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PERFORMANCE OF CALCIUM CARBONATE INHIBITION AND NEUTRALIZATION SYSTEMS FOR PRODUCTION WELLS AT THE MIRAVALLS GEOTHERMAL FIELD

Paul Moya and Federico Nietzen

Instituto Costarricense de Electricidad

P. O. Box 10032-1000, San José

COSTA RICA

PMoya@ice.go.cr, FNietzen@ice.go.cr

ABSTRACT

Power generation at the Miravalles geothermal field currently depends on the utilization of 21 systems for inhibition of calcium carbonate scale, as well as 3 acid-neutralization systems, in the field's production wells. The performance of the inhibition and neutralization systems is described in this document. The Miravalles field has been producing electric energy since March 1994, supplying steam to Unit 1 (55 MW), a wellhead unit (5 MW) installed in 1995, Unit 2 (55 MW) in 1998, and Unit 3 (29 MW) in 2000, with brine being supplied to Unit 5 (19 MW, a binary plant) since 2004. The calcium carbonate inhibition systems (in use since 1994) as well as the neutralization systems (since 2000) have been used successfully in the production wells that supply steam and brine to the generating units. Experience has indicated that the injection (at depth) of an appropriate dosage of inhibitor makes it possible to produce the geothermal wells with little or no deposition, at lower cost than performing periodic mechanical cleanouts.

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1. INTRODUCTION

Costa Rica is located in the southern part of the Central American isthmus, between Nicaragua and Panama. The country extends over an area of approximately 51,000 km² and has a population of about 4.5 million.

The most important Costa Rican geothermal area is located on the southwestern slope of the Miravalles volcano. The present field extends over an area of more than 21 km²; about 16 km² are dedicated to production and 5 km² to injection. The temperature of the water-dominated geothermal reservoir is about 240°C. Fifty-three geothermal wells have been drilled to date. They include observation, production and injection wells, with depths ranging from 900 to 3,000 meters. Individual wells produce enough steam to generate between 3 and 12 MW; injection wells accept between 70 and 450 kg/s of separated geothermal fluids each (Moya, 2006).

Commercial production of electricity using geothermal steam began at Miravalles in early 1994, when Unit 1, a 55 MW single-flash plant, was commissioned. The following year, ICE completed the installation of a 5 MW wellhead unit. This unit was located in the middle of the field for almost 12

years (1995-2006), but in early 2007 it was moved to a new location on the southeastern part of the field. Then, two temporary 5 MW wellhead plants came on line as part of an agreement between ICE and the Comisión Federal de Electricidad de Mexico (CFE). These two temporary units were disassembled in April 1998 and April 1999 (Table 1), and returned to CFE. Unit 2, the second 55 MW plant, started production in August 1998 and in March 2000, Unit 3, a 29 MW single-flash private plant, started delivering electricity to the national grid. Finally, in January 2004, Unit 5, a 19 MW binary plant, increased the total installed capacity at Miravalles to 163 MW (Table 1) Moya and Yock (2007). The history of growth of capacity at the field is shown in Figure 1, and the increase in energy production at the geothermal field is shown in Figure 2.

TABLE 1: Power units at Miravalles geothermal field. Abbreviations: ICE-Instituto Costarricense de Electricidad; CFE-Comisión Federal de Electricidad (Mexico); WHU-Wellhead Unit; and BOT-Build-Operate-Transfer

Plant name	Power (MW)	Owner	Start-up date	Shut-down 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	

