SUSTAINABILITY AND EXPLOITATION POLICIES AT THE MIRAVALLES GEOTHERMAL FIELD

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ABSTRACT

Electrical generation in Costa Rica relies almost completely in environmental-friendly, renewal type sources. By 2005, 78% of the installed capacity and 96% of the total energy generated came from hydro, geothermal and wind power plants. Electrical generation from geothermal has become very important since it has been used as replacement for the thermal power plants and as a basement for the electrical generation.

Geothermal energy in the country is generated by the 163 MW power plants complex at the Miravalles Field. Due to its strategic importance in the present and future energy supplies for the country, the sustainability of the field is considered and issue of special relevance. The Miravalles reservoir has evolved since the start of its massive production 12 years ago, and different actions and strategies have been and will be implemented for sustaining the steam supply to the power plants and for reservoir management. In this paper those strategies are presented and discussed.

1. INTRODUCTION

Costa Rica is worldwide recognized as a leader in environmental protection, and has developed and implemented policies in order to protect the country's natural resources. This situation has leaded the development and exploitation of the energy resources in the country according to these policies. The Instituto Costarricense de Electricidad (ICE – stands for "Costa Rican Institute of Electricity) is a state-owned company in charge of the development and management of electric power generation in Costa Rica, its distribution and commercialization. Small private-owned companies join it in the generation aspect but by law ICE must generate no less than the 90% of the country's electricity needs. This position allows and at the same time forces ICE to define the country's electrical generation plans, present and future. According to the Costa Rica's way of thinking in environmental issues, one of the main goals of ICE is to satisfy almost all the electrical generation needs by renewal type sources. At present this goal is fulfilled because in the last six years the renewal type sources have generated an average of 97% of the total electrical generation.

ICE develops and continuously reviews a 20-year plan for estimating the electrical demand of the country and the construction and installation of the necessary power plants for fulfilling such needs (expected to be about 23000 GWh by year 2025). This plan relies in the installation of high percentages of renewal and environmental-friendly type electrical generation sources (Table 1); actually this is, more than 70%. However, the environmental-friendly electrical generation is expected to fall in the future (Table 2). This is in part due to the condition of Costa Rica itself as a concerned country in environmental issues. Some of the hydro projects that ICE had in mind were cancelled or reduced in size because of the opposition of communities and environmental NGO's. The exploitation of geothermal resources is very limited at this time, because the majority of these resources are in the national parks and protected areas that are not allowed for exploitation. Different actions considered by ICE for reducing the dependency of thermal generation among others includes the use of less polluting fuels (gas, biomass) and changes is the Costa Rica's laws which permits a rational use of the geothermal resources in protected areas (Mainieri, 2006).

TABLE 1: Installed Capacity in Costa Rica (Actual [2005] – Estimated [2025]) (Modified from ICE(2), 2006).

Year	Hydro		Thermal		Geothermal		Wind		Renewables
	MW	%	MW	%	MW	%	MW	%	%
2005	1303,6	66,5	423,3	21,6	165,7	8,4	68,6	3,5	78,4
2025	2911,0	62,2	1286,0	27,4	231,0	4,9	253	5,4	72,5

TABLE 2: Electrical Generation in Costa Rica (Actual [2005] – Estimated [2025]) (Modified from ICE(1), 2006).

Year	Hydro - %	Thermal - %	Geothermal - %	Wind - %	Renewables
2005	78,1	3,7	15,3	2,9	96,3
2025	61,2	27,3	7,7	3,8	72,7

2. THE MIRAVALLES GEOTHERMAL FIELD

The Miravalles Geothermal Field is the only geothermal reservoir under exploitation in Costa Rica (Figure 1). Deep drilling started in 1978, when a high-temperature reservoir was discovered. Subsequent drilling stages completed the steam necessary to feed three flash plants commissioned in 1994 (55 MW), 1998 (55 MW) and 2000 (29 MW), and one binary plant in 2004 (19 MW), totaling an installed capacity of 163 MW. Three 5 MWe wellhead units have also produced for different periods, and one of them is still in use.

2.1. The reservoir

The reservoir is a 800-1000 m thick high-temperature liquid-dominated type, located at about 700 m depth with reservoir temperatures naturally declining to the south and west. The main reservoir fluids have a sodium-chloride composition with TDS of 5300 ppm, a pH of 5.7 and a silica content of 430 ppm and present a tendency for carbonate scaling in the wells. The main aquifer is characterized by a 230-255 °C lateral flow. A shallow steam dominated aquifer is located in the northeastern part of the field, and it is formed by the evaporation of fluid from the main aquifer that moves along fractures (Vallejos, 1996). Another important sector shows an acid aquifer located in the eastern-northeastern part of the field, and so far four out of five wells that have been drilled there are systematically exploited and neutralized.

