Helium anomalies at Los Azufres geothermal field, Mexico

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Abstract

Anomalies in helium concentrations in the gas phase of the Los Azufres (Mexico) geothermal field wells were studied from 1984 to 2001. The baseline concentrations of helium discharged by the wells ranged from 0.0001 to 0.005 (wt. % in dry gas). In the range, anomalous values reached as high as 0.09 and as low as 0.00001. These were correlated to fluid re-injection, seismicity and changes in the reservoir liquid/steam ratio. Differing behavioral effects of helium concentrations are discussed.

Keywords: Helium anomalies, seismicity, Los Azufres, Mexico, fluid re-injection, well simulation.

Anomalías de helio en el campo geotérmico de Los Azufres, México

Resumen

Se estudiaron las anomalías en la concentración de helio en la fase gaseosa de pozos del campo geotérmico de Los Azufres (México) de 1984 a 2001. Las "concentraciones base" de helio en las descargas de los pozos se encuentran entre 0.0001 y 0.005 (% en peso base seca). Con respecto a este rango, las anomalías presentan valores máximos hasta de 0.09 y mínimos de hasta 0.00001. Las anomalías se correlacionaron con los siguientes fenómenos: la reinyección de fluidos, la sismicidad y los cambios en la relación líquido vapor en el yacimiento. En este trabajo se presentan ejemplos de los diferentes efectos mencionados en el comportamiento del helio.

Palabras clave: Anomalías de helio, sismicidad, Los Azufres, México, reinyección de fluidos, simulación de pozos.

1. Introduction

Geochemical changes in ground-waters that include helium anomalies have been observed and related mostly to seismic events (Nieva *et al.*, 1987; Santoyo *et al.*, 1991; Kharatian *et al.*, 1999; Favara *et al.*, 2001, Balderer *et al.*, 2002). He content in geothermal fluids is originated from the atmosphere since waters were in contact with air before infiltration; however higher concentrations than expected of this process are due to the release of radiogenic He from the reservoir rocks (Mazor, 1978). The radioactive decay of ^{238}U, ^{235}U and ^{232}Th produces ^{4}He. $^{3}He/^{4}He$ ratios were measured at Los Azufres geothermal field, Mexico, in 1982 by Prasolov *et al.* (1999) who estimated a contribution of mantle helium of more than 50%. The objective of this work is to study the patterns of behavior of helium concentration as a function of time in some wells in order to investigate their possible correlation to the re-injection, seismicity and changes in the reservoir liquid/steam ratio.

2. The Los Azufres geothermal field

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 2800 meters above sea level. At present it is the second largest geothermal field producing electricity in the country, with an installed capacity of 188 MWe (Torres, 2003). The field was divided in two zones, according to the original characteristics of fluids. The northern zone (Maritaro) with two-phase fluids and the southern zone (Tejamaniles) with mostly vapor. Figure 1 shows the location of the wells. The reservoir engineering model for the Los Azufres reservoir was developed by Iglesias and Arellano (1984) and the geochemical model was postulated by Nieva *et al.* (1987). Studies on field evolution due to exploitation have been reported elsewhere (Torres and Flores, 2000; Arellano *et al.*, 2003; Barragán *et al.*, 2003). The behavior of the gas phase produced by the wells has been discussed by Nieva *et al.* (1987); Santoyo *et al.* (1991); Barragán *et al.* (2002, 2004), Suárez (2002) and Verma *et al.* (2002).

