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Variation of gaseous species concentration in the Los Azufres geothermal wells as a tool to study the reinjection effect

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RESUMEN

Desde 1982 ha sido monitoreada periódicamente la concentración de las especies gaseosas (CO_2, H_2S, CH_4, N_2, H_2, Ar, y He) en el campo geotérmico de Los Azufres, Mich., México por la CFE. En este trabajo se analiza la variación en las concentraciones de dichas especies para entender el efecto de la reinyección sobre el fluido geotérmico producido. Las proporciones relativas de H_2S/CO_2 y N_2/CO_2, son los parámetros útiles para determinar los cambios en las características del yacimiento y el efecto de reinyección, respectivamente. Se observaron altos valores de N_2/CO_2 en los pozos que fueron afectados por la reinyección en el área de Tejamaniles, zona sur del campo, mientras que no se observó un efecto significativo de la reinyección en el área de Maritaro, zona norte del campo.

El diagrama ternario N_2-He-Ar se usó para estimar cualitativamente la contribución de los componentes meteóricos (atmosféricos), cortezas y magmáticos. Los pozos en Tejamaniles tienen mayor proporción de componente meteórico que los pozos en Maritaro. En resumen, la geoquímica de los fluidos geotérmicos es una herramienta poderosa para estudiar el efecto de reinyección en los sistemas geotérmicos.

PALABRAS CLAVE: Los Azufres, especies gaseosas, reinyección, campo geotérmico, México.

ABSTRACT

Since 1982 the concentration of gaseous species (CO_2, H_2S, CH_4, N_2, H_2, Ar, and He) has been monitored periodically in the Los Azufres geothermal field, Mich., Mexico by CFE. Here we analyze the variation of gaseous species concentration in order to understand the effect of reinjection on the production fluid. The relative proportions of H_2S/CO_2 and N_2/CO_2 are useful parameters to determine the changes in the reservoir characteristics and the effect of reinjection, respectively. Higher values of N_2/CO_2 were found for all the wells, which are affected by reinjection fluid in the southern zone Tejamaniles, whereas there is no significant effect of reinjection in the northern zone Maritaro.

A N_2-He-Ar triangular diagram is used to estimate the contribution of meteoric (atmospheric), crustal and magmatic components. The wells in Tejamaniles have relatively higher atmospheric component than the wells in Maritaro. In summary the gas geochemistry of geothermal fluids is a powerful tool to study the effect of reinjection.

KEY WORDS: Los Azufres, gaseous species, reinjection, geothermal field, Mexico.

INTRODUCTION

Fluid geochemistry is a relatively less expensive powerful tool to evaluate the geothermal reservoir characteristics during exploration and exploitation. The existence of such systems is manifested on the surface in the form of hot spring, fumarole, steaming ground, mud volcano, etc. Various geochemical modeling approaches have been developed to estimate the deep reservoir parameters such as temperature, state of water-rock interaction, fluid flow pattern, recharge zone, size of the reservoir, etc. The effect of cooling processes of the fluid during ascent to the surface due to heat conduction and admixtures with cold waters or steam losses may be evaluated by means of changes introduced in the chemical and isotopic composition (Giggenbach *et al*., 1983). The first step in these approaches is to determine the deep reservoir fluid composition from separated water and steam from drilled wells and/or natural manifestations using the principles of conservation of energy and mass (Henley *et al.*, 1984). Some limitations in these approaches have been presented elsewhere (Verma, 2000).

The reinjection of spent geothermal brine is considered as an integral part of geothermal development in order to obtain a long-term sustainable geothermal production. Likewise, the reinjection helps to prevent the environmental degradation in the region. In case of Los Azufres all the available spent geothermal brine is reinjected. During the reinjection some atmospheric air is also injected in the reservoir. Here we will discuss qualitatively the effect of the injected air on the gas chemistry of production fluid.

