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THE LONG TERM OBSERVED EFFECT OF AIR AND WATER INJECTION INTO A FRACTURED HYDROTHERMAL SYSTEM

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ABSTRACT

Injection of atmospheric air mixed with waste reinjection liquid, has been occurring since 1982 at the Los Azufres, México volcanic hydrothermal system. Several chemical and thermodynamical evidences show that air injection into this fractured geothermal field, could be considered as a long term natural tracer test. Nitrogen and Argon separated from the air mixture migrate from reinjection wells to production zones following preferential paths closely related to high permeability conduits. These paths can be detected, looking into the N_2 solubility evolution of production wells.

The anisotropic natûre of the fractured volcanic rock, would demand considerably amounts of artificial tracer in order to be detected at the producing wells, specially when fluid extraction is low. This explains the unsuccessful recovery of the artificial tracer tests performed in past years at Tejamaniles, the southern field's sector. On the other hand, chloride concentrations and other salts, are increasing in the liquid produced by the oldest wells of the sector.

INTRODUCTION

Los Azufres reservoir is a fractured volcanic hydrothermal system, located at the western portion of the Mexican Neo-Volcanic Axis. Descriptions of this field have been previously published: Gutiérrez et al,1982; Dobson,1984; Cathelineau et al, 1985; Suárez et al, 1990. Los Azufres generates 90 MW_e and during the next two years, 53 additional MW_e are going to be installed. For nine years Tejamaniles, the field's southern sector (Fig. 1), has been in continuos increasing exploitation; today, 630 T/h of steam are extracted and 600 T/h of waste liquid are, by gravity, injected back into the formation. This is the only alternative to avoid the environmental impact of liquid waste disposal. Simultaneously with geothermal water reinjection, an important amount of air has been continuously inflowing to the reservoir through the open injection wellheads. There are evidences that this incidental injection of air provokes the separation of Nitrogen and Argon from the original gaseous mixture within the formation, and the migration of both gases from the reinjection zones to the production zones following high permeability preferential paths.

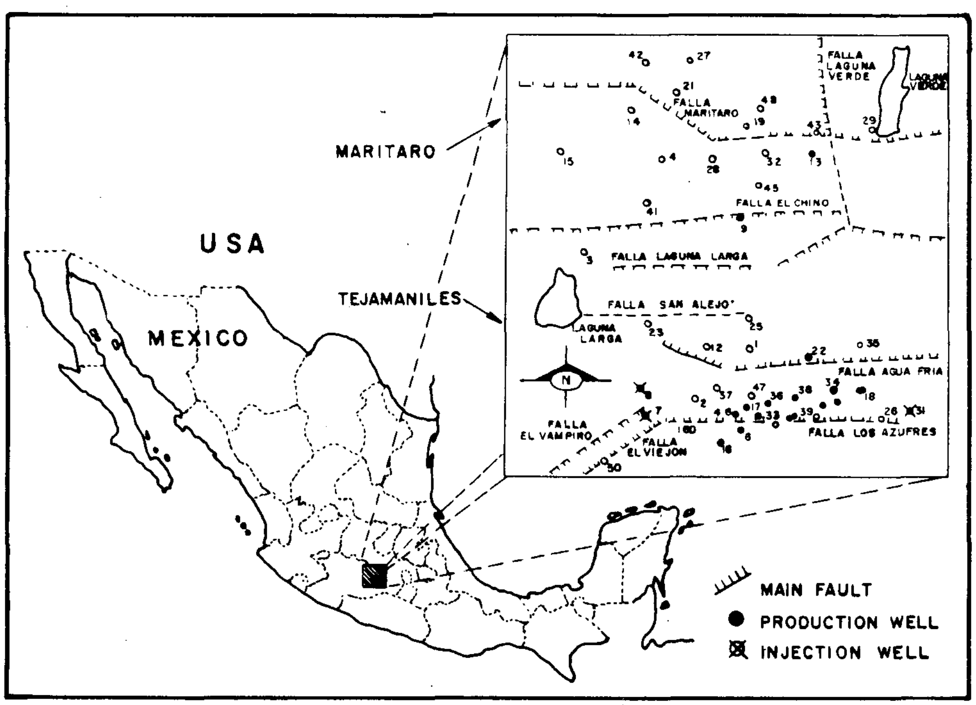


FIG. 1.- LOCATION OF THE LOS AZUFRES GEOTHERMAL FIELD

TABLE 1.- OLDER WELLS AT TEJAMANILES AND THEIR INTERSECTIONS WITH MAIN FAULTS.

