Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Commercial Production Wells Acid 15 Successful Years of Activity, Miravalles Geothermal Field, Costa Rica

Jessica Arias Hernández, Yalile Torres Mora, Eddy Sánchez Rivera

ICE, UEN PySA, CSRG, Apartado postal 10032-1000, San José, Costa Rica

jarias@ice.go.cr; ytorres@ice.go.cr; esanchezr@ice.go.cr

Keywords: acid fluids, commercial production, neutralization, NaOH, Miravalles Geothermal Fields, Costa Rica.

ABSTRACT

The main reservoir fluids Miravalles Geothermal Field are neutral Na-Cl. In the east-northeast of the field were drilled four wells, which produce fluid Na-Cl and pH between 2.3 to 3.2. Due to capacity presented by these wells, studies were conducted to develop a system that would allow neutralization of this commercial integration. The results demonstrated the feasibility of the neutralization system and three of these wells have been incorporated into commercial production, being one of them as a reserve. As a secondary effect of the neutralization process, the formation of deposits of complex amorphous silica and anhydrite is generated. Initially, it was required in six-month periods perform mechanical cleaning process in each well. A study to optimize the pH, allowed to determine the appropriate pH at which deposit formation is minimized and the minimum degree of corrosion is obtained. From this study wells have remained in continuous production. This year marks 15 years of commercial integration of wells in Miravalles acids, which has generated savings of 21.7 million dollars in annual thermal generation. At the same time contribute to the environment, representing 18.1 MW have been stopped to extract the neutral site of Miravalles, contributing to the sustainability of the resource.

1. INTRODUCTION

The Miravalles Geothermal Field (MGF) is located (Figure 1) in the northwest part of Costa Rica. This field has a major reservoir of liquid dominance with sodium-chlorinated fluids composition of neutral pH, which have a tendency to calcium carbonate scale within the wells. However of the 56 wells drilled, 4 of them have a different chemistry of fluids, characterized by sodium-chlorinated acidic fluids.

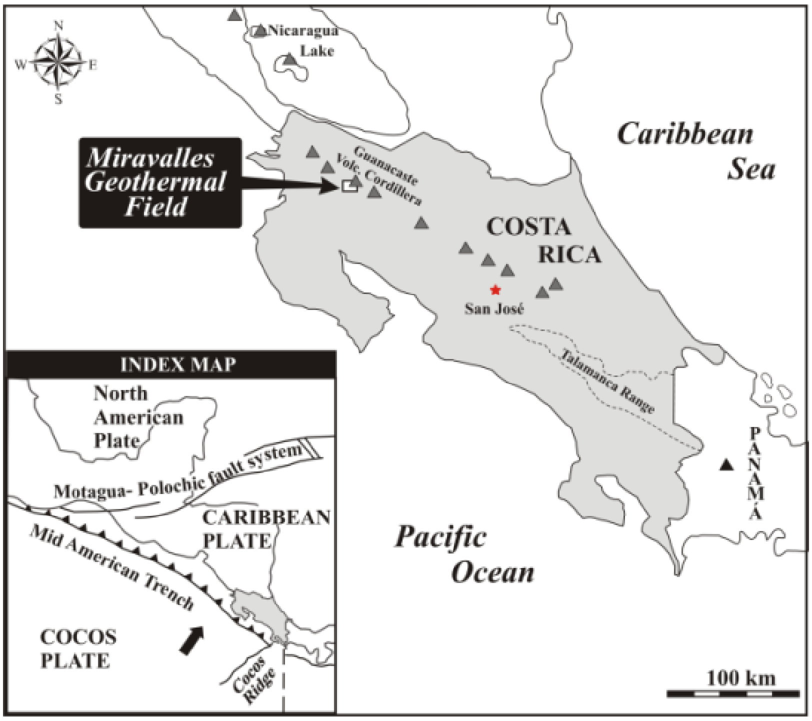

Figure 1: Location map (modified from Vega et al. (2005))

This group belongs to the wells in the northeast sector of the field, and corresponds to the PGM-02, PGM-06, PGM-07 and PGM-19 wells (Figure 2). The chemical properties of this area are similar to the main reservoir, differing mainly by their low pH (2.4 to 3:4), high sulfate content of 200 to 400 ppm and their low content or absence of bicarbonate, the percentage of gas in the steam varies from 0.8 to 1.5%, the chemical differences are shown in Schoeller Diagram (Figure 3, used data are in neutralized conditions). These wells are currently in operation through neutralization systems at depth.