THE LOS AZUFRES GEOTHERMAL SYSTEM

Los Azufres, a second prominent geothermal field in Mexico, is situated in the central part of the Mexican Volcanic Belt and is approximately 200 km west of Mexico City. The main field, 30 km^2 in extension, is highly fractured and faulted volcanic hydrothermal system and has an average altitude of 2800 masl, which is about 400 m higher than that of the surrounding valleys. Figure 1 shows the location map of the main field. Presently, there are 67 drilled wells: 37 production wells, 13 damaged wells, 8 wells under repairing, 6 reinjection wells, 1 well under study and 2 exploratory wells. The well depth varies between 627 and 3544 m and the maximum measured temperature is 358ºC (Suárez *et al.*, 1997; Tello, 1998). The total installed capacity of electricity generation is presently 88 MW: a central plant of 50 MW, seven well head units each of 5 MW and two binary units each of 1.5 MW.

The Los Azufres geothermal reservoir has a dome structure, which is divided in two principal zones: in north Maritaro having a liquid-dominated reservoir and in south Tejamaniles zone having a vapor-dominated reservoir. A one-dimensional vertical model of the reservoir suggests a layer structure to the reservoir fluids. The layers contain fluids in the order of superheated steam, two-phase vapor dominated, two-phase liquid dominated, and the lower one has hot compressed liquid (Iglesias and Arellano, 1985, Iglesias *et al.*, 1987).

González *et al.* (2000) summarized the geology and geochemistry of the field. The main reservoir consists of complex andesitic layer structure. The unit of ignimbrite deposit with intrusion of rhyolitic domes forms a caprock on the reservoir. The principal superficial hydrothermal activities, alteration zones, steaming ground, hot springs, hot mud lakes and fumaroles are associated with faults and fractures, which allow the ascent of geothermal fluid to the surface.

PRODUCTION AND REINJECTION HISTORY

Figure 2 shows the fluid production and reinjection history of Los Azufres geothermal field up to 1996. The production started in 1980, whereas reinjection in 1982. The

