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Maintenance of the Production in the Miravalles Geothermal Field, Costa Rica: New Productive Zones

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ABSTRACT

The Miravalles Geothermal Field has operated continually since 1994 when a 55 MWe power plant was commissioned, and has raised its installed capacity up to 163 MWe in the present time. As any other aquifer under exploitation, the sustainability of the resource depends on the exploitation policies and if they are able to let the aquifer to reach a steady state that allows the extraction rates being similar to the recharge rates, without showing a significant reservoir pressure and temperature decrease; at the same time these policies allow to control the derived adverse secondary effects of the chemical complexity of the fluids which in fact affect the production capacity.

The exploitation régime of which the reservoir has been operated affects its future performance and sustainability and it is showing indications of decline. If the reservoir continues to be exploited in the actual régime it could suffer an abrupt decline in its productivity. To assure a continuous production in the current levels, different productive zones and aquifers in the field have been studied. These new productive areas would contribute with new reserves (fluid) and distribute the production in a more extensive area, alleviating the pressure drop and improving the mass and energy extraction processes in the field.

1. INTRODUCTION

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

1.1 The Reservoir

The geothermal reservoir is 800-1000 m thick of the 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. At present there is a tendency for carbonate scaling in the wells. The main aquifer is characterized by a 230-255 ºC lateral flow. A shallow steam dominated aquifer is located in the northeastern part of the field, formed by the evaporation of fluid from the main aquifer that moves along fractures (Vallejos, 1996). Another important sector includes an acid aquifer, yet four out of five wells that have been drilled there to date are systematically neutralized and exploited.

The Miravalles field is associated with a 15 km wide caldera, which has been affected by intense neo-tectonic and volcanic phenomena (Figure 2). The interior of the caldera is in general characterized 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.

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. The acid aquifer is located at the east-northeast (red zone) and the highly bicarbonate east-southeast zone (beige zone, not actually under exploitation excepting for well PGM-29, see section 2.1). The injection zone is located to the west and the south (this last coincides with the zone where the waters exit the exploited reservoir).

1.2 Production History

Table 1 shows the commissioning sequence of the different power plants installed in Miravalles. All the presently operative units are owned by ICE.

1.2.1. Mass Production

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 under full capacity conditions, and 280 kg/s are steam used for generation (Moya and Nietzen, 2005). All the waste water is injected back into the reservoir.