The field is associated with a 15 km wide caldera, which has been affected by intense neo-tectonic phenomena (Figure 2). The interior of the caldera is characterized in general by a smooth morphology. The proven reservoir area is about 13 km2, and a similar area is classified as a sector for probable expansion. Another 15 km2 area is identified as also having some possibilities for future development (ICE/ELC, 1995). These areas may increase as the reservoir is investigated further.

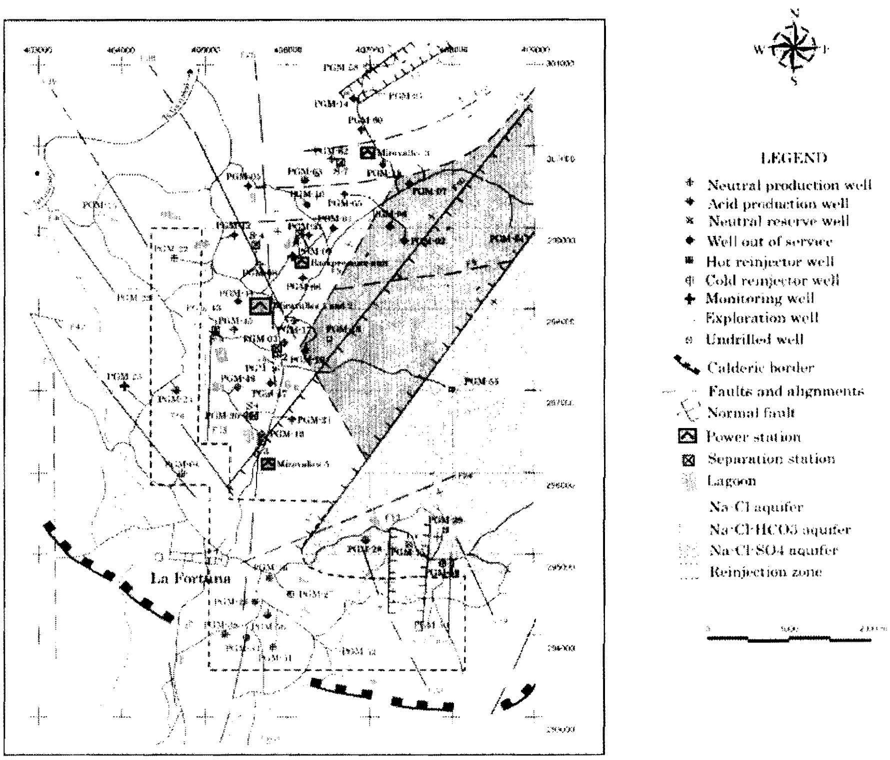


FIGURE 1: The Miravalles Geothermal Field Location of Facilities.

The main productive zone of the field can be seen in Figure 1 as the yellow area, where the majority of the production wells are located. Other important productive zones are the acid aquifer (red zone) and the east-southeast zone (beige zone, not actually under exploitation). The injection zone is located to the west and the south (this last coincides with the zone where the waters exit the exploited reservoir).

