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ACIDIC FLUID IN LOS HUMEROS GEOTHERMAL RESERVOIR: A PRELIMINARY OUTLOOK

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ABSTRACT

The Los Humeros geothermal system has been considered as being consisted of two reservoirs, although there is no separation layer (lithological unit) between them to differentiate. The shallow reservoir contains vapor and liquid whereas the deeper one has only superheated steam and high temperature (>300°C). The production of HCI vapor in the deeper reservoir is a result of water-rock interaction at high temperature and low amount of water. The high corrosiveness and scaling in the wells due to these deeper fluids has limited the exploitation of only the upper reservoir. The present work compiles the geological and geochemical literature with emphasis on present status of knowledge of the hydrothermal model and physiochemical processes in the reservoir.

It has been observed that the production fluid characteristics change with changing well opening. This leads to the conclusion that the well construction parameters have important contribution in controlling the production fluid characteristics. Similarly, the determination of pH of geothermal reservoir fluid is necessary, but it is sufficient to characterize the type, quantity and the origin of acidity. It is fundamental to measure alkalinity and reconstruct the reservoir fluid physiochemical parameters.

INTRODUCTION

The Occurrence of acidic fluid has been found in many geothermal reservoirs and their corrosiveness to geothermal plants demands a constant efforts to understand the origin and causes of the existence of acidic fluid in the geothermal reservoirs (Barragán et al, 1989, Truesdell, 1991, D'Amore et al, 1990, Salonga et al, 1997). It is mostly accepted that the geothermal fluids are the result of hot rock and deep infiltrated meteoric water interaction in the superior part of earth crust. Thus the chemical composition of geothermal fluid could be originated from leaching of rocks by hot water (Ellis and Mahon, 1964) and/or from neutralization of volcanic fluids (Giggenbach, 1981). The physical processes such as boiling and mixing also alter the chemical composition of geothermal fluids. Truesdell (1992) mentioned that the acidic waters, came to the surface through springs or drilled well, originated from the acidic reservoir in some fields; whereas in others, the boiling of high-temperature neutral or acidic brines or reactions in vapor-halite-silicate assembles generates HCI gas that is carried in superheated steam and becomes corrosive when the steam condenses, usually at the wellhead. Ascending superheated steam containing HCI may also mix with overlying neutral waters to produce acid solutions that rapidly corrode and scale well casings, possible without appearing at the surface.

D'Amore et al (1990) presented a thermodynamic calculation for reaction involving halite and silicate1 (+calcite). They come to conclusion that the HCI gas in vapor phase could be produced in hypersaline brine.

To understand the phenomenon of origin of acidic fluid the experimental study has been of vital importance. Bischoff and Pitzer (1989) presented the P-V-x characteristic for $NaCl-H_2O$ in the range of temperature 300 to 500°C with emphasis on the theoretical modeling and to understanding of two-phase behavior in saline geothermal systems, Fournier and Thomson (1993) presented the composition of steam in the system $NaCl-KCl-H_2O$-quartz up to 600°C. Recently, Bischoff et al (1996) indicated the generation of HCI in the $CaCl_2-H_2O$ in the temperature range 380-500°C and the pressure range **230-580** bar. These conditions are feasible in a geothermal reservoir.

In geothermal systems the fluid samples are generally collected from natural manifestations such as spring and fumarol and/or separated water and condensed vapor at the well separator. Sometimes sampling are also done at the bottom of a well. In case of Los Humeros we observed that the fluid boils during the ascending of the sampler towards surface. Thus this boiling correction should apply in calculating the deep reservoir concentrations, even for the samples collected at the bottom of a well.

To understand the deep reservoir fluid characteristics it is necessary first to calculate the deep reservoir physiochemical parameters in the reservoir. Similarly it also requires to define the parameters which characterize and quantify the acidity in a geothermal reservoir. The present work summarizes the experiences obtained during the exploration and exploitation of Los Humeros geothermal system. And a planning for future work to obtain thorough knowledge the problem of origin and causes of acidic fluid in Los Humeros geothermal reservoir.

