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THE USE OF AIR AS A NATURAL TRACER IN FRACTURED HYDROTHERMAL SYSTEMS. LOS AZUFRES, MEXICO, CASE STUDY

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ABSTRACT

Injection of atmospheric air mixed with cold water has been occurring since 1982 at the Los Azufres geothermal field. Several chemical and thermodynamical evidences show that air injection into this fractured hydrothermal system could be considered as a long term natural tracer test. Nitrogen and Argon separated from the air mixture migrate, under the action of the induced injection-extraction gradient, from reinjection sectors to production zones following preferential paths closely related to high permeability conduits. A coarse numerical estimation of the average permeability tensor existing at Tejamaniles, the southern sector, explains the unsuccessful recovery of the artificial tracer tests performed in past years: the anisotropic nature of the fractured volcanic rock would demand considerably quantities of tracer in order to be detected at the producing wells, especially when fluid extraction was low. At the same time concentrations of calcium, cesium, chloride, potassium, rubidium and sodium, are increasing in the liquid produced by the oldest wells of this field's sector.

INTRODUCTION.

Los Azufres is a fractured volcanic hydrothermal system, located in the western part of the Mexican Neo-Volcanic Axis at an elevation of about 2800 masl. With about 60 wells completed, Los Azufres generates up to date, 90 MWe. Some general descriptions of this field have been previously published elsewhere (Gutiérrez et al,1982; Cathelineau et al,1985; Suárez et al, 1990). Tejamaniles, the field's southern sector, has been in exploitation since August 1982 subjecting the reservoir gradually to mass and heat extraction. To avoid the environmental impact of liquid waste disposal from the Tejamaniles geothermal field, the only alternative has been to inject the waste liquid back into the formation by gravity, without pumping. Besides this need, a well done injection may produce a higher recovery of heat stored in the reservoir. Fluid extraction takes place at the center of the field, while reinjection is performed to the west of the production zone (Fig. 1). During the past years, there were some tracer studies about the fluid transport in this reservoir but they had null responses all of them (Horne and Puente 1989).

Simultaneously with geothermal water reinjection, an important amount of air has been continuously inflowing to the reservoir through the open wellheads of the injection wells; also, atmospheric air is 'dragged' from the open surface of the collection boxes (Fig. 2). There are several evidences that the incidental injection of air into this intensely fractured system could be considered as a long term natural tracer test because the Nitrogen separated from the air mixture is transported by the extraction-injection gradient through the high permeability conduits to the producing wells, by means of a hydrodynamic dispersion mechanism. The undesirable aspects of reinjection such as serious interference of the lower enthalpy of this water with the energy outflow of the producing wells, or decreasing formation permeability by chemical deposition, or contamination of groundwater have never been noticed either at this field.

TEJAMANILES SUBJECT TO EXPLOITATION

Since August 1982, two wellhead non-condensing units, generating 5 MW_e each, were installed at Tejamaniles: Unit 1 connected to wells Az-6 and Az-16D, and Unit 2 connected to well Az-17. In September 1987 Unit 6 has been connected to well Az-18 in order to generate 5 additional MW_e. In November 1988 a 50 MW_e unit was installed in Tejamaniles, feeding with steam coming from wells Az-22, Az-33, Az-34, Az-35, Az-36, Az-37, Az-38 y Az-46 (Fig.1). These plants have been in continuous operation with a total extraction mass of about 780 T/h.

