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# INITIAL CHEMICAL AND RESERVOIR CONDITIONS AT LOS AZUFRES WELLHEAD POWER PLANT STARTUP

P. Kruger and L. Semprini
Civil Engineering Department
Stanford University
Stanford, CA 94305

S. Verma and R. Barragdn
Instituto de Investigaciones Electricas
Cuernavaca, Mor., Mexico

R. Molinar, A. Aragón, J. Ortiz, C. Miranda,
A. Garfias and M. Gallardo
Comision Federal de Electricidad
Morelia, Mich., Mexico

## INTRODUCTION

One of the major concerns of electric utilities in installing geothermal power plants is not only the longevity of the steam supply, but also the potential for changes in thermodynamic properties of the resource that might reduce the conversion efficiency of the design plant equipment. Production was initiated at Los Azufres geothermal field with wellhead generators not only to obtain electric energy at a relatively early date, but also to acquire needed information about the resource so that plans for large central power plants could be finalized. Commerical electric energy production started at Los Azufres during the summer of 1982 with five 5-MWe wellhead turbine-generator units. The wells associated with these units had undergone extensive testing and have since been essentially in constant production.

The Los Azufres geothermal reservoir is a complex structural and thermodynamic system, intersected by at least 4 major parallel faults and producing geothermal fluids from almost all water to all steam. The five wellhead generators are associated with wells of about 30%, 60%, and 100% steam fraction. A study to compile existing data on the chemical and reservoir conditions during the first two years of operation has been completed. Data have been compiled on mean values of wellhead and separator pressures, steam and liquid flovrates, steam fraction, enthalpy, and pertinent chemical components.

The compilation serves both as a database of conditions during the start-up period and as an initial point to observe changes with continued and increased production. Current plans are to add additional wellhead generators in about two years followed by central power plants when the data have been sufficiently evaluated for optimum plant design. During the next two years, the data acquired at the five 5-MWe wellhead generator units can be compared to this database to observe any significant changes in reservoir behavior at constant production.

### The Los Azufres Geothermal Field

The Los Azufres geothermal field, located in the State of Michoacan about 200 km northeast of Mexico City, is in the Transmexico Neovolcanic Axis across central Mexico described by Mooser (1972). It covers an area of about 30 $km^2$ with many geothermal surface manifestations.

The first studies of the field as a geothermal resource were reported by de Anda (1951). Several geologic, geophysical, and geochemical studies were initiated in 1975. The first geological maps were produced by Camacho (1976). From 1977 to 1980 more detailed maps of the geothermal feservoir were prepared by Garfias, Casarrubias, and Rivera at CFE. Recent descriptions of the structural and volcanologic features were given by de la Cruz (1982) and Dobson (1984). A review of the mineralogy of the field has been reported by Cathelineau et al. (1983). The reservoir has been described as consisting of andesitic lavas as basement rock overlain by various rhyolitic and dacite units. It appears to be structured by a number of principal faults in an east-west orientation with a large angle of inclination and spacing of about 100 m with zones of influence ranging between 5 and 40 m.

### Preproduction Testing

Drilling investigations were initiated in 1976 over an area of about 25 $km^2$. During the 6 years prior to the startup of the 5 wellhead generators, an extensive program of chemical and production testing was carried out to characterize the resourbe. Based on observed differences among the production wells in both chemical composition and steam fraction, the field has been divided into two production modules, North and South, with wells having widely differing properties. By the beginning of 1979, the results of well tests already indicated an excellent geothermal prospect. Further well testing studies were carried out prior to the installation of the wellhead generators. An analysis and summary of the well testing studies in the South Module was given by Jaimes (1984).

Early geochemical characteristics of the field were described by Templos and Molina (1978). Recent descriptions of the brine chemistry and noncondensable gases have been given by Templos and Lopez (1980) and Templos and Laredo (1980). Los Azufres geothermal fluid is characterized as a sulphate type. Chloride measurements, made since the drilling of the first wells, have served as a useful natural chemical tracer. Significant correlation was noted between high chloride concentration and high resetvoir temperature in both the North and South Modules. High silica concentrations were also noted to be in accord with high temperatures recorded by well logs. Boron measurements have been observed to follow a similar distribution in the reservoir, small boron concentrations at the borders of the field, increasing in value towards the high-temperature zones.