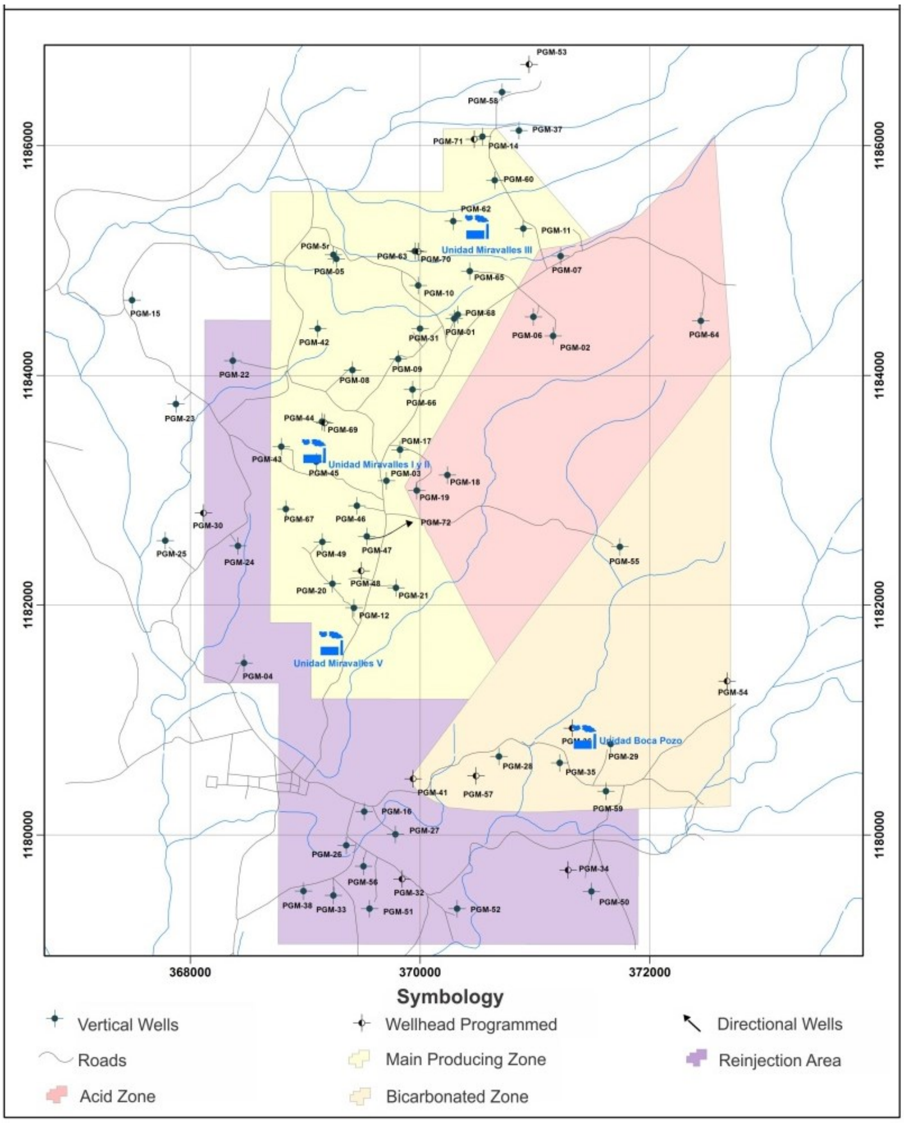

Figure 2: Location Map of acids wells in the Miravalles Geothermal Field.