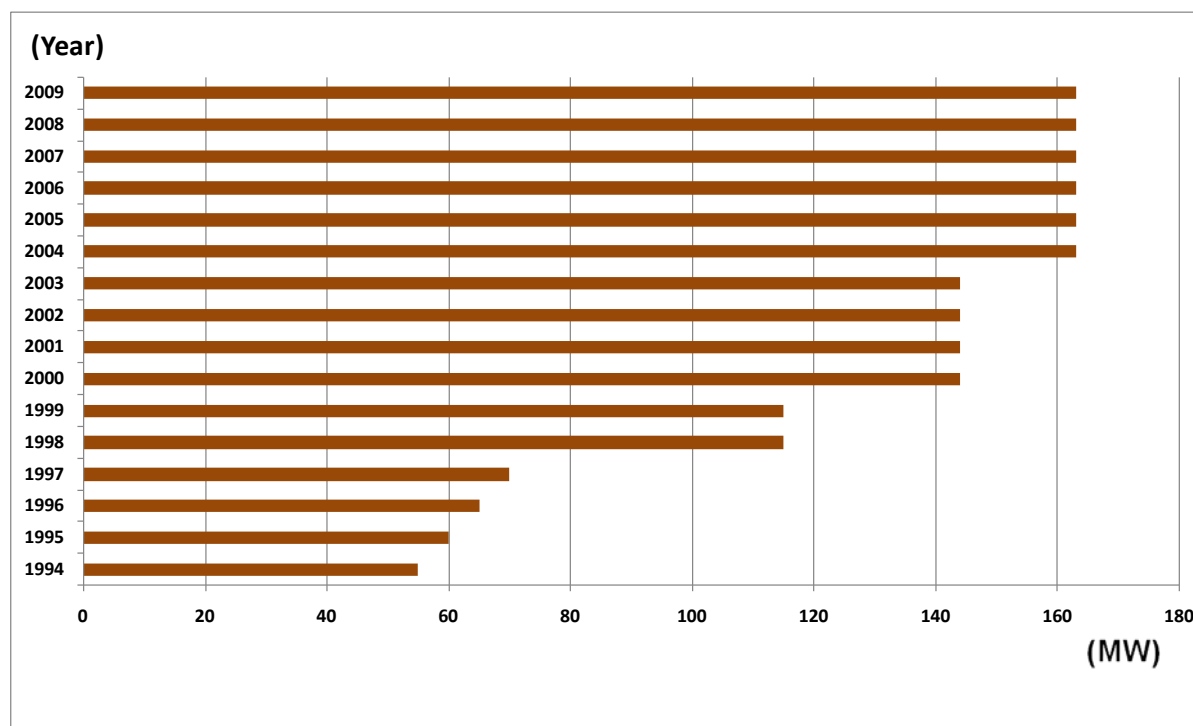


FIGURE 1: Geothermal installed capacity (1994 – 2009)

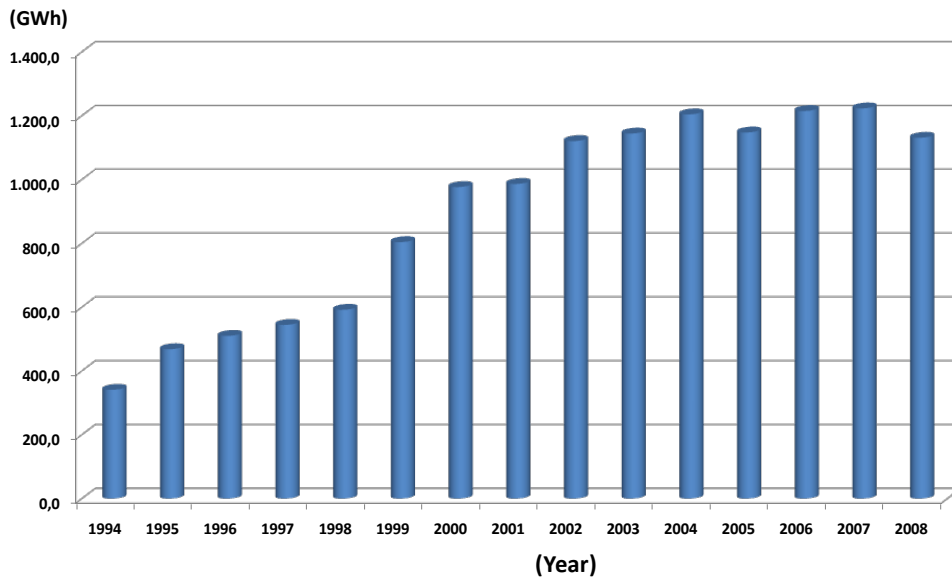


FIGURE 2: Energy production (1994 – 2008)

Figure 3 shows the monthly mass flow rates since production began at the Miravalles geothermal field. In this figure, steam production is represented by the green curve, brine by the blue line, and the sum of both by the red curve. It can be seen that the steam supply increased until March 1998, and since then it has been slowly decreasing up to the present (2009). The increase in steam supply from 1996 to 1998 was due to the operation of the wellhead units coming from CFE; once these units were disassembled, the steam requirement decreased.

Unit 5 extracts additional energy from the separated geothermal brine before it is injected back into the geothermal reservoir.

Currently, the total steam delivered to the power plants is about 330 kg/s. Around 1,235 kg/s of residual (separated) geothermal water is sent to injection wells, which are distributed in four areas of the field, i.e., the northern, southern, eastern and southwestern sectors. A total of about 150 MW is generated from these quantities of steam and brine.

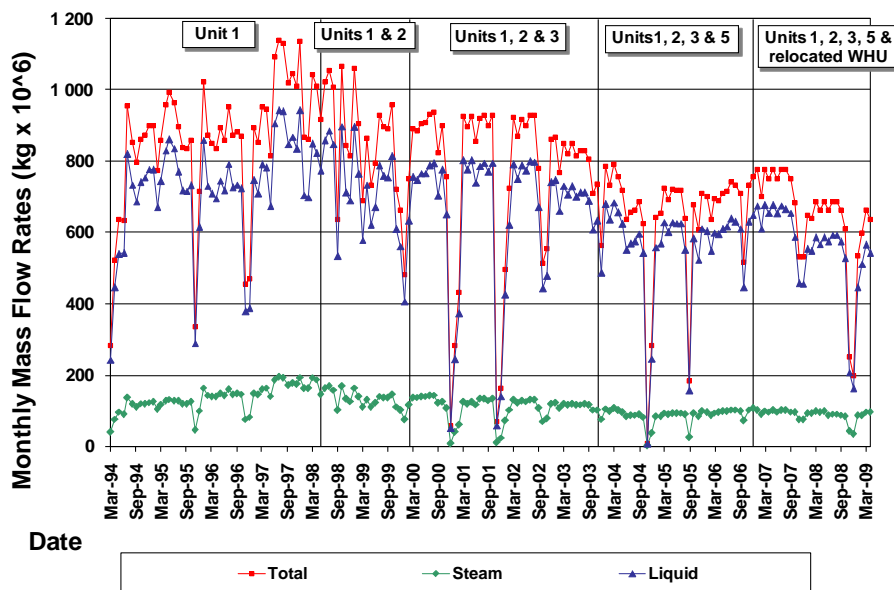


FIGURE 3: Monthly mass flow rates at the Miravalles geothermal field

2. INHIBITION SYSTEMS

In order to deliver the required steam to the power plants, it was necessary to install calcium carbonate scale inhibition systems as well as acid-neutralization systems in the production wells. Currently there are 21 calcium carbonate inhibition systems and 3 neutralization systems in operation in the production wells of the Miravalles geothermal field. They operate 24 hours a day, 365 days a year.

