 46 in the south and Az-5, 13, 19, 28, 32, 43 and 48 in the north are the other wells with significant boiling. Moderate boiling was identified in wells Az-22 and 62.

Boiling with steam loss consists of decrease in the boiling rate and it was identified in very few wells including Az-23 and 28A. Well Az-28A was chosen to illustrate this process. Enthalpy versus chloride and well bottom pressure versus well bottom enthalpy for well Az-28A are given in Figures 9A and B, respectively. On an enthalpy versus chloride plot, boiling with steam loss can be recognized by a data trend towards lower enthalpy and higher chloride values (Figure 9 A). The trend of decreasing enthalpy over time can also be seen in Figure 9B.

Time series of mass flow rates produced, total discharge enthalpy and estimated silica and Na/K enthalpies, CO_2, and liquid saturation at reservoir for well Az-28A are given in Figure 10. Steam production starts to decrease almost in the beginning (Figure 10A) and continues to decreases over time while liquid production varies intermittently possibly due to the entry of returns from reinjection. Enthalpy comparison pattern indicates that boiling decreases over time as confirmed by the data trend in Figure 10B. As boiling rate decreases, CO_2 decreases with decreasing enthalpy (Figure 10C). Although dilution is not clear, it is possible that well Az-28A is producing a condensed fluid from the boiling of degasified fluid (reinjection) as indicated by its highly depleted isotope composition (Figure 8A). This well maintains a very high liquid saturation (> 0.8; Figure 10D). It is possible for this well that the pressure is controlled by a constant pressure boundary; the well bottom pressure is gradually stabilized and the boiling front does not expand anymore. The temperatures tend to equilibrate within the stabilized boiling zone; ceasing the heat transfer from the rock to the fluid and causing a decrease in the excess enthalpy to negligible levels.

