Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

An Update of the Los Azufres Geothermal Field, after 21 Years of Exploitation

Marco A. Torres-Rodríguez, Alfredo Mendoza-Covarrubias and Moisés Medina-Martínez

Alejandro Volta 655 C.P.58290 Col. Electricistas, Morelia,Michoacán, México

marco.torres@cfe.gob.mx

Keywords: Los Azufres field, exploitation, power plants.

ABSTRACT

Los Azufres geothermal field, in the central portion of México, is located in the volcanic belt, at an average elevation of 2800 masl. It has been under commercial exploitation to generate electricity since 1982. At present, the installed capacity is 188 MW with seven backpressure units of 5 MW each, two binary cycle units of 1.5 MW each, one condensing unit of 50 MW and four new condensing units of 25 MW each. In order to sustain the generation, steam is supplied from 43 producing wells and brine is injected into seven injectors wells. In 21 years of continuous development, 120.3 million of tons of steam have been extracted. The Los Azufres hydrothermal system was studied thoroughly from the beginning of exploitation. Currently numerous geochemical, production and subsurface log data permit, in conjuntion with geological, geophysical and mineralogycal studies, the development of a conceptual model of the field and a reliable analysis of the evolution of the reservoir using numerical simulators. The average pressure decline in the south zone of the field is 0.71 bar/year and in the north zone is 0.33 bar/year. Decline in the south is higher than in the north because of the larger extraction of mass and energy. Those numbers are consistentes with the extration of fluids in the field. The numerical models show the feasibility of generating at least 120 MW in the north zone and 133 MW in the south, for more than 20 years of production. However, because of the four condensing units of 25 MW each, are generating electricity recently, since 2003, and mass extraction of the reservoir was duplicated , it is necessary to observe the behavior of wells and reservoir in order to verify the real pressure and mass declination versus the obtained from numerical models.

1. INTRODUCTION

The Los Azufres, México, geothermal field is located in the northern portion of the Transmexican volcanic belt, 80 km east of Morelia city and 250 km of Mexico city (Figure 1). It is an heavely fractured and faulted volcanic hydrothermal system, located in a sierra at an average elevation of about 2800 masl. It is found in a forest area with abundant vegetation, considered forest reservation zone.

In order to evaluate the feasibility of the existence of a geothermal system at Los Azufres, geological, geophysical and geochemical surveys were carried out in 1972. Drilling activity began in 1976 and currently 75 wells have been drilled at depths ranging between 700 and 3500 meters. In 1982 started the commercial exploitation of the field with the start-up of the first five backpressure power units of 5 MW each one. In 1994 the installed capacity reached 98 MW, and in 1996 two power units of 5 MW (U-1 and U-2) were dismantled and transported to the Miravalles geothermal field, Costa Rica, in order to accomplish a services contract signed between CFE and the Instituto Costarricense de Electricidad. In 2000 one of these units (U-2) went back to Los Azufres and in 2002 the unit number 8 of 5 MW was dismantled and transported to the Los Humeros geothermal field, México. In 2002 the installed capacity was 88 MW. One year before, 2001, started the Los Azufres II project consisting in the construction of four condensing power units of 25 MW each.

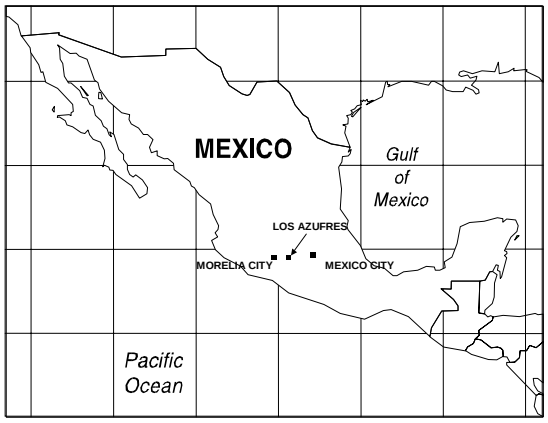

Figure 1: Location of the Los Azufres geothermal field

At present, the installed capacity is 188 MW. In order to sustain the generation, 1630 t/h of steam are supplied from 43 producer wells. Simultaneously, 891 t/h of brine and condensed steam are injected in six injectors wells located in west of the field. Of these, 280 t/h are sending to the binary cycle units before to be carried to the injection system.

From the beginning of the development of the field, exhaustive studies on the behavior of the reservoir have been accomplished. Each year new data of the wells are obtained in order to enriching the knowledge of the field permitting to accomplish the analysis on the reservoir behavior and forecasting on its evolution as a source of energy for electrical generation. As a result of additional 100 MW installed, mass extraction from the reservoir was increased and it is necessary to observe the reservoir behavior in order to verify the exploitation strategies of the field.