WELL	TYPE	z (masl)	Qmax (T/h)	LINER (m/depth)	FAULT	INTERSECTION (m/depth)	INTERSECTION (masl)
Az-6	prod.	2826	- 40	648-861	Los Azufres	900	1926
Az-7	inj.	2759	+325	1665-1706	El Viejón	1700	1059
Az-8	inj.	2808	+300	1991-2299	Tejamaniles	2020	788
Az-16D	prod.	2833	- 40	851-1039	(deviated)	?	?
Az-17	prod.	2820	- 50	561-622	Puentecillas	627	2193

Qmax represents a typical rate of mass extraction for producing wells, and a maximum value of injected liquid accepted by the well.

TRACER STUDIES AT LOS AZUFRES

Between August 1983 and July 1987 six tracer tests were performed at Los Azufres. In 3 of these tests some amount of artificial tracer (Potassium Iodide and Iridium-192) was injected into wells Az-7 and Az-8. Those investigations had very low effectiveness in the understanding of the real phenomena because no return of the tracer was detected at the two closest wells Az-2 and Az-16D; as has been reported by Horne and Puente in 1989. These 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 so important that this gas could be detected at the production region.

THE REINJECTION/PRODUCTION ZONE

The Tejamaniles' reservoir is formed by rhyolites in the upper levels, between 2300 and 2950 masl; below, by fractured andesites. The most important production zone is a two-phase portion located between 1600 and 2300 masl; wells Az-6, Az-16D and Az-17 that we have analyzed, are completed here. At these levels, the effective porosity ranges between 0.10 to 0.15 and the average reservoir permeability is high (≥ 100 → 1000 md; Suárez et al, 1990). A deeper liquid compressed zone has been found between 400 and 1200 masl. Several important faults exist in this sector, intersected by the wells at different depths (López, 1991); some intersections are shown in table 1. Between the Agua Fría and Los Azufres faults (Fig. 1), there is an intensely fractured region known as Puentecillas Fault, that could be a main responsible conduit of fluid through East-West direction.

SOME PRODUCTION AND INJECTION DATA

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 at Tejamaniles (the steam is coming from wells Az-22, Az-33, Az-35, Az-36, Az-37, Az-38 y Az-46; Fig.1). These plants have been in continuous operation with a total mass extraction of about 630 T/h.

The injected liquid mass evolution at each well is difficult to evaluate because the normal operation of the electrical plants requires, very often, to change the amount and direction of the waste liquid from one well to another (the current reinjection wells are Az-3, Az-7, Az-8 and Az-31 for the southern sector). The injection rate at well Az-7 has varied from 20 T/h to 260 T/h and for well Az-8 the same parameter has varied from 15 T/h to 300 T/h. The maximum amount of fluid accepted by each well is about 300 T/h. The temperature of injection varies between 40 to 50 ^{o}C at atmospheric pressure (0.73 bar).

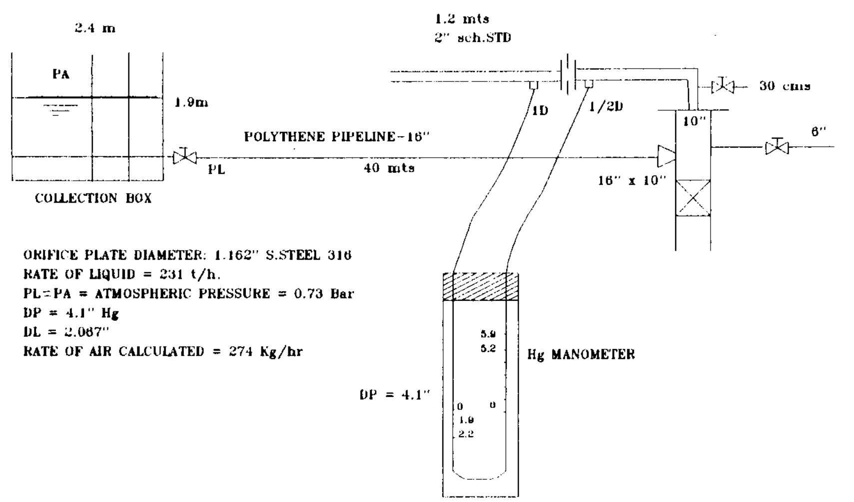
The horizontal distances of the reinjection wells from the nearest production wells ranges from 1000 to 2000 m.; the injection wells being 500 to 1000 m. deeper. The total vectorial distance between production and injection zones is a critical parameter because reinjection too close to the producing zone would sooner or later provoke a drop on the temperature of the produced fluid. Enthalpy data at Tejamaniles, with the only exception of well Az-33, show that the liquid is reinjected at adequate depth and distance from the production zones, (Suárez et al.,1990). Up to this moment, the thermodynamical effect of reinjection has been beneficial for the energy production and longevity of this geothermal field.