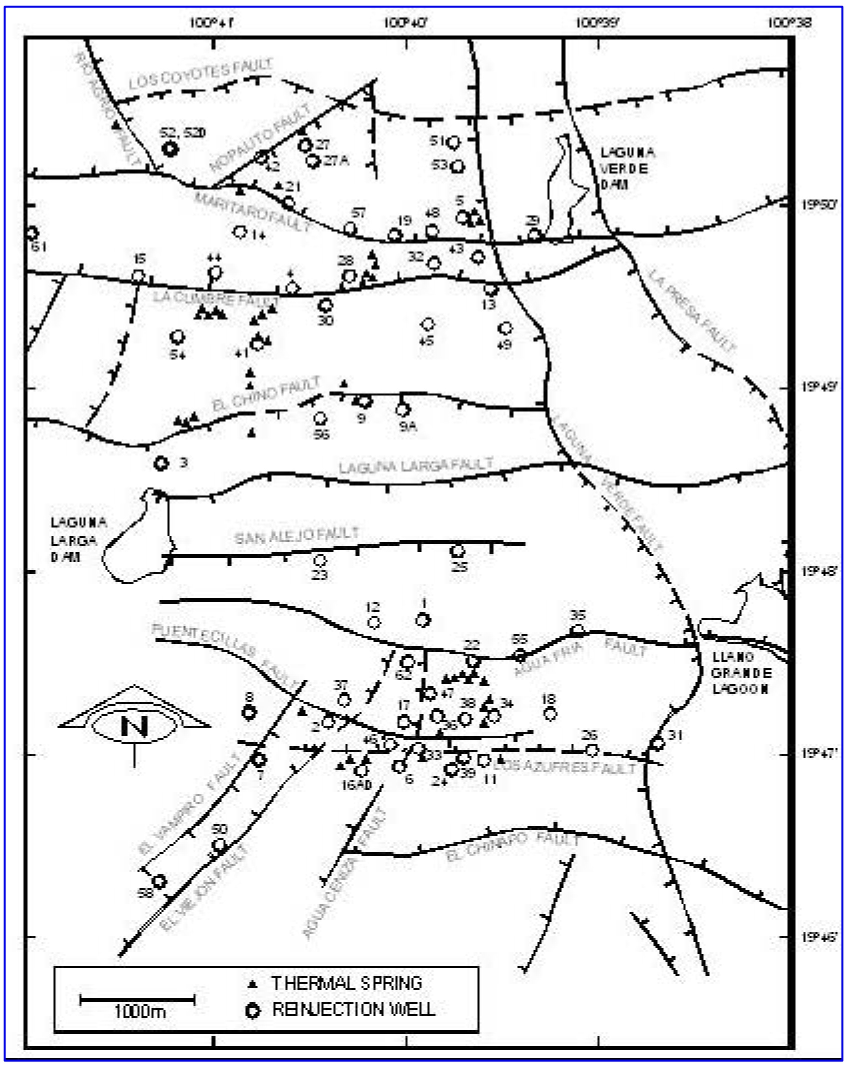


Fig. 1. Location of the wells at Los Azufres geothermal field

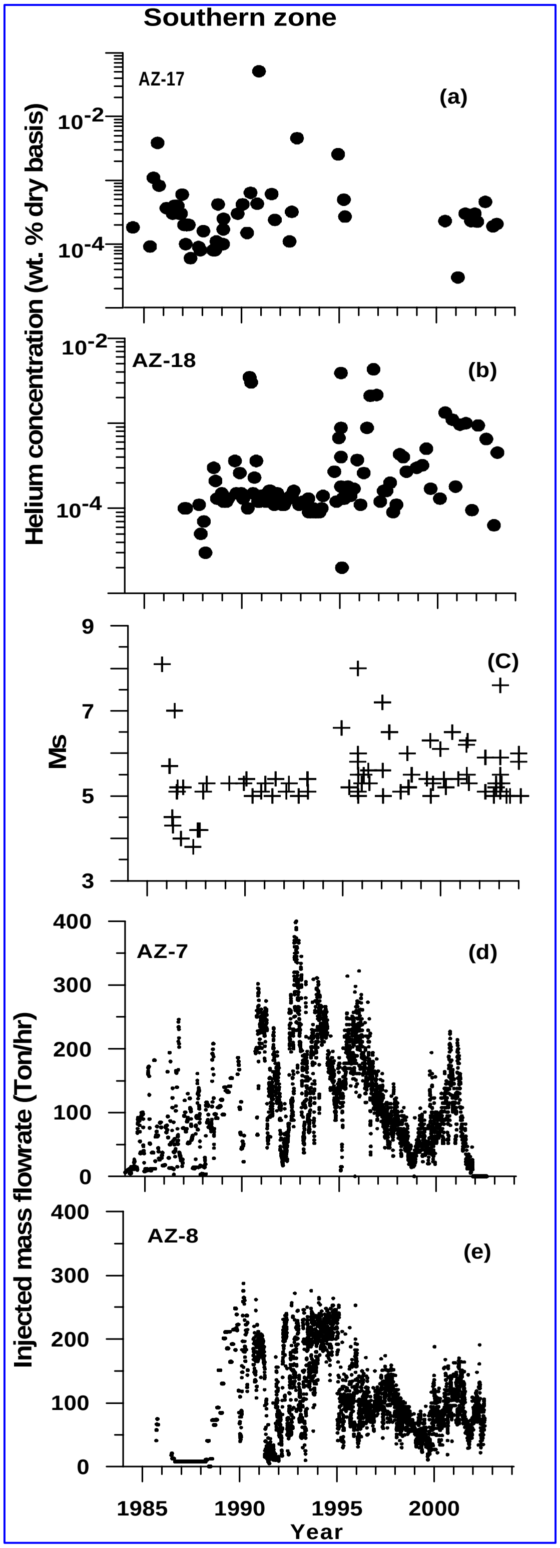
In all the wells of the field the helium concentration has increased with time (Suárez, 2002), as Ar has also increased in the wells. The effect could be due to re-injection, since the re-injection mixture consists of water and air.