A review of the distribution of chemical and isotopic composition of Los Azufres geothermal fluids prior to startup was reported by Nieva et al. (1983). Their data show a considerable degree of heterogeneity of the liquid phase in the reservoir. The chemical data show phase separation at the wells, without evidences of recharge by surrounding groundwaters. By several chemical geothermometers, the temperature range in the North Module has been estimated to vary between 248°C and 315°C, whereas in the South Module, the temperature was estimated to vary between 248° and 328°C.

In 1982, 5 wells were chosen to supply the initial set of wellhead generators. The completion and production characteristics of these wells are summarized in Table 1 Wells Az-6 and Az-17 with 100% steam fraction are in the South Module; the other three wells are in the North Module.

## INITIAL-PERIOD DATA

The production of electric power began in the summer of 1982 with the installation of the five 5-MWe wellhead units. A review of the first year's experience with the five generator units was given by Hiriart (1983). Initial evaluation of the steam zone in the southern part of the field indicated sufficient steam supply for at least a 50 MWe central power plant. In keeping with the objectives of recording the initial conditions of the Los Azufres field during the first two-year startup period as a basis for estimating changes under continued and increased future production, available production and chemical data for each of the five generator wells has been compiled and grouped into five time periods, the first part of 1982 prior to generator startup, and the first four six-month periods of production. For each of these periods, six-month averaged values have been calculated for the pressure, flowrate, and enthalpy production values, and for the aqueous chemistry, noncondensable gases, and in-situ tracer radon data collected under various sampling programs. From these data, mean values of the bottom-hole and reservoir initial condition$ for pressure, temperature, and enthalpy have been estimated for the original five generator wells, before additional wells were added to maintain steam production rates.

### Production Data

Table 2 shows the production characteristic# for the five generator wells. Period 1-82 is the pre-generator testing period data prior to startup. The two all-steam wells in the South Module (Az-6 and Az-17) have operated with essentially constant flowrate and enthalpy over the four 6-month periods. The three wells in the North Module showed varying characteristics. Wells *Az-5* and Az-13 have performed steadily at steam fractions of about 60%, but with a steeper decline in wellhead enthalpy at Az-13 compared to *Az-5*. Well Az-19 has not performed sufficiently well; the flowrate and enthalpy declined to insufficient levels to operate the turbine efficiently and the well was shut in January, 1984.

### Chemical Data

The chemical data for the startup period has been divided into three groups: aqueoua chemistry data, subgrouped into pH, conductance, boron, sulphate, arsenic, and chloride as key constituents fbr fluid chardacterization and sodium, potassium, calcium and silica for geothermometry estimates of reservoir temperature; (2) nonoondensable gas data of total gas content and key constituents $CO_2$ and $H_2S$ for gas-phase evaluation; and (3) radon data for application of the chemically-inert noble gas as an in-situ tracer of reservoir thermodynamic conditions.

#### A Aqueous Chemistry Data

Table 3 shows the 6-month averaged values of the chemical data for the selected constituents in the separated brine from the three wells in the North Module producing two-phase fluids. Chemical analysis for these constituents in brine separated at atmospheric pressure are performed routinely at the Los Azufres field laboratory and for specific investigations by the staffs at CFE and IIE. The data indicate that the chemical composition of the brine from the two-phase wells since startup of the generators has not changed appreciably from the chemical composition during the prior six-month period. Over the two-year production period, the composition of separated brine from wells *Az-5* and Az-13 show little variation, for example the standard deviation of the chloride concentration at well Az-13 is about