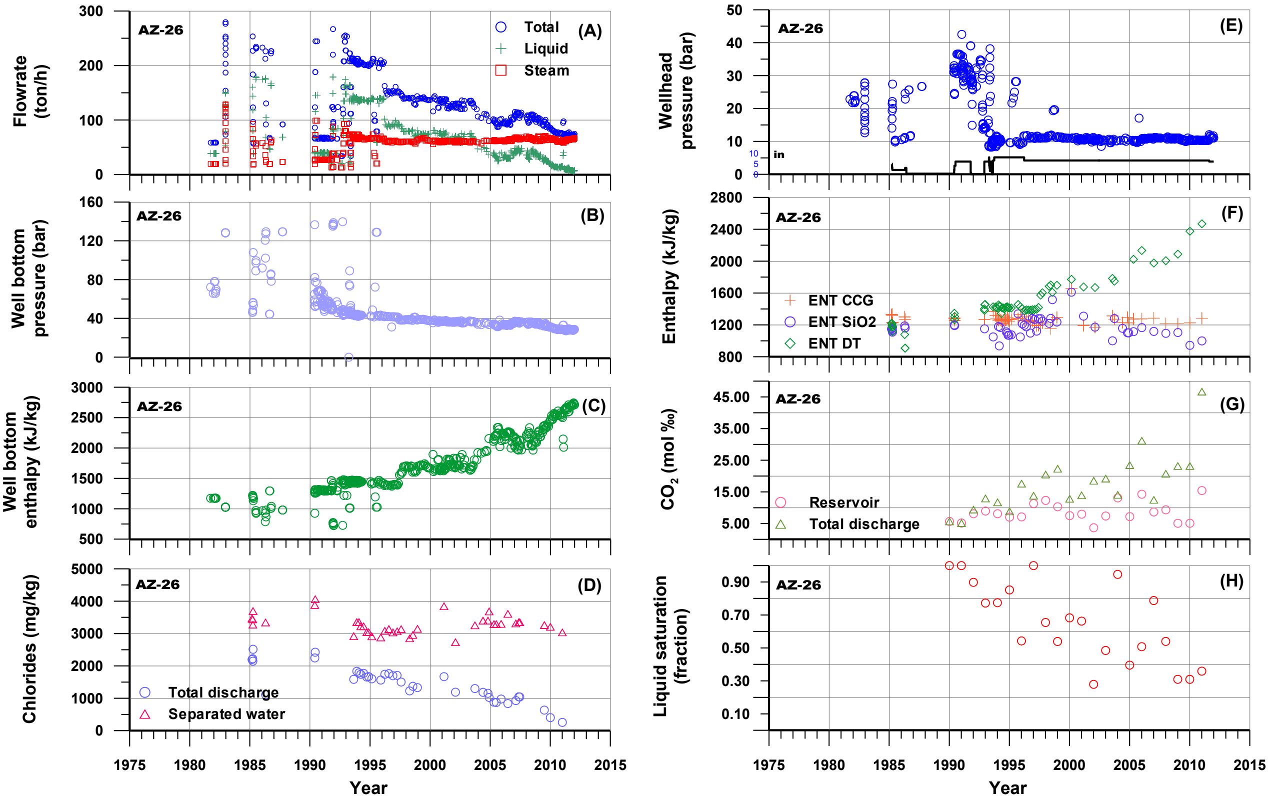

Figure 7: Time series of (A) mass flow rates, (B) well bottom pressure, (C) well bottom enthalpy, (D) chlorides, (E) wellhead pressure, (F) comparison of total discharge enthalpy and enthalpy estimations by geothermometers, (G) CO_2, and (H) reservoir liquid saturation of well Az-26, which is used to illustrate boiling with gaining steam.

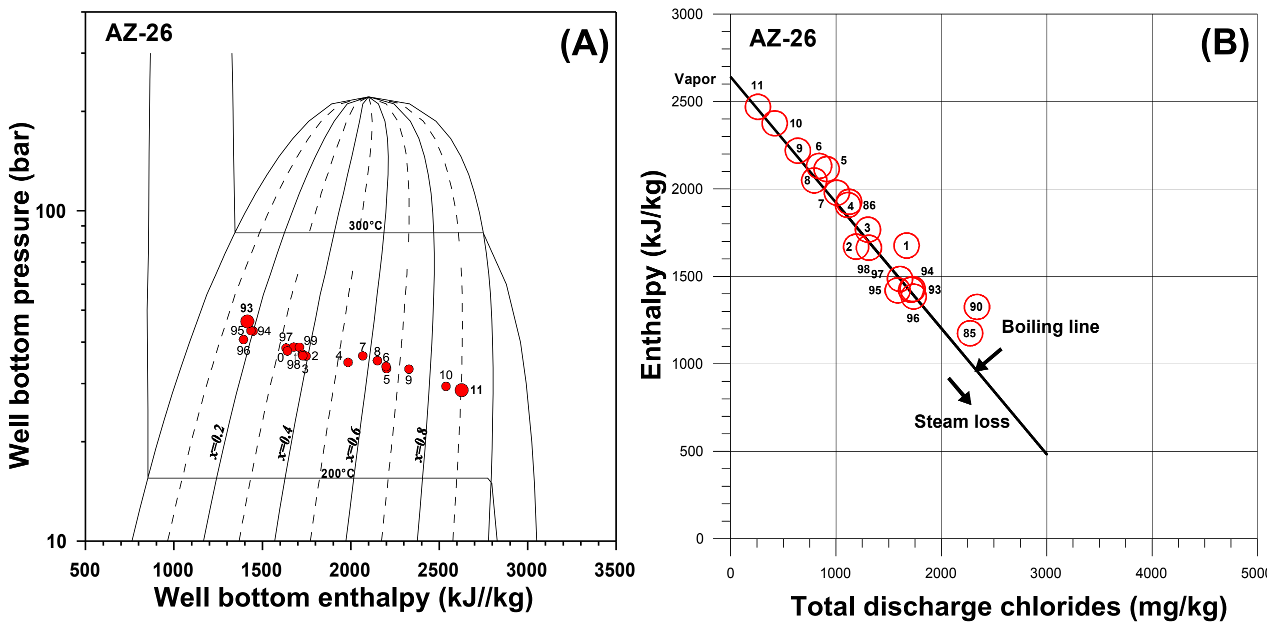

Figure 8: (A) Well bottom pressure versus well bottom enthalpy and (B) enthalpy versus chloride for well Az-26.