3. Sampling and analytical methods

Steam and gas samples were routinely collected in wells according to the method given by Giggenbach (1975) which consists in the collection of non-condensable gases from the steam line in an evacuated glass bottle containing a 4N solution of NaOH. The samples are analyzed by gas chromatography using molecular sieve and thermal conductivity detector. He is used as a carrier gas to determine Ar, N_2 and CH_4 whereas Ar is the carrier gas for He and H_2 determination. CO_2, H_2S and NH_3 of the gas sample are analyzed according to standard methods described in Giggenbach and Goguel (1989).

4. Results and discussion

4.1 Examples related to re-injection



Figures 2 (a) and (b) show the helium concentration (wt. % in dry gas) in the gas phase vs. time of the wells AZ-17 and AZ-18 (southern zone) while Figures 3 (a), (b) and (c) show the helium concentration in wells AZ-13, AZ-5 and AZ-32 (northern zone). The patterns of re-injection in wells AZ-7 and AZ-8 (southern zone) are given in Figures 2 (d) and (e) while the pattern of re-injection in well AZ-52 (northern zone) is given in Figure 3 (e).

Fig. 2 (a) Helium concentration (wt. % dry basis) of well AZ-17 (southern zone) vs. time; (b) helium concentration (wt. % dry basis) of well AZ-18 (southern zone) vs. time; (c) pattern of seismicity at Michoacán Coast vs. time; (d) re-injection pattern (Ton/hr of fluids injected) in well AZ-7 (southern zone) vs. time; (e) re-injection pattern (Ton/hr of fluids injected) in well AZ-8 (southern zone) vs. time.

In both zones of the field, at least the first important re-injection peak was correlated to a helium increase in the wells, regardless of the distance between re-injection and production wells. The effects of re-injection on helium (and on total gas) anomalies are due to the high diffusivity of the gas phase, which is distributed through faults and fractures of the system reaching the production zones of the wells.

Thus, according to available helium data of well AZ-17, three important anomalies in 1991, 1993 and 2000 were related to maximum mass flow rate injected in well AZ-7. The largest anomaly occurred in 1991 as a response to the first injection peak. Helium concentration in well AZ-17 had a baseline of 0.0003 (wt. % dry gas) while the concentration recorded in 1991 was as high as 0.06 (wt. % dry gas). The other two anomalies related to injection were seen when a new large injection peak occurred after minimum injection flow rates. The well AZ-17 is located relatively close to well AZ-7, thus, the effect of re-injection is easily understood, however the disturbance to the reservoir caused by re-injection (at least in wells within the same zone) could be observed in wells located relatively far from each other, such as in well AZ-18.

The concentration of helium in well AZ-18 has increased with time from 0.0001 to 0.0006 (wt. % dry gas) in average. In well AZ-18 the first important helium anomaly was seen in 1990 with a helium concentration of 0.004 (wt. % dry gas), which coincides with the high peak of injection in well AZ-8, whereas previous, smaller (up to 0.0003 wt. % dry gas) anomalies seem to follow the injection pattern.

The results indicate that only the first important peak of injection produced such increase in helium concentration, and regardless the injection pattern, the helium concentration stabilized in a "baseline value" of around 0.0001 (wt. % dry gas), from 1991-1995.

Similar effects were observed in the northern zone of the field in well AZ-32, in which the helium concentration baseline was 0.00015 (wt. % dry gas), in 1989. In this well, a correlation between an important helium anomaly and the mass flow rate injected in well AZ-52 is seen, at the beginning of 1995.