Table 1

WELLHEAD GENERATOR WELLS AT LOS AZUFRES

| Well No. | Production Interval (m,asl) | Initial Total Depth (m) | Steam Production (t/h) | Steam Fraction (%) |
|---|---|---|---|---|
| Az-5 | 1407-1829 | 1493 | 65 | 0.59 |
| Az-6 | 1918-2170 | 900 | 48 | 1.00 |
| Az-13 | 1710-1908 | 1219 | 62 | 0.53 |
| Az-17 | 2187-2253 | 627 | 100 | 1.00 |
| AZ-19 | 1173-1848 | 1666 | 29 | 0.43 |

Table 2

INITIAL-PERIOD SIX-MONTHLY AVERAGED PRODUCTION DATA

| Module | Well No. | Period | $P_{wh}$ ($kg/cm^2$) | $P_{sep}$ ($kg/cm^2$) | $Q_s$ (t/h) | $X_s$ (%) | $H_{wh}$ (kJ/kg) |
|---|---|---|---|---|---|---|---|
| South | Az-6 | 1-82 | 37.88 | -- | 13.5 | 1.0 | 2886.1 |
| | | 2-82 | 8.56 | -- | 44.5 | 1.0 | 2828.4 |
| | | 1-83 | 8.19 | -- | 42.0 | 1.0 | 2828.2 |
| | | 2-83 | 8.38 | -- | 42.0 | 1.0 | 2824.9 |
| | | 1-84 | 8.23 | -- | 42.0 | 1.0 | 2814.2 |
| | At-17 | 1-82 | 42.45 | | 38.0 | 1.0 | 2665.0 |
| | | 2-82 | 22.04 | 9.0 | 62.6 | 1.0 | 2769.3 |
| | | 1-83 | 20.60 | 9.2 | 62.0 | 1.0 | 2800.0 |
| | | 2-83 | 20.21 | 9.5 | 62.0 | 1.0 | 2799.0 |
| | | 1-84 | 19.14 | 9.8 | 60.1 | 1.0 | 2772.5 |
| North | Az-5 | 1-82 | 22.95 | -- | 34.0 | 0.44 | 1825.9 |
| | | 2-82 | 31.65 | 9.2 | 60.0 | 0.63 | 2023.4 |
| | | 1-83 | 28.21 | 9.2 | 59.2 | 0.62 | 2052.6 |
| | | 2-83 | 27.36 | 9.6 | 57.8 | 0.60 | 2023.0 |
| | | 1-84 | 27.75 | 9.8 | 58.9 | 0.62 | 2010.8 |
| | Ar-13 | 1-82 | 33.38 | -- | 26.5 | 0.59 | 1746.8 |
| | | 2-82 | 10.93 | 8.7 | 60.0 | 0.60 | 1954.0 |
| | | 1-83 | 8.97 | 8.7 | 61.0 | 0.60 | 1824.5 |
| | | 2-83 | 10.28 | 8.7 | 59.2 | 0.59 | 1809.4 |
| | | 1-84 | 9.32 | 8.5 | 60.9 | 0.57 | 1690.7 |
| | Az-19 | 1-82 | 34.25 | -- | 16.5 | 0.38 | 1223.4 |
| | | 2-82 | 8.51 | 8.5 | 27.0 | 0.44 | 1625.8 |
| | | 1-83 | 9.08 | 8.9 | 18.0 | 0.32 | 1409.9 |
| | | 2-83 | 7.75 | 7.6 | 16.0 | 0.28 | 1321.3 |
| | | 1-84 | | | * | | |

*well Az-19 vas shut-in January, 1984 due to insufficient production.