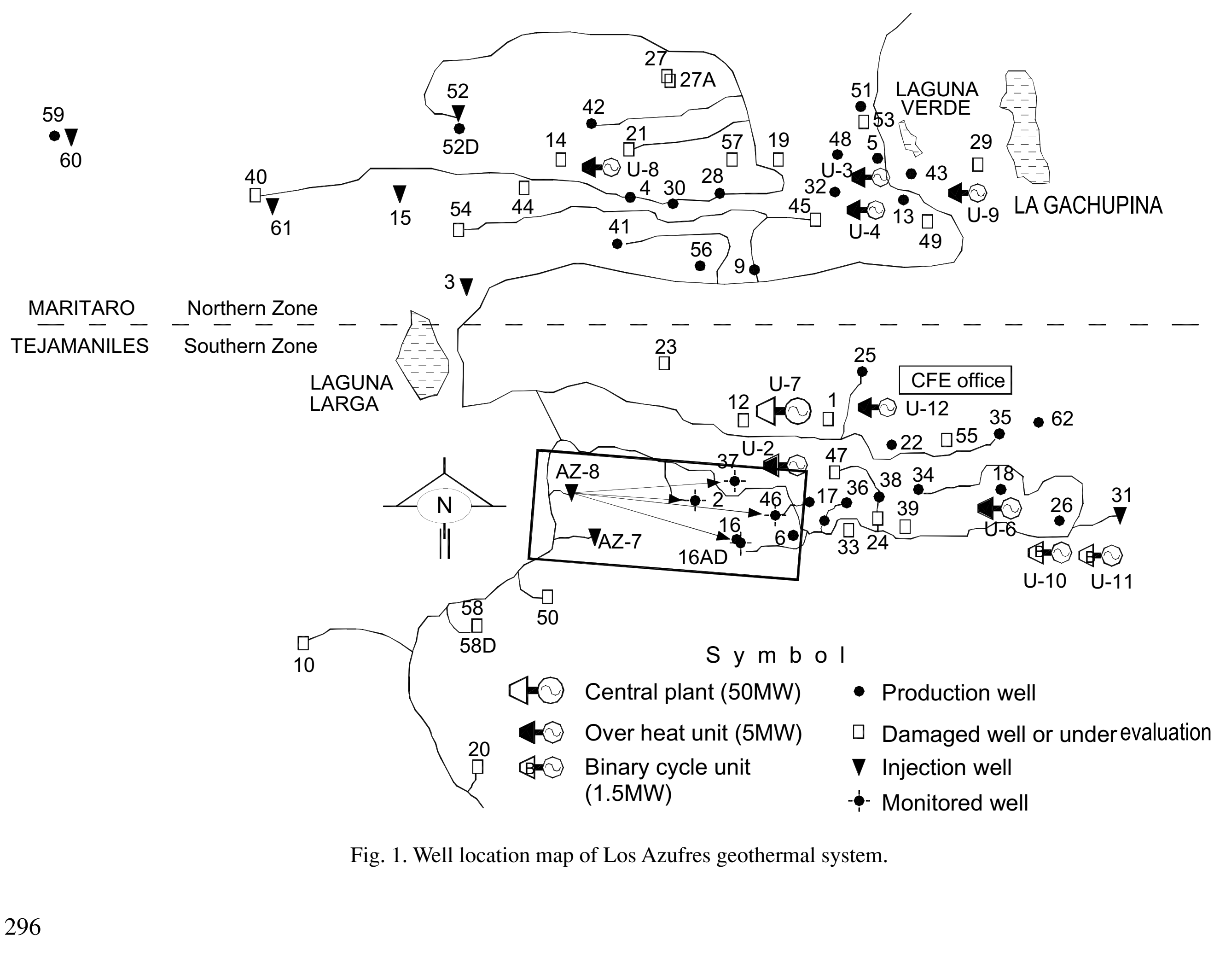

Fig. 1. Well location map of Los Azufres geothermal system.

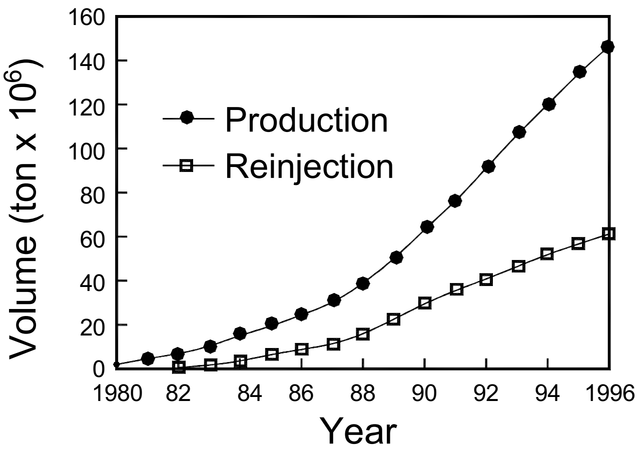

Fig. 2. Production and reinjection history of Los Azufres geothermal system.

commercial generation of electricity was started in 1982. The separated water and condensed vapor are cooled to the ambient temperature in a pool before their reinjection. The retention of the spent brine in a pool is to allow the deposition of supersaturated species, especially silica. This avoids the deposition of such mineral in the bottom of reinjection well and increases the well life (GIDROTEC, 1982). Actually, all the available spent geothermal brine is reinjected.

The cooled brine is injected through a plastic pipe in a reinjection well. There is a gap between the plastic pipe and the well. This gap permits the suction of air during reinjection. Thus the atmospheric air is also injected into the reservoir with the geothermal brines. The injection system was not designed with the objective of air injection, so the gaseous species variation in nearby production wells was initially considered as the effect of changing the reservoir characteristics due to production. But in later stage with observations on the variation of gaseous species concentration, air worked out as an excellent natural tracer system for a geothermal reservoir.

Figure 3 presents the history of the amount of water injected in the well Az-08 and its relation with the production of vapor and water in the well Az-46. The vapor production for the well Az-46 is approximately 55 ton/hr for the entire