2. STEAM SUPPLY AND BRINE INJECTION.

The Los Azufres geothermal field is divided in two zones: north zone and south zone, due to that geological, geochemical, production and reservoir characteristics differ in some looks, although it is believd that to depth the reservoir is the same (Esquivias et al, 1995 and Flores-Armenta et al, 1997). The south zone presents the highest temperatures and greater production of the field. The original thermodynamic state in both zones are different: the north zone is in the compressed liquid region (Figure 2) and the south is in the vapor dominated, liquid dominated and compressed liquid region depending on depth (Figure3).

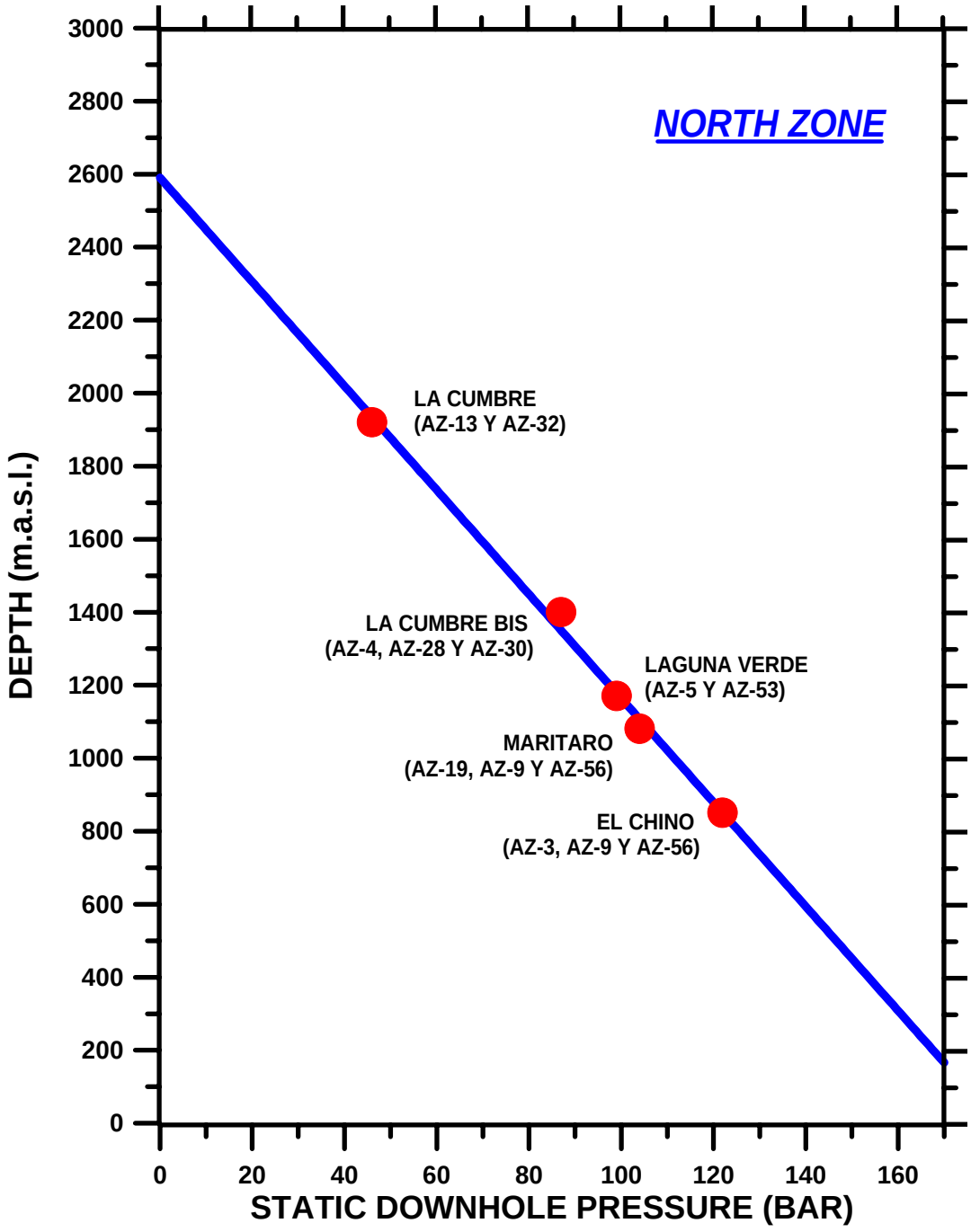

Figure 2: Original pressure profile for wells in the north zone

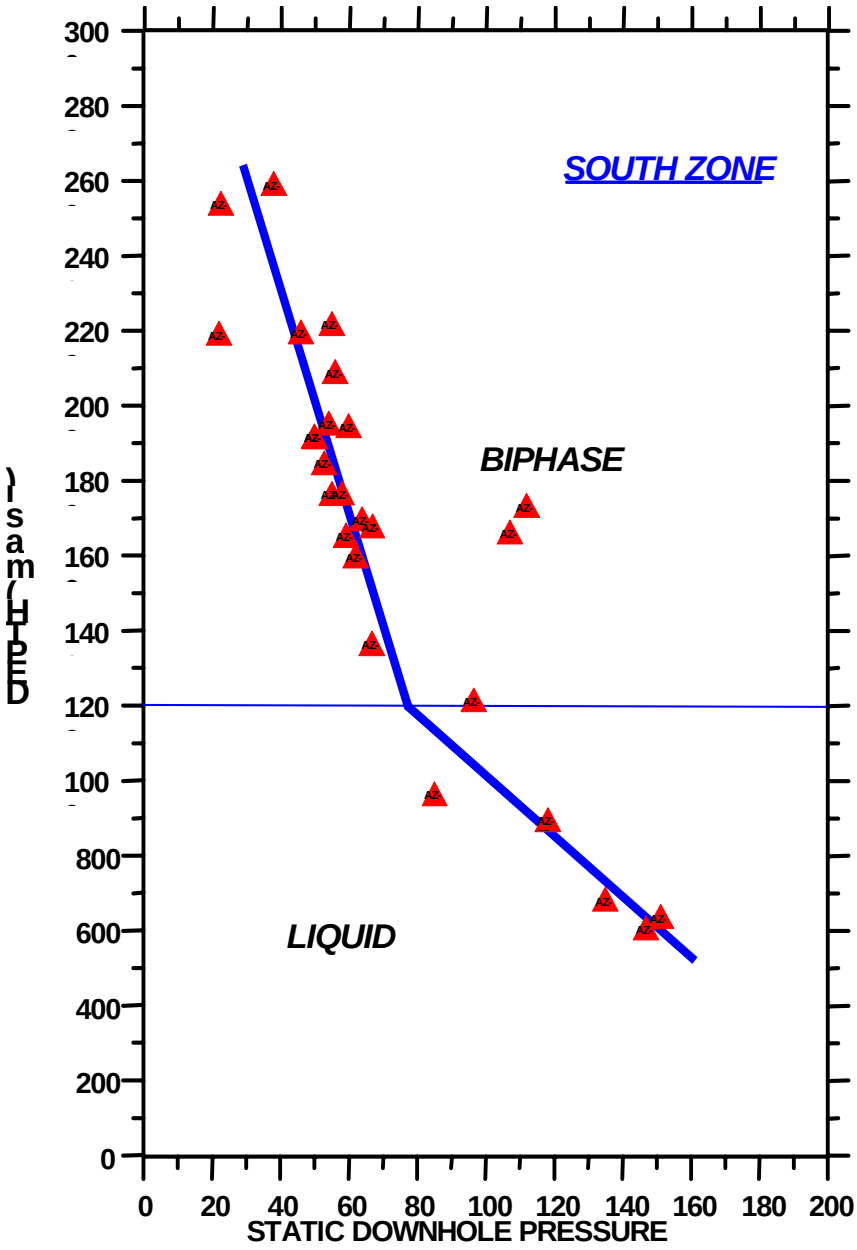

Figure 3: Original pressure profile for wells in the south zone

At present there are 43 producer wells suppying steam to the power units through a net of 25.6 of pipes, ranging between 10 and 42 mm of diameter. Depending of requirements of steam and rate of declining of each well, producer wells are controlled using orifice plates located on the side valve of the christmas tree,. There are wells with different termodynamical characteristics:

- Mixture producers wells
- Dry saturated steam producers wells
- Superheated steam producers wells

The wells and units of the south are independent of the wells and units of the north zone. After 21 years of operation of the field, only two producers wells have been repaired: AZ-26 and AZ-02, both in the casing of 9 5/8 inches of diameter. The first one is 22 years old and the last one is 26 years old. Have not been necessary to drill new replacement producer wells. In 21 years of electricity generation 120.3 million of tons of steam has been extracted from the reservoir (Figure 4). The average of wells in production in 1996 was 23 and during 1997 an average of 19 production wells were operating, 22 wellls between january and august and 13 in the last quarter of the year (C.F.E.,1997). This is because the unit of 50 MW (U-7) had to go out of the system for repairing its generator during those months and the first month of 1998. In 2002 steam production was less than other years, 5.02 million of ton, because the unit of 50 MW (U-7) was out of system for repairing the blades of the turbine. Compairing the steam production in 1996 (the maximum production) and 2003, there is an increment from 8.6 millions of tons to 11.26 millions of tons, that represents an increasing of 31%. This is due to the operation testing of the four new units of the Los Azufres II project.