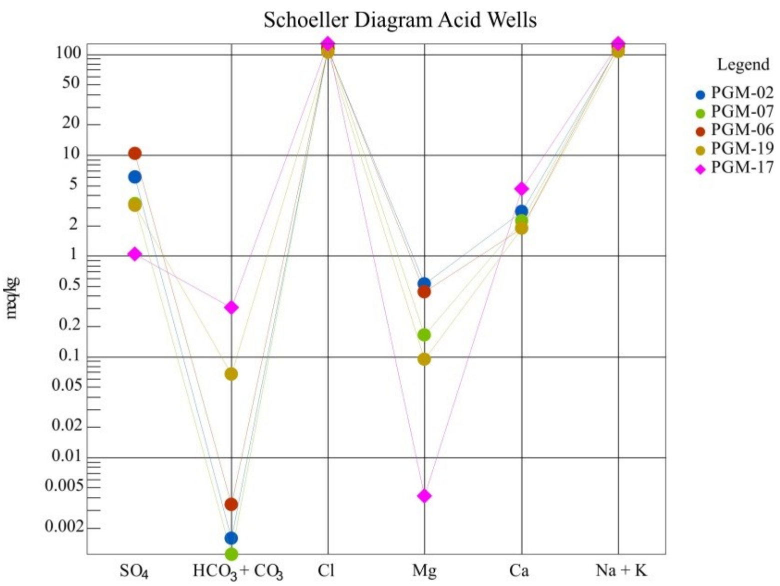

Figure 3: Schoeller Diagram representing the chemistry of acids fluids (PGM-02, PGM-06, PGM-07, PGM-19) vs neutral fluids (PGM-17).

1.1 PGM-19

It was drilled in 1993, being the first to enter commercial production in 2000 after making the necessary assessments to implement the neutralization system. It was determined that the well has two permeable zones, one around 961 and the other between 1110 and 1200 meters deep, with the shallow zone which contributes about 90% of production, which has acidic fluids with a pH close to 2.5; under these conditions precludes their integration into production, because these fluids would cause serious corrosion problems, Sánchez (1996).

In order to integrate it to commercial exploitation, a practical neutralization test was conducted in 1995 to determine the technical feasibility of neutralization and estimate the economic cost. The first test had problems with the capillary used because it was not suitable for operation acidic conditions. In 1996 a second test was made, the mass flow was stabilized at 150 kg / s and NaOH was injected at 950 m depth, the first variations of pH were measured 45 min after the start of injection, just as was done monitoring chemistry of fluids, Sánchez (1996). Subsequent incorporation was achieved successfully and worked until April 2012, the well is currently in standby.

1.2 PGM-02

PGM-02 completed its drilling in October 1984, reaching a total depth of 2000 m, being a deep zone (acid) between 1600 and 1700 m; fluctuations of sulfates, chlorides and gases suggest that acid production zone is not constant over time. This behavior has been observed in other acidic wells in MGF as PGM-07 and PGM-19, Castro and Sánchez (2007).

The initial objective of the well was to determine the existence of the geothermal resource in the foothills of Miravalles volcano as part of the feasibility study of the first geothermal unit in the country. Because the fluids produced by the well are acid, was used as injector since the beginning of commercial exploitation Miravalles Field until 2000. However, applying technology developed neutralizing acidic fluids in the well PGM- 19, a production test was designed with the aim of analyzing the feasibility of future use, as a well producer in Miravalles III. Prior 2000 a neutralization test , which was carried out mechanical cleaning with drilling machine in order to remove material that had accumulated over the years and to ensure the free movement of pressure and temperature elements, and neutralization head, Gonzalez et al. (2000) ; the results of the test showed positive results for subsequent commercial incorporation in May 2006.