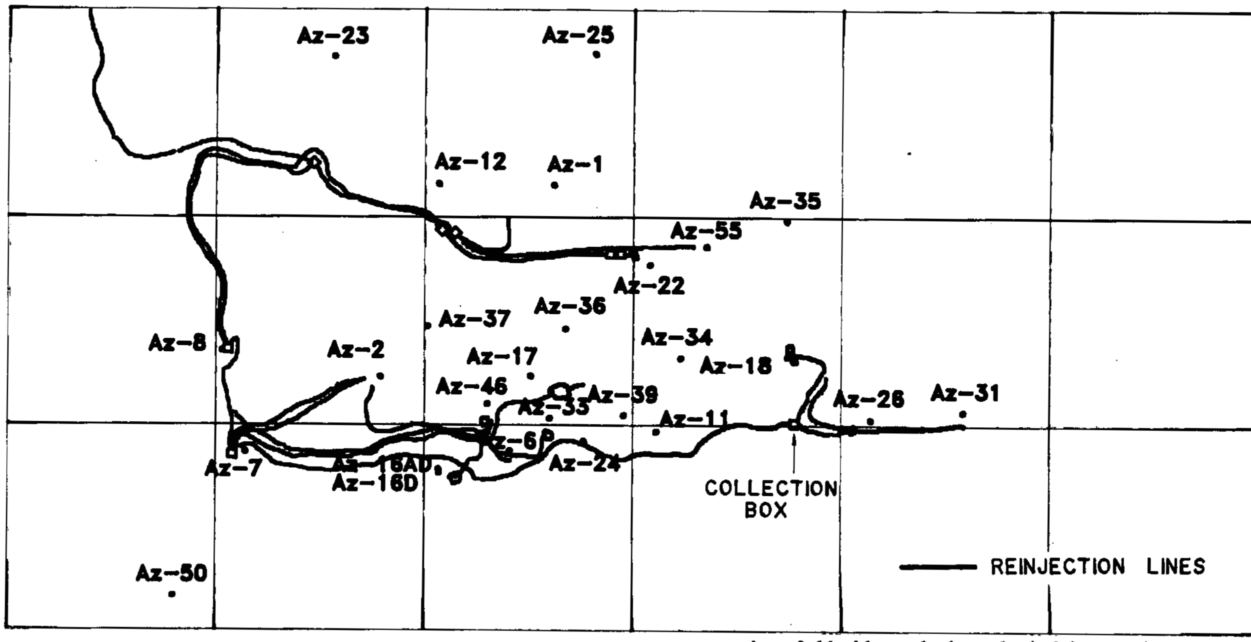
As we have explained, the exploitation of Tejamaniles occurs parallel to the injection of "cold" fluid and air. The temperature of injection varies between 40 to 50 °C at atmospheric pressure (0.73 bar). Figure 1 shows the areal disposition of reinjection lines and figure 2, exhibits the details of the injection system at well Az-8. The rates of mass extraction and of fluid injection are illustrated for wells Az-16D (2-phase), Az-17 (steam) and Az-7 (injector) in figures 3 and 4. For the rate of air injection we have a measured value at well Az-8: 274 Kg/h of air in 231 T/h of water.

In the southern sector, the extracted fluid is two-phase in natural state, with a non homogeneous steam saturation, which ranges between 0 to 70 %. Pressure and temperature profiles (Suárez et al 1990) show that between 1600 and 2500 masl, a nearly vaporstatic distribution of thermodynamic conditions exists and between 0 and 1550 masl the thermodynamic profiles correspond to hydrostatic conditions. The present pressure and temperature profiles of the production wells exhibit changes, indicating that the system as a whole, has started to abandon its natural steady state.

TRACER STUDIES

Between August 1983 and July 1987 six tracer tests were performed at Los Azufres. In three of these tests some amount of tracer (Potassium Iodide and Iridium-192) was injected into wells Az-7 and Az-8 in order to know where the reinjected water could go. Those investigations had very low effectiveness in the understanding of the real phenomena as has been reported by Horne and