THE ROS GEOTHERMAL SYSTEM

The Los Humeros geothermal field is situated in the eastern part of the Mexican volcanic belt, at an average altitude of **2800** masl and about **200** km east of Mexico City. Figure **1** shows the location map of the Los Humeros geothermal system. Exploration activities covering an extension of about **80** km^2 began in **1968** with using surface geology, geochemistry and geophysics. The first production well was drilled in **1980** and in **1990** the first over-wellhead power plant was constructed. At present there are 7 power plants each of ***5*** MWe generation capacity. Tello **(1994)** presents a relation of wells integrated to the power plants. The CFE is planning in near future the expansion of the field with installing two more units each of **20** MWe.

Geological **Settings**

The extensive geological study of Los Humeros has been described by many workers (Yañez, **1982;** Lira, **1982;** De la Cruz, **1983;** Gardufio, **1984** and Ferriz and Mahood, **1984).** Gonzalez et **al (1993)** presented the lithology of each well and Suarez and Puentes **(1993)** compiled the lithology of each well in tabular form. Verma et **al (1990)** presented some physical and chemical parameters of the Los Humeros volcanic center which were used to calculate the temperature profiles in the reservoir.

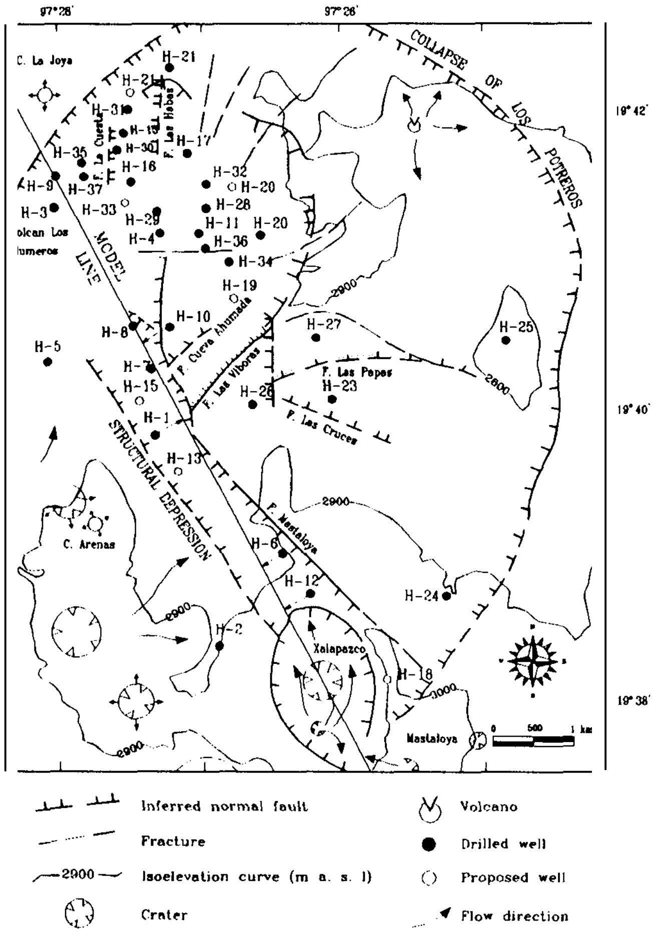

Fig. 1. ***The** Location **map** of **the** Los **Humeros geothermalfield.***

The reservoir consists of complex geological units of calcite, ignimbrite, andesite and some dacite and rhyolite. **A** simplified vertical cross-section could be considered as consisted of four principal units. The first unit is of thickness of 500 to **600** m from the surface and formed of spills of recent basalt and andesite which are covered with pyroclastic deposits. This unit is permeable and contains rocks with high water-storage capacity. The second unit lies in between **600** to **1000-1200** m depth. It is formed of ignimbrite and is highly fractured within the caldera, but it is sealed with the hydrothermal deposition and acts as the caprocks for the geothermal reservoir. The unit III **(150C** m thickness) is form of andesite and contains the geothermal reservoir. Below **2500** m there is unit IV. It is the basement formed of sedimentary rocks.

