PROCEEDINGS, Thirtieth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 31-February 2, 2005
SGP-TR-176

NON-CONDESABLE GASES AT THE MIRAVALLES GEOTHERMAL FIELD

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ABSTRACT

The Miravalles Geothermal Field has been producing electric energy since March 1994. It has provided steam for Unit 1 (55 MWe) since 1994, a Wellhead Unit (5 MWe) installed in 1995, Unit 2 (55 MWe) in 1998, Unit 3 (29 MWe) in 2000 and Unit 5 (19 MWe, a binary plant) in year 2004. The total installed capacity (163 MWe) has been increasing since 1994, and so have the non-condensable gases in the steam. With these increases, the compressors at the generating units have reached their maximum gas capacity without ejectors, and therefore options to decrease the non-condensable gases have been analyzed. Field management strategies have been implemented in order to minimize the total amount of non-condensable gases that are sent to the generating units.

INTRODUCTION

The Miravalles geothermal field is located on the southwestern slope of the Miravalles volcano. The extent of the geothermal field already identified is greater than 21 km^2, of which about 16 km^2 are dedicated to production and 5 km^2 to injection. There are 53 geothermal wells (Figure 1), including observation, production and injection wells, whose depths range from 900 to 3,000 meters. The production wells produce between 3 and 12 MW each, and the injection wells each accept between 70 and 450 kg/s. The reservoir has a temperature of about 240 ^{o}C and is water-dominated (Moya, 2003).

The Miravalles geothermal field has been producing since 1994. Normally, two or three production wells supply two-phase fluid to each separation station. Seven separation stations now supply the steam needed for Unit 1, Unit 2, Unit 3 and one active Wellhead Unit. At present there is a need to supply enough steam to produce 55 MWe (Unit 1), 5 MWe (Wellhead Unit), 55 MWe (Unit 2) and 29 MWe (Unit 3), for a total of 144 MWe. This capacity was increased to 163 MWe when a bottoming-cycle

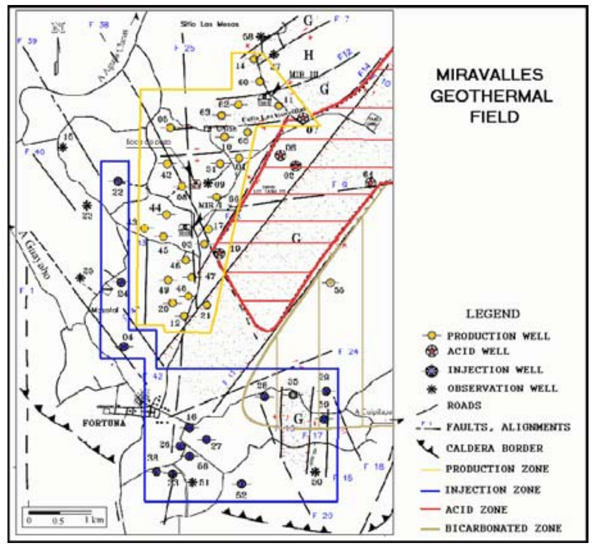

Figure. 1. Miravalles Geothermal Field.

binary plant came online in January of 2004. As indicated in Table 1, two wellhead units from the Comisión Federal de Electricidad (Mexico) were in operation while Unit 2 was being built, but these have been decommissioned.

Plant Name	Power (MW)	Belongs to	Start-up Date	Final Date
Unit 1	55	ICE	3/1994	
WHU-1	5	ICE	1/1995	
WHU-2	5	CFE	9/1996	4/1999
WHU-3	5	CFE	2/1997	4/1998
Unit 2	55	ICE	8/1998	
Unit 3	29	ICE (BOT)	3/2000	
Unit 5	19	ICE	1/2004	

Table 1: Units at the Miravalles geothermal field.

In Table 1, the abbreviations stand for: ICE - Instituto Costarricense de Electricidad; CFE - Comisión Federal de Electricidad (México); WHU - Wellhead Unit; and BOT – build-operate-transfer.

NON-CONDENSABLE GAS EVOLUTION

Data from the first wells drilled at the Miravalles geothermal field showed that there was a wide range of concentrations of non-condensable gases in the steam. As new wells were drilled, it was determined that, under natural conditions, the field´s non-condensable gas content ranged from 0.4 to 1.2 % w/w. Figure 2b shows the natural distribution of non-condensable gas contents. In Figure 2a the values are disturbed by air-drilling, which had begun in 1992.

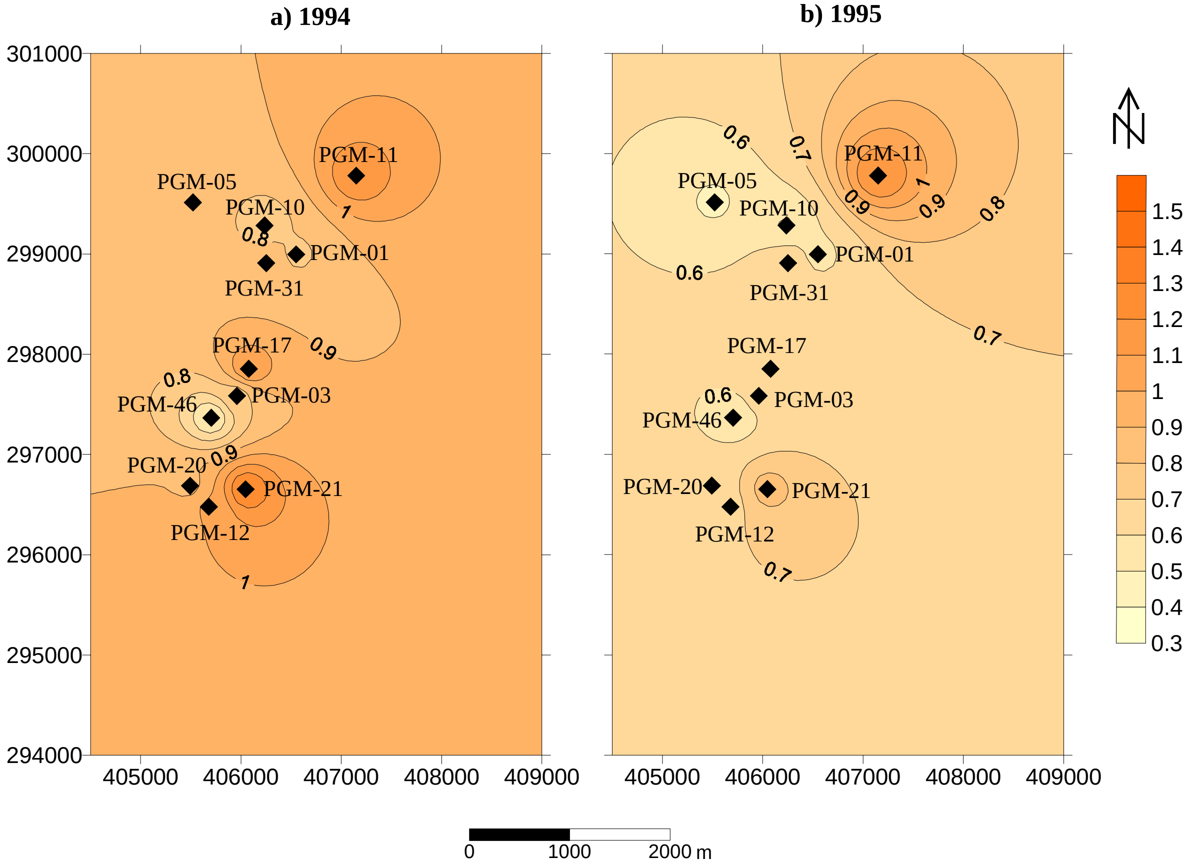

Figure. 2. Distribution of non-condensable gases in 1994 and 1995 (% w/w in steam separated at 7 bar a)