Table 3

AQUEOUS CHEMISTRY DATA

| Well No. | Period | pH | Cond. (mmho/cm) | Key Constituents (mg/kg) [B] | [$SO_4$] | [As] | [Cl] | Geothermometers (mg/kg) [Na] | [K] | [Ca] | [$SiO_2$] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Az-5 | 1-82 | 7.3 | 10.2 | 326 | 29.0 | 26.7 | 3590 | 1948 | 558 | 7.4 | 1215 |
| | 2-82 | 7.2 | 8.7 | 230 | 16.6 | 25.3 | 2920 | 1675 | 399 | 8.8 | 1060 |
| | 1-83 | 7.0 | 9.7 | 245 | 19.3 | 25.6 | 3070 | 1656 | 430 | 9.1 | 1070 |
| | 2-83 | 7.1 | 9.6 | 260 | 21.5 | 26.8 | 3150 | 1741 | 429 | 3.6 | 1108 |
| | 1-84 | 7.1 | 9.3 | 243 | 21.8 | 23.7 | 3030 | 1680 | 451 | 10.0 | 1156 |
| Az-13 | 1-82 | 7.6 | 8.9 | 268 | 42.6 | 25.9 | 2850 | 1586 | 365 | 8.5 | 886 |
| | 2-82 | 7.6 | 9.3 | 311 | 26.1 | 28.8 | 3000 | 1765 | 406 | 13.4 | 747 |
| | 1-83 | 7.7 | 8.7 | 270 | 26.2 | 25.8 | 2770 | 1507 | 355 | 12.0 | 865 |
| | 2-83 | 7.8 | 9.2 | 283 | 28.5 | 28.5 | 2940 | 1661 | 366 | 9.3 | 645 |
| | 1-84 | 7.7 | 8.9 | 256 | 28.0 | 23.8 | 2840 | 1572 | 394 | 12.8 | 918 |
| Az-19 | 1-82 | 7.2 | 9.1 | 229 | 27.5 | 22.3 | 3150 | 1724 | 479 | 5.8 | 1219 |
| | 2-82 | 7.4 | 8.9 | 235 | 29.1 | 23.4 | 2880 | 1633 | 387 | 7.4 | 1034 |
| | 1-83 | 7.4 | 8.3 | 211 | 26.5 | 20.4 | 2610 | 1445 | 343 | 8.1 | 910 |
| | 2-83 | 7 5 | 8.9 | 225 | 28.5 | 21.8 | 2800 | 1580 | 357 | 5.3 | 961 |
| | 1-84 | 7.2 | 9.0 | 229 | 25.3 | 20.7 | 2710 | 1537 | 412 | 8.1 | 1058 |

Table 4

NONCONDENSABLE GAS DATA

| Well | $P_{wh}$ (psi) | $P_{sep}$ (psia) | Q (t/h) | H (kJ/kg) | [NCG] (%) | [$CO_2$] (g/kg) | [$H_2S$] (mg/kg) |
|---|---|---|---|---|---|---|---|
| Az-5 | 360 | 140 | 97.0 | 2167 | 1.59 | 14.8 | 288 |
| Az-6 | 120 | 130 | 46.5 | 2761 | 7.10 | 67.2 | 311 |
| Az-13 | 118 | 115 | -- | 1770 | 0.60 | 5.5 | 193 |
| Az-17 | 280 | 130 | 89.7 | 2854 | 5.22 | 49.1 | 448 |
| Az-19 | 335 | 60 | 66.2 | 1541 | 0.17 | 1.5 | 118 |

5 percent. The standard deviation of the minor key constituents, e.g., calcium, is of the order of 30 percent. Some of the variability may be due to sample collection problems in the field. The composition of separated brine from well Az-19 shows a marked decrease in major constituents, indicating a dilution process caused by infiltration of colder water with lover total dissolved solids concentration.

B. Noncondensable Gas Data

Table 4 lists the available data for the sparse number of samples obtained for noncondensable gas analysis. The total gas composition is about 95 percent carbon dioxide and hydrogen sulphide. The data show a large variability in $CO_2$ concentration between the two modules, the all-vapor fluid from the South Module having a value of about 6fl percent, while the two-phase fluid from the North Module is about 0.73±0.68 percent. These data should be sufficiently precise to observe whether the noncondensable gas concentrations measured during the second two-year period show a significant change with sustained production at 25 MWe.

C. Radon Data

Radon measurements have been made at Los Azufres since early production testing from 1979 under a variety of collection conditions. The use of natural radon as an internal tracer in relation to reservoir thermodynamic conditions was described by Semprini and Kruger (1984). Following the availability of steam separators at the five generator wells, several samplings for radon measurement were taken by the Stanford Geothermal Program and the Instituto de Investigaciones Electricas under a NSF-Conacyt, U.S.-Mexico cooperative research grant.