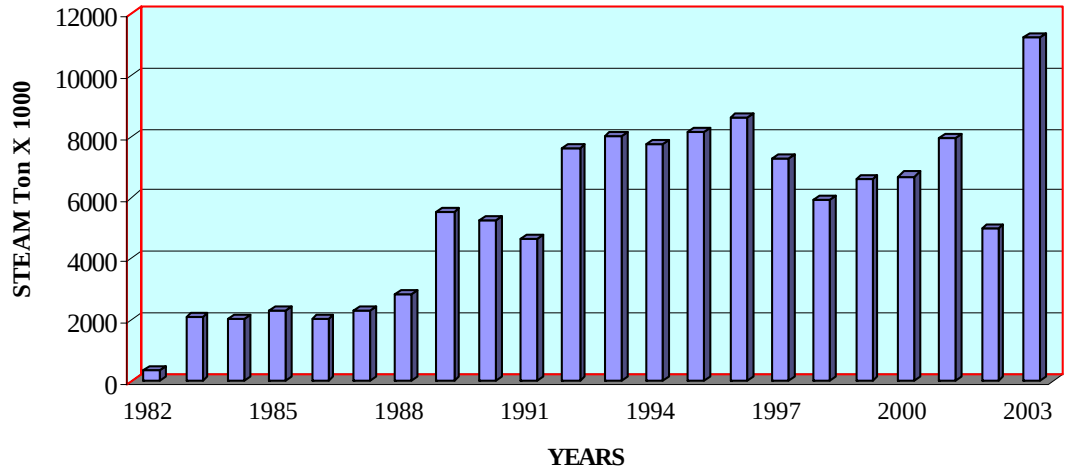

Figure 4: Steam production in Los Azufres in the period 1982-2003

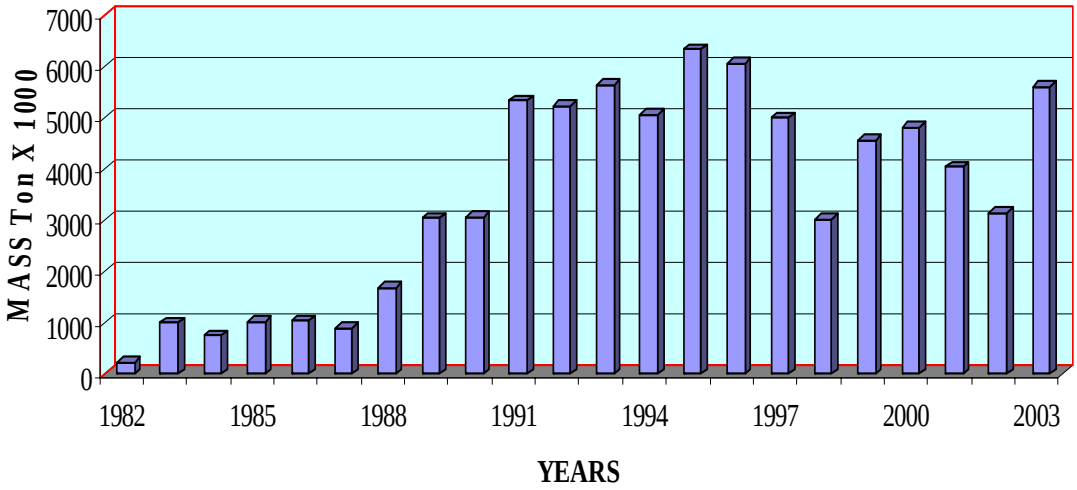

Figure 5: Brine and condensed water injection in Los Azufres in the period 1982-2003

As a result of the mass extraction, 641 t/h of brine are produced in the field and in conjunction of 250 t/h of condensed water from units are injected in order to recharge the reservoir and to preserve the ecological system. After 21 of mass extraction, 76.6 millions of tons of brine and condensed water have been injected into the reservoir (Figure 5). As in the case of the steam production, the injected water was reduced in 2002 because the unit of 50 MW (U-7) was out of system. In 2003 injection was 5.6 million of tons, less than 6.07 millions of tons in 1995,because some wells are producing dry saturated steam.

The injection system is operated by gravity, using a net of 40 km of high density polyethylene pipes. All of the brine produced by the wells and the condensates produced by the plants are injected in six injector wells located on west of the field: four in north zone (AZ-03, AZ-15, AZ-52, AZ-61) and 2 in the south zone (AZ-07,AZ-08). Before to be sending the brine to the injectors wells, 280 t/h at 180^0C are sent first to the binary cycle units and then toward the injection system and finally to the injector wells. In order to avoid silica scaling in the pipelines, a preventive maintenance system has been implemented using reamers with a frequency of 45 days depending on silica content of the brine (Estrada, 1996). From reservoir engineering studies, it has been identified that in the south zone the water production is increased in some producer wells when the injection rate is increased in the wells AZ-07 and AZ-08, however, negative effects have not been detected in the steam flow rate. In order to avoid possible negative effects on producers wells, 66% of the total brine is injected in the north zone.

3. POWER UNITS

Electrical generation in the field began in 1982 with five Mitsubishi backpressure units of 5 MW each, and in 1987 one more Toshiba backpressure unit was installed (Figure 6).

Figure 6: Backpressure unit of 5 MW

In 1989 started-up a General Electric condensing unit of 50 MW (Figure 7).

Figure 7: Condensing unit of 50 MW (U-7)

In 1991 were started-up two backpressure units of 5 MW, Ansaldo, and in 1994 one backpressure unit, Ansaldo, of 5 MW, and two Ormat binary cycle units of 1.5 MW each (Figure 8).