2.1 Calcium carbonate inhibition system

Most production wells at the Miravalles geothermal field require the implementation of a calcium carbonate inhibition system to prevent calcite precipitation inside the casing. As the hot brine rises towards the surface in a production well, equilibrium is reached between the pressure in the wellbore and the boiling point of the brine, causing flashing inside the well. When flashing occurs as the deep fluids ascend to the wellhead, the fluid tends to become supersaturated with calcite and hence there is a high potential for calcite to be deposited (Moya et al., 2005). Figures 4 and Figure 5 show the different parts of the calcium carbonate inhibition system.

The diluted inhibitor is stored in the inhibitor tank located at each well (Figure 6).

The tank has a sensor that indicates the inhibitor level in the tank, which can be seen at the control room, allowing the supply of inhibitor to be managed. The inhibitor is pumped into the production well through the capillary tubing to a depth 50 to 100 m below the depth of boiling in the well (between 1,000 and 1,400 meters, depending on the well). The capillary tubing is connected to the injection head and its weight bar. The weight bar helps to stabilize the components as well as lift and lower the inhibition head. The length of the capillary tubing ranges between 1,100 and 1,500 meters, and the material is an alloy of 316L.

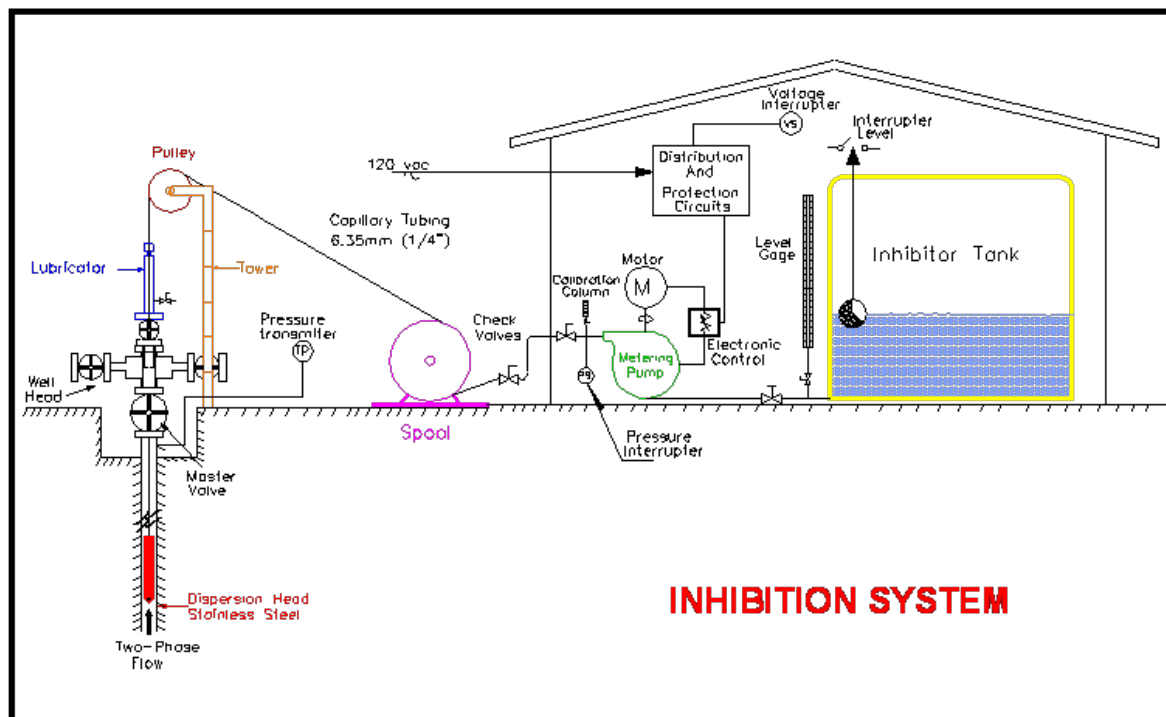


FIGURE 4: The calcium carbonate inhibition system



FIGURE 5: The calcium carbonate inhibition system at well PGM-03 (Photo by P. Moya)



FIGURE 6: Inhibitor storage tanks (Photo by P. Moya)

Some of the control parameters are:

Operating parameters

- Consumption time, T100 (seconds): time that takes a column of 100 ml of inhibitor to be injected into the well. This parameter is indicative of the rate of inhibitor flow.
- Pumping pressure (bar m): the pumping pressure is important for detecting possible problems in the capillary tubing (example: partial or total obstruction inside the capillary tubing, or broken tubing).
- Tank levels (m): indicates the level of inhibitor in the tank.
- Wellhead pressure (bar): pressure at the wellhead, it is also the operating pressure of the well.