Over the startup period, some 35 measurements were made including four sets of replicate samples at the five generator wells. Table 5 lists the radon concentration and corresponding production data. The radon data show the difference in concentration with steam fraction, ranging about 50 nCi/kg for the two all-vapor wells, 10 to 20 nCi/kg for the two larger steam-fraction wells, and about 3 nCi/kg for the low steam-fraction well. The standard deviations range from about 5 to 30 percent, reflecting the variability in sampling procedures and the small number of samples obtained at each well.

The radon data in relation to production data do not show any appreciable changes over the initial two-year period. Mean values for the total data set were calculated as the initial value for each well. Table 6 shows the data with respect to specific volume in the reservoir calculated from observed wellhead enthalpy and estimated reservoir temperature obtained from geothennometry. The coefficients of variation (in percent) are included with the radon measurements. The estimated standard deviations of 20 to 30 percent in the wellhead radon concentration does not include additional uncertainty for the reported flowrates. The data for wellhead enthalpy and steam fraction, determined by CFE, had standard deviations estimated at 1 to 10 percent. The reservoir temperatures, estimated by the Na-K-Ca geothermometer had a variability of the order of 5 percent.

Reservoir specific volumes were calculated by the method of Semprini and Kruger (1984). The relationship between radon concentration and specific volume for the five wells followed the pattern observed *in* the larger radon study at the Cerro Prieto field. Regression of the data shows a relationship given by

$$[Rn] = 2240\, v_s^{1.3}$$

indicating a non-linear relationship between the two parameters. As additional radon measurements are made with mort reproducible sampling techniques over the next two-year production period, a more preaise relationship between wellhead radon concentration and specific volume in the restrvoir should emerge.

## ANALYSIS OF RESERVOIR CONDITIONS

The compilations of averaged production and chemical data have been used to estimate bottom-hole and reservoir temperature conditions during the startup period. The wellhead temperatures are based on vapor-phase saturation at the measured wellhead pressure and the steam fractions are based on the separated vapor and brine flowrates. The bottom-hole conditions were estimated by the wellbore simulator of Ortiz (1983) which is based on pressure loss for two-phase flow in vertical pipes given by Orkisaewski (1967). The reservoir temperatures for the three two-phase wells were estimated by a combination of geothermometers, including the Na-K-Ca geothermometer of Fournier and Truesdell (1973), the cationic composition geothermometer of Nieva and Nieva (1982), and the silica (quartz) geothermometer of Fournier and Potter (1982). The steam fraction in the resevoir was estimated from the silica geothermometer data. The reservoir temperature and steam fraction for the two all-vapor wells Az-6 and Az-17 in the South Module were estimated by Ortiz and Landa (1984), based on stabilized temperatures and using a single-phase gas vertical-flow computer program developed by Puente (1985).

Table 7 is a summary of the Calculated reservoir temperatures. In general it appears that the temperatures calculated by the Fournier and Truesdell algorithm is consistently greater by about 12°C compared to the Nieva