Hydrology of the region

The first preliminary study of regional hydrology of the region is presented by Cedillo (1988). He divided the region in catchment blocks and calculated infiltration and runoff with the precipitation data for each block. **Moro** (1994) compiled the hydrological studies in the region. The **N-E** of the region has high precipitation (2000 mm), whereas the precipitation is 492 mm within the caldera. This is an effect of the topography of the region.

Verma et al (1997) conducted an study to measure isotopic composition of rainwaters in seven stations in the region. There is a wide spread in the isotopic values. It was concluded that it requires a long term rainwater isotopic data to assess the average isotopic composition of the precipitation in the region. The local meteoric water line with using the preliminary data is $\delta D = 8.64\ \delta^{18}O + 14.05$.

Geochemical studies

The Los Humeros geothermal reservoir has very different characteristics than that of Los Azufres, although both of them are in the same volcanic province (Mexican Volcanic Belt). The Los Azufres geothermal reservoir has been well characterized. Nieva et **al** (1986) proposed a one-dimensional vertical layer structured model of Los Azufres reservoir. The layers contain fluids in the order superheated steam, two-phase vapor dominated, two-phase liquid dominated and the lower one has hot compressed liquid; whereas in case of Los Hiimeros reservoir characteristics are quite different. Some workers have identified two reservoirs (Tello, 1989, 1992, Barragan et al, 1991, Truesdell, 1991 and Portugal et al 1994). The shallow reservoir has two-phase fluids, whereas the deep reservoir has superheated steam. Barragan et al (1989) mentioned that the generation of HCI vapor in the deeper reservoir was due to high temperature (300-350°C), high salinity (3000-7000 ppm) and low pH. The exploitation of this reservoir had produced the transport of HCI in some wells which could had corroded and produced scaling in the wells. An extensive petrographic studies of well H-16 showed that the principal minerals deposited in the well were anhydrite ($CaSO_4$) and silica (amorphous and quartz).

Barragan et al (1991) carried out a geochemical study to investigate reservoir processes which are responsible to the observed fluid chemical composition. The well H-1, H-6, H-7, H-8 and H-12 produce two-phase fluid. These well are located in the "Corredor de Mastaloya". The well H-1 produces only from the upper reservoir and has no excess steam. Whereas the wells H-10, H-11, H-15, H-16 and H-23 produce only vapor phase and are located in the Central Collapse. There exist two types of reservoirs: the upper one is liquid dominated and the deeper one **as** vapor dominated. Tello (1989, 1994) presented the chemical and isotopic behavior of geothermal fluids. The chemical characteristics of the fluids showed that the brine produced by the wells is a low-saline water, whose geochemical character varied according to well type and production zone. The shallow wells produced sodium-bicarbonate **type** water, whereas the deeper wells exhibited a sodium-chloride **type.** He also confirmed that the well H-1 was in liquid dominated zone, while the other wells were in two-phase zone.

Tello (1994) argued the existence of only one geothermal reservoir as there is no impermeable rock layer to separate the reservoirs. The origin of acidic fluid in the lower part of the reservoir could be explained as a consequence of the low permeable basement rocks (sedimentary rocks of geological unit IV) and high temperature. This limits the infiltration of water and creates to produce HCl vapor as observed in laboratory (Bischoff et al, 1995). This explains the difference between the Los Azufres and Los Humeros reservoirs, although both of them are in same geological province.

Truesdell (1992) explained the occurrence of acid fluid in geothermal reservoirs as it could be either the introduction of volcanic fluids or from the volatilization and transport of HCI in superheated steam. Acid from volatilization of HCI is expected to appear in boiling high-temperature reservoirs as they lose reservoir liquid and start producing superheated steam. The occurrence of Superheated, high HCl steam at Los Humeros is unusual because the steam is produced by **flow** from a deep dry reservoir to a shallow water-saturated reservoir with strong corrosion and scaling resulting from fluid mixing and reaction with casing and rock.