All values of non-condensable gas concentration presented here are in weight percent (weight/weight). In Figure 2b, it can be seen that in 1995 the non-condensable gases in the northern part of the field (at wells PGM-11and PGM-10) were 1.21 % and 0.48% respectively, in the central part (at PGM-46) they were 0.52 %, and in the southern zone (at well PGM-21) they were 0.86 %. Almost every well fell within the range mentioned above (Sánchez, 2004a).

Non-condensable gas contents have been affected during commercial operation by the following factors:

1. The "bubble effect", which takes place when drilling with aerated fluids (to protect open fractures) causes the upper layers of the reservoir to become richer in non-condensable gases, due to the carbon dioxide (CO_2) present in the reservoir as well as the nitrogen (N_2) provided by air injection when drilling. Figure 3 shows the non-condensable gas content behavior in well PGM-21 from 1994 to 2004. The gas content was close to 1.3 % initially and decreased a year later to around 0.8 % (Figure 3, yellow box).

A similar behavior of the non-condensable gases is shown in Figures 4 and 5, in which the wells PGM-10 (northern zone) and PGM-20 (southern zone), respectively, experienced an increase followed by a decrease within a year.

2. Changes in the hydrogeology of the system due to continuous exploitation cause fluids which may have high or low gas contents to move from one sector of the field to another.

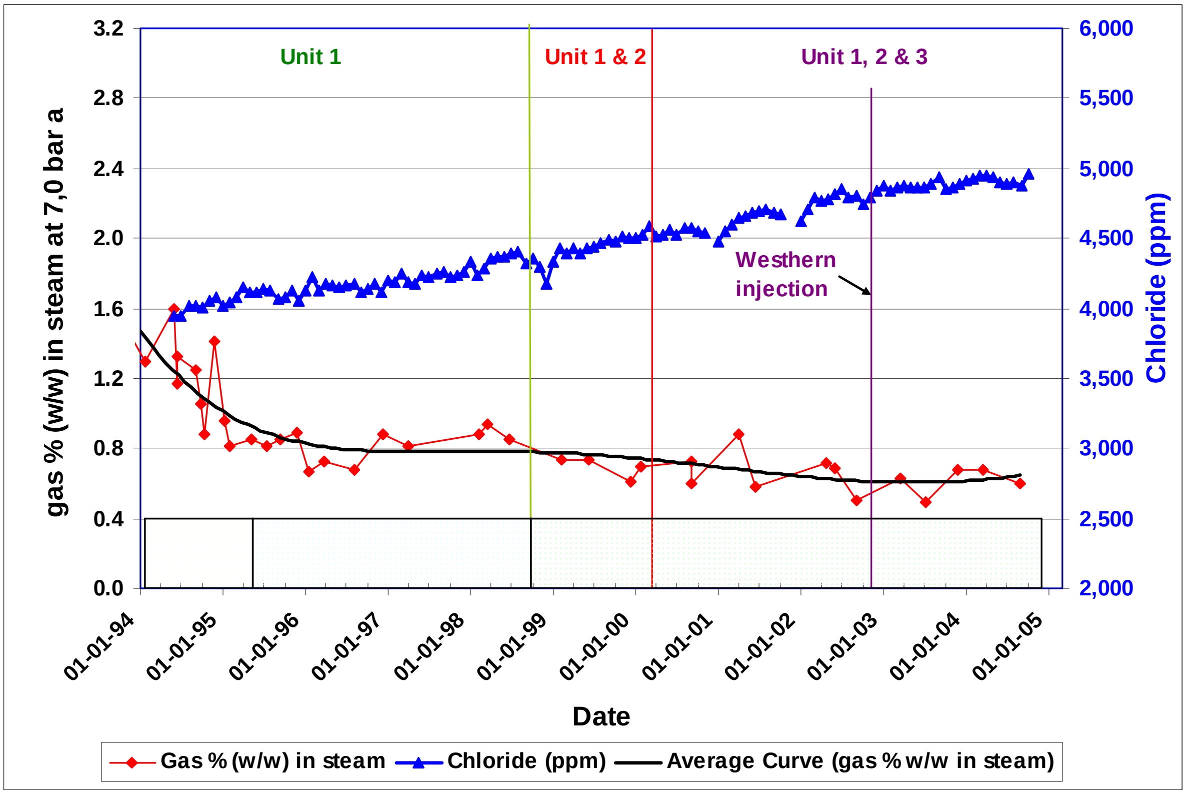

Figure. 3. History of non-condensable gases in well PGM-21 (% w/w in steam separated at 7 bar a)