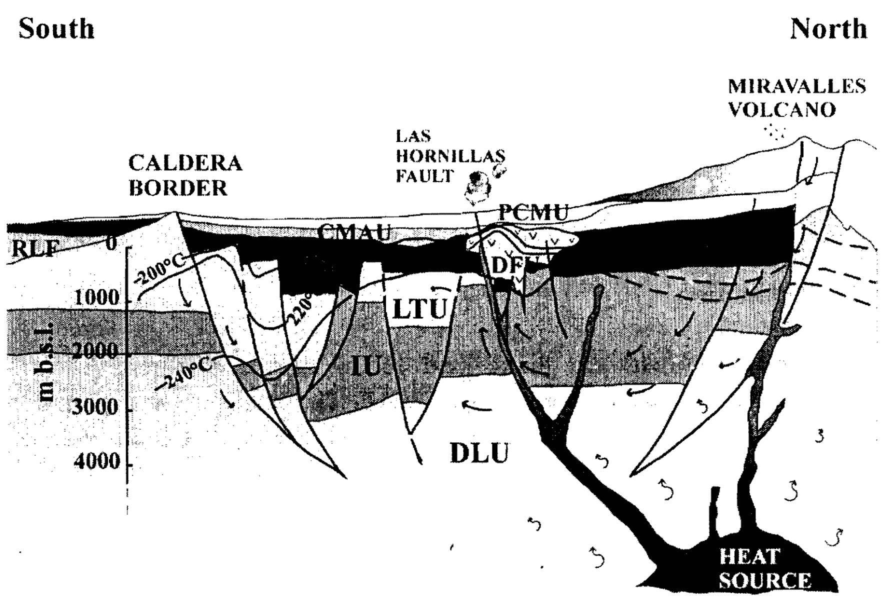
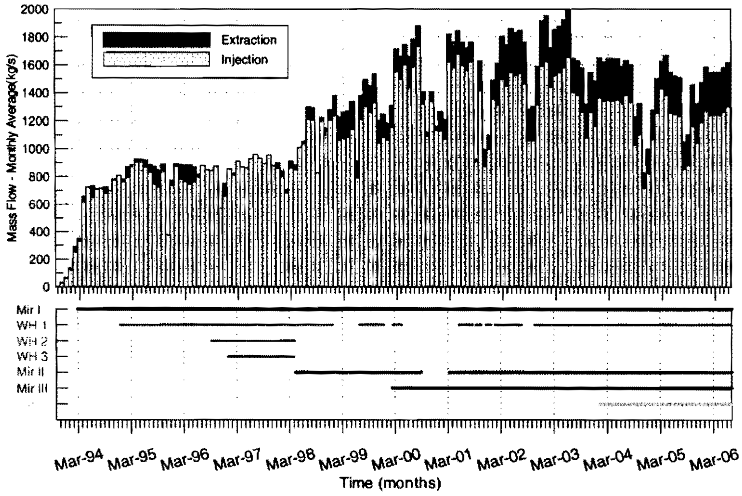


FIGURE 2: The Miravalles Geothermal Field Conceptual Model (Vega et al, 2005).

2.2. Mass Production History

The total mass extraction and injection rates in Miravalles are shown in Figure 3. Around 1610 kg/s of total mass are extracted from the reservoir, and 280 kg/s are steam used for generation (Moya and Nietzen, 2005). All the waste water is injected back to the reservoir. The annual maintenance of the different power plants is historically scheduled during the second half of every year; this explains the observed decrease in the mass production over this period of time. Injection has been an important factor of the Miravalles operation, and the injection rates account for around 83% of the total mass extracted from the field.



Injection into the different sectors at the Miravalles Field is shown in Table 3 as a percentage of the total injected mass into the field (Vallejos et al, 2005).

FIGURE 3: Mass Production and Injection at the Miravalles Field.

TABLE 3: Injection Into the Miravalles Field.

Start	End	South	PGM22	PGM24	PGM04
1994	1998	30%	30%	30%	10%
1998	2000	65%	13%	13%	9%
2000	2002	73%	9%	9%	9%
2002	2003	63%	11%	17%	9%
2003	2006	65%	14%	15%	5%

West injection zone comprises PGM-22 and 24.
South (injection zone) means injection in wells PGM-16, 26, 27, 28, 51, 56 and 59.

2.3. Electrical Production

The electrical generation and the plant load factor of the different power plants in Miravalles are shown in Table 4 (ICE(2), 2006). The main power plants have been working at high plant load factors (90% under normal operation conditions), due to their excellent performance, maintenance and the good behavior the reservoir has showed along these years of exploitation.

TABLE 4: Electrical Generation of the Miravalles Power Plants (March 1994 – July 2006).

Units	Generation (GWh)												
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Unit 1	341.7	436.5	464.6	460.2	451.0	446.0	438.7	413.9	450.3	450.1	393.3	453.5	275.1
Unit 2	------	------	------	------	70.6	345.8	344.4	332.4	417.6	436.2	428.1	361.0	269.8
Unit 3	------	------	------	------	------	------	186.0	222.1	224.4	224.1	219.2	215.0	123.0
Unit 5	------	------	------	------	------	------	------	------	------	6.3	144.4	18.1	72.4
WHU 1	4.0	31.5	34.7	26.1	31.6	11.3	7.3	18.3	28.6	27.3	20.4	100.6	16.5
WHU 2-3	------	------	10.3	58.0	38.6	0.7	------	------	------	------	------	------	------
Total	345.7	468.0	509.6	544.3	591.8	803.8	977.9	986.7	1120.7	1143.9	1205.3	1149.0	756.8