In 1994 the installed capacity in the field reached 98 MW. On May of 1996 two units of 5 MW were moved to the Miravalles, Costa Rica, geothermal field as part of a contract that CFE signed with the Instituto Costarricense de Electricidad. Consequently, in 1996 the installed capacity was 88 MW distribuited 25 MW in the north zone (28%) and 63 MW in the south zone (72%) of the field.

Figure 8: Binary cycle unit of 1.5 MW

The knowledge that is had of the reservoir and their potential, with the necessity of commercial utilization of the surplus of steam and, at the same time, the supplement of the energy deman of the zone, were the main reasons to expound the construction of 4 units of 25 MW each. This project was named Azufres II 100 MW, starting on november 2000 and finishing on july 2003. One of the units is located in the south zone and the other three in the north zone.

The Los Azufres II project contributes 788 gigawatts-h per year to the national electrical net. This project consisted in four condensing units with a simple flow turbine, inlet pressure of 8 bara and 3600 rpm. The condenser is of the type of direct contact at an operation vacuum pressure of 0.12 bara (Figure 9).

Figure 9: Condensing unit of 25 MW

In the year 2003 the installed capacity was increased from 88 MW to 188 MW and distribuited 95 MW in the north zone and 93 MW in the south zone (Figure 10).

During 21 years of development 9326 GWh have been generated (Figure 11). In 1996 were generated 744 GWh bacause all units were in operation at nominal power. In 2002 were generated 300 GWh because the unit of 50 MW (U-7) was repaired. In 2003, with the start-up of the four new units of 25 MW each, the generation was increased to 845 GWh.

4. RESERVOIR BEHAVIOR

In this section we will show briefly the reservoir behavior before the additional 100 MW. The reservoir of the Los Azufres Geothermal Field is divided in two zones: north and south due to reservoir characteristics differ in some ways as we can see briefly in next paragraphs.

NORTH ZONE.- The reservoir is constitued by two lithological units (Pérez-Esquivias H. Et. Al., 1995): Mil cumbres andesites that host the reservoir and Agua Fría riolite that it is operating as a sealant cap. Fluids in the reservoir are of the type sodium-chloride and thermodynamicaly are in the subcooled liquid region (Figure 2).

SOUTH ZONE.- The reservoir presents the highest temperatures, greater production in the field and is shallower than in the north. The reservoir is constitued by three lithological units: Mil Cumbres andesites hosting the reservoir, Agua Fría riolite that it is operating as a sealant cap and the Tejamaniles dacite that it is the most recent volcanic event and where most of the thermal springs are located (Torres-Rodríguez et al, 1998) and is one of the factors that have impigned on better thermodynamic characteristics with respect to the north. Fluids in reservoir are of the type sodium-chloride and thermodynamicaly are in three different regions (Figure 3):

- Dominant steam zone: 2300 to 1900 masl
- Dominant liquid zone: 1900 to 1200 masl
- Compressed liquid zone: 1200 to 1300 masl

In order to make an controlled exploitation of the resource, continous data of the reservoir pressure are obtained in observer wells, bleeding wells and production testing in wells.