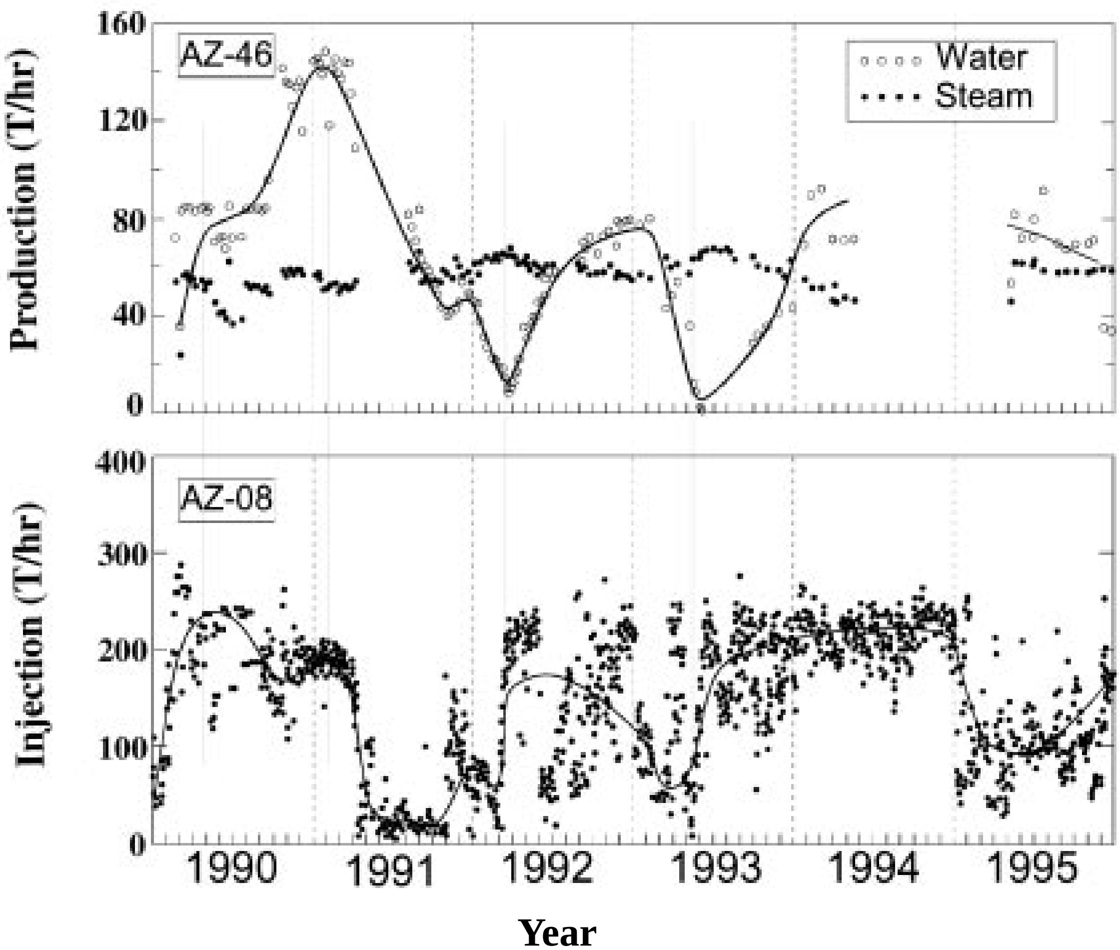

Fig. 3. Monitoring the effect of reinjection in well Az-08 on nearby production well Az-46. The amount of water production is directly related to the amount of reinjection.

life of production, whereas there is variation in the amount of produced liquid (separated water). It can be observed in Figure 3 that the amount of separated water in the well Az-46 is related with the amount of water injected in the well Az-08. When there is a maximum in the curve for injected water, there is also a maximum in the amount of water produced in the well Az-46. Puente and Ramírez (1991) explained the behavior as a consequence of a good hydraulic connection between injection and production zones and in the meantime the hot reservoir rocks provides sufficient heat to keep the vapor production constant.

Figure 4 shows the production history of well Az-09 and reinjection history of nearby well Az-03 in the northern zone Maritaro. The production of vapor and water in the well Az-09 is significantly constant with time, although there is still decrease in vapor production with time. There is variation in the amount of water injected in the well Az-03 with time, but there is no appreciable effect in the production of well Az-09 except at the beginning of 1995. Thus there is little effect of reinjection in the northern zone Maritaro.