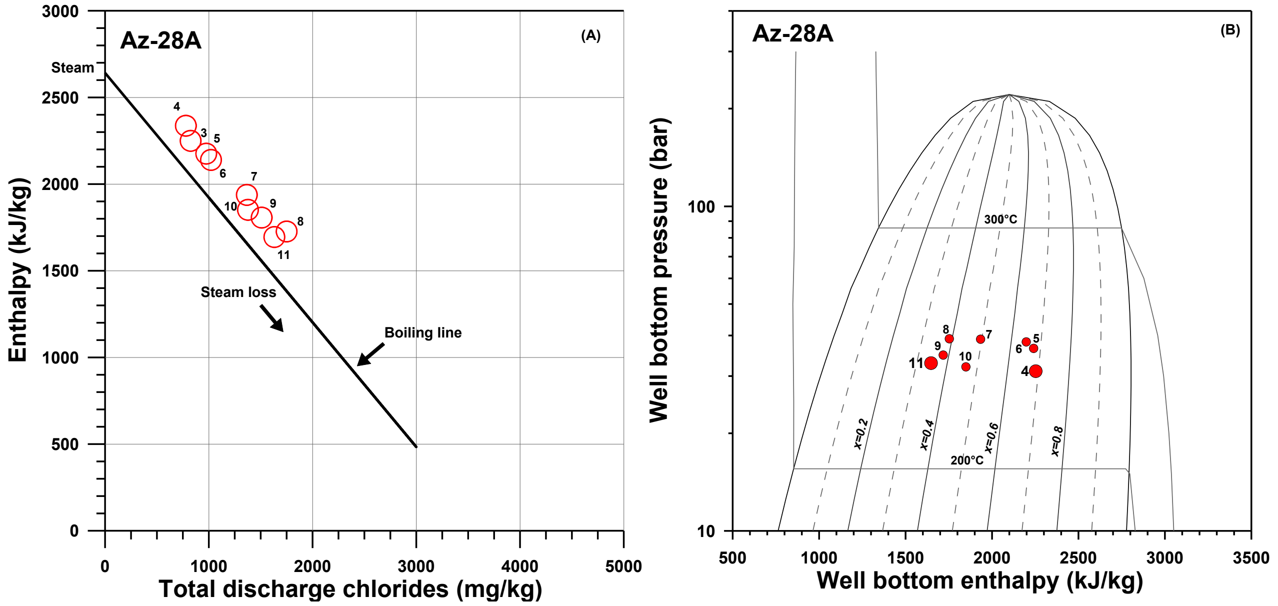

Figure 9: (A) Enthalpy versus chloride and (B) well bottom pressure versus well bottom enthalpy for well Az-28A.