THE INJECTION OF AIR AND WATER

The exploitation of Tejamaniles occurs parallel to the injection of "cold" liquid and air. Simultaneously with the extraction/injection of geothermal fluid, an important amount of air has been continuously flowing into the reservoir through the open injection wellheads; some amount of atmospheric air is also'dragged' from the open surface of the collection boxes. Figure 1 shows the areal disposition of the reinjection/production system; figure 2 exhibits the details of the injection system at well Az-8 and the device used to measure the amount of air injected. We have measured at well Az-8: 274 Kg/h of air in 231 T/h of water. Using a similar method, some careful measures have been done at well Az-3: in 120 T/h of liquid, 350 kg/h of air are injected. These values are just two indicative points of an unknown air injection history. For technical reasons it was not possible to perform the same experiment at well Az-7.

Data coming from two-phase wells, show that concentration of chlorides and other salts (calcium, cesium, potassium, rubidium, sodium, etc.) dissolved in the separated liquid, have been growing since June 1986, (Fig. 7). This effect extends to wells Az-16D, Az-33, Az-37 and Az-46 and could have a close relation with the injection of liquid into the reservoir by inducing successive concentration of the same injected water within the production zones.

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



THE AIR INJECTION EFFECT

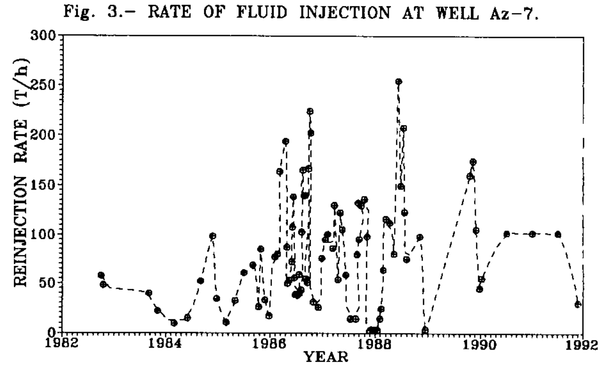
Reinjection of nearly 18 million tons of water since 1982 up until December 1991, has been accomplished mainly through wells Az-7 and Az-8. The injection of liquid has been accompanied by some amount of air. The rich geochemical history of wells Az-6, Az-17 (both, producing superheated steam) and Az-16D (two-phase), shows that Nitrogen in steam, has been increasing remarkably since 1986, but in different amounts at each well. Well Az-6 has the lower trend on its N_2 evolution, while well Az-16D has the highest.

The natural N_2 solubility in the fluid at Los Azufres reservoir represents about 0.2 % in weight. Figures 4, 5 and 6 show the behavior of N_2 and Ar as a function of time; the vertical axis has a different scale for every figure, but the effect is the same: the amount of Nitrogen has been continuously growing since 1986 until the first semester of 1989. After that date, the value is descending until the first semester of 1990 when it grows again, until the beginning of 1991, when N_2 decreases one more time.

This behavior is closely related to the injection evolution and the air inflow to the reservoir. This history is very irregular because of the practical field's operation (Fig. 3). At the same time, molar ratio N_2/Ar has been decreasing with time reaching, in some cases, an atmospheric value equal to 83.6.

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.

Fig. 3.- RATE OF FLUID INJECTION AT WELL Az-7.



INTERPRETATION AND DISCUSSION OF FACTS

With those evidences, the injection of air into this intensely fractured system could be considered as a long term natural tracer test. Nitrogen separated from the air mixture is transported by extraction/injection gradients, to the production zones. At reservoir thermodynamical conditions, N_2 mobility is superior to the mobility of steam; therefore, Nitrogen must arrive first to the extraction zones through higher permeability conduits. It is enough to look into the field's wells with the highest N_2 content, in order to know where are the preferential paths of the reservoir. This is the case for wells Az-16D and Az-17. The first one has been deviated 66° NW at an inclination of 56°; thus it could intersect El Viejón Fault establishing a good communication with the injector Az-7. Well Az-17 intersects Puentecillas System, communicating with both injectors through El Viejón and Puentecillas crossing. Well Az-6, shows a lower N_2 influence thus, average permeability decreases in this section.