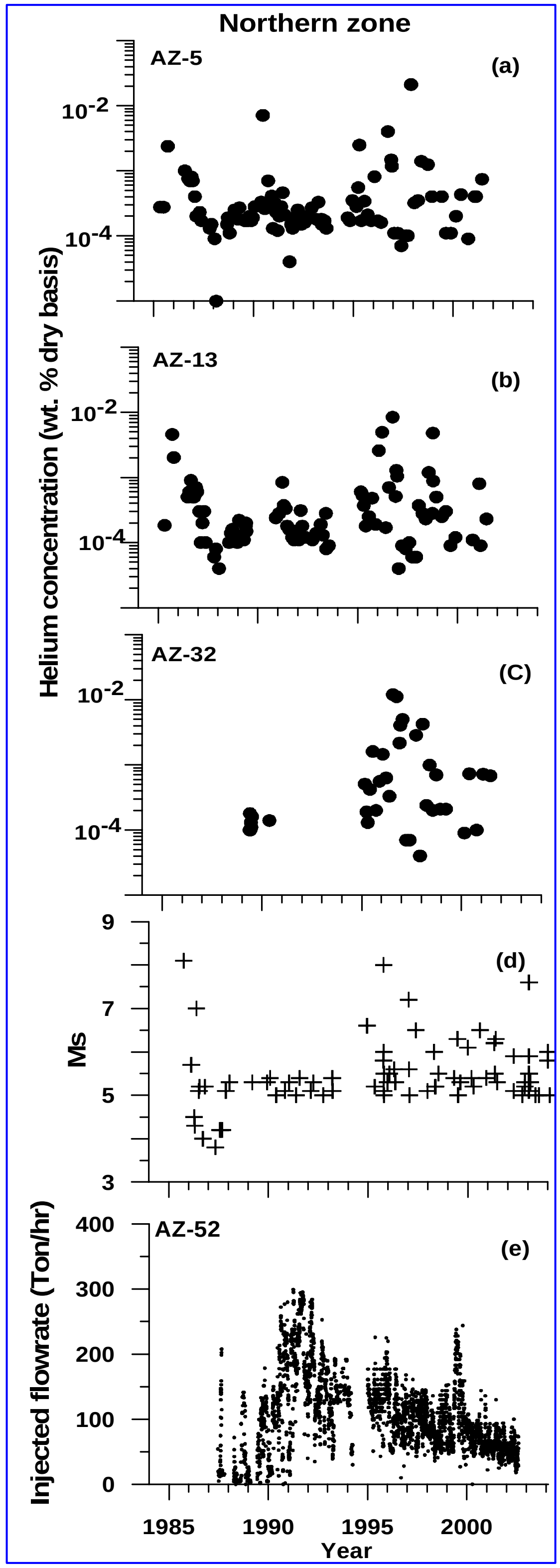


Fig. 3. (a) Helium concentration (wt. % dry basis) of well AZ-5 (northern zone) vs. time; (b) helium concentration (wt. % dry basis) of well AZ-13 (northern zone) vs. time; (c) helium concentration (wt. % dry basis) of well AZ-32 (northern zone) vs. time; (d) pattern of seismicity at Michoacán Coast vs. time; (e) re-injection pattern (Ton/hr of fluids injected) in well AZ-52 (northern zone) vs. time.

The pattern of re-injection in well AZ-52 shows a minimum value in 1994 and then a large peak between 1995 and 1996. The most important peak of injection in well AZ-52, in 1991-1992, produced anomalously high helium concentration in wells AZ-5 and AZ-13. In fact, the behavior of helium in well AZ-13 follows quite well the pattern of re-injection in well AZ-52, until 1997. The wells AZ-32, AZ-5 and AZ-13 are located relatively far from the well AZ-52 and, until recently, it was stated that re-injection had minimum impact in the northern zone of the field. However, the analysis of geochemical and production data provided evidence of such interference (Arellano *et al.*, 2003).

4.2 Examples related to seismic events

The pattern of seismicity (magnitude > 5) at Michoacán Coast (16°-21° N; 101°-105° W) from 1985 to 2004 is shown in Figures 2 (c) and 3 (d). Previous data including events with magnitudes less than 5, were taken from Santoyo *et al.* (1991). The hipocenters of the seismic events ranged from 10 to 98 km depth. The pattern of seismicity shows that the Los Azufres field is located on a highly seismic zone, one of the most active seismic zones of the world. Thus, tectonics plays an important role, since new-formed fractures and faults release both magmatic and radiogenic helium enriching the geothermal fluid.