3. IMPORTANCE OF THE GEOTHERMAL ENERGY IN COSTA RICA

The installed capacity of Miravalles accounts for about 8% of the country's total installed capacity; however, it represents around 15% of the country's total generation (ICE(2), 2005). Since the geothermal plants produce constantly throughout the year round, they are used as a base for the country's electrical generation, because of the variation in the hydro electrical plants production due to the seasonal variations of the Costa Rica's weather (Figure 4). Also, the geothermal and hydro electrical power plants are intensively used to generate instead of the thermal power plants. Since ICE is the only seller of the electricity to the end users, its final price is directly related with the averaged costs of the all sources. For this reason, the substitution of the most expensive generation sources with geothermal (or cheaper energy sources) is very important for the economy of the country.

The importance of geothermal energy in Costa Rica is increasing. In 2001, geothermal represented the 8.6% of Costa Rica's total electrical production and accounted for 14.2% of the country's total generation. By July 2005, the installed capacity was essentially the same (8.4%) but the generation was 15.3% of the total supplied by the National Electrical Grid or SEN (in Spanish). SEN includes all the electrical generation companies of Costa Rica (public and privates), and the total installed capacity of the country reaches 1961 MW (Figure 4) and generated 8061 GWh in 2004 (ICE, 2005).

Geothermal energy in the country is generated by the 163 MW power plants complex at the Miravalles Field (Figure 5). Due to its strategic importance in the present and future energy supplies for the country, the sustainability of the field is considered and issue of special relevance. The Miravalles reservoir has evolved since the start of its massive production 12 years ago, and different actions and strategies have been and will be implemented for sustaining the steam supply to the power plants and for reservoir management.

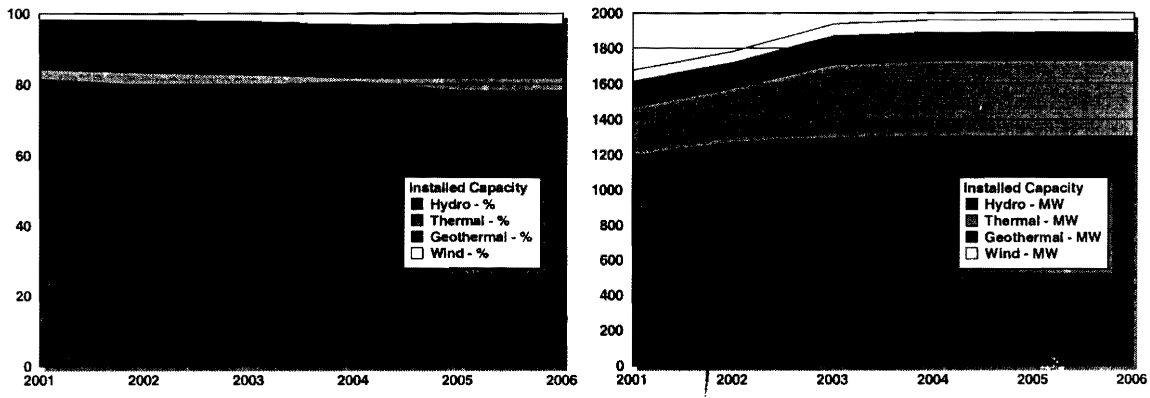


FIGURE 4: Costa Rica Installed Capacity (% and MWe) 2001 – 2006.

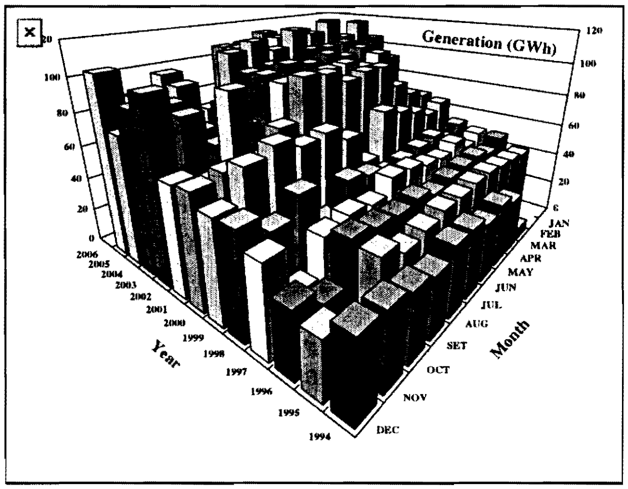


FIGURE 5: Electrical Generation at the Miravalles Geothermal Field.