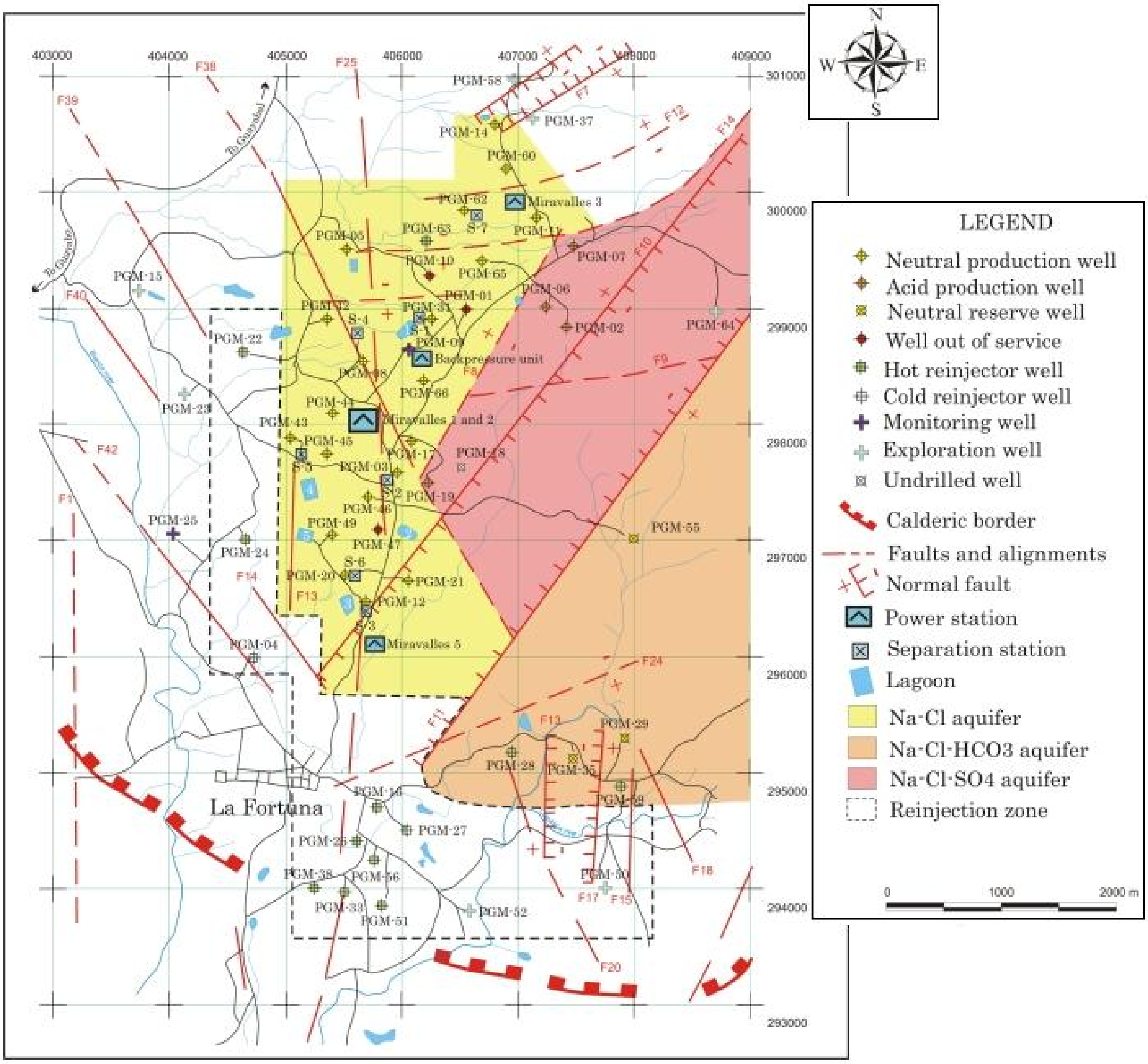


Figure 1: The main features of the Miravalles geothermal field.

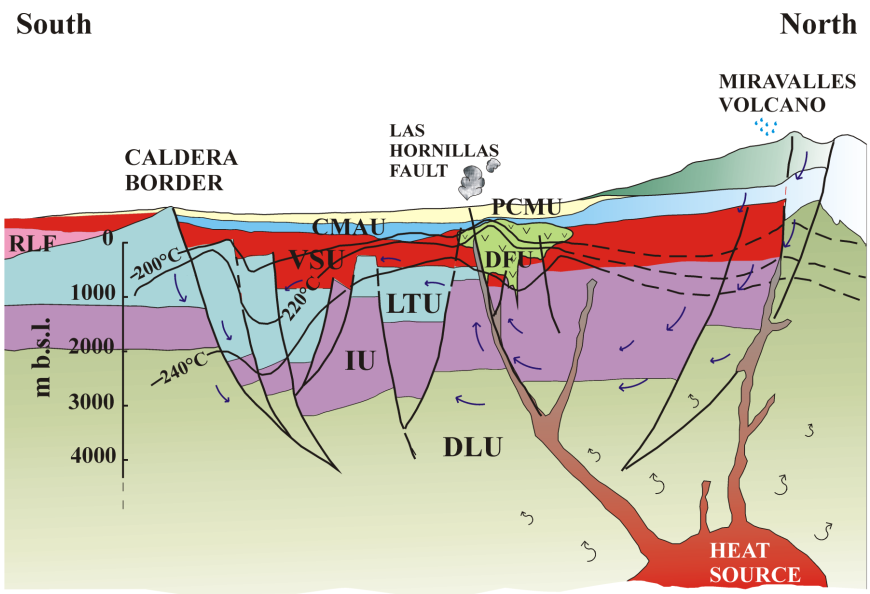


Figure 2: Conceptual model of the Miravalles geothermal field (Vega et al., 2005).