1.3 PGM-07

Perforation of the PGM-07 ended in 1998, reaching a total depth of 1998 m. The well has three input zones located at 1032, 1280 and 1400 m depth, due to the behavior shown in the openings thereof are believed to have different characteristics of salinity and pH; coinciding with the presence of two aquifers: one neutral shallower and other acid deeper, Castro and Sánchez (1998).

In this well production tests were conducted in August 1998, to determine the optimum conditions for neutralization before joining the system and evaluate the feasibility of the use of the well. It was determined that the best results were injecting a solution of 50% NaOH to the depth of 950 meters, Castro and Sánchez (1998). Finally its trade integration is achieved in October 2001.

This well, due to the competition zones by pressure difference, sometimes presents a more acidic pH requiring higher doses of NaOH, whereas when the contribution of the neutral zone dominates the mass that produces the well, the pH is predominantly neutral and therefore require a dose adjustment.

1.4 PGM-06

The PGM-06 well was drilled in July 1999, reaching a total depth of 1180 m. In July 1999 a short opening was made, in which fluids showed a pH of 3.2 and a conductivity of 12110 µS/cm, then a neutralization test was carried out in November 1999, where it was found that technically fluids acids could be neutralized by injecting a concentrated depth NaOH solution. However this well being withheld to date, Rodríguez *et al.* (2013).

2. NEUTRALIZATION SYSTEM OF ACIDS FLUIDS

The neutralization process comprises adding a solution of sodium hydroxide geothermal fluid; this neutralized hydronium ions (H_3O^+) present by simple acid-base reaction, increasing the pH. NaOH injection must be continuous, and is carried out by a capillary placed at depth in the well. The exact position of the capillary into the well will depend on a number of factors present in the medium as permeability zones, location and characterization of acid aquifer in reservoir, depth of slotted casing and location of the boiling point. All these factors must be previously known in order to design an appropriate system of neutralization.

The dose and concentration of sodium hydroxide solution used in the neutralization is obtained based on a neutralization test performed on each well. Where different concentrations of the base are injected to the acid fluid and the neutralization capacity of the fluid and its stability over time is determined. For Miravalles was found that the optimum NaOH concentration is 30% (m/m). The reaction medium generated is highly exothermic producing an increase temperature of the fluid and reduces its viscosity, enhancing the performance of the pumping equipment used. A detailed description of the equipment used in the neutralization system can be accessed and Nietzen Moya (2010).

3. MONITORING OF ACIDS WELLS AT MIRAVALLES GEOTHERMAL FIELD

3.1 Geochemical Control

Since 2000 which came into commercial operation on PGM- 19 under the neutralization process is performed successfully the control of different surface chemical parameters: pH, sulfate content, calcium and iron. Geothermal fluids having a low content of iron (< 0.07 ppm), so that a pH -neutralized and iron contents indicate that the neutralization process operates normally. The data for iron are particularly important because it indicates a possible rupture of the capillary where the neutralization process in depth not being performed , showing surface by a pH neutralized and an increase in the iron content, product from acid attack of fluids to the casing well. Calcium allow monitor the formation of anhydrite (Calcium Sulfate , $CaSO_4$) in the casing, a decrease in concentration may indicate the presence of the mineral , which at a pH above 6 and high temperatures its precipitation is favored by their inverse solubility.

Also of particular importance is the control of sulfate content due to the presence of different production zones corresponding to different aquifers, which have their own chemical characteristics and reservoir fluids evolving product of exploitation of the field. Sulfates monitoring allows control titration of NaOH used in this way a high sulfate content indicates increased acidity in the medium, which leads to increase the dose of the base to achieve proper neutralization and thereby adjust to a suitable pH (Figure 4).

In the case of PGM-07 production conditions of this well are very unstable because it has three production zones, which by pressure difference are trying to compete with each other (a neutral, an acid and a vapor zone). For that reason, it is a little difficult to maintain a specific pH for a long time, for this case a mean dose of NaOH used and the controls are strict. Monitoring of pH and Fe is performed every 8 h daily non-stop, while the control of the other parameters is done weekly.