Tovar (1996) and Tello (1994) reported the change in the separated water characteristics with changing the wellhead opening. They attributed it to the change in the well production zone with changing wellhead orifice. Verma (1997a) developed a two-phase flow method to calculate the deep reservoir parameters including the effect of well parameters such as diameter, depth, and opening of wellhead orifice. The method will be applied in deep reservoir parameter calculations in the future work.

Tovar (1996) plotted the averaged chemical compositions of geothermal fluid from most of the wells in a triangular diagram in Na, K and Mg. The diagram was suggested by Giggenbach (1988) to determine the state of geothermal fluid in the reservoir. The **fluids** are in the regions of shallow and partially equilibrated waters.

Isotope geochemistry

Verma et al **(1997)** conducted a monitoring the chemical and isotopic composition of rainwater at Los Humeros and its surroundings. The objective of this study **was** to determine the rainwater quality in the region. **A** side product of that study was the local meteoric water line. The isotopic **data** had a wide spread in the isotopic **data.** The effect of altitude, precipitated volume, temperature are very prominence. However, the **data** have very good linear correlation between FD and $\delta^{18}O$ values and equation of this line (local meteoric water line) is $\delta D = 8.64\ \delta^{18}O + 14.05$. The precipitation volume weighted average isotopic composition of rainwater is -10.90 and -82.4 for $\delta^{18}O$ and FD, respectively.

The isotopic compositions ($\delta^{18}O$ and δD) surface manifestations (spring and hydrological well) are taken from Tello (1992). Figure 2 shows all the isotopic composition of all types of water in the region including **local** and world meteoric water lines. An analysis of lab calibration of mass spectrometer showed that the $\delta^{18}O$ values for the spring samples were sufficiently precise, but the δD values could have a shift of about 3 ‰ due the data were not corrected for the **(V-SMOW** and SLAP) scaling factor. Thus the values could be 3 ‰ higher in δD than the actual values. It **looks** most justified as the δD lowered by 3 ‰, the spring data will fall on the local meteoric water line. This will be confirmed, once the samples of 1995 were analyzed.

The tritium values were analyzed by the **IAEA,** Vienna for the samples of 1987 (Tello, 1992) and the samples of 1995. The data shows a quite interesting behavior. There is no appreciable change in tritium values for the samples which had low values of tritium (>4 TU) in 1987. But the samples which had higher tritium values showed a decrease in tritium values. This could be associated with the different sampling periods and/or a decay in the natural tritium value in the region. There are some chemical evidence of changing in the chemical composition of some springs with the **period** of sampling. The data will be analyzed with considering both the effects.

The tritium values for all the geothermal wells as well as one deep hydrological well within the caldera of Los Humeros are near to zero. This indicates that the deep hydrological aquifers and geothermal reservoir both have relative old meteoric waters.

The averaged isotopic composition of geothermal wells (production and reinjection wells) are also plotted in the Figure 2. The deep reservoir

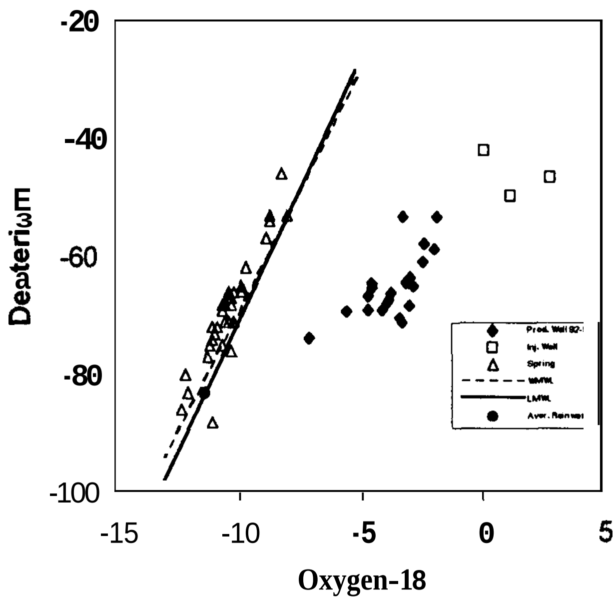

Fig. 2. Isotopic composition of the fluid from geothermal wells, natural manifestation and weighted averaged rainwater in the Los Humeros geothermal field.