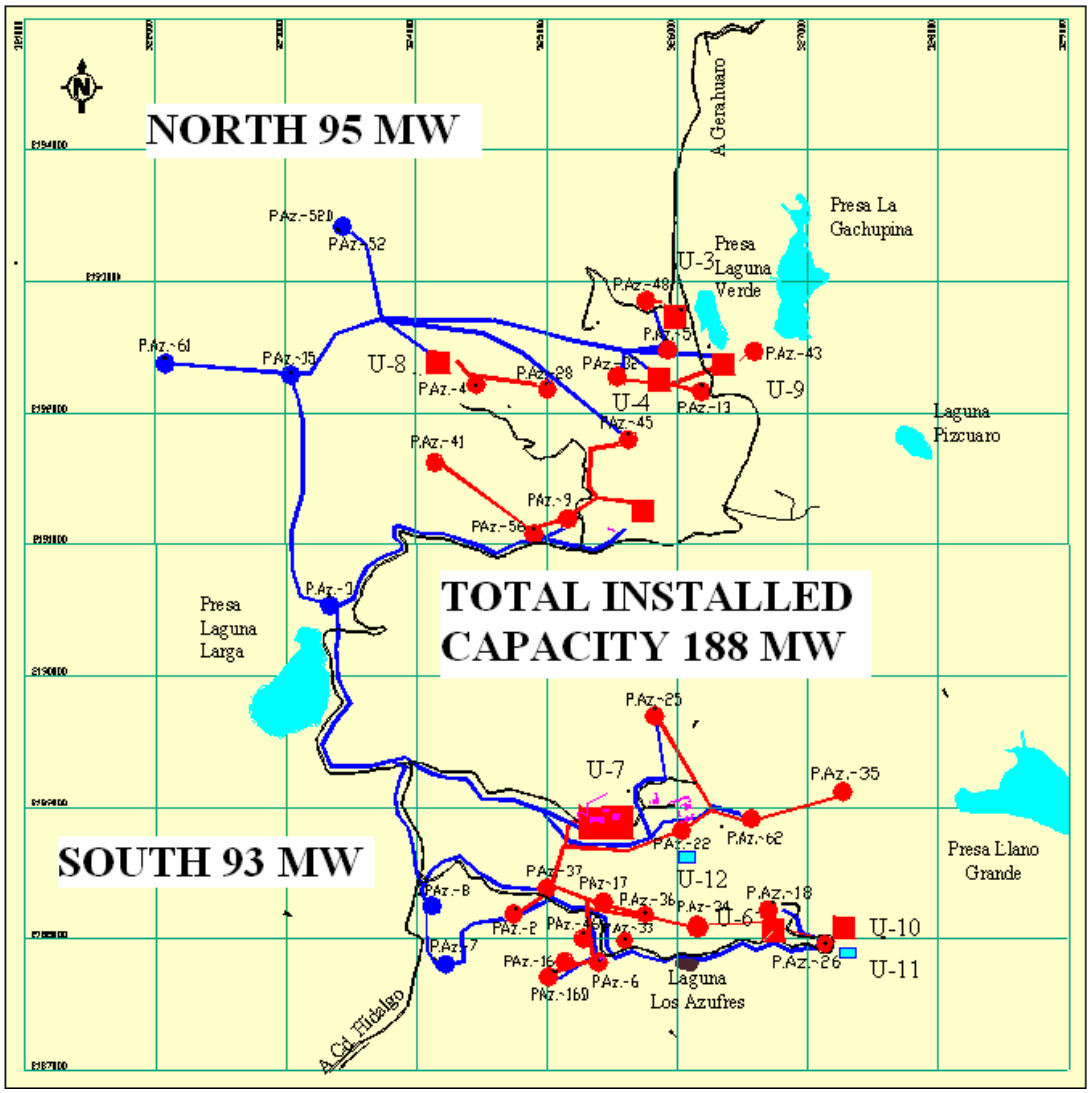

Figure 10: Location of units and wells in Los Azufres field

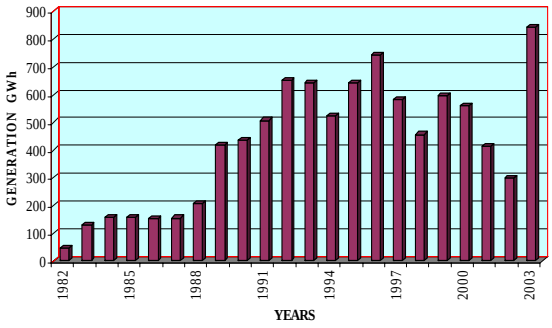

Figure 11: Electricity generation in Los Azufres field in the period 1982-2003

Plotting the time versus well bottom pressure we observe that data trend is linear and the slope corresponds to the

pressure drop in the time (Torres-Rodríguez et al, 1998). The pressure drop in the north zone is 0.33 bar/year (Figure 12) smaller than the average pressure fall in the south that is 0.71 bar/year (Figure 13). This behavior of both zones is due that the 40% of the total mass extracted from the reservoir corresponds to the north zone. Exploitation in the south was higher than in the north due to a higher installed capacity in this zone before the Los Azufres II project.

The enthalpy behavior is related to the pressure drop. The zones in wich the biggest increments of enthalpy are observed, correspond to the zones of greater individuals pressure drop of the reservoir in wich the greater fluid extraction is also done (Torres et al, 2000).

Concerning the chemistry evolution, in the north zone sensitive changes have not been observed. Content of chlorides range 2900-3500 ppm. In the south zone changes in the chlorides content have been observed, from an average content of 3150 ppm to 5250 ppm. This behavior is related with brine injected into reservoir (Torres et al, 2000).

The behavior of the Na/K geothermometer has shown decline from the west part of the field (Figure 14). In the beginning of the development there were two high temperature areas. In the north zone, at about well AZ-9, were calculated until 335^{0}C and in the south zone, at about well AZ-22 , was 320^{0}C. In 21 years, there has been a movement movement of the isothermal lines from the west, being more notable in the south zone, in which in AZ-22 that initially had 285^{0}C, currently is 250^{0}C. This behavior is explained by the brine injection. The injector wells are located to the west of the field and a high communication has been identified between the injector wells of the south zone (AZ-8 and AZ-7) and the producers wells of that same zone (AZ-16D, AZ-33, AZ-37, AZ-46).