4. RESERVOIR EVOLUTION

The initial condition of the reservoir showed a similar chloride concentrations over the entire field and calcium-enriched fluids in the western sector. Higher temperatures were present the northeast, and diminished naturally toward the southwest. After the start of commercial exploitation of the field until April of 1999 some arrival of injection fluids coming from the west (wells PGM-22 and 24) toward the center of the field were noticed. This injection return were mixed with more calcium-rich waters belonging to this sector. A general temperature increase along a northeast-southwest trend were observed, indicating that the established exploitation regime at that time could be supported by the natural recharge of the field. The existing injection returns did not show any negative thermal breakthrough.

From May 1999 to October 2002 a increasing influence of the injection return in the southern zone of the field were noticed,, as chemical breakthrough is evident. A temperature and enthalpy decline along a southwest-northeast trend were observed, indicating not only the arrival of the chemical front but also mixing with colder fluids. A production decline in some of the wells were also observed. After that and starting in November 2002, a steady production decline is observed in some of the wells located in the northern sector of the field, in association with a reservoir pressure decline and a strong drop in wellhead pressures (PGM-01, 10 and 63). PGM-01 can no longer produce and PGM-10 is seriously affected. A remarkable steam cap has formed in the northern part of the field due to the massive exploitation. This steam cap seems to be extending to the rest of the field. The effect of the relocation of reinjection toward the western part of the field in late 2002 (to mitigate the pressure drop) has been noticed chemically, but it is still too soon to quantify its effect on the pressure of the reservoir. The effect of this action is less than expected, because of a lack of reinjected water coming from the northern productive wells (at present only one of five wells connected to the separation station in this zone is producing).

Currently, the northern zone of the field is the most strongly affected by the continuous exploitation of the reservoir. The Miravalles field is still able to supply enough steam to produce at its maximum installed capacity (163 MW), but different actions must be taken in order of avoid future problems. Figures 6, 7 and 8 show the variation of some parameters in selected wells of Miravalles, specially the changes observed in some wells of the main productive zone of the field.

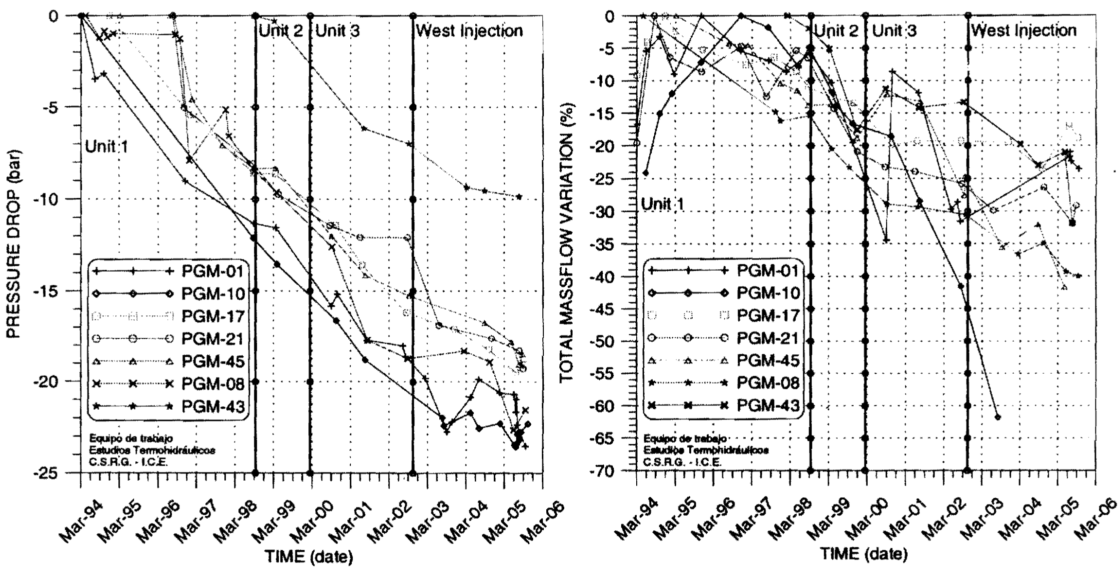


FIGURE 6: Pressure Drop and Total Mass Variation (%) in Some Miravalles Central Zone Wells.