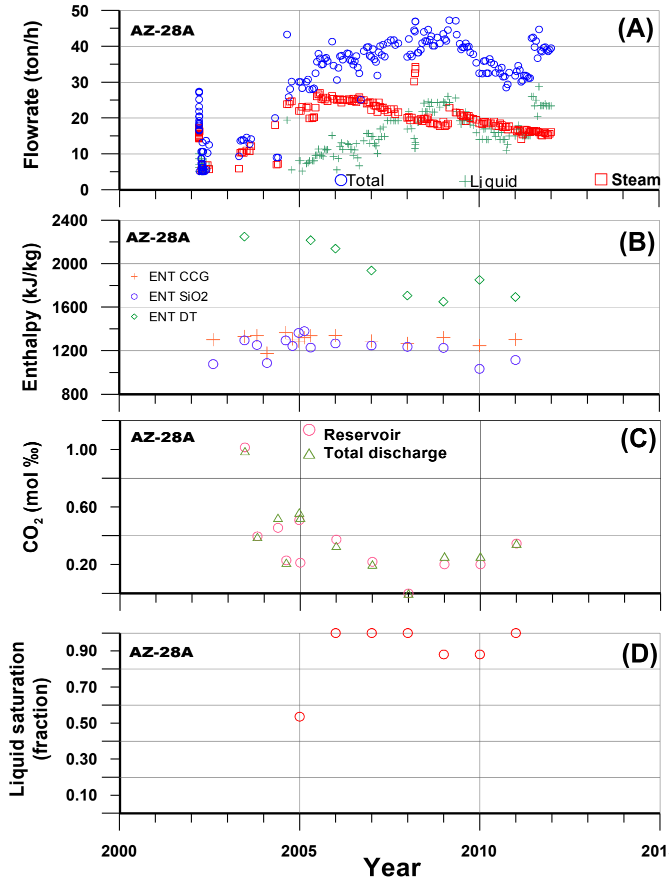

Figure 10: Time series of (A) mass flow rates, (B) comparison of total discharge enthalpy and enthalpy estimations by geothermometers, (C) CO_2, and (D) reservoir liquid saturation of well Az-28A, which is used to illustrate boiling with steam loss.

4.2 2005-2011 Reservoir Evolution

The occurrence of the described reservoir exploitation-related processes has changed the distribution of geochemical indicators through time as follows. In Figure 11 the temperature distributions of the Los Azufres reservoir for 2005 and 2011 are given. Relatively more important changes include temperature variations in the North Zone, where the 300°C contour is located towards east in comparison to 2005. In 2011, the temperature iso-contours are aligned in an approximately N–S direction in the center of the North Zone with a decreasing trend towards west, where injection wells are located. In 2011, the 290°C contour lies along both zones, whereas minimum temperatures are located in the west of the South Zone, where injection wells are located.