Table 5

RADON DATA SINCE STARTUP

| Well | Period | No. Obs. | $[Rn]_v$ (nCi/kg) | $[Rn]_{wh}$ (nCi/kg) | $P_{wh}$ (MPa) | ov (t/h) | $Q_1$ (t/h) | $H_{wh}$ (kJ/kg) |
|---|---|---|---|---|---|---|---|---|
| Az-6 | 2-82 | 1 | 43.3 | 43.3 | 1.14 | — | — | — |
| | 1-83 | 2 | 40.0 | 40.4 | 0.92 | 11.7 | — | -- |
| | 2-83 | 2 | 63.5 | 63.5 | 0.82 | 15.4 | — | 2782 |
| | 1-84 | 4 | 52.4 | 52.4 | 0.87 | 11.7 | — | 2782 |
| AI-17 | 2-82 | 1 | 34.0 | 36.0 | 0.85 | — | — | — |
| | 1-83 | 1 | 51.8 | 51.8 | 2.12 | 15.8 | — | — |
| | 2-83 | 3 | 53.5 | 53.5 | 2.01 | 15.9 | — | 2766 |
| | 1-84 | 4 | 50.6 | 50.6 | 1.89 | 15.5 | — | 2766 |
| AI-5 | 1-83 | 2 | 18.9 | 12.5 | 2.91 | 16.1 | 8.4 | - |
| | 2-83 | 1 | 15.8 | 10.3 | 3.03 | 15.8 | 8.3 | 2066 |
| | 1-84 | 2 | 11.2 | 7.2 | 2.95 | 15.7 | 8.4 | 2057 |
| Az-13 | 1-83 | 2 | 9.2 | 5.6 | 0.87 | 17.1 | 10.9 | — |
| | 2-83 | 1 | 14.9 | 8.6 | 0.94 | 16.9 | 12.2 | 1896 |
| | 1-84 | 3 | 9.1 | 5.2 | 0.87 | 17.0 | 12.5 | 1887 |
| Az-19 | 1-83 | 2 | 38 | 11 | 0.85 | 4.0 | 10.0 | — |
| | 2-83 | 1 | 24 | 0.71 | 0.92 | 4.0 | 9.7 | 1301 |

Table 6

STARTUP PERIOD AVERAGE RADON DATA

| Well No. | $[Rn]_v$ (nCi/kg) | $[Rn]_{wh}$ (nCi/kg) | $H_{wh}$ (kJ/kg) | $T_{res}$ (°C) | $X_s$ (%) | $V_s$ ($m^3$/kg) |
|---|---|---|---|---|---|---|
| Az-6 | 51.1±10.3 | 51.1(±20%) | 2836 | 262 | 100 | 0.0418 |
| Az-17 | 49.8±14.1 | 49.9(±28%) | 2761 | 260 | 100 | 0.0413 |
| Az-5 | 15.2±4.5 | 9.9(±30%) | 2000 | 299(±3%) | 47 | 0.011 |
| Az-13 | 10.1±3.1 | 5.9(±30%) | 1928 | 286(±5%) | 43 | 0.012 |
| Az-19 | 3.3±0.9 | 1.0(±27%) | 1402 | 290(±6%) | 8 | 0.0033 |

Table 7

GEOTHERMOMETER RESERVOIR TEMPERATURES

| Well No. | Period | T(Na/K)[a] (°C) | T(CCG)[b] (°C) | $T(SiO_2)$[c] (°C) | $\bar{T}$ (°C) |
|---|---|---|---|---|---|
| Az-5 | 1-82 | 326 | 312 | 305 | 314 |
| | 2-82 | 302 | 290 | 291 | 294 |
| | 1-83 | 309 | 300 | 292 | 300 |
| | 2-83 | 320 | 294 | 295 | 303 |
| | 1-84 | 311 | 304 | 300 | 305 |
| AZ-13 | 1-82 | 298 | 286 | 273 | 286 |
| | 2-82 | 295 | 286 | 258 | 280 |
| | 1-83 | 294 | 289 | 271 | 285 |
| | 243 | 294 | 281 | 266 | 274 |
| | 1-84 | 299 | 2% | 276 | 290 |
| AZ-19 | 1-82 | 323 | 308 | 305 | 312 |
| | 2-82 | 303 | 290 | 290 | 294 |
| | 1-83 | 299 | 289 | 276 | 288 |
| | 2-83 | 303 | 284 | 281 | 289 |
| | 1-84 | 311 | 304 | 290 | 302 |

(a) Fournier and Truesdell (1973)
(b) Nieva and Nieva (1982)
(c) Fournier and Potter (1982)

Nieva, D., L. Quijano, A. Garfias, R. Barragán, and F. Laredo, Heterogeneity of the Liquid Phase, and Vapor Separation in Los Azufres (Mexico) Geothermal Reservoir, Proceedings, Ninth Workshop on Geothermal Reservoir Engineering, Stanford University Report SGP-TR-74, December, 1983.