RELATION BETWEEN GASEOUS SPECIES CONCENTRATION AND REINJECTION

The water geochemistry of Los Azufres has been well understood (Giggenbach and Quijano, 1981; Nieva *et al.*, 1986; 1987; Ramírez *et al.*, 1989; Verma *et al.*, 1989; Barragán *et al.*, 1997, González *et al.*, 2000). There is no direct infiltration of meteoric water within the field (Giggenbach and Quijano, 1981). Ramírez *et al.* (1989) suggested a possible infiltration of meteoric water to the reservoir in the south-east of the field on the basis of chemical and isotopic composition of natural manifestations and production wells

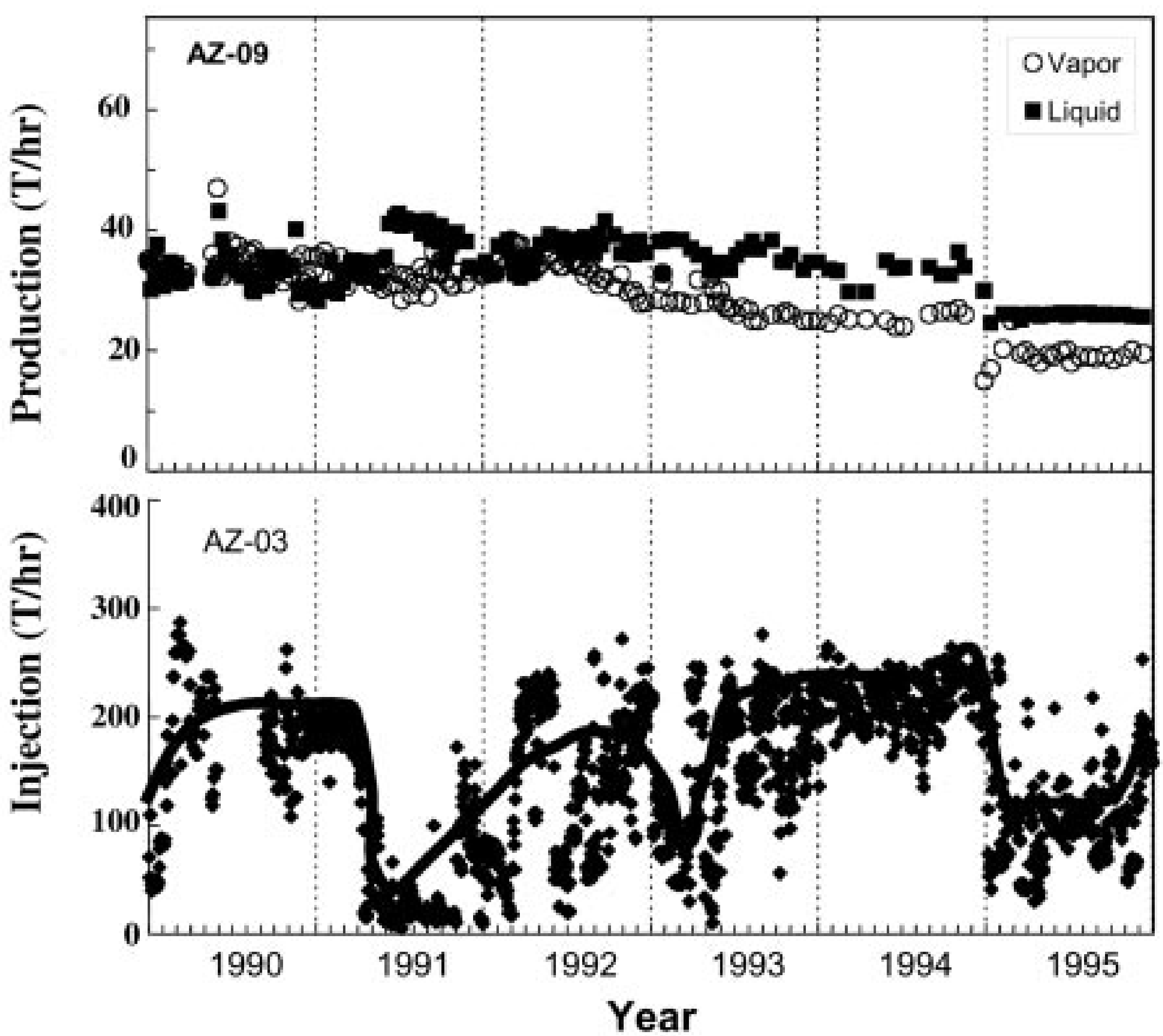

Fig. 4. A comparison between the production history of well Az-09 and reinjection history of nearby well Az-03 in the northern zone Maritaro. There is no appreciable effect of reinjection on the water-vapor production.