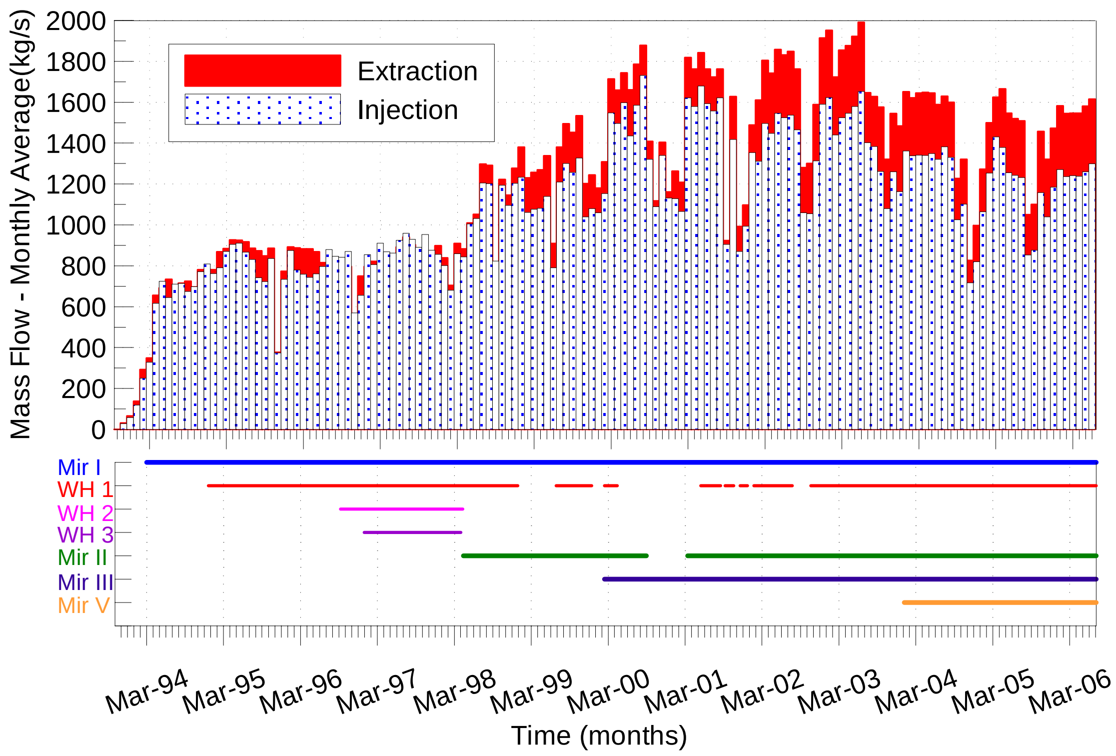


Figure 3: Mass Production and Injection in the Miravalles Field.

Table 1: Generation at the Miravalles Geothermal Field.

Unit	Operator	Power Output (MW)	Operation Time	
			Start	End
Unit 1	ICE	55	03/1994	---
Wellhead 1	ICE	5	11/1994	---
Wellhead 2	CFE	5	09/1996	08/1998
Wellhead 3	CFE	5	04/1997	01/1999
Unit 2	ICE	55	08/1998	---
Unit 3	Geo	29	03/2000	---
Unit 5	ICE	19	12/2003	

Annual maintenance of the different power plants is historically scheduled during the second half of every year; this explains the observed decrease in mass production during the corresponding periods.

1.2.2. Waste water injection

Injection has been an essential part of the Miravalles operation from the beginning. Injection normally accounts for about 83% of the total mass extracted from the field. Injection into the different sectors at the Miravalles Field is shown in Table 2 as a percentage of the total injected mass into the field (Vallejos et al., 2005).

The injection of waste brine has mostly been performed under "hot" condition, which is at a temperature around 165 °C, while a small proportion has been injected under "cold" conditions (temperature less than 60 °C). These conditions changed when the Unit 5 came online as it recovers some of the heat from the waste brine, lowering its temperature to 136 °C. A great part of the total waste brine will pass through Unit 5 and then be injected into the southern injection zone (see Figure 1). The western injection zone will continue receiving brine at around 165 °C.

Table 2: Injection into the Miravalles injection zones.

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%

1.2.3. Electrical Production

The electrical generation, and the plant load factor, for the different power plants in Miravalles are shown in Table 3 (ICE, 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 during the more than 12 years of exploitation.

2. OPERATIVE CONDITIONS OF THE MIRAVALLES FIELD

The producing Geothermal Field Miravalles wells have unwanted side effects during their operation. The wells fed by the main aquifer has a low to medium tendency to the formation of calcium carbonate (5-50 mg of $CaCO_3$ per kg of produced fluid); wells in the acid aquifer area produce an acid highly corrosive fluid, and those producing from the bicarbonate aquifer have a high tendency to form calcium carbonate (70 - 80 milligrams of $CaCO_3$ per kg of produced fluid). This requires that fluids must be chemically treated in depth, to ensure their continued production.