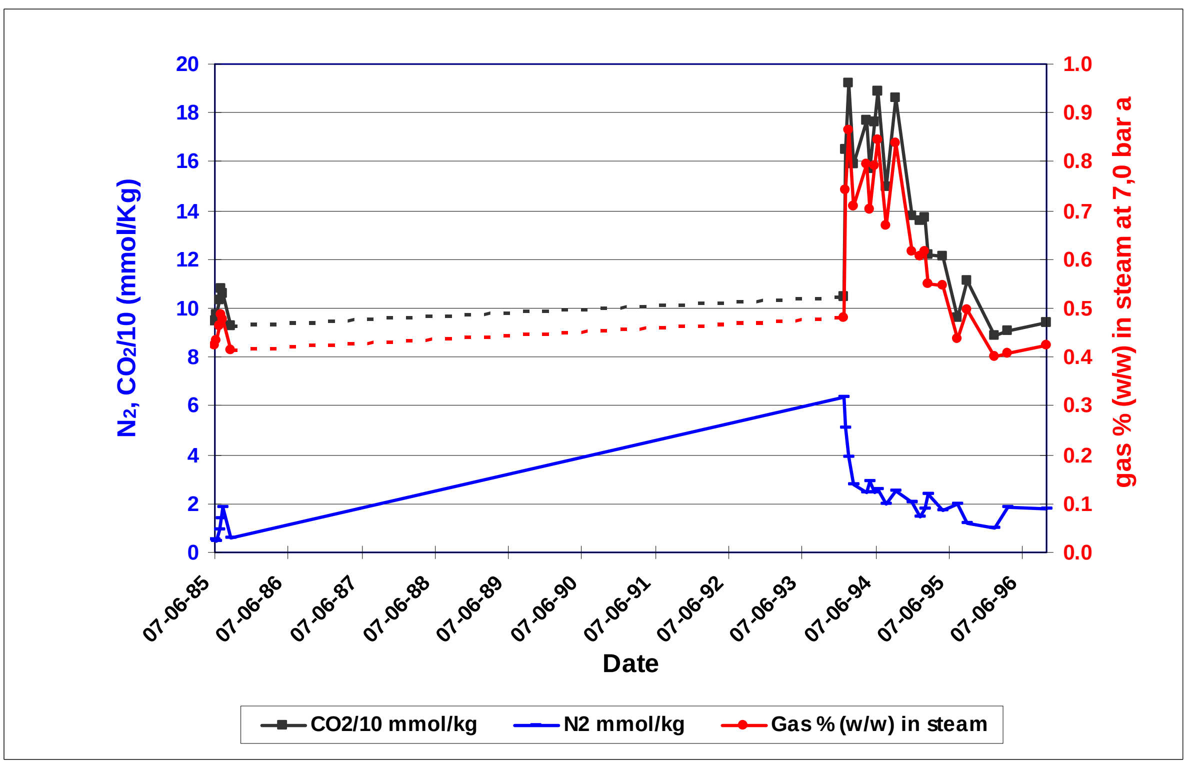

Figure. 4. History of non-condensable gases in well PGM-10 (% w/w in steam separated at 7 bar a)

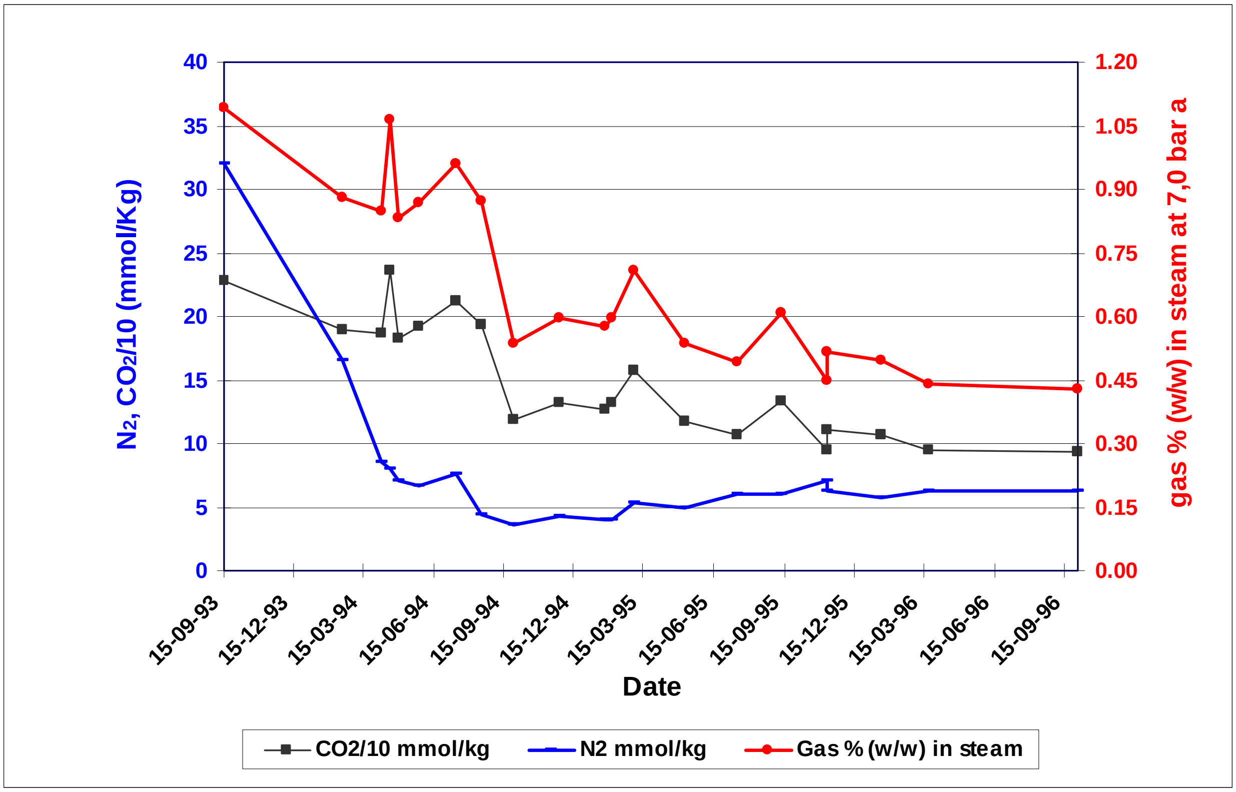

Figure. 5. History of non-condensable gases in well PGM-20 (% w/w in steam separated at 7 bar a)

3. Injected fluids, which are degassed, travel back to some production sectors, causing a decrease in the non-condensable gases in those particular zones. In Figure 3 (green box) it can be seen that the non-condensable gases decreased from the end of the year 1999 to the end of 2004. The decrease coincided with an increase in the chloride content, also shown in Figure 3 (green box), which indicates that injected water was reaching that sector of the production zone

4. Sustained production due to continuous exploitation generates a pressure drawdown in the reservoir and an increase in the steam fraction. This increases the steam fraction, but at the same time increases the non-condensable gases in the steam. Figure 6 shows the behavior of the non-condensable gases in well PGM-10. The well was drilled during 1984, but air-drilling in the surrounding wells (PGM-09 and PGM-31) increased the non-condensable gases to a value close to 0.8% in early 1994. The gases then began to decrease (until the end of 1997) and finally increased from the end of 1997 to the end of 2004. The increment in the non-condensable gases coincided with an increase in enthalpy values for the same period (1997 to 2004). In well PGM-10, the pressure drop (close to 2 bar/year from 1998 to 2003) caused the wellhead pressure to decrease, impeding PGM-10 from supplying its two-phase flow to the gathering system, which finally caused the well to stop producing.

The bubble effect was transitory; that is, it increased the non-condensable gases up to 100% in some cases, but it disappeared within the following year, leaving non-condensable gas content of the particular zone at its natural level. The other three effects (hydrogeology, injected fluids and pressure drop) have been present since production started and have influenced the increase in non-condensable gases one way or another. Figures 7 and 8 show that, in several production wells and reservoir sectors (respectively), the non-condensable gases have been increasing from 1994 to 2004. It can be seen from these two figures that the non-condensable gas increase in the reservoir has taken place since the three major units (Units 1, 2 and 3) began been producing continuously.

The bubble effect due to air-drilling, as well as the hydrogeologic effects and pressure decline caused by the continuous exploitation of the reservoir, have produced a strong increase in the non-condensable gases at the Miravalles geothermal field. Only the effect of injected fluids has tended to decrease the non-condensable gas content.