Chemical parameters

- Calcium: calcium content to calculate the ratio Ca/Cl. It indicates the effectiveness of the inhibition process.
- Chlorides: chloride content to calculate the ratio Ca/Cl. It indicates the effectiveness of the inhibition process.
- Bicarbonates: used to adjust the inhibition dosage.
- The above parameters are monitored periodically. If any parameter is out of range, a corrective action is taken to adjust the system to normal conditions.

Together with the operation of the system, there are some other processes related to it, such as:

- Reception of the inhibitor (pure product). The inhibitor is received at the dilution plant (Figure 7). It is verified, quantified and stored in tanks of 50,000 kg each.
- Dilution of the inhibitor. The pure inhibitor and water are mixed for dilution to different concentrations, depending on the pumping system and on the recommended dosage. This is done at the dilution plant.
- Distribution of the diluted inhibitor. The diluted inhibitor is distributed to the various storage tanks located at the wells (Figures 5 and 6). A cistern is used to distribute the inhibitor in each well at the geothermal field.

Corrective maintenance is done whenever required. Preventive maintenance as well as electrical and mechanical maintenance follows yearly maintenance programs which have been improved continuously.

The quantity of injected inhibitor might change over time for a single well. Figure 8 shows the bicarbonate evolution in well PGM-49. Initially, the well needed a dosage of 0.50 ppm of inhibitor, but at present it needs a dosage of 2.50 ppm. In some other wells, the behavior has been just the opposite, and therefore the inhibitor consumption might increase or decrease with time.

The calcium carbonate inhibition system has become very reliable, allowing constant production from the geothermal wells at the Miravalles geothermal field. Samples are taken weekly at each well to verify the effectiveness of the inhibition, and if it is found that the bicarbonates have changed, then further studies are carried out to adjust the inhibitor dosage. Also, when a deliverability test takes place in the well, a verification of the inhibition process is done. Different types of inhibitors have been tested at the Miravalles geothermal field since 2000. The inhibitors that passed the tests were: Nalco 1340 HP Plus, Geosperse 8410CN+ and BWA DP 3537.



FIGURE 7: Dilution plant at the Miravalles geothermal field (Photo by P. Moya)

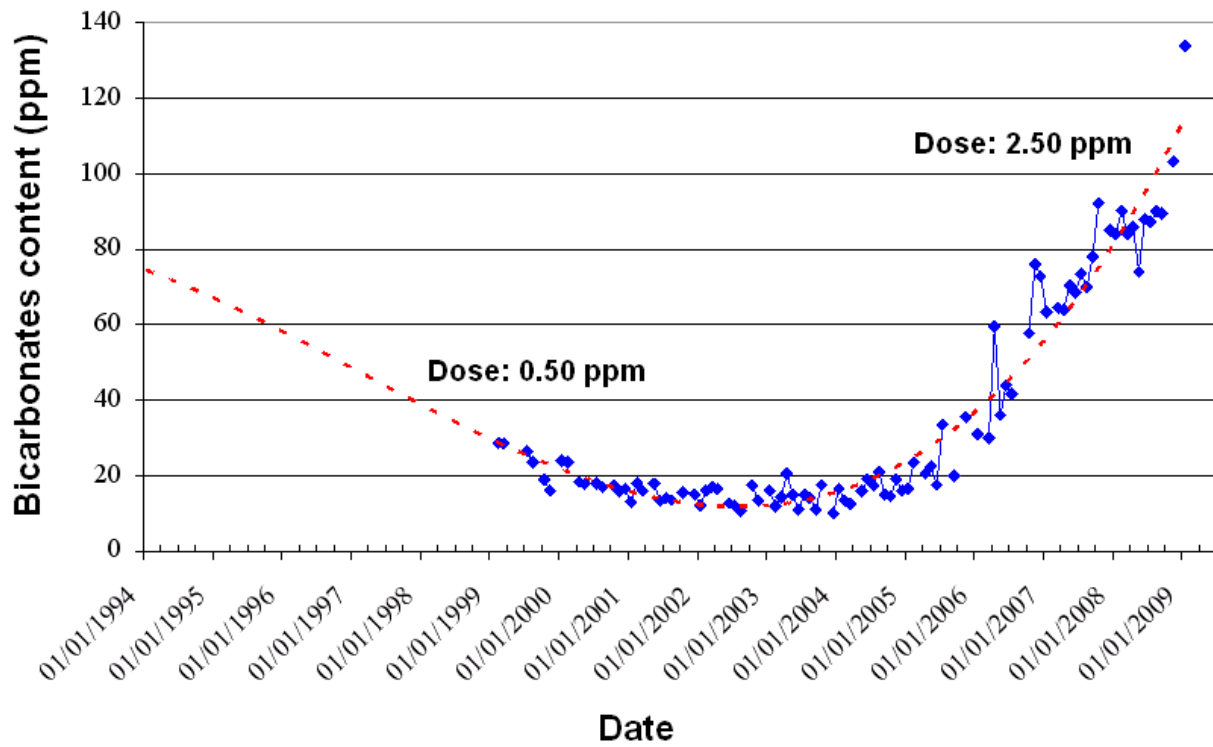


FIGURE 8: Bicarbonates evolution in well PGM-29 (Torres et al., 2009)

2.2 Neutralization system

To meet the steam supply requirements of the power plants, it has been necessary to utilize three wells that produce acid fluids: PGM-02 (in operation since March 2006), PGM-07 (since October 2001) and PGM-19 (since February 2000). The implementation of neutralization systems was required to neutralize the acidity of the produced fluids, and at present there are 3 neutralization systems in continuous operation at the Miravalles geothermal field.