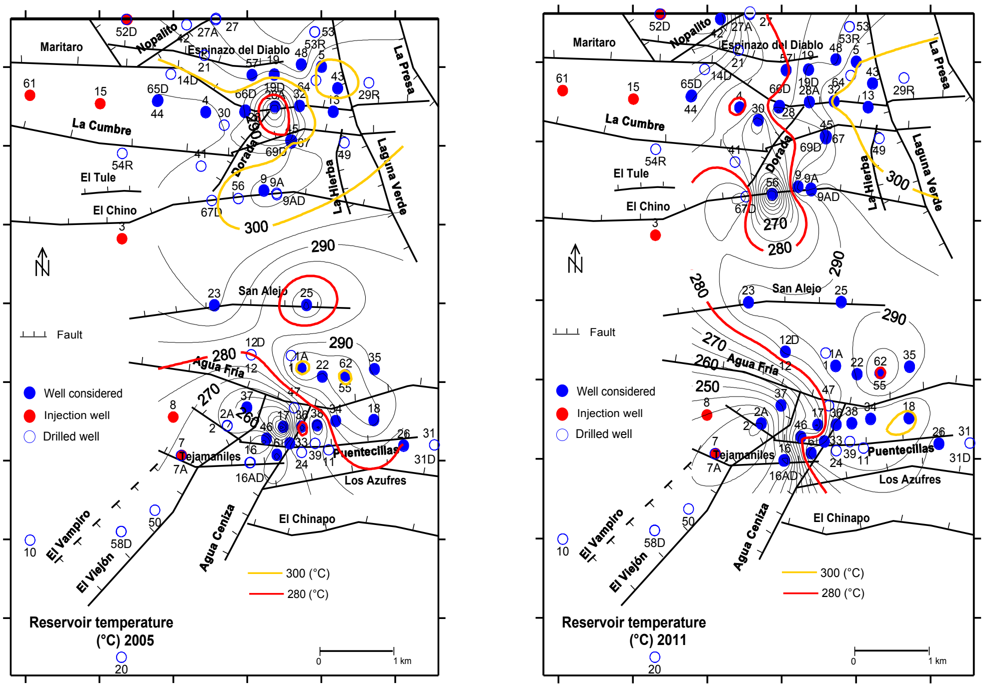

Figure 11: 2005 and 2011 distributions of reservoir temperature in the Los Azufres geothermal field.

Total chloride discharge distributions for 2005 and 2011 are given in Figure 12. In both years, maximum chloride discharge is found to the west of both zones due to injection effects. Considering that two-phase wells receive some liquid from reinjection in Az-2A, Az-33, Az-42, Az-4, diluted fluids were observed in 2011 to the east of the South Zone and in the center of the North Zone.

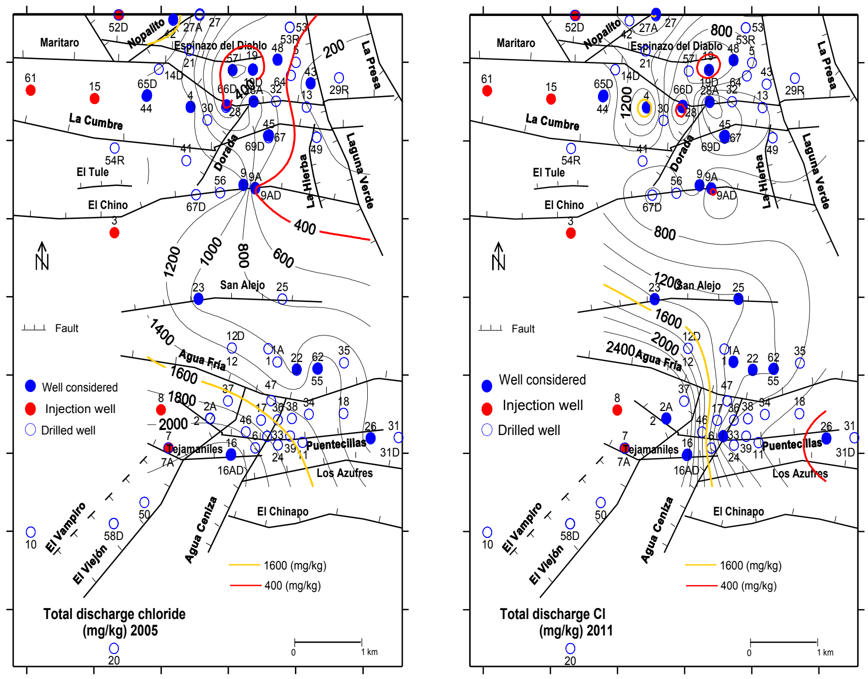

Figure 12: 2005 and 2011 distributions of total chloride discharge in the Los Azufres geothermal field.

The N_2/Ar molar ratio distributions for 2005 and 2011 are given in Figure 13. Contours for 2005 indicate that the entry of condensed steam originated by boiling of de-gasified fluids (reinjection) is localized from the north central part of the North Zone to the center of the field, where $N_2/Ar < 38$. N_2/Ar contours for 2011 indicate the presence of fluids generated by boiling of de-gasified brines (injection) in a large portion of the North Zone, in the center part, and in the northeast of the South Zone. It is evident in Figure 13 that production of reinjection returns in the form of steam or condensed steam generated by boiling of injection fluids seem to be more important due to exploitation (Barragán et al., 2013).