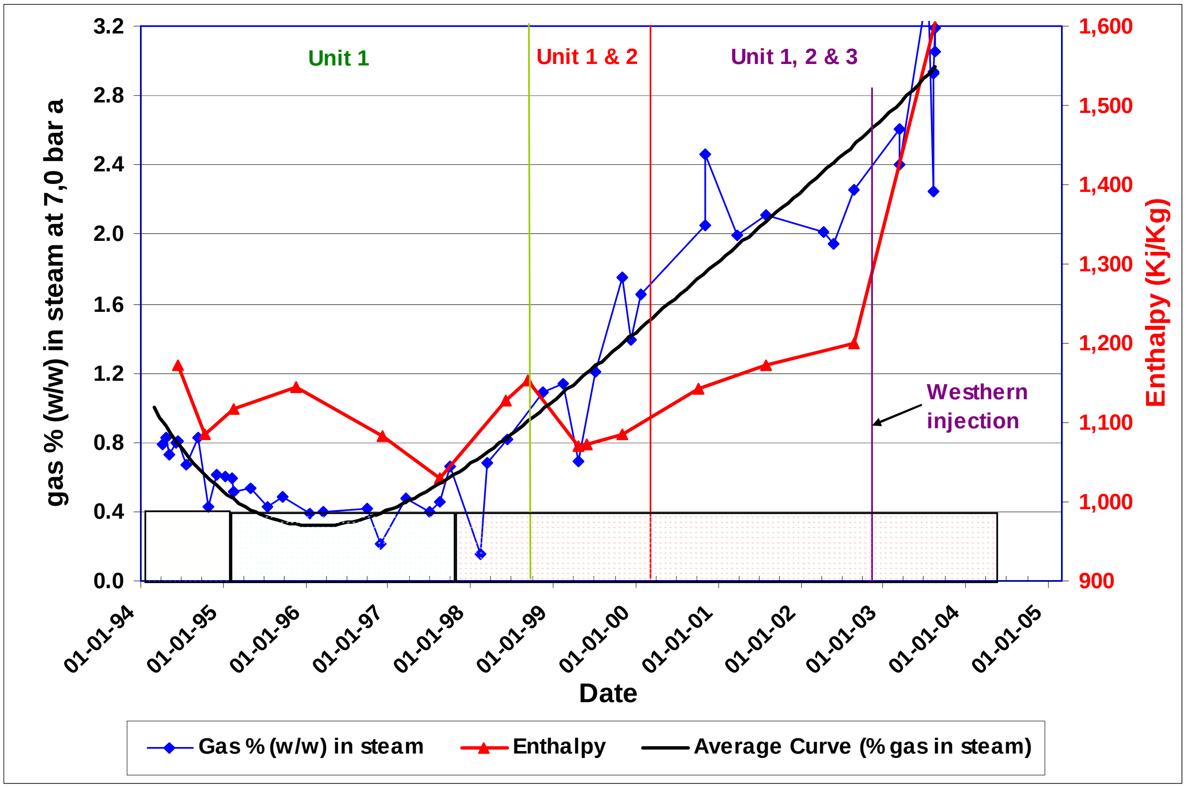

Figure. 6. History of non-condensable gases in well PGM-10 (% w/w in steam separated at 7 bar a)

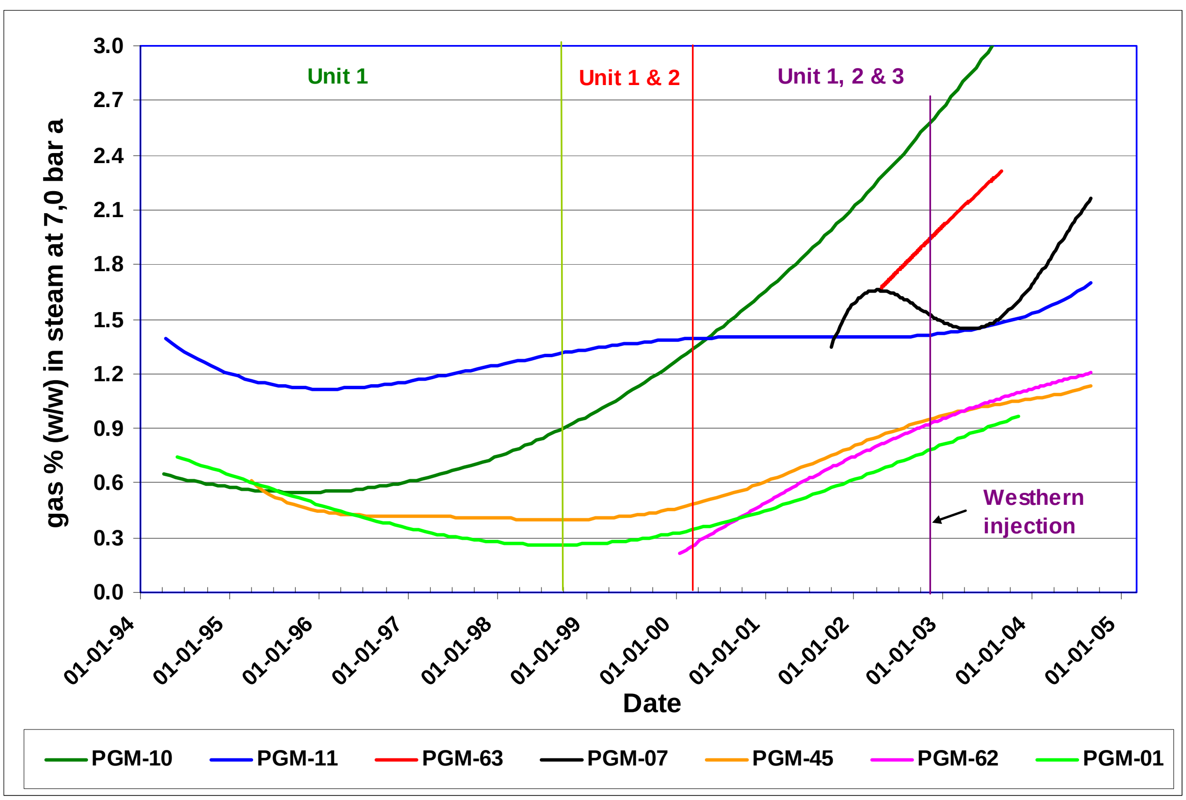

Figure. 7. History of non-condensable gases from 1994 to 2004 (% w/w in steam separated at 7 bar a)