Table 3: 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

Another secondary factor is the unwanted content and increasing trend of non-condensable gases present in the steam, which are 0.2 to 2.4% weight/weight (w/w) in the main aquifer, from 0.9 to 1.75% w/w acid in the aquifer and approximately 3 to 18% w/w in the bicarbonate aquifer. Under the current production configuration and due to the limited design of the extraction capacity of the power plants, the content of gases in the steam delivered to the generation units are near their maximum capacity of extraction and in sometimes this capacity is surpassed. This condition has generated a continuous problem since the power plants have been forced to permanently use the ejectors and the compressors in order to extract the non condensable gases arriving to the turbines and the condensers.

The evolution of the Miravalles field, and the continuous effort of ICE in assuring an adequate mass production for electrical generation, have forced the drilling of some make-up wells as well as a search for new production zones, since additional drilling into the central zones of the field will not increase the actual production in Miravalles. Currently, the northern zone of the field is most strongly affected by the continuous exploitation of the reservoir. The decline in mass production of the main aquifer has been compensated so far by the production of 22 MWe from the acid aquifer. This condition has maintained the high electric generation rates of the Miravalles Field.

2.1 Characteristics of East-Southeast Sector

One of these new zones is the east-southeast zone that contains wells PGM-28, 29, 59, 55 and 35 (beige area in Figure 1). Currently, except for PGM-55, these wells are integrated into the exploitation system. All of them except well PGM-59 (at the time of its initial evaluation) showed injectivity indexes above 15 l/s/bar, indicating the high permeability of this area. Even though, well PGM-59 is actually able to accept near 450 l/s (Hernández, 2009). The temperature range of the wells in this sector is between 228 and 230 ºC, except for PGM-59, which at the time of its initial evaluation showed a temperature of 220 ºC. From the geochemical point of view this sector shows some differences relative to the main and acid reservoirs. The main differences are high bicarbonates content and the Na/K relationship, which shows a significant difference between geothermometer results and measured temperatures. Similar differences can be seen in calcium and magnesium content. The fluids in this sector have a high tendency to form calcium carbonate deposition as well as high NCG content in the steam. The first problem needs to be treated successfully by applying the correct inhibitor dosage, but the latter presents a big restriction in the face of the current limited non condensable gas extraction capacities of Units 1 and 2.

It is important to mention that only the well PGM-29 has had long production periods, which allowed a good characterization. Other wells in this sector have been tested for very short periods, and although data are stable on temperature, enthalpy and mass flow, the non-condensable gases in the steam has not shown a stabilization value. This is an important fact to consider for the possible use of the steam of this zone in a condensing plant.

Actual and future studies are now oriented towards defining the dimensions of this aquifer, the relationship it would have with the main aquifer, the stable productive characteristics of wells drilled into it and the correct way to handle the high non-condensable gas content (Sánchez et al., 2006 and Cumming et al., 2006). Future drilling in this zone is not intended to increase, but rather to support the current rate of production in Miravalles (163 MW), which is believed to have reached its maximum.

2.2 Deep Aquifer

By the year 2001 there were an increasing concern regarding the pressure decline observed in the Miravalles reservoir. This situation moved to consider the possibility of drill new wells deeper than used to be in order to minimize the problems related with the flashing point reaching the permeable zones. The majority of the permeable zones found in the central part of the reservoir were around -198 to -1034 m a.s.l. (Castro, 1999). During the drilling of PGM-44 a deep permeable zone was found at -1404 m a.s.l. and the well became a 4 MWe productor. After that, another deep zone was found in well PGM-46 (-1470 m a.s.l.). Prior that PGM -24 (-1314 to -1384 m a.s.l.) and PGM-25 (-1619 m a.s.l.) crossed also deep permeable zones but for different reasons there were not considered an important issue. These results showed the existence of a deep aquifer related with the main aquifer of Miravalles (yellow zone in Figure 1) in the zone around -1400 to -1600 m a.s.l.