5. FIELD EXPLOITATION AND MANAGEMENT POLICIES

Since the field exploitation began, the Miravalles reservoir has been carefully monitored to assess the changes produced by commercial exploitation. The reservoir response over a thirteen-year exploitation period has evolved notably due to massive production and injection in some sectors of the field. These changes (even though re normal and expected) have to be assessed in order to avoid future problems. The reservoir management in Miravalles includes different actions and strategies that have been implemented for sustaining the steam supply to the power plants and maintaining the productive conditions of the reservoir.

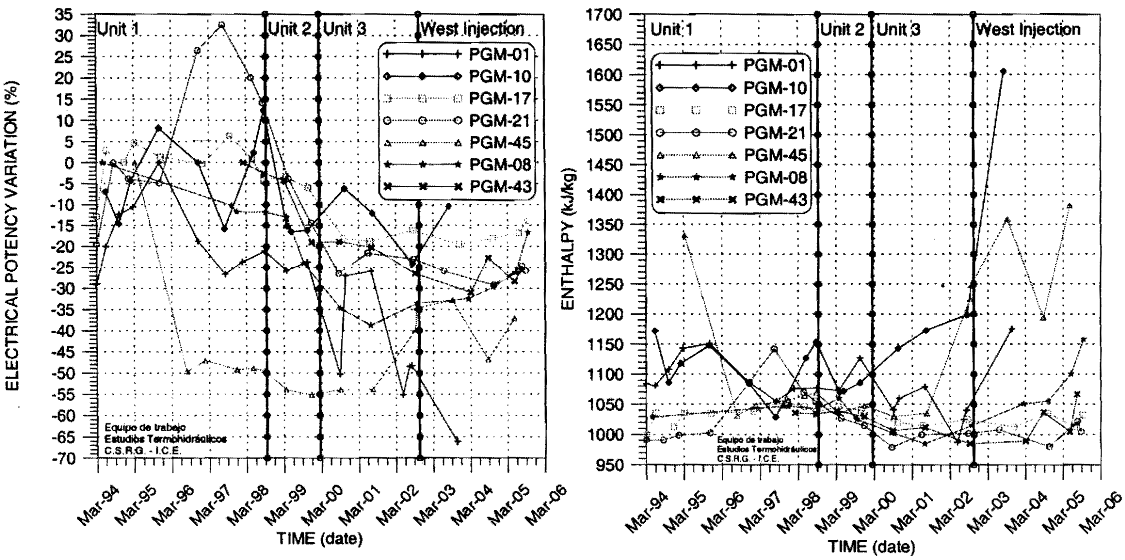


FIGURE 7: Potency Variation (%) and Enthalpy in Some Miravalles Central Zone Wells.

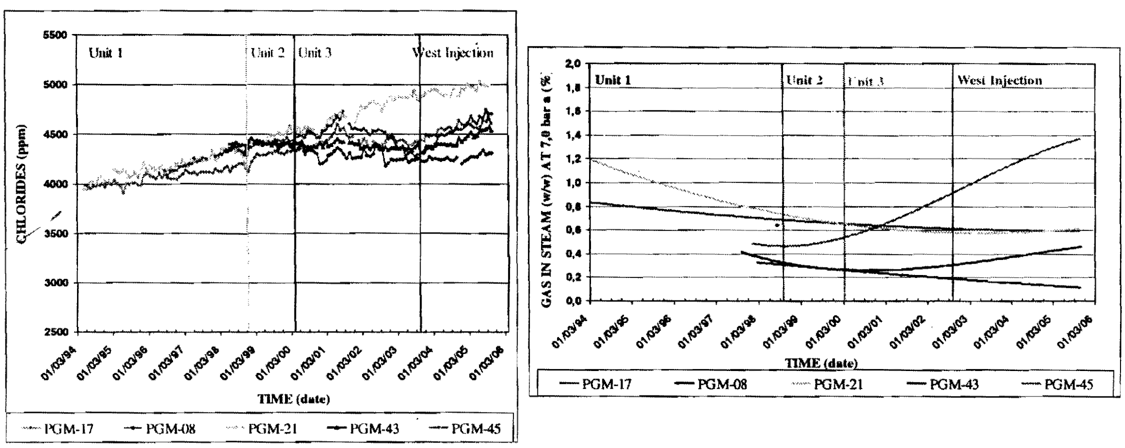


FIGURE 8: Chlorides and Non Condensable Gas Content in Some Miravalles Central Zone Wells.