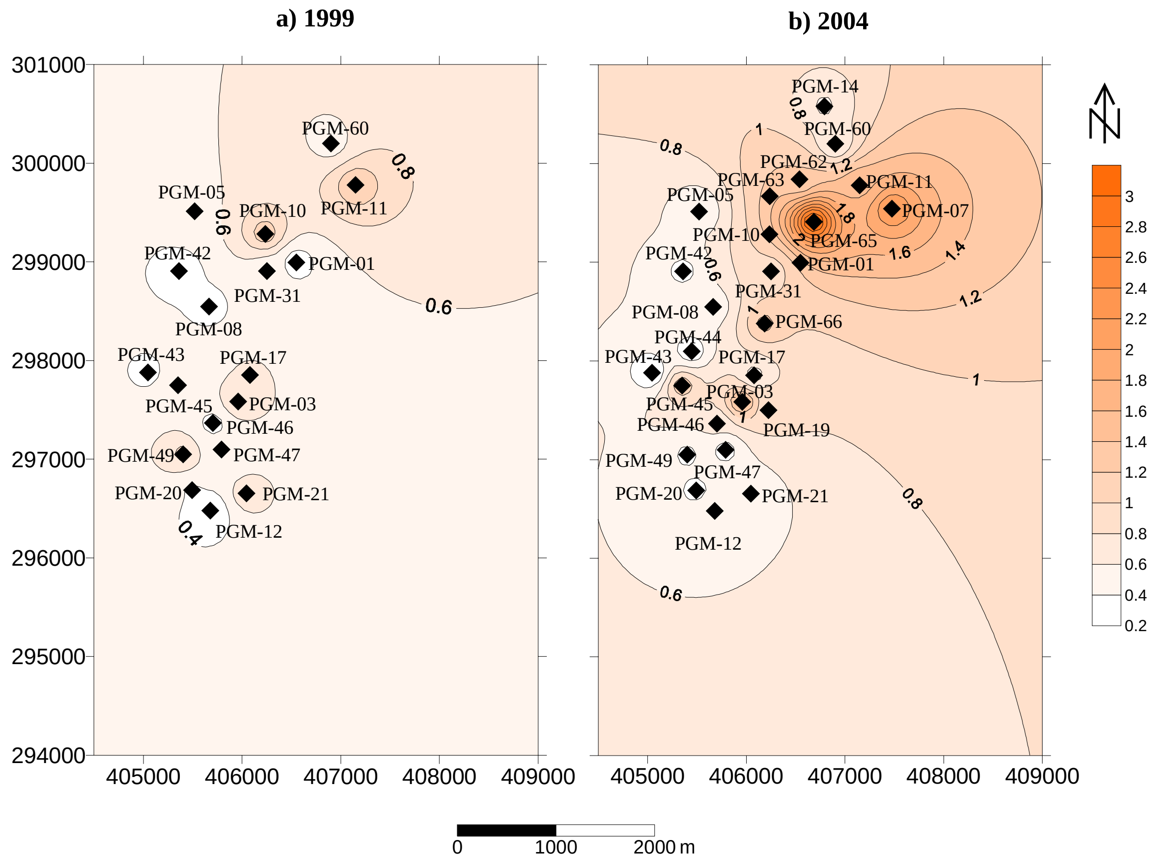

Figure. 8. *Distribution of non-condensable gases from 1999 to 2004 (% w/w in steam separated at 7 bar a)*

FIELD STRATEGIES

The continuous exploitation of the reservoir has tended to increase the non-condensable gases in the reservoir, which in turn has provoked the establishment of a program of detailed monitoring of the non-condensable gases at each well in order to determine the principal causes of the increase, and also the implementation of injection and production strategies to improve the current operating conditions.

The studies that have been carried out have indicated that the principal cause of the increase in non-condensable gases is the pressure decline of the reservoir. In order to minimize this tendency, three different strategies have been or will be implemented. First, by increasing the volume of fluids injected in the western sector (wells PGM-22 and PGM-24), it was possible to decrease the non-condensable gases in the vicinity of well PGM-45 and also in all of the wells located in the western sector. Figure 9 shows that well PGM-45 had a trend of increasing non-condensable gases from early 1999 to late 2003. Diverting more fluid to the western sector caused an immediate decrease in the non-condensable gases reported in this well (a positive effect). Also, the enthalpy began to decrease as a consequence of the arrival of injected fluids in the reservoir near well PGM-45.

Since positive results have been obtained by injecting hot fluids in the western and southern parts of the production zone, in the near future it is planned to inject more hot fluids into PGM-63, which could contribute to stopping the current pressure drop as well as decreasing the non-condensable gases in the northern zone. Wells such as PGM-01, PGM-10 and also PGM-63 were initially production wells (in 1994), but due to the pressure drop in the northern zone they have had to be taken out of production.

Second, the studies carried out have indicated that the non-condensable gases were increasing rapidly in the northern part of the production zone, that is, near wells PGM-11, PGM-60 and PGM-62. It has been necessary to produce these wells at a minimum flow rate in order to reduce the pressure drop and consequently the non-condensable gas contents. The resulting deficit in steam supply for Unit 3 (located in the northern sector) is compensated for by steam from the central part of the field. This strategy has at least allowed the non-condensable gas content in that particular area to be kept constant. Third, two existing acidic wells (PGM-02 and PGM-06) are planned to be placed online to extract fluids from the "acidic zone" instead of the main production zone. The production from the acidic zone will add to the steam supply in the northern zone (Unit 3), and will stabilize or slow down the pressure decline and consequently moderate the increase in non-condensable gas content in that sector of the reservoir.