3. EXPLOITATION POSSIBILITES OF THE DEEP ZONE

Recovering production losses for some wells in Miravalles has been undertaken by either acidizing or through deepening of wells. Well PGM-46 started as an 11.7 MWe producer, but its production rate began to slowly decline and several years later it was down to 4.3 MWe. Deepening the well was the option chosen for recovering the lost mass flow, after geoscientific information from nearby wells was studied to infer what would likely be encountered below the wells' initial depth (1,200 m). The hope was to intercept the recently hypothesized deep zone. Between July and September 2001 the well was re-completed to intercept a deeper, permeable fracture. Well PGM-46 now actually produces about 10 MWe (Moya and González, 2003).

The extension of this deep zone is not completely known, but the results showed that it can be found at least in the western part of the main aquifer. Further studies must be oriented in knowing its extension. The exploitation possibilities of this zone resides in the future deepening of the wells located in this area, say PGM-43, 45, 46 and 49 just to name a few of them. Also, the drilling of new makeup wells with a planned deep targeting. Having this deep zone reached will alleviate the impact of the pressure decline of the reservoir, since the flashing point won't reach the permeable zones and the lost in production due to the deposition of carbonate scaling in the fractures won´t be present. This resource would be used for recovering the productive levels of the Miravalles Field rather than increase them.

4. EXPLOITATION POSSIBILITES OF EAST-SOUTHEAST ZONE

The bicarbonate aquifer shows good conditions to being exploited for production maintenance purposes; that is, not intended to increase the Miravalles Field capacity but to feed additional mass to the actual power plants. Even though, two different production scenarios have been envisioned and are discussed in the following paragraphs. The other scenario included the possibility of increase the installed capacity of Miravalles, provided that the Miravalles reservoir is able to sustain the new installment.

4.1 Utilization of the East-Southeast Sector Resource for Feeding Units I and II.

Based on the currently drilled wells, the neutral bicarbonate aquifer covers the east-southeast sector of the Miravalles Field not even being clear its eastern boundary. Despite its large size, it has only been considered using the wells located in the section known as the "window" (a small area not covered by a recent lava flow) to the vicinity of the well PGM-55 as replacement wells for the units 1 and 2. This is considered due to the nature of the topography and distance between wells and power plants (beige zone in Figure 1).

With the aim of modeling the possibility of using the steam from the area of the window in the Miravalles Units 1 and 2 the following scenarios were considered:

Unit 1: to replace the steam necessary for generating 15 MWe coming from the south for their equivalent in mass from the eastern sector (PGM-55 and nearer wells to be drilled), starting in the year 2010. It was considered the values of gas in the steam of 5 and 7% w/w (Figure 4).

Unit 2: to replace the steam necessary for generating 15 MWe coming from wells PGM-31 and PGM-45 for their equivalent in mass from the eastern sector (PGM-55 and nearer wells to be drilled), starting in the year 2010. It was considered the values of gas in the steam of 5 and 7% w/w (Figure 5).