FIGURE 1.– AREAL DISTRIBUTION OF REINJECTION LINES AT THE TEJAMANILES RESERVOIR



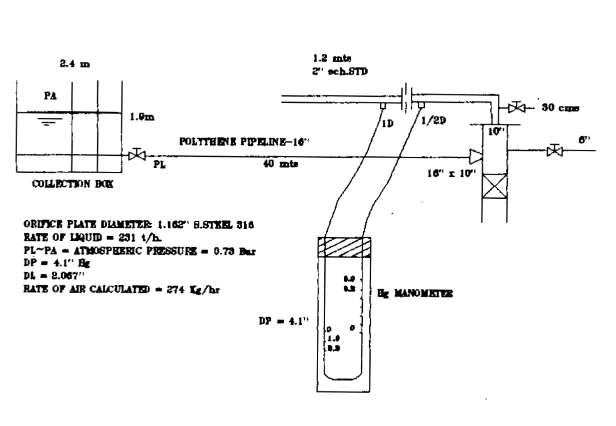
Puente in 1989. Tracer injection into the wells was effectively achived yet no return of the tracer was detected at the two closest wells Az-2 and Az-16D. The authors concluded either: the tracer was retained within the reservoir by some mechanism, or the return occurred after the monitoring was terminated, or was at such low concentration as to escape detection. The general conclusion was that tracer return times could be longer than expected at this portion of the reservoir. At that time, the effect of global production could not be taken into account. Roland Horne (*ibidem*) was one of the first investigators to notice that N_2 concentration at well Az-16D was higher than the normal N_2 solubility of the reservoir's fluid, suggesting that the intake of atmospheric air was important.

THE EFFECT OF AIR INJECTION

Reinjection of nearly 15 million tons of water since 1982 up until December 1990, has been accomplished mainly through wells Az-7 and Az-8. Today, the maximum amount of waste water accepted by well Az-7 is about 260 T/h and about 250 T/h by well Az-8 (nevertheless, well Az-7 could accept more than 325 T/h in 1985). The horizontal distances of the reinjection wells from the nearest production wells ranges from 1000 to 2000 m.; the injection wells being 500 to 1000 m. deeper. The total vectorial distance between producing and injection wells is a critical parameter because reinjection too close to the producing zone would sooner or later provoke a drop in the temperature of the fluid produced. Apparently fluid is reinjected at an adequate distance from the production zones at Tejamaniles, with the only exception of well Az-33 (after data in Suárez et al., 1990). If it is so, the thermodynamical effect of reinjection could increase the production and longevity of this geothermal field.

In the other hand, the rich chemical history of wells Az-6, Az-16D and Az-17 shows interesting evolutions. This information together with data coming from another group of younger productors (Az-2,33,37 and 46) show that Argon and Nitrogen in steam, concentration of chlorides and other salts (calcium, cesium, potassium, rubidium, sodium, etc.) in liquid, have been growing since June 1986 (Figs. 5, 6 and 7). This effect has a close relation with the injection of fluids into the reservoir by inducing successive evaporation of the injected water within the production zones. Molar ratio N_2/Ar has been decreasing with time reaching, in some cases, the same value as in the atmosphere (83.6); this is also a consequence of the continuous injection of fluid into wells Az-7 and Az-8. The air mixed with the fluid could flow through the fractures and high conductivity faults finally arriving to the production zones. This effect extends to wells Az-16D, Az-33, Az-37 and Az-46. Wells Az-22, producing vapor and liquid and well Az-6 producing superheated steam, do not show any important trend on their chemical behavior, suggesting the existance of some kind of impervious boundaries around the zones where these wells are located.

FIG. 2.– DETERMINATION OF THE RATE OF AIR INJECTED IN WELL Az-8



Oxygen coming together with Nitrogen into the reservoir is not taken into account beacause it does not appear in any production well; it must be "consumed" by chemical reducing agents present in the reservoir, probably within the neighborhood of the injection wells. The influence of all the other gases forming the air mixture is neglected.

EXTRACTION/REINJECTION MODELING

We have performed numerical simulations in order to investigate some particularly important aspects of this phenomenon. The calculations were performed using MULKOM-TOUGH, a powerful multicomponent simulator, with a water-air equation of state (Pruess, 1988). The simulation consisted in numerical experiments concerning a 3-D simplified porous model representing Tejamaniles, which included production and reinjection of geothermal water and air with heat inflow at the bottom of the reservoir. The idealized physical processes involved anisotropic flow of heat, liquid, vapor and air within a saturated porous media.