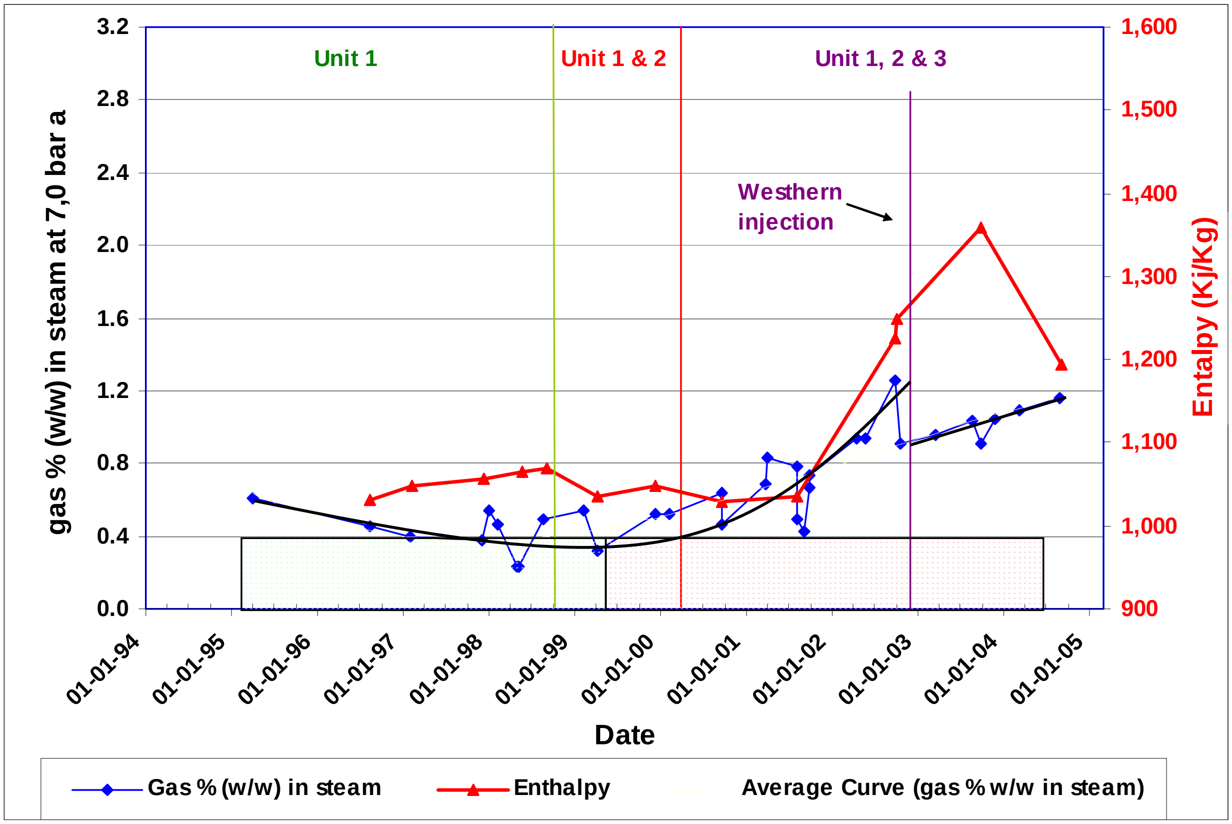

Figure. 9. History of non-condensable gases in well PGM-45 (% w/w in steam separated at 7 bar a)

IMPROVEMENTS

The strategies described in the above section have allowed optimization of the available steam supply for the generating plants. A new strategy has been established for managing the steam supply from the field. Initially (in 1994) there was no particular strategy for supplying steam to the various units, but now it is important to manage the supply based on non-condensable gas contents, in order to maximize the final power output.

The compressor capacities for the main units are 0.66% (Unit 1), 0.88% (Unit 2) and 1.5 % (Unit 3). If the non-condensable gas content is higher than the compressor capacity, then the ejectors provide the extra capacity needed to process the steam. Unfortunately, the ejectors require some of the supplied steam to operate, decreasing the efficiency of the energy generation.

Higher compressor capacities were specified for the new units coming online, but nevertheless those capacities are becoming too small to process the current levels of non-condensable gases being sent to the units.

Initially, separation stations 1, 2 and 3 supplied their steam to Unit 1, while separation stations 4, 5 y 6 supplied their steam to Unit 2. Separation station 7 supplies steam to Unit 3, but this unit can also receive steam from a pipeline coming from separation station1.

Figure 10 indicates that, by the end of 2003, the compressor capacity of Unit 1 (0.66%) was insufficient for the non-condensable gases coming from separation stations 1 (1.66%), 2 (1.0%) and 3 (0.46%), with a weighted average of 0.94%. On the other hand, the compressor capacity of Unit 2

(0.88%) was much higher than the capacity required for the steam from separation stations 4 (0.37%), 5 (0.75%) and 6 (0.44%), with an average of 0.58%.
After studying the case and looking for the best option, it was decided to interchange separation stations 1 and 4. Beginning in early 2004 the steam coming from separation station 1 was sent to Unit 2 and vice versa, that is, the steam from separation station 4 was sent to Unit 1. The interchange resulted in a better distribution of the non-condensable gases among the compressors (Figure 11).

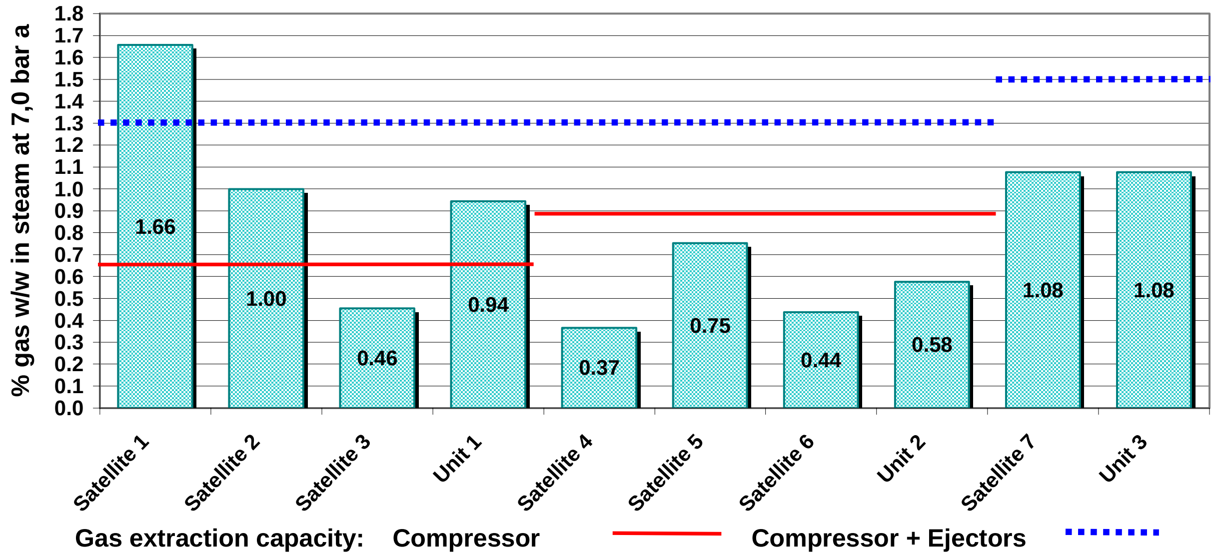

Figure. 10. Non-condensable gases per satellite in 2003 (% w/w in steam separated at 7 bar a)

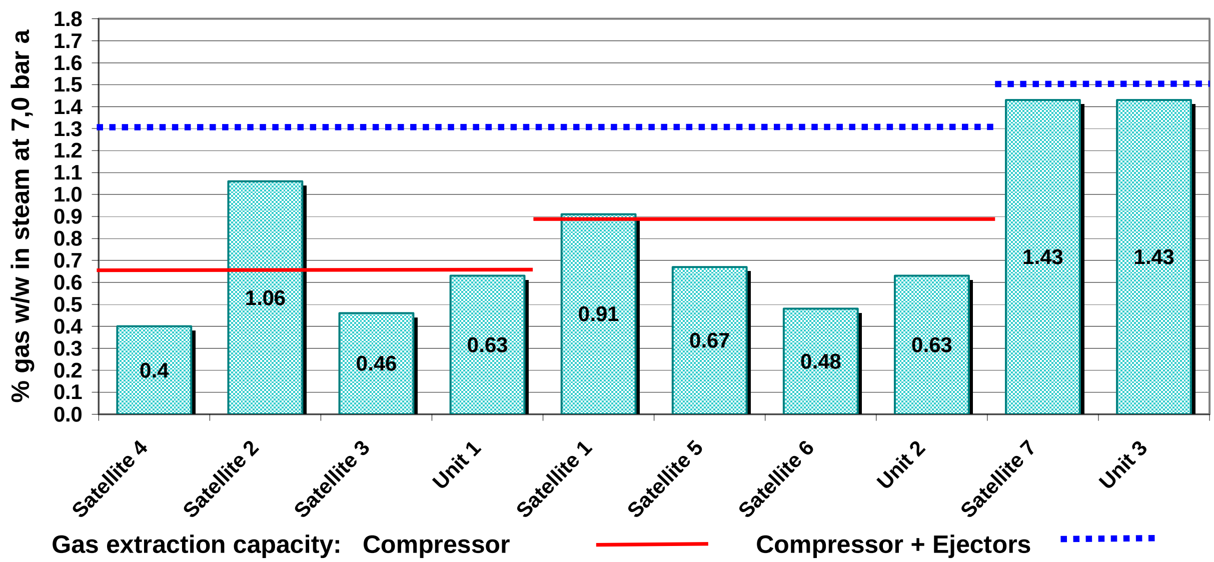

Figure. 11. Non-condensable gases per satellite in 2004 (%w/w in steam separated at 7 bar a)