Nieva, D. and R. Nieva, A Cationic Composition Geothermometer for Prospection of Geothermal Resources, Manuscript, 1982.

Ortiz, J., Two-Phase Flow in Geothermal Wells: Development and Uses of A Computer Code, Stanford University Report SGP-TR-66 June, 1983.

Ortiz, J. and A. Landa, personal communication, (1984)

Orkiszewski, J., Predicting Two-Phase Pressure Drops in Vertical Pipes, J. Petrol. Engr., June, 1967.

Puente, H, Caida de Presion en Pozos de Gas, Professional Thesis. U.N.A.M. School of Engineering, 1985.

Semprini, L. and P. Kruger, Relationship of Radon Concentration to Spatial and Temporal Variations of Reservoir Thermodynamic Conditions in the Cerro Prieto Geothermal Field, Geothermics 13, 103-115, 1984.

Templos, L. A and F. Laredo, Geoquimica de los Gases Incondensables del Campo Geotermico de los Azufres, Michoacan, Mexico, Third National Symposium on Geothermy and Geology, Mexico. DF, September, 1980.

Templos, L. A and J. M. Lopez, Estudios Quimicos del Agua Separeda de los Pozoa Productores del Campo Geotermico de Los Azufres Michoacan, Mexico, Third National Symposium on Geothermy and Geology, Mexico DF, September, 1980.

Templos, L. A. and R. Molina, Exploración Geoquímica del Campo Geotérmico de Los Azufres, Michoacán CFE Technical Report, June, 1978.

Table 8

INIIIAL TEMPERATURE CONDITIONS AT STARTUP

| Well No. | Wellhead $T_{wh}$ (°C) | Wellhead $X_{wh}$ (%) | Bottom Hole $T_{bh}$ (°C) | Bottom Hole $X_{bh}$ (%) | Reservoir $T_{res}$ (°C) | Reservoir $X_{res}$ (%) |
|---|---|---|---|---|---|---|
| Az-6 | 171 | 100.0 | 207 | 100.0 | 262 | 90.0 |
| Az-17 | 213 | 100.0 | 221 | 100.0 | 260 | 95.0 |
| Az-5 | 231 | 62.0 | 256 | 54.9 | 299 | 41.0 |
| Az-13 | 178 | 59.1 | 212 | 44.7 | 286 | 36.3 |
| Az-19 | 171 | 34.5 | 219 | 20.5 | 290 | 37.4 |

Table 9

TWO-YEAR AVERAGED INITIAL CONDITIONS

| Well No. | $P_{wh}$ (MPa) | $Q_{wh}$ (t/h) | $H_{wh}$ (kJ/kg) | $[Cl]_1$ (g/kg) | $[CO_2]_v$ (g/kg) | $[Rn]_{wh}$ (nCi/kg) | $T_{res}$ (°C) | $X_{res}$ (%) |
|---|---|---|---|---|---|---|---|---|
| Az-6 | 0.82 | 42.6 | 2824 | -- | 67.2 | 51.1 | 262 | 90.0 |
| Az-17 | 2.01 | 61.7 | 2785 | — | 49.1 | 49.9 | 260 | 99.0 |
| Az-5 | 2.82 | 95.2 | 2027 | 3.04 | 14.8 | 9.9 | 299 | 41.0 |
| Az-13 | 0.95 | 102.1 | 1820 | 2.88 | 5.5 | 5.9 | 286 | 36.3 |
| Az-19 | 0.92 | 58.5 | 1452 | 2.76 | 1.5 | 10 | 290 | 37.4 |

and Nieva algorithm using the same concentration data for sodium, potassium, and calcium. On the other hand, the silica derived temperature is smaller than the Nieva algorithm, averaging about 3 to 6°C lover for wells Az-5 and Az-19, and about 23°C lover for well Az-13. In the absence of apriori judgment of the relative quality of the chemical analyses and the algorithms, it was decided to use a linear average of the three values for each period. The standard deviation of the individual values is estimated to be about ±10°C.