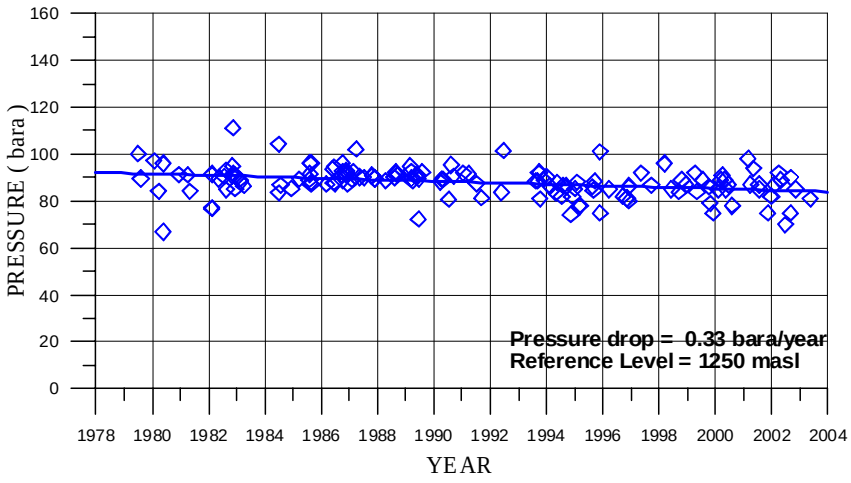

Figure 12: North zone average pressure drop

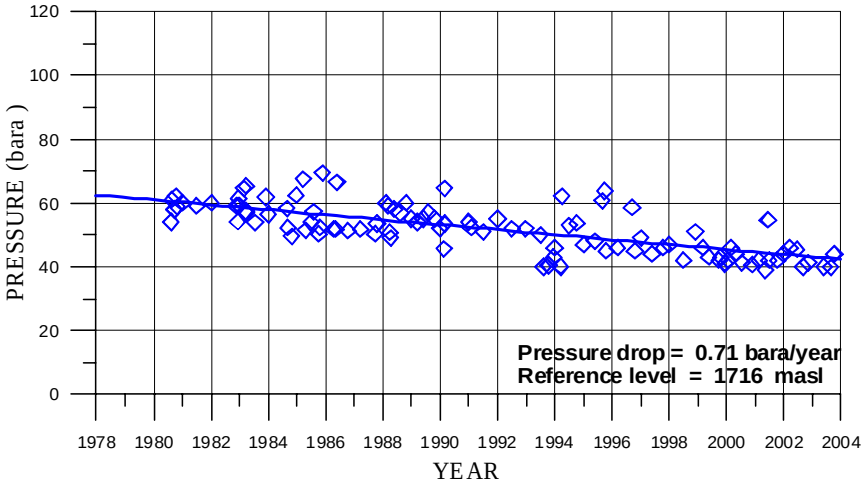

Figure 13: South Zone average pressure drop

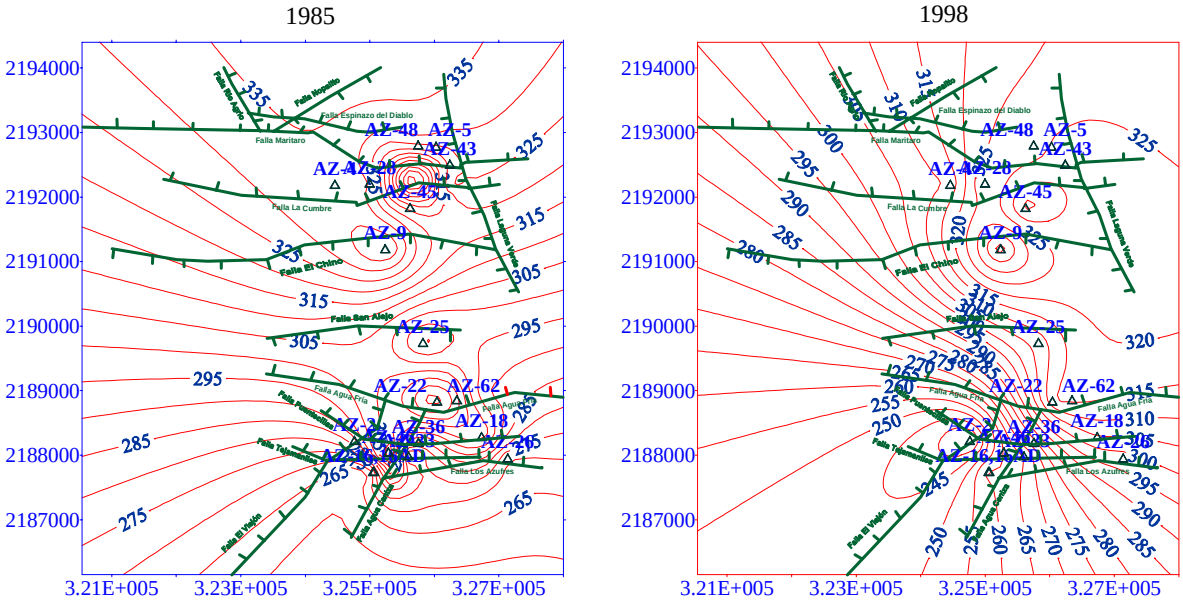

Figure 14: Geothermomether Na/K evolution in Los Azufres Reservoir

Every year is carried out the isotopic characterization of fluids, collecting samples from producers and injection wells. Patterns of behavior of chemical constituents and oxigen isotope ($\delta^{18}O$) and deuterium (δD) have been analyzed in order to diagnosis the exploitation effects (Arellano et al.,2003). As a consequence of brine injection has modified the original isotopic tendency mainly in the

south zone of the field, maximum values fo N2, oxygen-18 and deuterium were found.