The effect of the switch can be observed in Figures 12 and 13. Figure 12 shows the measured non-condensable gas data, the average curve for the measured data and the maximum compressor capacity at Unit 1. Once the interchange was made, a decrease in the total non-condensable gas content was observed (Figure 12). In contrast, Figure 13 shows an inverse effect, that is, an increase occurred after switching the non-condensable gases from the separation stations 1 and 4. Since the non-condensable gas content in the reservoir keeps increasing, due to continuous exploitation, the gas content at the three units has consequently increased (Figures 12, 13 and 14).

Even though interchanging the separation stations had a positive effect, at present the non-condensable gas contents are getting close to the maximum compressor capacities at Units 1, 2 and 3 (Figures 12, 13 and 14).

In order to fully utilize the compressor capacities at Units 1 and 2, there is the option of installing a set of valves (upstream of the steam collectors of these Units) that would allow the steam from separation stations 1 and 4 to be variably distributed to Units 1 and 2. This would permit the non-condensable gas levels to be matched as closely as possible to the available compressor capacities.

The second and most expensive option would be to increase the non-condensable extraction capacity of the main units. This can be done by: a) increasing the current capacity of the compressor (improving it), b) adding a vacuum pump to the system, c) increasing the existing ejectors (increasing the amount of steam required per ejector), or d) buying a new compressor with the required capacity.

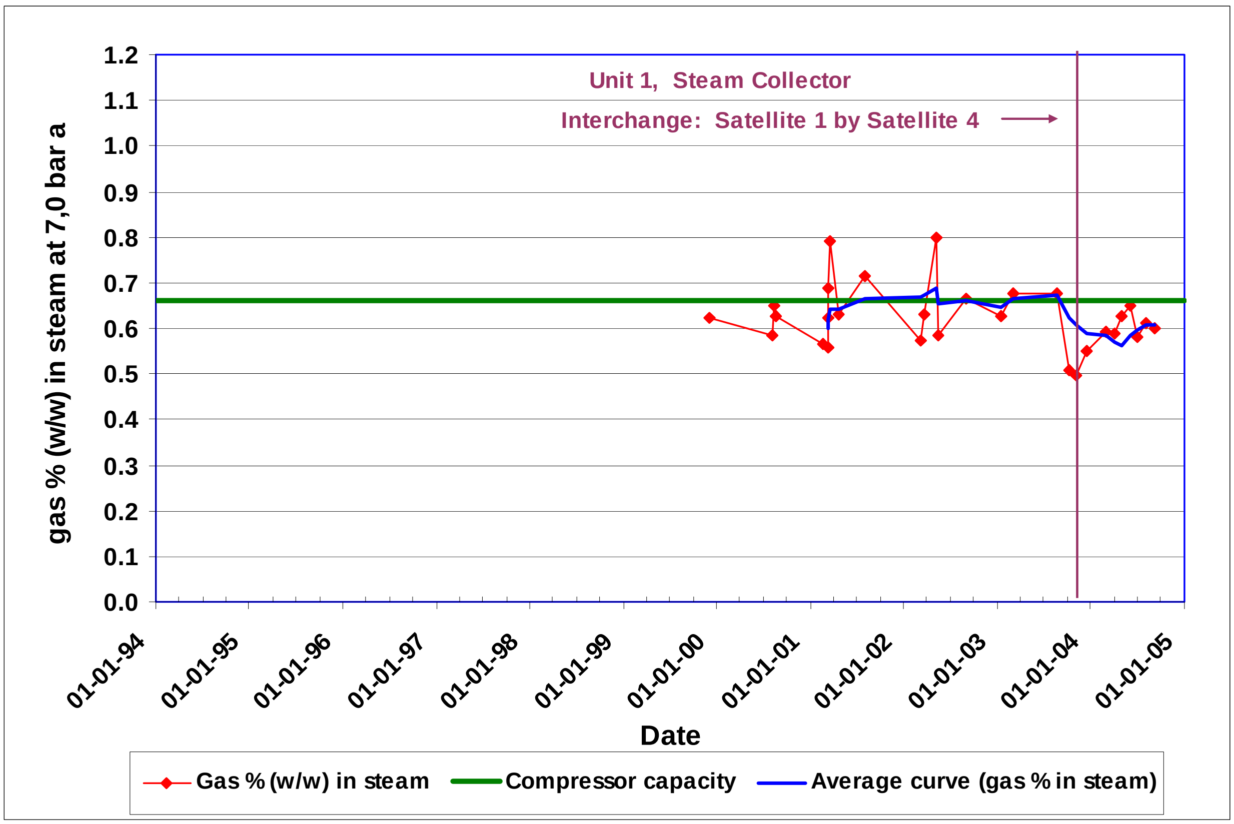

Figure. 12. History of non-condensable gases at Unit 1 (% w/w in steam separated at 7 bar a)