5.1. Reservoir Management

The Miravalles Field has been monitored after the first power plant commissioning (in 1994) in order to have reference parameters for assessing the changes that would be produced due to the reservoir exploitation. The program includes well output testing, chemical sampling and downhole surveys (flowing temperature and pressure profiles) in all the productive wells every six to twelve months. A control on the calcium, chloride and bicarbonates content are also performed in the production wells, as part of the calcium carbonate inhibition program. Sometimes, the temperature and pressure static profiles, godevils and caliper surveys are taken. A downhole pressure data gathering system monitored the reservoir since June 1994. The reservoir pressure is also measured by taking hydraulic levels in all the idle wells and several tracer tests have been conducted in the field, for tracing the waste brine injection returns and preventing possible problems due to the cooling of the reservoir.

Different numerical models of the Miravalles reservoir have been developed over the years, for forecasting the future behavior of the field according to the data collected. The actual model is a 5110 blocks TOUGH2 numerical model, comprising an area of 12 km long N-S and 9 km long E-W, extending from +100 to –1500 m m.s.l. (1600 m total thickness) and divided into six layers of non-uniform thickness. This model uses the double porosity and two-waters options (this last was used for matching the chloride returns observed in the fluids). This current model (GeothermEx, Inc., 2002) has been used for evaluating different possible exploitation scenarios which have been proposed, i.e. increasing the generation capacity of Unit 5, injecting waste brine into the north zone of the field, moving the wellhead unit to PGM-29, etc.

In the Miravalles Geothermal Field 26 out of 27 producing wells require the application of chemical treatments to the produced waters. The CaCO3 scaling is observed in 23 producing wells and four other production wells present acid fluids that require an acid neutralization treatment. The appropriate chemical treatment of these wells has assured an uninterrupted production for years and continuous operation of the different geothermal plants installed so far (Sánchez et al, 2005).

5.2. Exploitation Strategies

Different exploitation strategies have been implemented in answer to specific situations presented in the field. Those situations range from operational problems to changes in the reservoir (pressure drop, gas content increase, mass production).

5.2.1. Production

Since the northern part of the main productive zone has been greatly affected for the intensive production, the acid aquifer has acquired big importance. The lost in production in this zone has been substituted by the acid wells commissioned. Shifting of the 5 MW wellhead unit to well PGM-29 in the southeastern part of the field (supported by numerical modeling results) is intended to alleviate the mass extraction from the central part of the field, since this unit used to run with steam taken from this zone.

Drilling of new wells or deepening of older ones looking for deeper productive zones is intended to avoid scaling problems into the wells casing and nearer fractures due to the expected local pressure drop and the flashing point reaching the fractures level. An example of this is well PGM-46 (originally producing 11.7 MWe), which was deepened in 2001 from 1198 to 2055 m depth and recovered its production from 4.3 to 10 MWe (Moya and González, 2003).

In some of the wells of Miravalles the mass production is limited by the manipulation of the wellhead valves. The operation of some wells at MDP (maximum discharge pressure) is intended to lower the mass extraction and the local pressured drop observed in these wells and also in order to lift the flashing point into the well, thus avoiding the silica deposition into the fractures.

Another exploitation strategy recently implemented in Miravalles is to decrease the electrical generation during the rainy season, when the hydroelectric power plants of the national grid are working under ideal conditions (rainy season). This help in reducing the reservoir pressure drop by reducing the overall mass extraction.

5.2.2. Injection

The injection into the reservoir have been changed along the exploitation life of the field. At the beginning its most important purpose was to avoid the environmental impact that the waste water could cause and then by operational reasons, but soon the importance in the sustainability became more and more evident when the reservoir showed to be affected by injection returns.

The first change was made when Unit 2 was commissioned in 1998. At that time the most part of the waste water was diverted toward the southern injector wells, and this actions proved to be negative because of the lost of pressure support in the central part of the field and some increase in the thermal breakthrough seen in the southern producer wells. This situation was partly reverted with the shifting of some portion of the southern injection back to the east zone.

The commissioning of Unit 5 has become a new challenge in the injection schemes because of the need of the waste water for feeding this new unit and the need of pressure support in the central part of the field. The geographical location of Unit 5 forces the location of the main injection of the waste water to the south zone; this condition actually is limiting the capacity of sending more water to the eastern zones. One of the new strategies to be implemented in the near future is to build a new injection line at the exit of Unit 5, in order to send more fluid to the eastern injection wells.