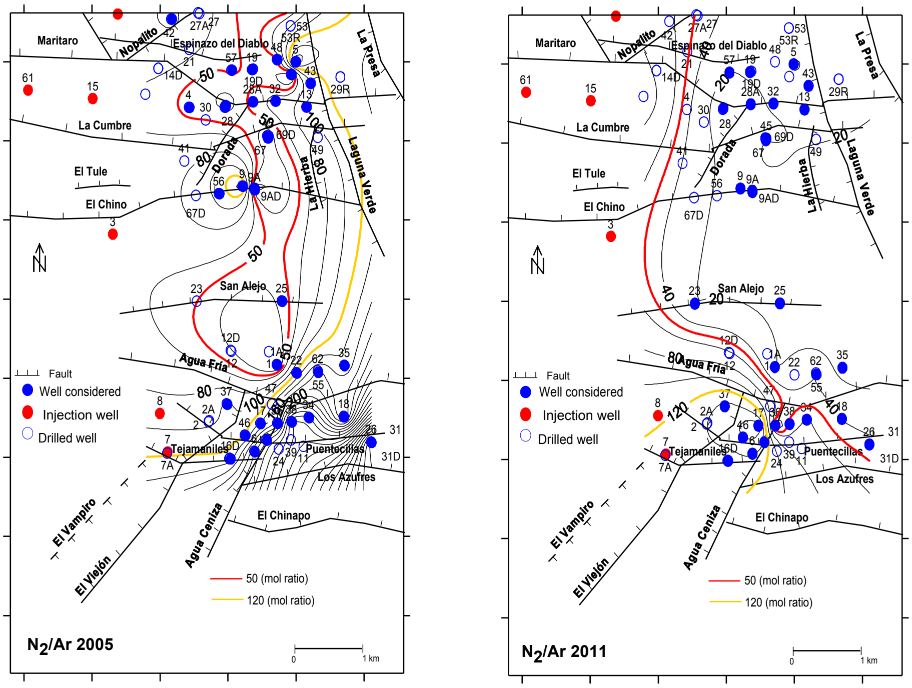

Figure 13: 2005 and 2011 distributions of N_2/Ar in the Los Azufres geothermal field.

5. CONCLUSIONS

The analysis of chemical and production data for the Los Azufres geothermal field allowed identification of the main reservoir processes related to exploitation. According to these results, after 27 years of commercial exploitation, very moderate decline in production parameters were estimated due to an efficient artificial and natural recharge to the reservoir. The extraction and reinjection of fluids from and to the reservoir have mainly induced the occurrence of two physical processes: (a) the production of returns from reinjection, and (b) boiling. Production of reinjection returns either as liquid or steam was relatively more important than the production of steam and sometimes condensed steam from boiling of injection fluids. It is reported for the first time that when returns from injection consist of condensed steam, salinity decreases in two-phase wells and isotopic compositions become relatively-depleted. In order to identify the production of such reinjection returns, analysis of gas data (in particular the N_2/Ar molar ratio) is necessary. The other process induced by exploitation was boiling, which can take place either with gaining steam, in which rates of boiling over time tend to increase, or with steam loss, in which the boiling rates over time tend to decrease.

It is recommended to continue the monitoring of geochemical and production data to trace the evolution of the reservoir in response to exploitation and to support decisions on extending the resource lifetime.

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REFERENCES

Arellano, V.M., Torres, M.A., and Barragán, R.M.: Thermodynamic Evolution of the Los Azufres, Mexico, Geothermal Reservoir from 1982 to 2002, *Geothermics*, **34**, (2005), 592-616.

Arellano, V.M., Barragán, R.M., López, S., Paredes, A., and Aragón, A.: Respuesta del Yacimiento de Los Azufres a la Explotación 2003-2011, *Final Report,* IIE/11/14283/02F, Instituto de Investigaciones Eléctricas for the Comisión Federal de Electricidad, Cuernavaca, Morelos, México (2012).

Arnórsson, S.: Injection of Waste Geothermal Fluids: Chemical Aspects, *Proceedings*, World Geothermal Congress, Kyushu-Tohoku, Japan (2000).