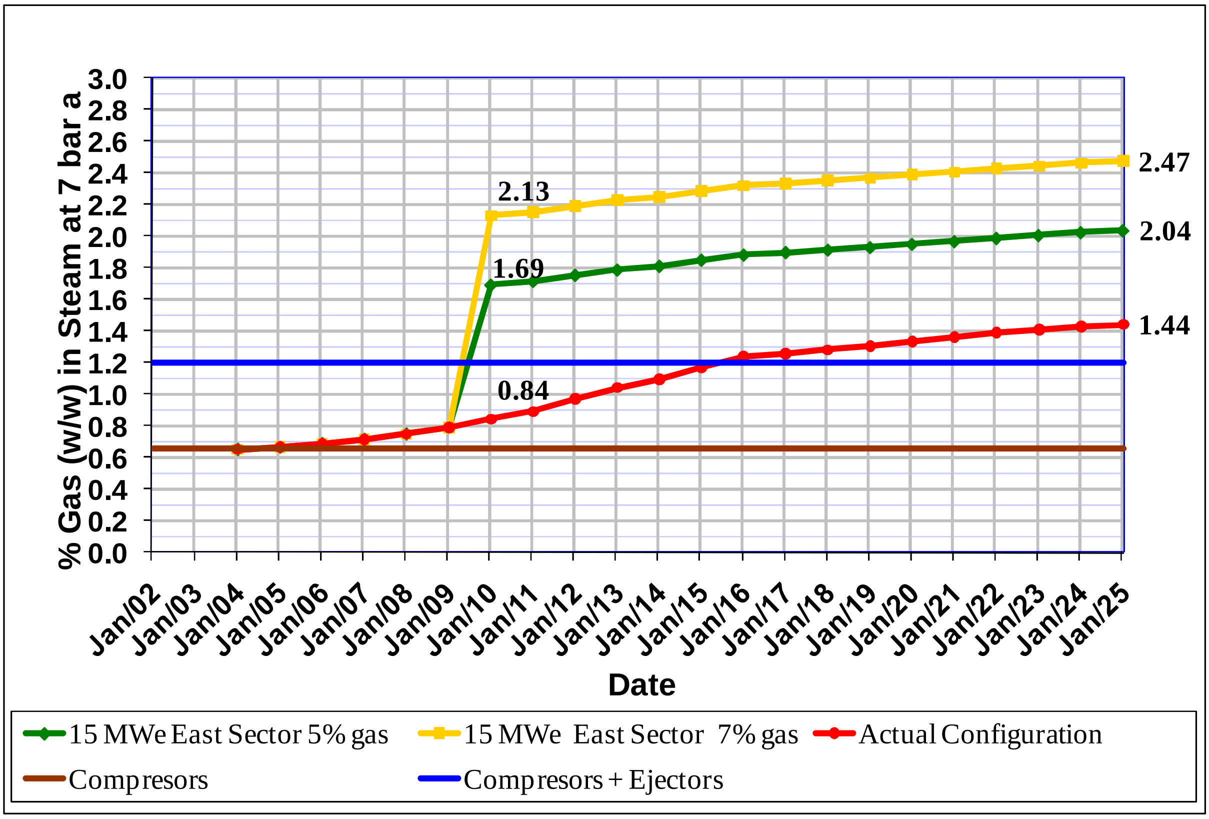
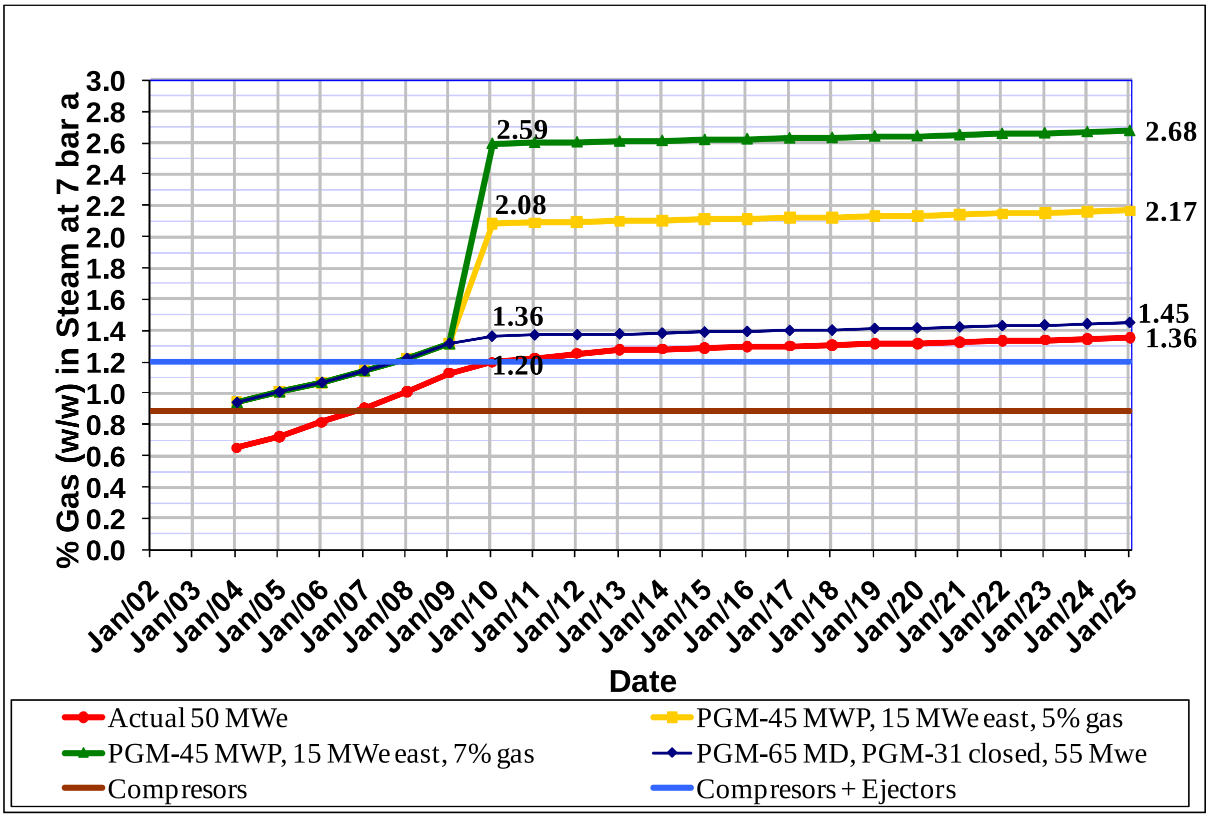