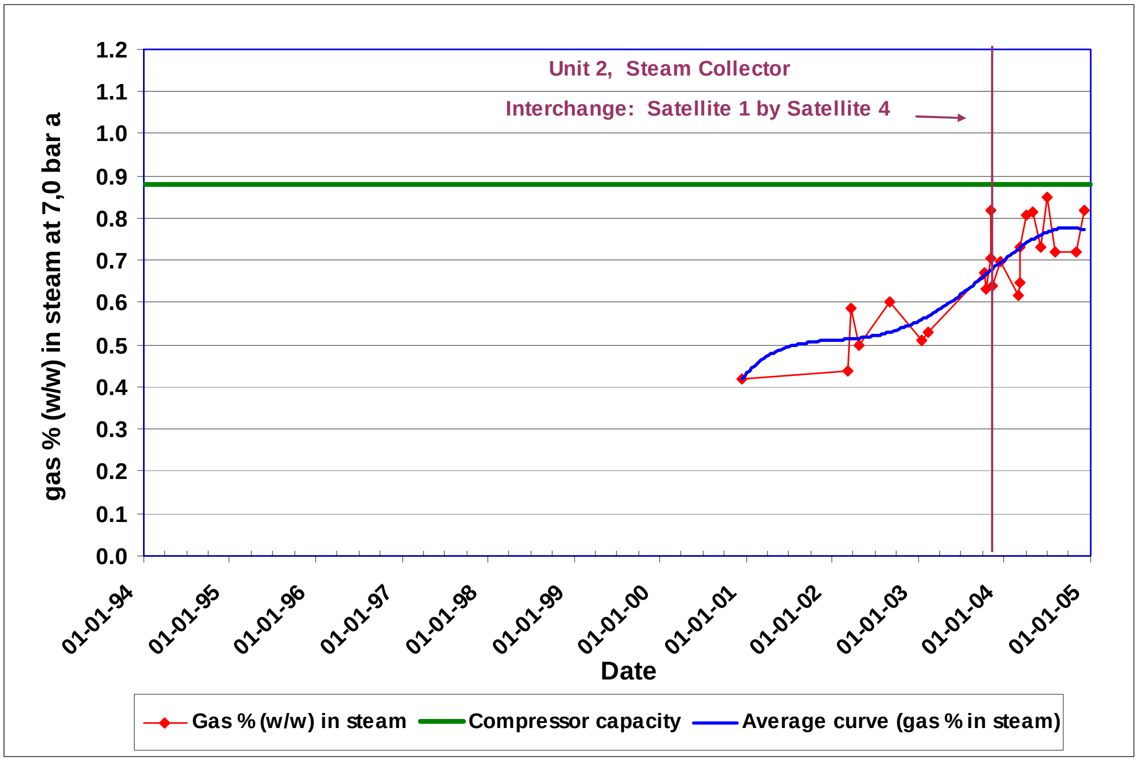

Figure. 13. *History of non-condensable gases at Unit 2 (% w/w in steam separated at 7 bar a)*

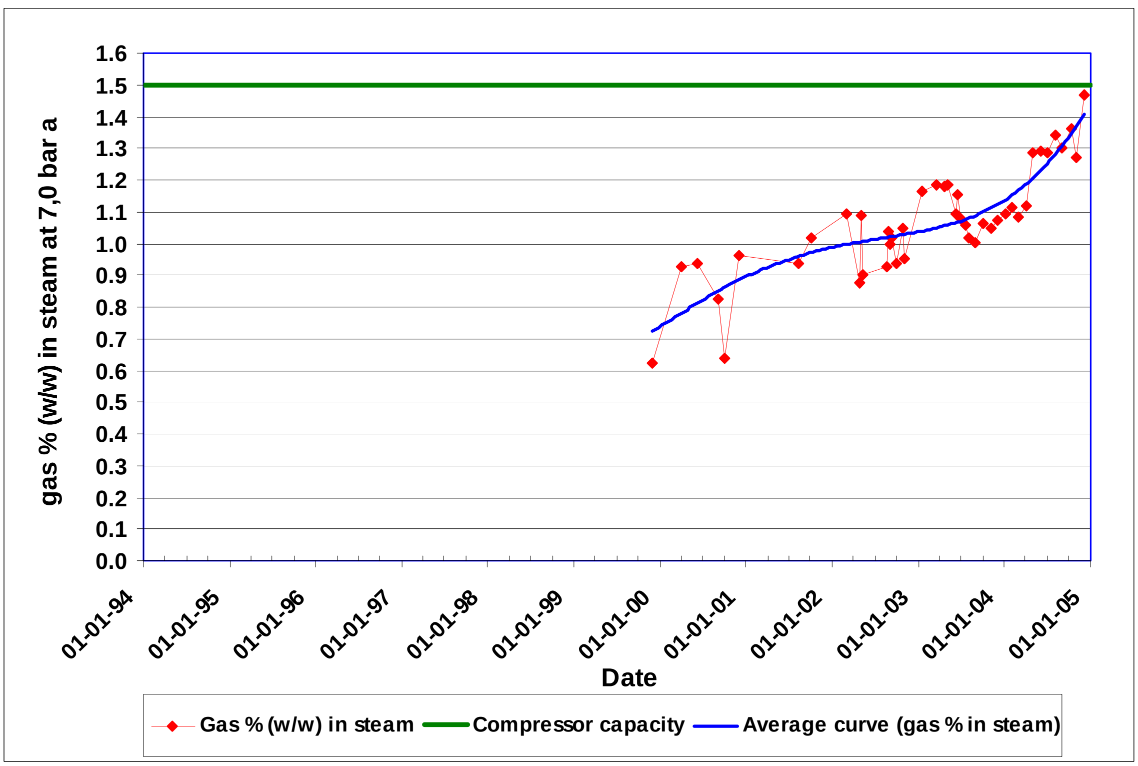

Figure. 14. *History of non-condensable gases at Unit 3 (% w/w in steam separated at 7 bar a) (Sánchez, 2004b).*

FINAL REMARKS

Air-drilling caused a temporary increase in non-condensable gases in the Miravalles reservoir that lasted for about a year.

The arrival of the injected fluids to some production sectors has contributed to a decrease of the non-condensable gases in those sectors. So far, most of the production wells in the western and southern sectors have been benefited from hot injection.

Hot fluid injection into PGM-63 should contribute to stopping the current pressure drop as well as decreasing the non-condensable gases in the northern zone.

Minimum flow production from the wells located in the northern sector has at least allowed the non-condensable gas content in that particular area to be kept constant.

Wells PGM-02 and PGM-06 are planned to be placed online to extract fluids from the "acidic zone" instead of the northern sector. This will allow a reduction of both, the pressure drop and the non-condensable gases in this part of the reservoir.

The pressure drop in the reservoir, due to continuous exploitation, is the principal cause of the increase in the non-condensable gas content of the system.

Interchanging the fluids from separation stations 1 and 4 contributed to obtaining a better distribution of the non-condensable gases at Units 1 and 2.

At the present non-condensable gas levels, the compressors of the main units are very close to their maximum capacities. The trend of increasing non-condensable gases suggests that in the near future the current compressor capacities will be exceeded.

A set of valves installed upstream of the steam collectors of Units 1 and 2 will allow diversion of part of the non-condensable gases to the compressor that is not operating at its maximum capacity, thus optimizing the current compressor capacities.

Under normal exploitation of the reservoir, it is expected that the trend of increasing non-condensable gas contents is going to persist. Investments in higher extraction capacities are foreseen at the generating units.

ACKNOWLEDGEMENTS

The authors thank Roger Henneberger (GeothermEx, Inc.) for editing and improving the manuscript.

REFERENCES

Moya, P., (2003), "The Costa Rican Geothermal Energy Development," *The IERE Central America Forum Transnational Electrical Interconnections and Sustainability in Central America*, Session 2, November 24-25, 2003. San José, Costa Rica.

Sánchez, E. (2004a), "Evaluación y tendencias del contenido de gases en el vapor entregado a las unidades 1 y 2 de Miravalles, periodo 2000-2004," *ICE Internal Report*, Equipo de Geoquímica, Area de Geociencias, 18 de setiembre de 2004.

Sánchez, E. (2004b), "Evaluación del contenido de gas en el vapor entregado a la Unidad 3 de Miravalles y pozos del Satélite 7, causas y consecuencias," *ICE Internal Report*, Equipo de Geoquímica, Area de Geociencias, 31 de octubre de 2004.