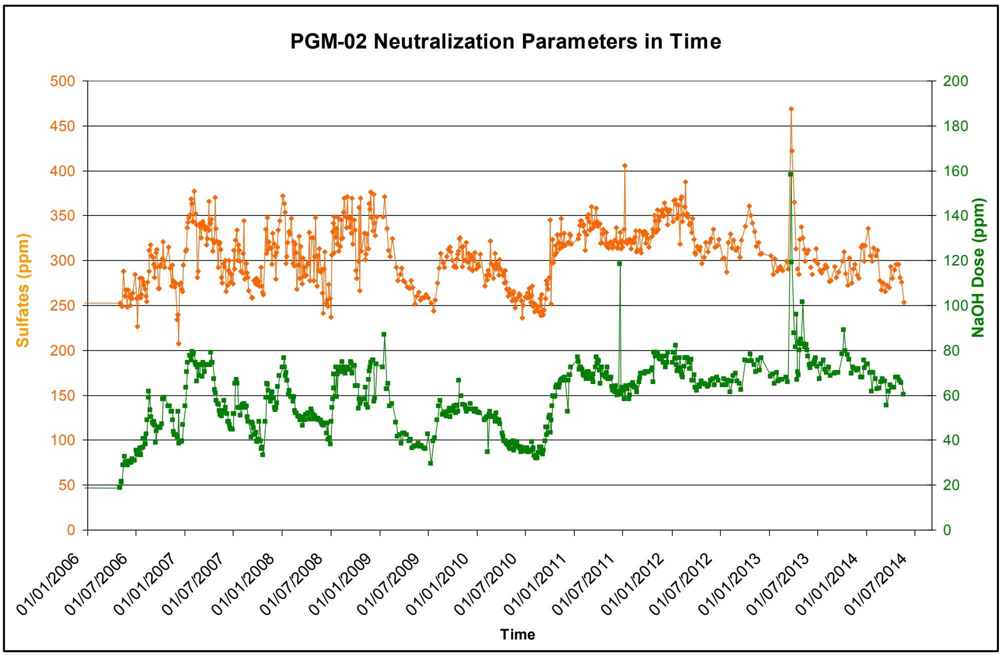

Figure 4: Evolution of the sulfate content of the PGM-02

3.2 pH Optimization

At the beginning of the integration of the system wells acids, sought a pH close to 7.0 in order to minimize surface corrosion of casing and pipes (Figure 5a example of corrosion). However secondary processes of deposit formation in depth, including anhydrite and silica were generated. These deposits obstructing the well, getting it to lose production and require the system are removed for mechanical cleaning (Table 1). Sometimes were generated surface silica deposits, leading to decrease the diameter of the reinjection pipe, that transport the fluid to collection lagoon (Figure 5b).

Table 1: Mechanical cleanouts in acid wells

Well	#	Inicial Date	Final Date	Duration (days)*
PGM-02	1	03/11/2003	07/12/2003	38
PGM-06	1	05/10/2003	09/10/2003	13
PGM-07	1	19/01/1998	28/02/1998	44
	2	05/06/2002	08/06/2002	8
	3	28/06/2002	30/06/2002	7
PGM-19	1	28/06/2000	04/07/2000	11
	2	24/06/2001	04/07/2001	15
	3	11/07/2002	22/07/2002	16
	4	10/07/2003	21/09/2003	76

#: Number of mechanical cleanout in the well, modified from Moya and Nietzen (2010).
*the duration not consider the recuperation time of the well.

Between July 2003 and March 2004 pH optimization studies, together with NEDO's International Co-operation were performed. This study consisted in taking measurements of corrosion and deposition of silica both biphasic pipe and the separate fluid to determine the pH at which the minor corrosion and minor deposition rate was achieved. Tests at different pH values (4.5, 5 and 6) were performed, it was determined that a condition of pH 5 to the well PGM-07 producer is recommended, since an acceptable balance is obtained which is achieved low silica deposition and low corrosion. Following this study acid wells were adjusted to these conditions and since 2003 are not necessary interventions to running mechanical cleaning.