composition are calculated with conservation enthalpy approach. The wellhead enthalpy depends on the wellhead opening. Thus it would be more accurate to calculate the deep reservoir composition with the two-phase flow approach presented by Verma (1997a).

There is a wide spread in the total discharge composition of production wells. It could be associated with the mixing of type of deep geothermal reservoir fluids. Although the rainwater data are only for one year, the variation with altitude, precipitated volume, and annual temperature are quite consistent as observed in the isotopic **data** of WMO-IAEA data for the world wide sampling stations.

The isotopic data of a hydrological well within the caldera are -11.89 and -85.0 for $\delta^{18}O$ and δD, respectively. These slightly lighter than the averaged rainwater **data.** The isotopic data of geothermal wells heavier in both oxygen and deuterium. This could be an effect of evaporation.

RESERVOIR HYDROTHERMAL MODEL OF LOS HUMEROS

With the geological, hydrogeological and geochemical evidences it is possible to construct a very simple hydrothermal model of the Los Humeros geothermal reservoir. The Los Humeros caldera is located on the boundary of two regional aquifers. Thus it is difficult to explain the association of regional hydrology to the formation of the hydrothermal system. Apart form it the preliminary hydrological studies indicates that the impermeable nature of the caldera wells limited the hydrological connection of the caldera with rest of the region. In other words the part of the precipitation within the caldera infiltrates and slowly reaches to the reservoir. The geothermal rcservoir is formed in andesitic rocks and lower part of the reservoir has sedimentary rocks (calcite). The sedimentary basement rocks has low permeability, whereas the heat source is still very hot and nearby to the reservoir. This produces superheated steam and HCI vapor (Bischoff et al, 1996). If so, the reinjection in the deeper reservoir could help in neutralization of this HCI acidity.

CONCLUSIONS AND FUTURE WORKS

The Los Humeros has a unique featured two reservoirs. The deeper reservoir has HCI vapor which condenses within the wells and produces high corrosion and scaling on the well pipe. The fluid chemistry is bit complicated as very less amount water reaches on the wellhead. And the fluid characteristics depend on opening or in other words well contraction parameters.

The local meteoric water line is $\delta D = 8.64\ \delta^{18}O + 14.0$. All the spring and shallow groundwaters lie around the meteoric water line. The shallow ground aquifer has almost zero tritium. On the other hand some springs have high tritium and others have low. The tritium concentration in the spring which had high values in 1987 has decrease significantly in 1995. This could be seasonal and/or a decay in the concentration of tritium with time. The flow measurement data with time will be very helpful in understanding the tritium behavior the springs.

The shallow groundwater aquifers donot have tritium concentration. It is a direct indication that it take much time to reach the rainwater to the aquifers. Some spring also donot have much tritium concentration. This could be interpreted as they are fed from the regional flow water.

It has been accepted by many workers that the deeper reservoir has HCI vapor, but the scaling of well H-16 had anhydrite ($CaSO_4$) and silica. This demands a deep knowledge of the chemistry associated with deposition of anhydrite and silica.

In case of rainwater it was argued that the measurement of pH is necessary, but it is not sufficient to characterize and quantify the acidity in rainwater samples (Verma, 1997b). The determination of alkalinity is fundamental in rainwater characterization. Same could be true in case of acidic geothermal fluids. Thus in the future work the importance of the determination of alkalinity and reconstruction of reservoir fluid physiochemical parameters will be emphasized.

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