in the region. A LiqVap model is proposed by Iglesias *et al.* (1986) to show an accumulation of vapor phase on the upper part of the reservoir. Nieva *et al.* (1987) presented a systematic study of variation of chemical and isotopic composition of deep reservoir fluid with depth and concluded that the vapor phase in the upper part of the reservoir is formed with a process of evaporation and partial condensation of the reservoir fluid.

There are few studies on the geochemistry of gaseous species in Los Azufres (Suárez *et al.*, 2000; Barragán *et al.*, 2002). Here we will concentrate mainly on the variation in gaseous species in Los Azufres with the reinjection. The production of gaseous species and vapor fraction depends on various factors like the separation pressure, well opening, the reservoir characteristics at the bottom of the well, etc. Therefore, the relative variation of gaseous species concentration is more reliable. Figure 5 shows the relative variation of H_2S/CO_2 and N_2/CO_2 in well Az-46 in the southern zone Tejamaniles, whereas the similar behavior for well Az-09 in the northern zone Maritaro is shown in Figure 6. The gases CO_2 and H_2S are mainly associated with the geothermal fluid and their concentration in air is relatively small. Thus the relative concentration of H_2S/CO_2 should not be affected with reinjection. It can be observed that there is no variation in the ratio of H_2S and CO_2 gases in both wells with time. However, nitrogen is the main proportion of air. Thus the ratio of N_2/CO_2 should show the effect of reinjection (see Figures 5 and 6). It can be observed in Figure 5 that the ratio of N_2/CO_2 was low initially in Az-46, but increased significantly after injection. The variation pattern is quite complicated. It shots very high in the initial phase of reinjection and then decreases with time. As mentioned above the experiment was not designed for the specific purpose of air injection. So there is not a controlled record on the amount of injected air. It can be explained qualitatively that there was high initial permeability in the injection zone of well Az-08. The permeability got reduced with the progress of reinjection, probably due to the deposition of some minerals. Thus the suction of air in the initial stage was higher than that of the present day. An exponential decrease in the relative gas ratios of N_2/CO_2 supports the hypothesis. In case of well Az-09 there is no appreciable variation in the concentration of N_2/CO_2. The amount of reinjection in the northern zone is relative lower. Similarly it also depends on the connection between the reinjection and production wells. It has not been identified any connection between the reinjection and production wells in the northern zone. A chemical and isotopic study presented by Barragán *et al.* (1997) also indicates that there is higher injection effect on the characteristics of production wells in the southern zone Tejamaniles.

Giggenbach (1980) proposed a ternary diagram between He-Ar-N_2 to identify the relative proportion of three components: *Atmospheric, crustal and magmatic* in the geothermal fluids. We plotted the gaseous concentrations of wells in Tejamaniles and Maritaro (Figure 7). The Tejamaniles wells are closer to the atmospheric component. The wells