The helium concentration at wells AZ-17, AZ-5 and AZ-13 (among others) showed an important anomaly related to the Mexico, September, 1985 (Ms=8.1) earthquake (Santoyo *et al.*, 1991) (Figures 2 (a), 3 (a), 3 (b)). In well AZ-17 the helium concentration increased up to 0.004 (wt. % dry gas) about a week before that date, being the maximum before the anomaly related to re-injection in 1991. At least three other anomalies in this well in 1995, 2000 and 2001 could be related to the occurrence of seismic events, of magnitudes higher than 6.

A “stable” behavior in the pattern of seismicity is shown from 1989 to 1995, in which all the earthquakes had magnitudes close to 5. Thus, the important helium variation during 1988-1995 in well AZ-17 could be due to re-injection in well AZ-7 considering that both wells are near each other.

The helium behavior of well AZ-18, after the first anomaly related to re-injection in well AZ-8, accurately follows the seismicity pattern showing higher peaks when seismic events with magnitude higher than 6 occurred. This is supported by the fact that no helium anomalies were observed in well AZ-18 during 1990-1995, when all the seismic events had magnitudes around 5. Thus, it is concluded that helium anomalies in well AZ-18 followed the first important peak of injection in well AZ-8 and, after this, it followed the seismicity pattern.

Similar behavior was observed at well AZ-32 (northern zone) in which, since 1995, helium showed maximum peaks when earthquakes occurred, although no helium data was recorded between middle-1990 to 1995.

As mentioned before, the pattern of seismicity indicates the occurrence of a good number of important earthquakes (MS>6) since 1995 to date. Thus, helium anomalies in wells AZ-5 and AZ-13 are more noticeable since 1994-1995, with variations in helium concentration of more than two orders of magnitude and could be related to tectonics.

Explanations of helium anomalies related to seismicity have been given by Santoyo *et al.* (1991), Segovia *et al.* (1991), Favara *et al.* (2001), and Balderer *et al.* (2002), among others. They associate the high helium concentration to the high mobility of helium to escape through fissures produced by earthquakes from deeper zones to the surface.

The anomalous helium behavior in fluids was also explained by the creation of new fractures under higher reservoir pressure, allowing the release of fluid confined in surrounding rocks. Pressure increases could occur before or after the occurrence of earthquakes near geothermal or underground water systems and they are of tectonic origin (Segovia *et al.*, 1991). However, to determine the contribution of mantle helium, the measurement of $^3He/^4He$ ratios is needed to analyze such cases when anomalies follow both the peaks of injection and the seismic events occurring at about the same time. As it is seen, many earthquakes with epicenters in the Michoacán Coast coincide with peaks in re-injection rates, which masks the data interpretation.

4.3 Examples related to temporary changes in reservoir liquid/steam ratio

Some helium anomalies and some anomalies in the gas phase composition of geo-thermal wells are due to temporary changes of the liquid/steam ratio of reservoir fluids. By using the WELFLO simulator (Goyal *et al.*, 1980) with production data as input (Arellano *et al.*, 2003) the enthalpy, pressure and temperature of reservoir fluids can be obtained to define the thermodynamic state of the fluids entering the well.

Examples are given to explain the important helium anomaly found in wells AZ-17 (September, 1985) and AZ-5 (September, 1985) where pressure well tests were carried out at the sampling dates. Figure 4 shows the pressure vs enthalpy graph of wells AZ-17 and AZ-5, where the solid line corresponds to the saturation curve of water. The points corresponding to the well AZ-17 in the graph show a slight decrease in enthalpy and an increase in well-bottom pressure for the anomalous point (September 12, 1985) as compared with the other data points. This indicates that a small fraction of liquid phase was formed at the reservoir as a result of higher reservoir pressure (compression process). When a liquid fraction is formed from an original mass of steam in a closed system, the volatile components remain in the steam phase providing the observed increase in non condensable gases at the discharge. In this particular case, the compression process was due to (a) tectonics related to the September 19-20 (MS 8.1) Mexico earthquake and (b) the change of the orifice plate at wellhead, since a pressure well test was performed in the well during September 4- 12, 1985, whereas the samples were taken on September 11.