In order to outline expansion plans of the field was carried out a numerical simulation in 1999. Because conceptual models of the north and south zones were separately, the numericals models were constructed in the same way. The results showed that the average pressure drop was incremented by about 52%, from 0.71 bar/year to 1.08 bar/year, because of the increment of mass extraction. For this scenario, 16 producer wells were enabled in diverse locations of the field, with an average productions of 85 t/ h in order to sustain 160 MW during 25 years. No one of the wells will arrive to the abandonment pressure (Alcántara-Suárez et al, 1996, Flores-Armenta, 1999).

In the year 2003 was accomplished a numerical simulation in order to optimize the development of the resource before starting the new plants of the Los Azufres II project. In this case was elaborated one conceptual model where were included both zones and in consequence only one numerical model was obtained. In conclusion, the reservoir has the capacity to sustain the 188 MW installed during 30 years. It is possiible to increase the installed capacity with additional 65 MW, distribuited 25 MW in the north and 40 MW in the south, in order to reach a total capacity of 253 MW. Obviously it is necessary to verify this last result with new data obtained from the wells with the new capacity of 188 MW.

At present, there is a detailed program of monitoring and well testing in order to obtain new data of the behavior of the reservoir with the new 188 MW scenario of exploitation. It is necessary to enrichment the data base of the field with geochemical data, reservoir pressure, mass production, isotopic trend and other studies related to the reservoir behavior.

5. CONCLUSIONS

After 21 years of development of the los Azufres geothermal field, 9326 GWh have been generated. In order to sustain this generation of electricity, 120.3 millions of tons of steam have been produced. 76.6 millions of tons of water have been injected into the reservoir.

In 2003 the installed capacity in the field was increased from 88 MW to 188 MW, an increment of 113.6%, with the start-up of the four condensing units of 25 MW each, Los Azufres II project.

The installed capacity is distribuited uniformly on both zones of the field: 95 MW in the north and 93 MW in the south.

In order to sustain the capacity of 188 MW, total steam production was increased from 910 t/h to 1630 t/h, an increment of 79%. Brine production is not increased like steam because some producer wells are in the dry saturated steam region.

Before the start-up of the additional 100 MW, exploitation rate has provoked the transistion of geothermal fluids from compressed liquid to steam dominated region. The production of steam in wells has stayed constant and in some cases has been incremented. The production of brine in wells has shown declination.

The numerical simulation shows that the reservoir has the capacity to sustain the 188 MW installed, during 30 years and it is possible to increase the capacity with additional 65 MW in order to reach a total capacity of 253 MW.

It is carry on an exhaustive monitoring of production, geochemical, geological and geophysical variables in order to obtain new data of the behavior of the field under the new exploitation rate and in consequence to confirm the exploitation strategies.

REFERENCES

Alcántara-Suáres, J.G., and Flores-Armenta, M,: Simulación numérica de la Zona Norte, Campo Geotérmico Los Azufres, *Internal Report*, Comisión Federal de Electricidad, México (1996).

Arellano-Gómez, V., and Barragán, R.M,: chemical and isotopic ($\delta^{18}O$, δD) behavior of the Los Azufres (México) geothermal fluids related to exploitation , Annual Meeting, Geothermal Resources Council, Reno, Nevada (2003).

C.F.E..: Informe Operativo mensual, *Internal Report*, Gerencia de Proyectos Geotermoeléctricos, Comisión Federal de Electricidad, México (1997).

Estrada-Serrano, R., and Torres-Rodríguez, M.A.,: Injection Experiences in the Los Azufres, México, Geothermal Field, *Transactions, vol.20*, Annual Meeting, Geothermal Resources Council, Portland, Oregon (1996).

Flores-Armenta, M, García-Cruz, A., Pérez-Esquivias, H., Gómez, J.G., and Sandoval-Medina, F.: Modelo Conceptual de la Zona Sur del Campo Geotérmico de Los Azufres, *Internal Report*, Comisión Federal de Electricidad, México (1997).

Flores-Armenta, M,: Simulación numérica de la Zona Sur, Campo Geotérmico Los Azufres, *Internal Report*, Comisión Federal de Electricidad, México (1999). Torres-Rodríguez, M.A. and Flores-Armenta, M.: Reservoir Behaviour of the los Azufres Geothermal Field, After 16 Years of Exploitation, *Transactions*, World Geothermal Congress, Japan (2000).

Pérez-Esquivias, H., Flores-Armenta, M, García-Cruz, A., Gómez, J.G., and Sandoval-Medina, F.: Modelo Conceptual de la Zona Norte del Campo Geotérmico de Los Azufres, *Internal Report*, Comisión Federal de Electricidad, México (1995).

Torres-Rodríguez, M.A. and Flores-Armenta, M.: Pressure and Enthalpy Evolution in Wells of the los Azufres Geothermal Field, *Transactions, vol.22*, Annual Meeting, Geothermal Resources Council, San Diego, CA (1998).