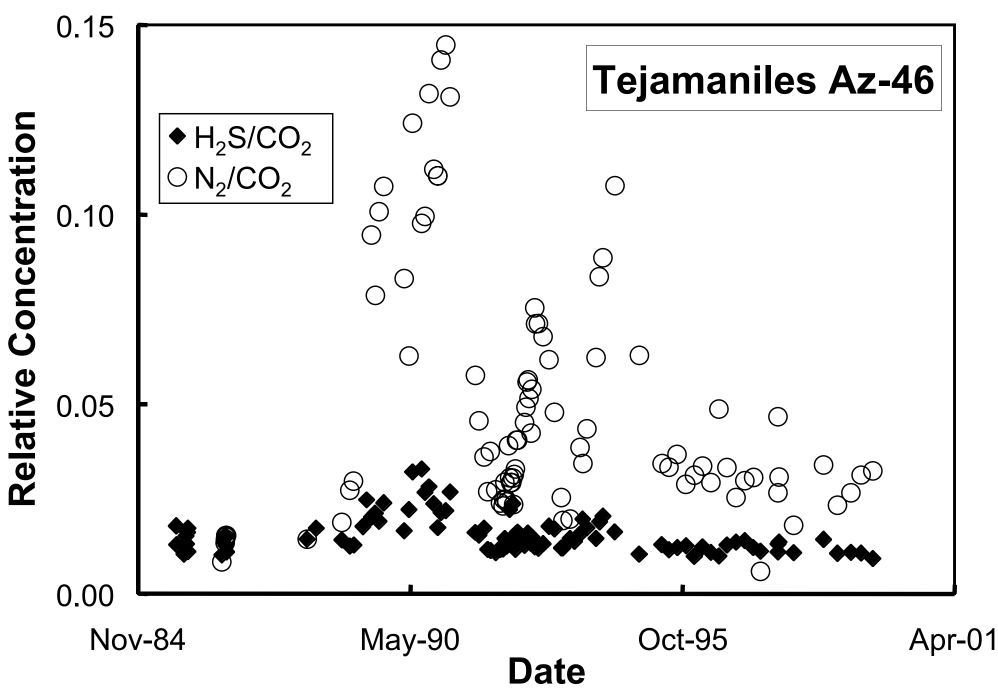

Fig. 5. Relative concentration of gaseous species in well Az-46 in the southern zone Tejamaniles. The concentration of H_2S/CO_2 is associated with reservoir, whereas the concentration of N_2/CO_2 may be a consequence of reinjection effect.

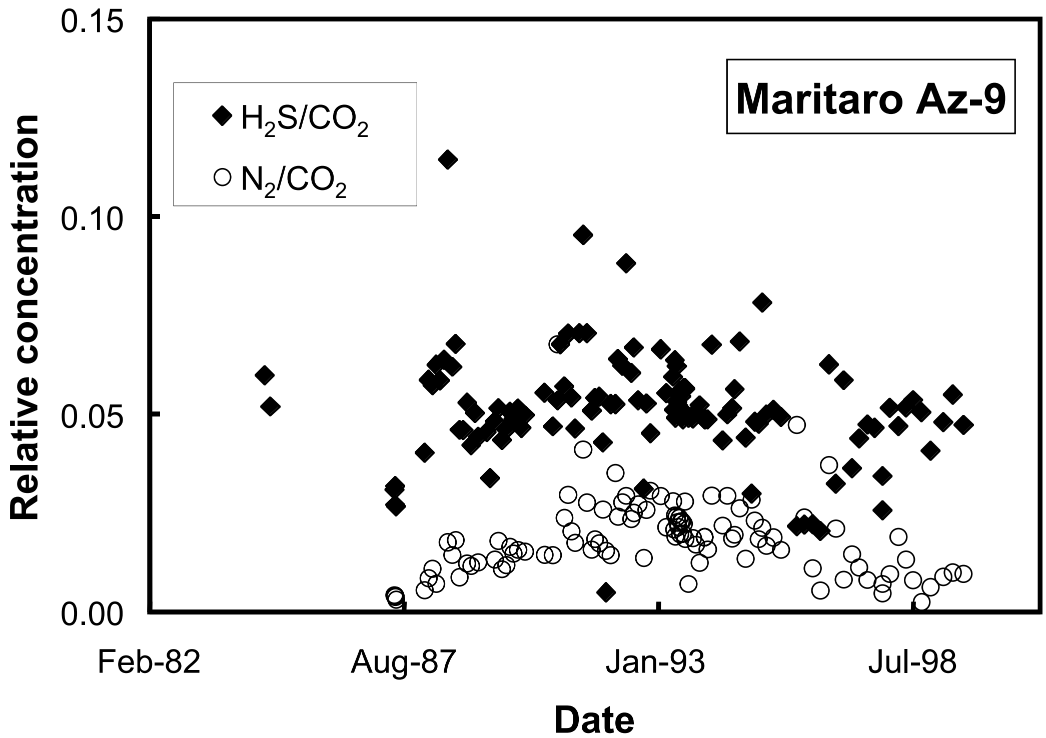

Fig. 6. Relative concentration of gaseous species in well Az-09 in the northern zone Maritaro.