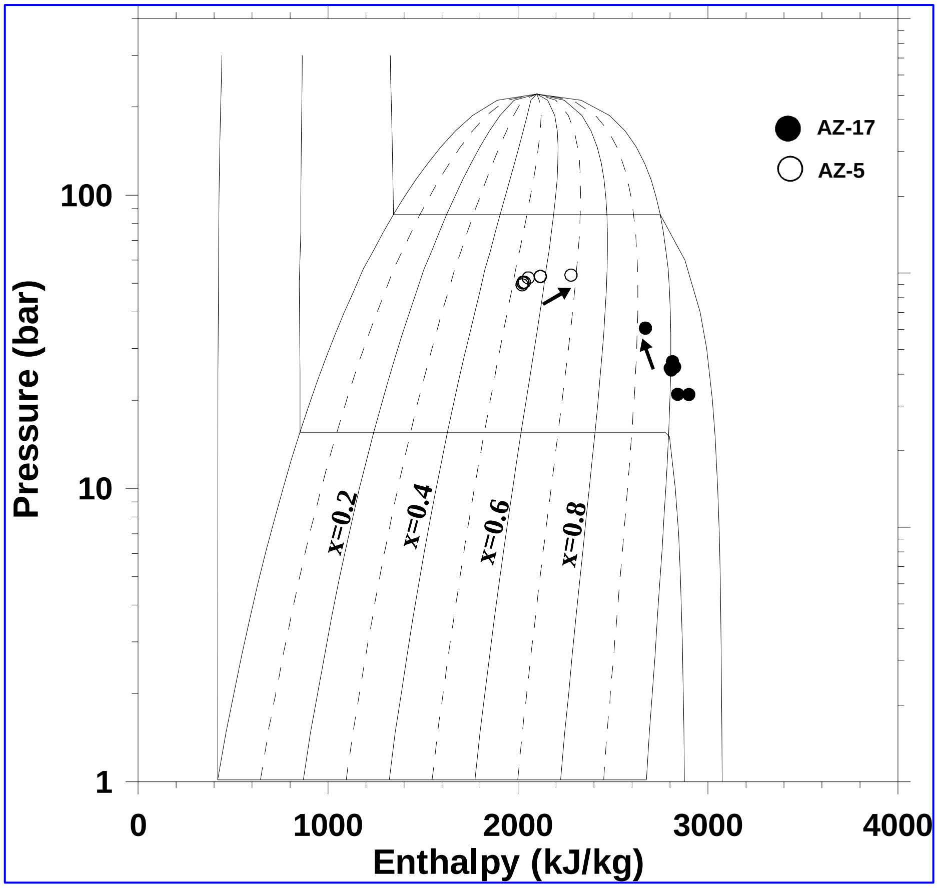


Fig. 4. Pressure (bar) vs enthalpy (kJ/kg) of wells AZ-17 and AZ-22 at reservoir obtained by the WELFLO simulator. The solid line shows the saturation curve of water. In well AZ-17 a small fraction of liquid was formed as a result of a compression process at September, 1985. In well AZ-5 a higher vapor fraction at reservoir explains the enthalpy increase at September, 1985.

As another example, the important helium anomaly in well AZ-5 in September 1985, was probably due to the change in the reservoir liquid/steam ratio, since changes in the wellhead pressure occurred due to a pressure test. The points corresponding to the well AZ-5 show that the bottom-hole enthalpy increased as a result of an expansion process. This enthalpy increase was due to the change in the liquid/steam ratio at reservoir and implies a higher vapor fraction in the reservoir fluid. These changes are temporary and when the compression or expansion process finishes, the composition of the gas phase tends to the “baseline” values.

5. Conclusions

The behavior of helium in Los Azufres gas phase was correlated to re-injection, seismicity and to a lesser extent to the change in reservoir liquid/steam ratio. The anomalies seem to be associated to the first important peak of re-injection of fluids to the reservoir. However, after this first anomaly, the helium anomalies follow the seismicity pattern, when the events have magnitudes higher than 6. Some helium (and gas) anomalies are due to the change in reservoir liquid/steam ratio. This occurs either due to tectonics, considering that Los Azufres is a highly seismic zone, or is induced by physical changes at wellhead as in the case of pressure tests in the wells.

Sampling wells under controlled conditions is recommended to avoid difficulties in the interpretation of chemical gas composition. It is concluded that monitoring helium in wells helps in identifying well interference and that simulation of wells is useful to understand changes in chemical gas composition. The measurement of $^{3}He/^{4}He$ ratios is necessary to better understand helium anomalies in geothermal fluids.

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