Figure 5: Problems related to acidic fluids, a) casing in acidic conditions, PGM-02 b) Deposits of silica in the PGM-07 channel.

This is exposed in Table 2, where the control system in the neutralization carried PGM-07 is shown; there are two conditions of well, the initial in 2002 and the current. In 2002, pH values ranged were handled in a range of 7.70 to 6.50; due the generated deposits the well went into a maintenance mechanic in June of that year and subsequently required a period of recovery and evaluation, meaning four months out of the system. In the second case the April-2014 pH within the optimum range (5.5-6.0), this ensures minimal scaling and maintains continuous production. Prior to the use of neutralization in the PGM-19 well this well required an annual mechanical cleaning (Table 1).

Table 2: Typical Neutralization System Control

Well	Date	Ca+2	Cl-	Rate*	pH	Fe	SO4	WHP	Qp
		ppm	ppm			ppm	ppm	b.a	kg/s
PGM-07	10-abr-02	31	3881	24.0	7.61	0.17	225.0	5.8	38.90
PGM-07	29-abr-14	44	4280	30.7	5.78	0.74	153.0	7.8	40.45

WHP: Wellhead Pressure, Qp: Mass Flow
*Rate: Ca^{+2}/Cl^{-}*3000

By optimizing the pH, the clogging of the wells and the removal system for mechanical cleaning was avoided, and it was also possible to send the brine from these wells to reinjection system hot, after passing through the binary unit for generating about 3 MWe.

4. BENEFITS ASSOCIATED TO NEUTRALIZATION PROCESSES

Table 3 shows the approximate annual cost of neutralization (NaOH diluted in water 1 +1) of well PGM-02 since 2011 to the present; these costs do not consider the operational management. In the case of well PGM-07 since 2006 has dominated the neutral zone leftover acid and only short intermittent periods neutralization system is activated due to this are not considered costs in this section.

Table 3: Annual cost of neutralization in PGM-02 at Geothermal Field Miravalles

Year	NaOH Consumed (Kg)	Annual Costs (US$)
2011	240000	81277
2012	240000	80890
2013	239677	80930
2014 at date	79416	26922
Total	***799093***	***270020***

As shown in Table 4, the commercial production of acids wells represented a saving of 21.7 million dollars annually for the country thermal generation, reducing the environmental impact; and in regard to these 15 years of production represents approximately US$ 259 million. Additionally these wells provide steam to drive Miravalles 3; it means that 216 MWe have not been extracted to Miravalles neutral reservoir.

To estimate the annual cost savings in thermal generation due the commercial exploitation of acid wells (PGM-02, PGM-07 and PGM-19), the following assumptions were developed:

- A commercial value of energy of US$ 136.06 /(MW/h), Instituto Costarricense de Electricidad (2013).
- A generation capacity of the wells shown in Table 4.
- An annual plant capacity factor of 98%, for reasons of assessment tests or some maintenance the well does not work seven days a year.
- For the PGM-02 is considered a neutralizer consumption of 800 tons per year. It is assumed that the well is produced continuously throughout the year and consuming NaOH. The PGM-07 does not require neutralization.

Considering these assumptions, well PGM-02 generates US$ 2,587, 200.00 per year. Considering the average cost of NaOH at US$ 81,000.00 per year, the well generates the country $ 2,506,200.00 per year. While the PGM-07 generates U.S. $ 8,820,000.00 per year. If we take into account the years of operation of the 3 wells since its commercial integration to present these gross profit generated goes beyond the US$ 259,080,000.00 in these 15 years of successful use.

Table 4: General data of generated power and its economic benefits from acid wells.