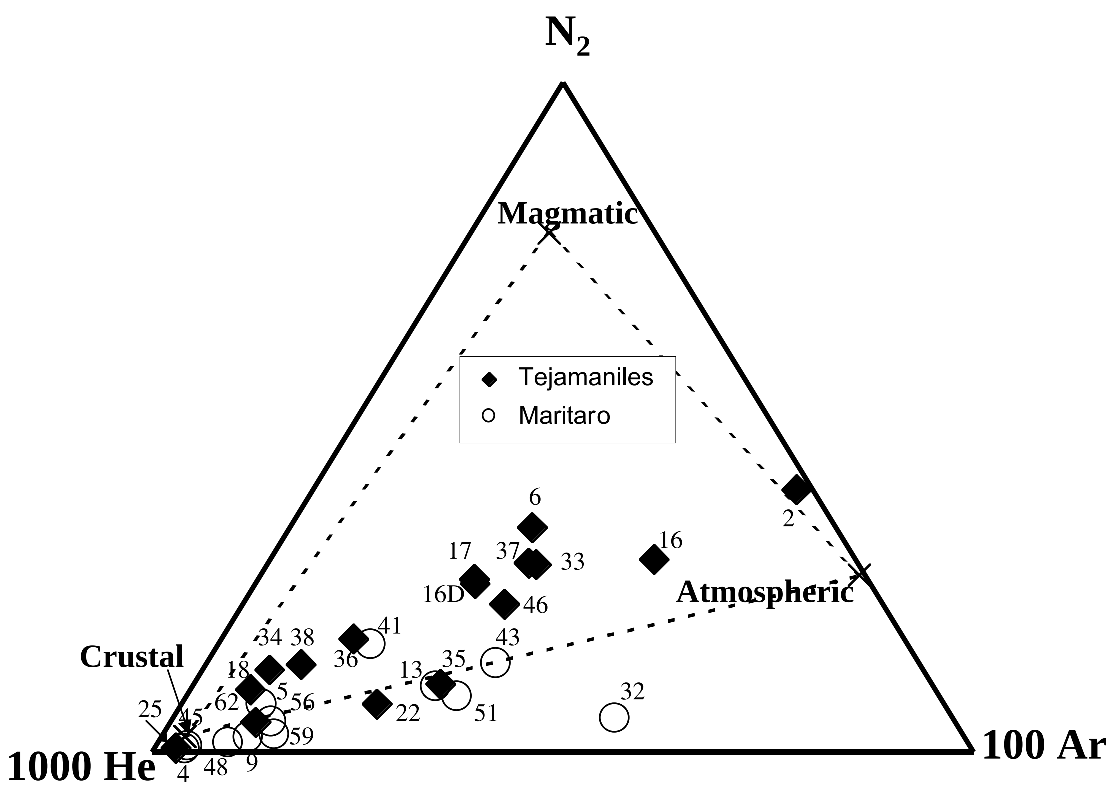

Fig. 7. A relative concentration triangular diagram for the wells in Tejamaniles and Maritaro (Giggenbach, 1980). The wells Az-02, Az-06, Az-16, Az-16D, Az-17, Az-33, Az-37 and Az-46 in Tejamaniles are more affected with the reinjection.

Az-02, Az-06, Az-16, Az-16D, Az-17, Az-33, Az-37 and Az-46, which are closer to the injection wells, have higher shift towards atmospheric component. Some wells are outside the triangle formed with the three components. Theoretically, there should not be any point outside the components triangle, if the gaseous composition of geothermal fluid is formed with mixing of the three components. The positions of all the outside wells except Az-32 are within analytical errors.

CONCLUSIONS

A good correlation between injection and production is found in the southern zone of the Los Azufres geothermal field, Tejamaniles; whereas there is no appreciable effect of reinjection in the production wells in the northern zone, Maritaro. A small amount of air is sucked into the reservoir with injection fluid. The ratios of H_2S/CO_2 y N_2/CO_2 are useful parameters to identify the changes in the reservoir characteristics and injection effect, respectively. The variation of gaseous species concentration supports the effect of reinjection in the production zone in Tejamaniles.

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