Arnórsson, S., and D´ Amore, F.: Monitoring of Reservoir Response to Production, in: Isotopic and Chemical Techniques in Geothermal Exploration Development and Use, Ed. International Atomic Energy Agency, Vienna, (2000).

Barragán, R.M., Arellano, V.M., Portugal, E., and Sandoval, F.: Isotopic (δ18O, δD) Patterns in Los Azufres (Mexico) Geothermal Fluids Related to Reservoir Exploitation, *Geothermics*, **34**, (2005), 527-547.

Barragán R.M., Arellano, V.M., Aragón, A., Martínez, J.I., Mendoza, A., and Reyes, L.: Geochemical Data Analysis (2009) of Los Azufres Geothermal Fluids (Mexico): *Proceedings* Water Rock Interaction, Birkle & Torres–Alvarado (Eds.), Taylor & Francis Group, London, (2010), 137- 140.

Barragán, R. M., Arellano, V. M., Mendoza, A., and Reyes, L.: Chemical and Isotopic ($\delta^{18}O$, δD) Behavior of Los Azufres (Mexico) Geothermal Fluids Related to Injection as Indicated by 2010 Data, *Geothermal Resources Council Transactions*, **35**, (2011), 603-608.

Barragán, R. M., Arellano, V. M., Aragón, A., Torres, R., Reyes, N., López, S., and Patiño, A.: Estudio Isotópico de Fluidos de Pozos Productores y de Reinyección del Campo Geotérmico Los Azufres, Mich. 2013, *Final Report*, IIE/11/14154/I 01/F, Instituto de Investigaciones Eléctricas for the Comisión Federal de Electricidad, Cuernavaca, Morelos, México (2013).

Fournier, R.O., and Potter II, R.W.: A Revised and Expanded Silica (quartz) Geothermometer, *Geothermal Resources Council Bulletin*, (Nov. 1982), 3-12.

Goyal, K.P., Miller, C.W., and Lippmann, M.J.: Effect of Measured Wellhead Parameters and Well Scaling on the Computed Downhole Conditions in Cerro Prieto Wells, *Proceedings*, 6th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (1980).

Iglesias, E.R., Arellano, V. M., Garfias, A., Miranda, C., and Aragón, A.: A One-Dimensional Vertical Model of the Los Azufres, México, Geothermal Reservoir in its Natural State, *Geothermal Resources Council Transactions*, **9** (2), (1985), 331-336.

Iglesias, E.R., Flores-Armenta, M., Torres, R.J., Ramírez-Montes, M., Reyes-Piccaso, N., and Reyes-Delgado, L.: Estudio con Trazadores de Líquido y Vapor en el Área Tejamaniles del Campo Geotérmico de Los Azufres, Mich., *Geotermia, Revista Mexicana de Geoenergía*, **24** (1), (2011), 38-41.

Nieva, D., and Nieva, R.: Developments in Geothermal Energy in Mexico-Part Twelve: A Cationic Geothermometer for Prospecting of Geothermal Resources, *Heat Recovery Systems & CHP*, **7**, (1987), 243-258.

Nieva, D., Verma, M., Santoyo, E., Barragán, R.M., Portugal, E., Ortíz, J., and Quijano, L.: Chemical and Isotopic Evidence of Steam Upflow and Partial Condensation in Los Azufres Reservoir, *Proceedings*, 12th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (1987).

Siega, F.L., Salonga, N.D., and D'Amore, F.: Gas Equilibria Controlling H2S in Different Philippine Geothermal Fields, *Proceedings*, 20th Annual PNOC-EDC Geothermal Conference, Manila, Philippines (1999).

Truesdell, A.H., Lippmann, M., Quijano, J.L., and D'Amore, F.: Chemical and Physical Indicators of Reservoir Processes in Exploited High-Temperature, Liquid-Dominated Geothermal Fields, *Proceedings,* World Geothermal Congress, Florence, Italy (1995).