There is an acidic sodium-chloride-sulphate (Na-Cl-SO₄) aquifer located in the northeast sector of the Miravalles geothermal field. The pH of the aquifer water ranges between 2.3 and 3.2, making it highly corrosive, so it is necessary to use chemical treatment to avoid corrosion inside the wells and surface equipment (pipes, casings, capillary tubing, separators, etc.). The neutralization system injects at depth (more than 1,000 m for Miravalles wells) a neutralizing agent such as caustic soda (NaOH) inside the well through the capillary tubing, using a pump that delivers the agent from the tank located at each well. The neutralization systems (Figures 9 and 10) operate 24 hours a day, 365 days a year (Moya et al., 2005).

The acid fluid from the wells is neutralized with NaOH solution whose initial concentration 40 %wt. This concentration is diluted with water that is simultaneously pumped into the NaOH solution (dilution online). Normally there are two NaOH storage tanks located in a small house at each well (Figure 10). The time that the NaOH is stored depends on the rate of consumption (the storage time is between 15 and 30 days for the Miravalles geothermal wells). The material of the storage tanks can be carbon steel or high-density polyethylene (Nietzen, 2007).

Two pumps (Figure 11) inject the NaOH into the well, alternating their operation so that one serves as a backup pump. This way the pumps are operated routinely, in order to maintain their internal components under normal operation. These pumps are specially designed for chemicals such as NaOH, and for high pressures (more than 100 bar); the delivery rate is between 10 and 50 l/h (depending on the well).

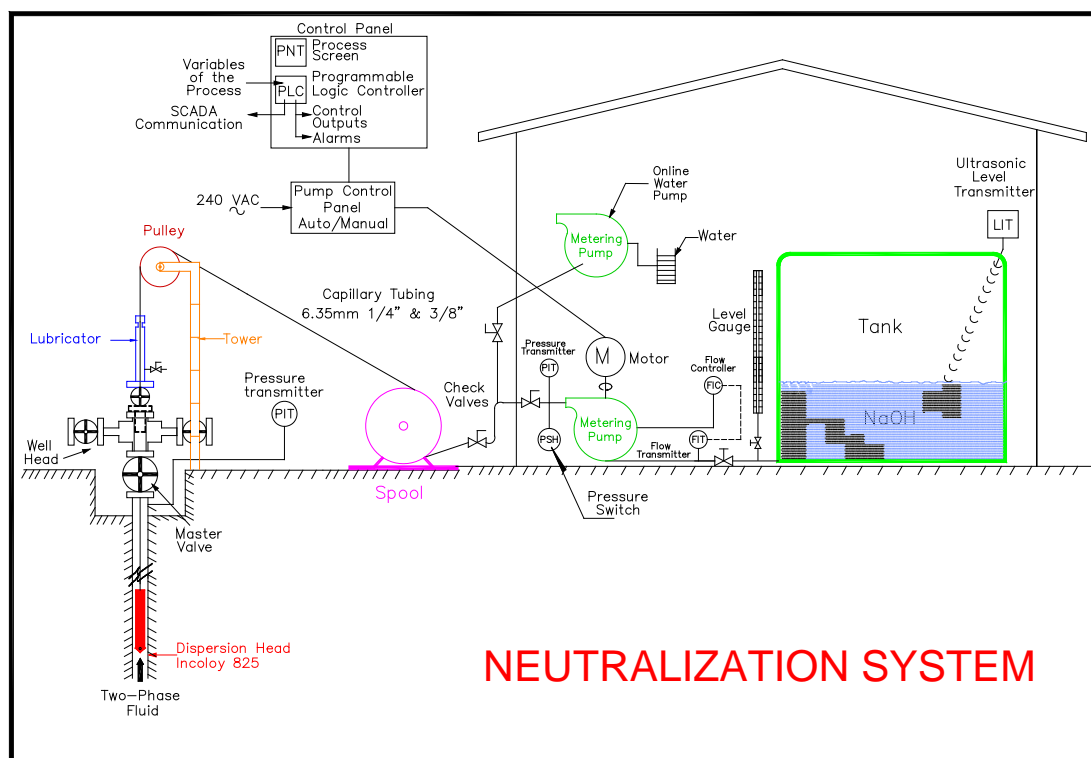


FIGURE 9: Neutralization system at Miravalles geothermal field



FIGURE 10: Neutralization system at well PGM-19 (Photo by P. Moya)



FIGURE 11: Metering pumps at PGM-02 (Photo by P. Moya)

There is another pump that is only used to inject water into the neutralization system. This pump (Figure 11) keeps the concentration of NaOH around 30 % (m/m) and increases the temperature of the fluid, reducing its viscosity and helping the pumps to work effectively. All of the pumps are of positive displacement (diaphragm) type.