Figure 4: Evolution Estimation of Gas Content in Steam Delivered to the Unit 1.



Notes: MWP- Maximum Wellhead Pressure; MD – Maximum Discharge

Figure 5: Evolution Estimation of Gas Content in Steam Delivered to the Unit 2.

When comparing the evolution trend of the content of NCG for both scenarios mentioned in the above paragraphs, it appears that the use of the fraction of steam coming from the east sector demands that the power plants increase their gas extraction capacity by 100% with respect to the actual condition of the system. It must be added the fact that the short period of assessment of PGM-55 does not guarantee that the maximum content of non-condensable gases in the steam would be maintained at 7.0% w/w. This means that for any increase in gas the mass of steam sent to those units must decrease in order to maintain the evacuation capacity of the extraction system.

4.2. Utilization of the East-Southeast Sector Resource in Back Pressure Units.

The independence of the back pressure units allows their location anywhere in the east-southeast zone. Because the gas content in the steam does not affect the production of these plants, it is possible to take advantage of the current condition and even accept a possible trend towards higher gas content. The limitation of these units is their low efficiency (about 50% for a condensing power plant), which would mean that the profitable use of the resource in this sector only through this kind of plants would be a waste of steam thus causing a possible unacceptable pressure decline. This approach would increase the installed capacity of Miravalles even though is not desirable at this point. Some studies including extended exploitation of the aquifer and simulation runs must be done with an updated model in order to confirm a positive scenario to increase the installed capacity in this area.

Using the back pressure system is not new in Miravalles, as the well PGM-29 had a 5-MWe unit in the period between January 1997 and April 1998 and continuously since December 2006. This unit used to run on steam taken from separation station 1, but shifting of the wellhead unit to well PGM-29 was supported by numerical modeling results, intending to alleviate the mass extraction load from the central part of the field.

4.3. Utilization of the East-Southeast Sector Resource in Binary Systems.

The use of a 230 ºC temperature and a high non-condensable gases content in steam resource in combined cycle binary systems must be analyzed, both for the independence of these units and for their high performance compared with backpressure units, and also for the feasibility of operating with fluid with these characteristics.

The area of the window (after the appropriate studies) might be an appropriate site for the development of a pilot scheme allowing long-term assessment of existing resources by installing a small binary type combined plant. For this it can be used the resources from the existing well PGM-55 and a possible new neighbor productor well toward the north, and reinjecting in a new well to be drilled in the periphery of the window, headed south. This approach would work in a small area without extensive surface infrastructure. This approach also would increase the installed capacity of Miravalles.

5. CONCLUSIONS AND RECOMMENDATIONS

The Miravalles Field is a complex reservoir which contains several aquifers that although they present similar thermal-hydraulic conditions, have different chemical characteristics.

The main aquifer of Miravalles (neutral sodium-chloride type) is well defined. This is not the case of the acidic aquifer and the bicarbonate aquifer. The latter has not defined its eastern boundary. Studies should be conducted to determine the eastern boundary of the bicarbonate aquifer in order to quantify the resource.

The Miravalles Field has showed signals of being impacted due to the high exploitation levels maintained over the years. The mass extraction levels have been maintained thanks to the exploitation of the acid zone, which has fed the fraction of mass lost that the main aquifer is no longer able to deliver. Also, the pressure decline observed has increased other negative effects, like the increase in non condensable gas fraction and the danger of calcite scaling deposition in fractures produced when the flashing point reaches the permeable zone. A deep zone has been found at least in the western productive area of the main aquifer. This resource would be used to sustain the field production of the Miravalles Field rather than increase it.