The numerical results have been reported in Suárez and Mañón (1990). Some resumed results are as follows: We could partially match the production/injection history of the field as well as the observed behaviour of Nitrogen and fluid enthalpy. We could estimate, by trial and error, average values for the absolute permeability tensor existing between injection and production zones; for the region between well Az-7 and well Az-16D the figures are:

$$K_x = 1 \times 10^{-16}\ m^2;$$
$$K_y = 15 \times 10^{-15}\ m^2;$$
$$K_z = 8 \times 10^{-12}\ m^2$$

These roughly numbers correspond to some preferential dispersion paths followed by Nitrogen during its rapid migration from reinjection to extraction zones. We estimated as well that the air injected in well Az-7 and/or in well Az-8 takes about 50 days to arrive at well Az-16D, corresponding to an average velocity equal to 22 m/day, and about 35 days to arrive at well Az-17, meaning an average velocity equal to 46 m/day. The total amount of air injected into the Tejamaniles reservoir up until December 1990, is about 24,000 tons, for an average rate of 13.2 T/day.

CONCLUSIONS

- Air is a good and cheap natural tracer.

- Reinjection of liquid and air at Los Azufres geothermal field, could be considered as a long term injection test using the Nitrogen of the air as a natural tracer that migrates following non-isotropic paths from injection sectors to production zones.

- When extraction starts simultaneously with reinjection, the Nitrogen of the air mixed to the injected water propagates very fast through the fractures network and arrives to the producing regions with negligible thermal interference.

- No Oxygen effects have been noticed up to date.