Table 8 is a summary of the averaged temperature conditions over the initial two-year production period. The data show the quality difference between the two production modules at Los Azufres. The South Module contains reservoir fluid of 90 to 95 percent steam at 260°C flashing to all-steam by the time it reaches the wellbore, whereas the North Module contains reservoir fluid of about 35 to 40 percent steam at about 295°C flashing to about 60 percent steam at the wellhead. The exception is well Az-19 for which the depressed value of the bottom-hole steam fraction has been attributed by CFE Departamento de Evaluacion y Yacimientos (1984) to an influx of low-enthalpy fluid into the well at a depth of 1096 m.

## CONCLUSIONS

By compiling existing data gathered for a variety of objectives, it has been possible to obtain an estimate of the initial conditions of the Los Azufres geothermal field during the first two years of sustained production at a generating capacity of 25 MWe. The data clearly show by several indices the differences in the two production modules of the resource. From the geothermometer and wellbore simulator data, the South Module can be described as a vapor-dominated reservoir with an initial temperature of about 260±5°C, and the North Module as a two-phase reservoir with an initial temperature of 295±10°C.

The data evaluated in four six-month averaged periods show that the thermodynamic drawdown, under sustained production at 25 MWe, except for well Az-19 where colder —ater intrusion is evident, appears to be small. On that basis, the data can be regrouped into single two-year values of initial conditions. Table 9 summarizes the average values for several key parameters useful for long-term observation of performance at Los Azufres. These values can serve as the baseline from which changes occurring through continued and increased production can be evaluated over the useful life of the resource. Compilations of similar data for new wells should be initiated as they go into sustained production.

At the present time, little quality control has been applied to the compiled database. It is anticipated that judicious analysis of the sampling and measurement procedures will allov estimation of the 2-year averaged data with increased precision, and hopefully increased accuracy. If successful, the ability to observe smaller significant differences in the key parametere with production time will allow accelerated evaluation of the Los Azufres geothermal field as the electric power generation capacity increases.

## REFERENCES


CFE Departmento de Evaluaciones y Yacimientos, Evaluacion del Potencial del Pozo Az-19, CFE Technical Report, 1984.

Camacho, P., Mapa Preliminar del Area Geotermica de Los Azufres, Mich., CFE Technical Report, 1976.

Cathelineau, M., R. Oliver, G. Izquierdo, A. Garfias, D. Nieva, and O. Izaguirre, Mineralogy and Distribution of Hydrothermal Mineral Zones in Los Azufres (Mexico) Geothermal Field, Proc., Ninth Workshop on Geothermal Reservoir Engineering, Stanford University Report SGP-TR-74, 269-274, December, 1983.

de Anda, L. F., Primer Estudio para el Aprovechamiento de la Energia Geotermica para la Generacion de Energia Electrica en Mexico, International Geological Congress, 1951.

de la Cruz, V., Estudio Geologico Estructural a Detalle del Campo Geotermico de Los Azufres, Mich., CFE Technical Report, 1982.

Dobson, P. S., Estratigrafia Volcanica del Centro Geotermico de los Azufres, Mich. , CFE Technical Report, 1984.

Fournier, R. O. and A. H. Truesdell, An Empircal Na-K-Ca Geothermdmeter for Natural Waters, Geochim. et Cosmochim. Acta 37, 1255-1275 (1973).

Fournier. R. O. and R. W. Potter, A Revised and Expanded Silica (Quartz) Geothermometer, Bulletin GRC 11, 3-12 (November, 1982).

Hiriart, G., One Year Experienae with Portable Back-Pressure Turbines in Los Azufres, Proceedings, Ninth Workshop on Geothermal Reservoir Engineering, Stanford University Report SGP-TR-74, December, 1983.

Jaimes, M. G., Resumen de Pruebas de Presion en la Zona Sur, CFE Technical Report, 1984.

Mooser, F., El Eje Neovolcanico Mexican, Debilidad Cortical Prepaleozoica Reactivada, Part 3, Proceedings, Second National Convention Sociedad Geologica Mexicana, 1972.