By the beginning of year 2003, the northern part of the main productive area showed to be very affected by the productive regime observed. Three wells (PGM-01, 10 and 63) were not able either to produce or stay online due to their low wellhead pressure production. At that time the idle acid wells were not ready for being commissioned, so it was decided to conduct studies in order to inject a part of the waste waters produced by the separation station 7 and try to get some pressure and mass support in this part of the field. It was then carried out some studies involving the geology, geochemistry and reservoir engineering characteristics of this zone and also some numerical modeling simulation runs in order to find the best candidate wells for injection, if any. For this was considered a theoretical injection of 25 to 80 kg/s of 165 °C water in three different wells: PGM-01, 10 and 63. The results showed that well PGM-10, because its centralized location, would be location for better pressure support, and PGM-63 if the concern of a possible thermal impact were the main decision factor (Vallejos, 2005). Other factors considered were the location of surface facilities (separation station, pipelines already build and the ones for be constructed, etc.).

Well PGM-63 was then chosen due to its favorable geographical location and the test started in July 2005, injecting 40 l/s and monitoring the nearby producer wells (water chemistry and occasional temperature and pressure surveys). Further increments in the injection regime (up to 80 kg/s) showed no impact in temperature nor thermal and hydraulic parameters, as the pressure and chlorides parameters in the nearby wells showed (González and Sánchez, 2006). In early 2006, a short production test was done in well PGM-46 and it showed some recovery in its productive parameters. This were expected because of the intensive injection done, but these conditions are not expected to last. Actually, it is implemented a change in the injection scheme by the future use of PGM-01 and PGM-10 (one or both of them) in order to get a noticeable and positive change in the pressure and mass production of this zone. This change is expected to be completed in the next months.

5.2.3. Exploration and Development of Actual and New Zones

The evolution of the Miravalles field and the continuous effort of ICE in assuring an adequate mass production for electrical generation has forced the drilling of some wells for maintenance and to look for new productive zones, since new drilling into the main productive zone of the field will not increase the actual production of Miravalles.

One of these zones is the east-southeast zone that comprises the wells PGM-28, 29, 59, 55 and 35. From geochemical point of view this sector shows some differences regarding the main and acid reservoirs. The main differences are in the high bicarbonates content and their Na/K relationship, which shows an important difference between the geothermometers and the measured temperatures. Similar differences can be seen in the values of calcium and magnesium. For their characteristics, these fluids present a high tendency to form calcium carbonate deposition and a high non condensable gases content in the steam. The first point has been treated successfully with the correct inhibitor dosage, but the later presents a big restriction in the face of the current non condensable gas extraction capacities Units 1 and 2.

Actual and future studies are now oriented to define the dimensions of this aquifer, the stable productive characteristics of their wells and the correct way to handle the high noncondensable gas content (Sánchez et al, 2006 and Cumming et al, 2006). Future drilling in this zone is not intended in first instance to increase but to give support to the current production of Miravalles (163 MW), which has reached its maximum.

6. FINAL REMARKS

Electrical generation in Costa Rica actually relies almost completely in environmental-friendly, renewal type sources. This type of energy accounts for more than 78% of the installed capacity and 96% of the total energy generated. Among them, electrical generation from geothermal has become very important since it has been used as replacement for the thermal power plants and as a basement for the electrical generation.

The Miravalles Geothermal Field has completed more than twelve years of successful exploitation, and the continuous exploration and development has increased its installed capacity from 55 to 163 MWe, accounting for more than 8% of the country's installed capacity, and producing more than 15% of the country's total generation. This position must give the sustainability of the Miravalles reservoir an important subject under the energetic planning strategy of ICE.

ICE have implemented different actions focused on sustaining the steam supply to the power plants and also on reservoir management. So far, these actions have been very successful in sustaining the production of the field to the actual levels but the Miravalles reservoir faces an actual evolution that must be carefully monitored in order to avoid a future decline in production and electrical generation.

The actual knowledge of the reservoir and the evolution trend observed have headed to conclude that the Miravalles field has actually reached its maximum extraction rates, and more steam would be necessary in the future if the reservoir continues with the same behavior actually observed. There are still more zones under exploration (east zone, acid aquifer) which can help (and actually does) to solve the production decline observed in the main aquifer, and in a future to evaluate an expansion of the field if its is proven that these other zones are independent and not following the same declining rates of the main aquifer.

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