The capillary tubing is coiled in a drum (spool, Figure 9 and Figure 12). During the operations of lowering or lifting up the injection string, the spool is set on a truck and the depth of the capillary tubing inside the well is controlled and measured by an instrument. The tubing is made of a special stainless steel (Incoloy 825), with a diameter of 9.5 mm (3/8"). Its total length is approximately 1,300 m, and its position inside the well depends on the boiling zone and the well completion (Nietzen, 2007).

The capillary tubing must remain steady inside the well. For this reason, it is connected to a neutralization head, which is connected to a weight bar made of a special stainless steel tube (Incoloy 825) and filled with lead.

The control variables are:

- pH (between 5.5 and 6.0);
- Iron (ppm Fe);
- Pressures and levels;
- Flows;
- Others.



FIGURE 12: Spool with capillary tubing (Photo by P. Moya)

All recorded variables or parameters are incorporated into an integral record, which helps to keep control of the parameters related to the neutralization system for the acid wells. The parameters are taken continuously (24 hours a day) by operators at each well. The analysis of each parameter (or group of parameters) generates sufficient information for the operator at the site to take corrective action on the neutralization system, if necessary to keep the parameters within their normal range.

There are some other items that need to be considered to keep the neutralization system running properly (Nietzen, 2007):

- Supply of NaOH: The NaOH is brought to the Miravalles geothermal field in cisterns. A cistern with 20,000 kg capacity carries the NaOH to the well every 15 or 30 days, depending on the consumption rate of each particular well. The safety measures for personnel and the environment are the responsibility of the supplier during the transport. At the well, the safety measures are ICE's responsibility.
- Winch: Its function is to lift or lower the capillary tubing in the well. It is a truck with a hydraulic winch and a hydraulic arm to lift and lower the spool with the capillary tubing. The system generates high torque; therefore, care must be taken when the system is pulling up the capillary tubing, to avoid exceeding the rupture strength of the capillary tubing. This equipment is used for the calcium carbonate inhibition system also.

3. COST OF THE INHIBITION SYSTEM

The purpose of using chemical treatment systems in geothermal production wells is to allow for commercial exploitation of the wells. It may be possible to operate wells without calcium carbonate scale inhibition systems, instead withdrawing them from production periodically when they require cleaning. Even when this option is possible, it has several disadvantages, such as loss of production during the mechanical cleanout periods, production decline over time, and possible further damage to the formation near the wellbore, among others.

On the other hand, it is not possible to produce an acidic well without a neutralization system. The internal walls of the well (production casing) and surface equipment will suffer considerable damage after the well is produced for even a few days, due to the effects of corrosion.

The following section compares the cost of using chemical inhibition systems with the cost of the mechanical cleanout option for calcium carbonate scale control.

3.1 Calcium carbonate inhibition system

The inhibition system lengthens the lifetime of the well, as well as its production periods, without the need to carry out frequent mechanical cleanouts. The calcium carbonate inhibition system may be divided into three modules:

- Systems in the field (see parts in Figure 4);
- Dilution plant system (Figure 7);
- Auxiliary machinery and equipment.

Each module consists of special equipment used to transport the inhibitor from the dilution plant to the boiling zone inside each well. A summary of the costs per module is shown in Table 2; it indicates an initial investment of a little more than million and a half dollars (\$1,528,124) for the inhibition system in a field with 5 producers, and an annual cost of \$205,203, which includes depreciation, operation and maintenance costs.

TABLE 2: Inhibition system annual costs

Item	Total cost (\$)	Annual depreciation (\$/year)	Operation and maintenance costs (\$/year)	Total annual cost (\$/year)
System in the field (single producer)	70,347	11,805	4,680	16,486
System in the field (5 producers)	351,737	59,027	23,402	82,430
Plant systems	501,509	74,928	2,699	77,627
Auxiliary machinery and equipment	674,877	37,348	7,798	45,146
Inhibition system	1,528,124	171,304	33,899	205,203

On average, a well without an inhibition system could produce for only 3 months at the Miravalles geothermal field. However, for this analysis, a conservative case was considered, where the well would produce for a year without an inhibition system (one mechanical cleanout per year per well). Table 3 shows some parameters used to compare the options (with or without a calcium carbonate inhibition system), considering an average output of 7 MW per well.

TABLE 3: Parameters for comparison of scale control options

Parameter	Value	Unit
Wells		
Average generation per well	7	MW
Average price of energy delivered (2003)	0.04113	\$/kWh
Total wells integrated to the system	5	
Mechanical cleanouts		
Mechanical cleanout average cost	136,223	\$
Average costs of operation and maintenance before and after a mechanical cleanout	10,042	\$
Average time for the cleanout	15	days
Process without the CaCO₃ inhibition system		
Estimated time without inhibition	350	days
Decay rate of the well	0.0280	MW/day

Most likely, more than one mechanical cleanout will be required per well per year, but if the conservative assumption results in a higher net cost than the use of the calcium carbonate inhibition system for a production period of a year, then the calcium carbonate inhibition system will always be cheaper than mechanical cleanouts in wells that require one or more mechanical cleanouts in a year (considering a total of 5 wells). Without an inhibition system, the productivity of the wells will decline over time, until their wellhead pressures are too low to allow their integration to the gathering system. To produce the well again, a drilling rig would be required to perform a mechanical cleanout. This creates additional costs, such as equipment, personnel and the generation lost during the cleanout period, which on average lasts for 15 days.