Fig. 3.- RATE OF FLUID EXTRACTION AT TEJAMANILES

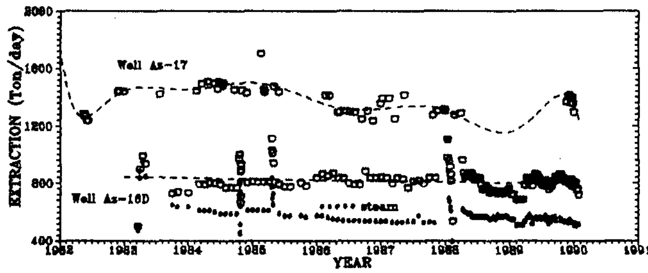


Fig. 4.- RATE OF FLUID INJECTION AT WELL Az-7

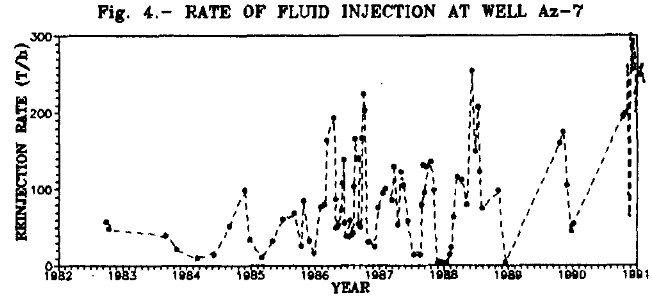


Fig. 5.- NITROGEN EVOLUTION AT WELL Az-16D

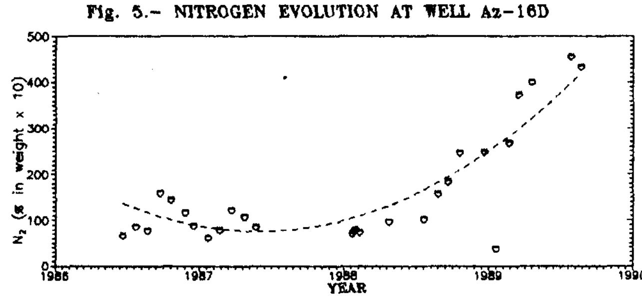


Fig. 6.- NITROGEN EVOLUTION AT WELL Az-17

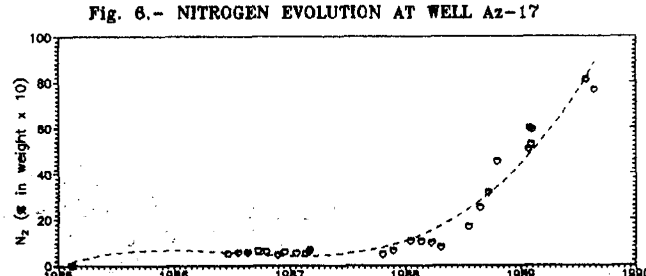
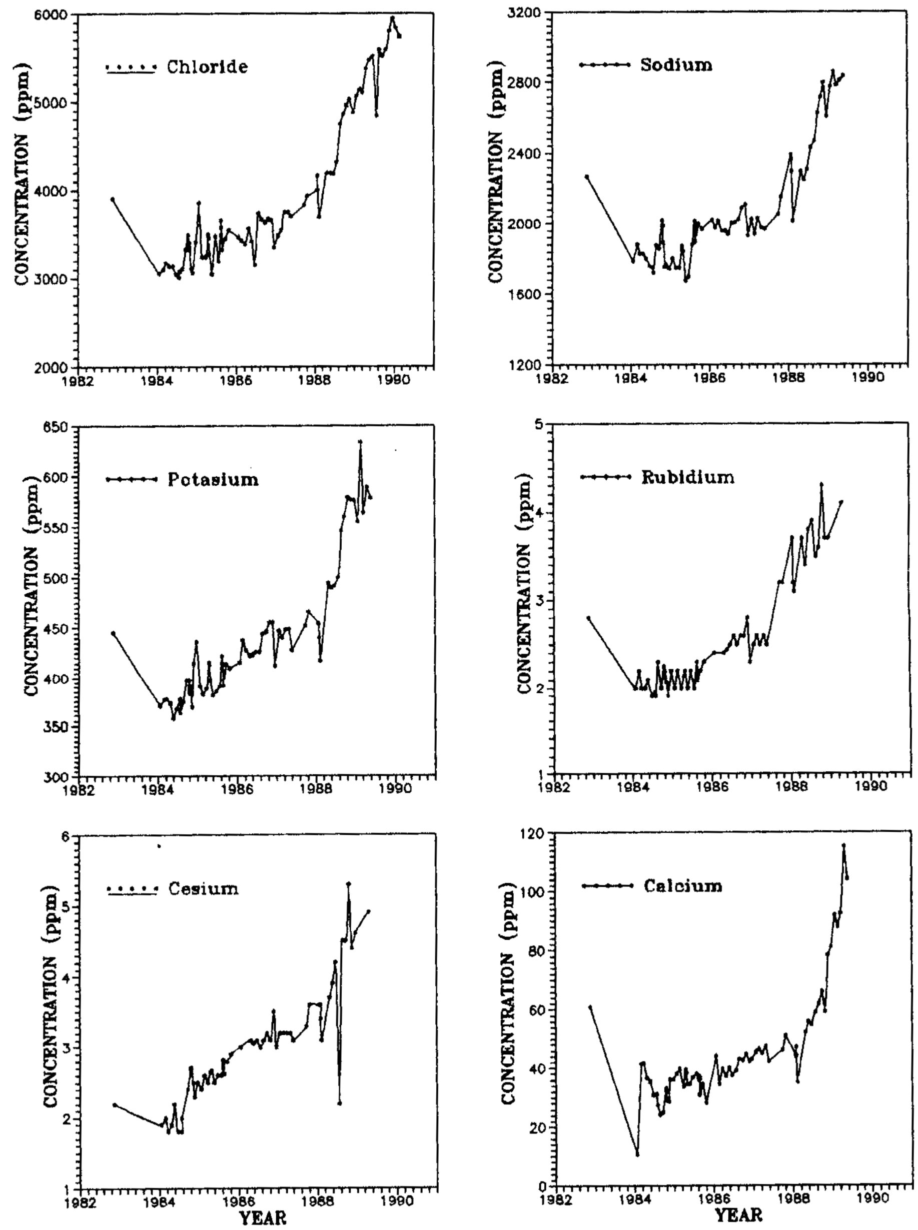


Fig. 7.- EVOLUTION OF SALTS AT WELL Az-16AD



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