Fig. 4.- NITROGEN AND ARGON EVOLUTION AT WELL Az-6

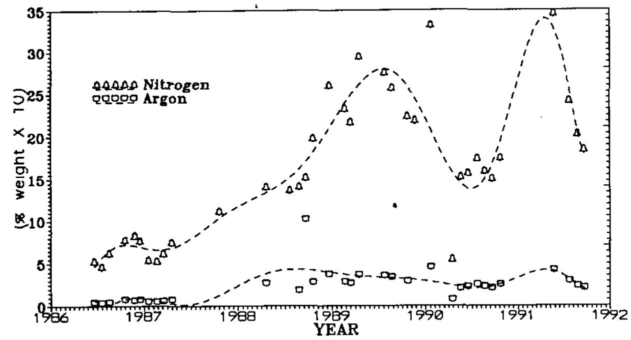


Fig. 5.- NITROGEN AND ARGON EVOLUTION AT WELL Az-17.

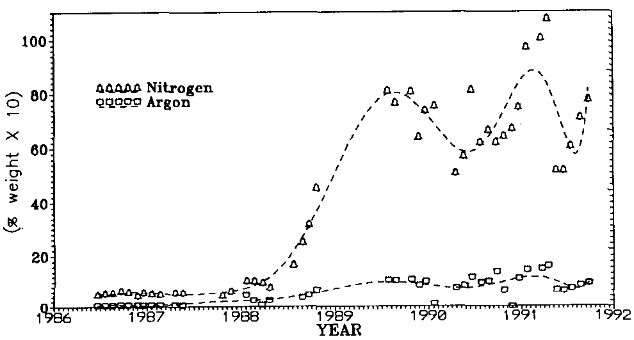


Fig. 6.- NITROGEN AND ARGON EVOLUTION AT WELL Az-16D.

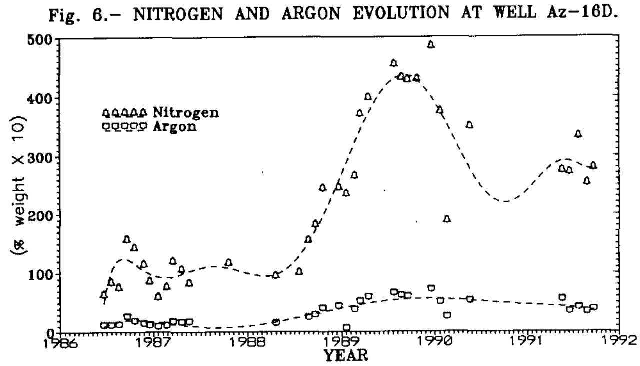
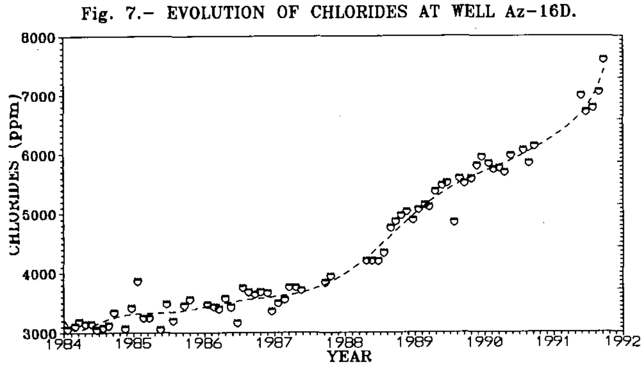


Fig. 7.- EVOLUTION OF CHLORIDES AT WELL Az-16D.



Well Az-37 and Az-46, younger steam productors, present the same trend as well Az-17. For well Az-2, closest to the reinjection section, there is no data. Well Az-33, with some higher N_2 content, behave similar to well Az-6; its distance to the injection area (1500 m.) seems to be a limit for Nitrogen transport and detection: no N_2 effects are noticed in any other well located after this sector.

The undesirable aspects of reinjection such as serious interference of the lower enthalpy 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.

CONCLUSIONS

- 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.

- Air mixed with the liquid, breaks up into its primary components; Nitrogen propagates very fast through the fractures and faults network finally arriving to the production zones by means of a hydrodynamic dispersion mechanism with negligible thermal interference.

- It suffices a very simple analysis of Nitrogen production data, in order to detect preferential fluid paths into the reservoir.

- The use of numerical multicomponent reservoir simulators, together with the preceding analysis, could permit realistical estimation of the permeability tensor acting in the zone.

- Air is a good and cheap natural tracer.

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