The cost of energy not produced is the most significant item; it is calculated by subtracting the energy produced by a well without an inhibition system from the energy produced by a well with an inhibition system over a given period of time. The energy delivered by the well without an inhibition system is reduced by two main factors: the decline in output over time due to obstruction by calcite, and the energy not produced during the mechanical cleanout. These two components are detailed in Table 4 for a common year (365 days). Also in Table 4, it can be seen that 15 days are estimated for a

mechanical cleanout, resulting in 350 days of “constant production”. During these 350 days, more energy is delivered by the well with the inhibition system than by the well without the inhibition system, due to the decline caused by wellbore scaling. Table 4 shows that the energy not produced due to the absence of an inhibition system is 12,812,450 kWh per year per well; for 5 wells the annual loss is 64,062,250 kWh.

TABLE 4: Energy not produced (per well/year)

Parameter	Production	Mechanical Cleanout	Total
Days	350	15	365
Energy delivered without inhibition system (kWh)	48,507,550	0.00	48,507,550
Energy delivered with inhibition system (kWh)	58,800,000	2,520,000	61,320,000
Difference (total energy undelivered due to the lack of an inhibition system) (kWh)	10,292,450	2,520,000	12,812,450

The calculation of the energy not produced is used to determine the cost of lost generation (Table 5). This cost, and those associated with the mechanical cleanouts, are compared to justify the inhibition system. Table 5 details the two scenarios, with and without an inhibition system, indicating that the net cost is significantly lower when an inhibition system is used.

TABLE 5: Comparison of annual costs for mechanical cleanouts and lost generation versus inhibition system costs

Costs and expenses	Cost (\$)
Annual costs per well without a CaCO ₃ inhibition system	
Mechanical cleanout cost	146,265
Costs of lost generation	527,037
Total cost	673,302
Mechanical cleanout annual cost (for 5 production wells)	3,366,510
Inhibition system costs on annual basis (Table 2)	205,203
Cost ratio: Mechanical cleanout annual cost/Inhibition system annual cost	16.4

Anhydrite and amorphous silica were found in two of the acid wells at the Miravalles geothermal field (PGM-19 and PGM-07), before it was realized that the pH should be maintained between 5.5 and 6.0. It was necessary to perform mechanical cleanouts on PGM-19 and PGM-07 to restore their normal production rates. Once the acid wells were cleaned out, a careful control on the dosages was implemented to avoid the formation of anhydrite and amorphous silica. Since this pH control was implemented (beginning in March 2004), no further mechanical cleanouts have been required (as of 2009).

Table 6 shows the mechanical cleanouts of acid wells that have been carried out at the Miravalles geothermal field. The effectiveness of pH control (starting in March 2004) in reducing the need for cleanouts is seen in the production history of these wells, particularly PGM-07. Figure 13 shows the steam production rates of the acid wells since 2000. Well PGM-07 had three mechanical cleanouts before March 2004, but since then the pH value has been kept near 5.5, and there has been no need to shut in the well for a mechanical cleanout.

TABLE 6: Mechanical cleanouts in acid wells

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

#: Number of mechanical cleanout in the well

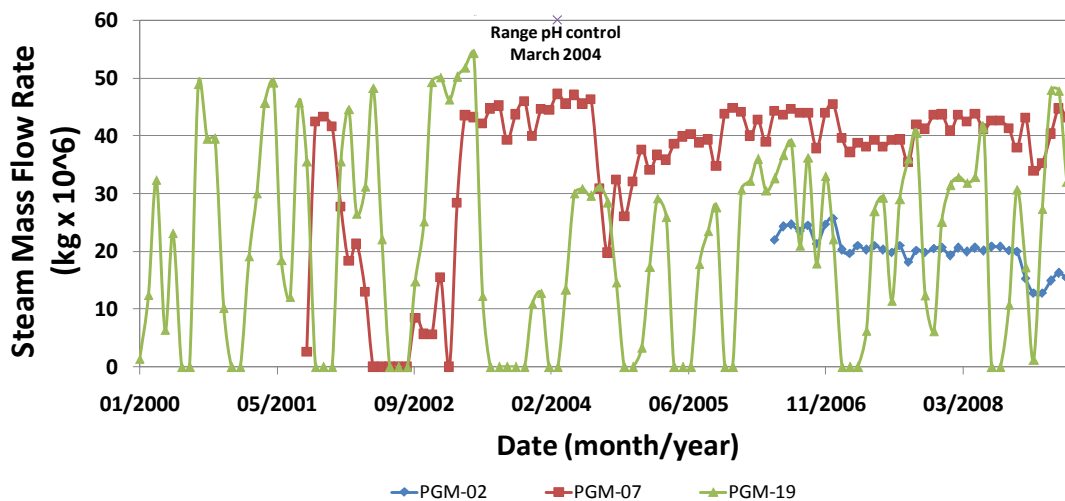


FIGURE 13: Steam production history of acid wells

Well PGM-19 was the first acid well to be placed online (Figure 14), but its production has not been constant over the years, due to the formation of anhydrite and amorphous silica, as well as some other problems related to production decline that are not well understood yet. The second well online was well PGM-07; its production has been more or less constant, in part because the well has become basically neutral since 2007. The last two wells that have been connected to the gathering system have been wells PGM-02 and PGM-06. PGM-06 is not producing yet; it is a spare well to supply steam to Unit 3, once that unit is able to manage a level of non-condensable gases greater than 1.5%.