Well	Currently State	Power Output (MWe)	Rate Flow Steam (Kg/s)	Enthalpy (kJ/kg)	Operation Years	Annual Profit (US$)	Profits at 15 year (US$)
PGM-02*	Production	2.2	3	889	8	2,587,200	20,697,600
PGM-07*	Production	7.5	15	1486	13	8,820,000	114,660,000
PGM-19**	Closed temporarily (february 2012)	8.4	18.4	967	12	9,878,400	118,540,800
PGM-06	Reserve	10.5	23.3	1868	--	--	--
Total Generated		***18.1****				***21,720,000.00***	***259,080,000.00***

*2014 Data. **2012 Data. *** PGM-06 Not considered.

Additional benefits include:

Neutralized separated fluids at 165 ° C of the PGM-19, PGM-06 and PGM-02 wells are integrating hot reinjection system, it is possible to use the residual heat in the binary cycle plant line which is passed by heat exchangers. The exiting liquid is at a temperature of about 130 ° C; and continues its journey to the injection wells, thus generated near 3MWe. Otherwise would be sent to the sewer system, later to be re-injected cold.

5. CONCLUSIONS

- Neutralization of acidic fluids of the PGM-02, PGM-07 and PGM-19 wells has allowed the commercial exploitation providing 18.1 MWe annual of power generated, which is an achievement for the country because to high investment costs in drilling.

- Geochemical monitoring of the neutralization process should be consistent and thorough; because small variations in the concentrations of the analyzed parameters may indicate important changes occurring at depth, and if these are not detected on time can cause significant damage as casing corrosion, scale silica and anhydrite; that affects the proper operation of the well.

- The well-PGM-02 operates continuously with neutralization system. The well PGM-07 In recent years a competition of zones is given by the pressure change between a neutral surface aquifer and an acid deeper aquifer, so that the well presents continuous oscillations of pH. This implies a more rigorous monitoring and neutralization system is activated only for defined periods of time when acidic conditions are detected.

- Using optimal neutralization process (pH optimum) avoid scaling and corrosion problems in the well, are a successful way to replace the mechanical cleaning, as well require stopping the production system for a period of time, leading to a decrease in power generated and involves a high economic cost to the country.

- With pH optimization, residual fluids to 165 ° C have been able to take advantage of the bottoming binary cycle plant, contributing 3 MWe additional production of clean energy.

- In the last fifteen years of commercial operation of wells acids, gross profit of 3 well incorporated goes beyond the US$ 259,080,000.00.

REFERENCES

Castro, S.; Sánchez, E.; (1998): Informe Prueba de Producción PGM-07-Informe Interno - C.S.R.G, UEN-PySA, ICE, 14 pp.

Castro, S.; Sánchez, E., (2007): Informe de evaluación de PGM-02 (28-07-2007-Informe Interno - C.S.R.G, UEN-PySA, ICE, 7 pp.

Gonzales, C.; Sánchez, E.; Torres, Y., (2000): Informe Prueba de Producción PGM-02-Informe Interno - C.S.R.G, UEN-PySA, ICE, 24 pp.

Instituto Costarricense de Electricidad, 2013: Generación y Demanda. Informe Anual - Centro Nacional de Control y Energía, 22 pp.

Moya, P., Nietzen, F.: Performance of Calcium Carbonate Inhibition and Neutralization Systems for Production Wells at the Miravalles Geothermal Field, Proceedings, World Geothermal Congress, Bali, Indonesia, 25-29 April (2010).

Rodríguez, A.; Sánchez, E.; Torres, Y., (2003): Informe final PGM-06-Informe Interno - C.S.R.G, UEN-PySA, ICE, 11 pp.

Sánchez, E. (1996): Informe final prueba de neutralización PGM-19-Informe Interno - C.S.R.G, UEN-PySA, ICE, 10 pp.

Vega, E., Chavarría, L., Barrantes, M., Molina, F., Hakanson, E.C. and Mora, O.: Geologic model of the Miravalles Geothermal Field, Costa Rica, Proceedings, World Geothermal Congress, Antalaya, Turkey, (2005), CD, 5 pp.