Of the wells drilled in the bicarbonate aquifer, only the well PGM-29 has had an adequate period of production which allows their evaluation. The remaining wells (PGM-28 PGM-35 PGM-55 and PGM-59) must be subjected to more extensive evaluation period, to determine their stable thermal, hydraulic and chemical parameters.

The non-condensable gas content in the steam is a key factor in the possible use of the bicarbonate aquifer to feed Units 1 and 2, since the technology used for their exploitation (condensing) is dependable on their final values and stability. The current capacity of extraction of non-condensable gases in the steam of Units 1 and 2 does not allow the use of this steam. Currently, it is undertaken an increase in the capacity of the NCG extraction system of Units 1 and 2 (designing stage).

Due to the high content of non-condensable gases in the steam and their changes in time, topography conditions and the distance of this sector from the central sector of the field, it is recommendable the use of small independent systems for evaluation purposes and use of resources in key sectors of the east-southeast zone. To this effect it should be analyzed the viability of using units either back pressure or binary combined-cycle, depending on their technological compatibility with the fluid and the performance of them. This approach does not consider the idea of not increasing the installed capacity of Miravalles. This is a sensible issue to be considered in the viable and sustainable exploitation strategies to be implemented in the Field. Special care must be taken in monitoring this sector looking for some relationship between the main aquifer and the bicarbonate aquifer.

REFERENCES

Castro, Sergio: Caracterización de las zonas permeables de los pozos de Miravalles, Instituto Costarricense de Electricidad, Área de Geociencias, Grupo de Ingeniería de Yacimientos. Internal report (In Spanish), October 1999. (1999).

Cumming, William; Di Pippo, Ronald; Duffield, Wendell; Horne, Roland; Truesdell, Alfred: Final Report, *Miravalles Geothermal Field 20th Advisory Consultant Panel Meeting*, Instituto Costarricense de Electricidad, Costa Rica, March, 2006. (2006).

Hernández, Orlando: Personal communication about information of field logs for well PGM-59 from 1998, (2005).

ICE: SIGEST (Sistema de Indicadores de Gestión), UEN Producción, Instituto Costarricense de Electricidad. Internal communication. November, 2006. (2006).

ICE/ELC: Proyecto geotérmico Miravalles: Informe de factibilidad 3ª y 4ª Unidad. Instituto Costarricense de Electricidad and ELC Electroconsult. *Report GMV-2-ELC-R-12400(R01)*. San José, Costa Rica. (In Spanish). (1995).

Moya, Paul and González, Carlos: Successful Deepening of Well PGM-46 at the Miravalles Geothermal Field, *Geothermal Resources Council Transactions*, Vol. 27, October 2003. (2003).

Moya, Paul and Nietzen, Federico: First Ten Years of Production at the Miravalles Geothermal Field, Costa Rica, *Proceedings World Geothermal Congress 2005*, Antalya, Turkey, April 2005. (2005).

Sánchez, Eddy; González, Carlos and Vega, Eduardo: Campo Geotérmico Miravalles. Aprovechamiento del recurso del sector este – sureste, *Miravalles Geothermal Field 20th Advisory Consultant Panel Meeting*. Instituto Costarricense de Electricidad, Costa Rica, March, 2006. (In Spanish). (2006).

Vallejos, Osvaldo: A Conceptual Reservoir Model and Numerical Simulation Studies for the Miravalles Geothermal Field, Costa Rica. *Geothermal Training in Iceland 1996. UNU G.T.P. Report 18*, United Nations University – Geothermal Training Programme, Reykjavík, Iceland. (1996).

Vallejos, Osvaldo; Sánchez, Eddy and González, Carlos: Reservoir Management at the Miravalles Geothermal Field, Costa Rica, *Proceedings World Geothermal Congress 2005*, Antalya, Turkey, April 2005. (2005).

Vega, Eduardo; Chavarría., Leyner; Barrantes, Manuel; Molina, Fernando; Hakanson, Edward; Mora, Oscar. 2000. Geologic Model of the Miravalles Geothermal Field, Costa Rica, *Proceedings World Geothermal Congress 2005*, Antalya, Turkey, April 2005. (2005).