The neutralization system for each acid well has an initial cost, and costs to maintain production over time. The general costs of the neutralization system can be separated into two categories: fixed costs and variable costs. Table 7 shows the main types of costs related to the neutralization system.

Costs of the neutralization system are summarized in Table 8. These costs are substantially less than the estimated income obtained by producing an acid well over the course of a year. The initial costs involved in a neutralization system can be recovered within a year (Table 8).



FIGURE 14: Acid well PGM-19 (Photo by P. Moya)

TABLE 7: Costs involved in neutralization systems

Type cost	Description
Fixed costs	Neutralization system (controllers, general equipment such as valves, pipes, fittings, tanks) Infrastructure (civil works, towers, etc.) Design, supervision and implementation Lands Well Drilling
Variable costs	Operating costs Chemicals for neutralization (NaOH) Chemicals analysis of water (kits) Chemicals for monitoring equipment Staff in product testing Monitoring system Technical – professional support Sampling and chemical analysis Maintenance Electrical energy consumed by the neutralization system Water, phone Capillary tubing Mechanical cleanouts

TABLE 8: Estimated costs and income of an acid well

Parameter	Value	Unit
Fixed costs	3,342,170	\$
Other fixed costs (pipe racking, separator, valves)	600,000	\$
Variable costs (per year)	226,695	\$/year
Total costs (annual basis)*	489,506	\$/year
Income from energy sales	5,286,207	\$/year

*Includes depreciation of total fixed costs over 15 years

4. RESULT AND ANALYSIS

The chemical treatment systems (for inhibition of calcium carbonate and for neutralization) are excellent options for maintaining production from geothermal wells that produce calcite deposition and/or acid fluids. It is because of these two systems that production at the Miravalles geothermal field has been stable.

As indicated by the data in Table 5, it is cheaper to install a calcium carbonate inhibition system than to carry out mechanical cleanouts in a geothermal well that will require at least one cleanout per year. The main cost saving comes from eliminating lost production, since there is no need to withdraw the well from production for a mechanical cleanout. There is also the benefit of increasing the well's lifetime, by avoiding possible damage to the inside of the wellbore during a mechanical cleanout, and avoiding adverse effects on cement bonds that may be caused by cooling and re-heating the well in the cleanout process.

From the data in Table 8, it can be seen that the cost of a neutralization system can be recouped within a year. A neutralization system must be implemented if an acid well needs to be tested or connected to the gathering system; corrosion will not allow the well to be produced for long unless such a system is used. The costs associated with the neutralization systems are higher than the costs for the calcium carbonate inhibition systems (controls, personnel, chemical fluxes, capillary tubing, etc.). All these controls are needed to maintain the pH value between 5.5 and 6.0, which is necessary to avoid the deposition of amorphous silica and anhydrite.

5. CONCLUSIONS

Currently, the total steam delivered to the power plants at Miravalles is about 330 kg/s. Around 1,235 kg/s of residual (separated) geothermal water is sent to injection wells, which are distributed in four areas of the field (the northern, southern, eastern and southwestern sectors). With these quantities of steam and brine, the total generation from the field is about 150 MW.

In order to supply the required steam to the power plants, it was necessary to install calcium carbonate inhibition systems as well as neutralization systems in the production wells. Currently there are 21 wells with calcium carbonate inhibition systems and 3 with neutralization systems. The systems operate 24 hours a day, 365 days a year.

The calcium carbonate inhibition system has become a very reliable system that has allowed constant production from the Miravalles wells. Different types of inhibitors that have so far passed the tests are Nalco 1340 HP Plus, Geosperse 8410CN+ and BWA DP 3537.

The implementation of a calcium carbonate inhibition system is cheaper than relying on mechanical cleanouts. The annual cost for a calcium carbonate system is more than 16 times the cost of

mechanical cleanouts per year, for a group of 5 production wells.

In the acid wells, it was necessary to change the initial value of the pH (7.0) to minimize the formation of amorphous silica and anhydrite. When the neutralization systems are regulated to keep the fluid pH between 5.5 and 6.0, no corrosion problems are reported, nor is it necessary to perform mechanical cleanouts to remove amorphous silica or anhydrite deposits.

The neutralization system has also become a very reliable means of allowing for production from acid wells. The system still requires technical personnel on site to manually modify the NaOH dosage to regulate pH. A further improvement to the neutralization system could be the automation of the NaOH dosage control. It has recently been possible to automate the monitoring of the pH value (Moya and Mora, 2009), so the next step would be to input these pH readings into a controller, to allow for automated control on the NaOH dosage.

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