

Benefits from the Utilization of a Calcium Carbonate Inhibition System for Production Wells 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 the year 2004. During the first production tests of wells in the field, it was found that the reservoir fluids are over-saturated with respect to calcium carbonate at the flashing zone, causing deposition of this mineral and obstruction of the production casing within few days. A test conducted in 1989 proved that systematic chemical inhibition inside the production wells could prevent the formation of calcite scale. All the inhibitors tested in the field are described in this article. Since 1994, the inhibition system has been used successfully in the production wells that supply steam to the generating Units. Experience has indicated that the injection of an appropriate dose of inhibitor makes it possible to produce the geothermal wells with little or no deposition of calcium carbonate, and it is less expensive than performing mechanical cleanouts.

1. 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 km², of which about 16 km² are dedicated to production and 5 km² 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°C and is water-dominated.

Seven separation stations supply the steam needed for Unit 1, Unit 2, Unit 3 and one active Wellhead Unit. Normally, two or three production wells supply two-phase flow to each separation station. The total steam flow to the plants is now about 280 kg/s, and the residual geothermal water sent to the injection wells is about 1,330 kg/s.

The Miravalles Geothermal Field has been producing since 1994. Table 1 shows the increments of generation during these first ten years. 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. At present there is a need to supply enough steam to operate 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 binary plant came online in January of 2004.

In order to supply the steam to the power plants, it was necessary to install a calcium carbonate scale inhibition system in each production well. There are 23 inhibition systems installed, which are used for the production wells when sending steam to the power plants. They operate 24 hours a day, 365 days a year. The inhibitors tested in the field, and the economic benefit of this system versus mechanical cleanouts, are described in the following sections.

2. FORMATION OF CALCIUM CARBONATE

Production wells at the Miravalles Geothermal Field showed a high potential for calcite deposition even before exploitation of the field began. The degree of calcite saturation (log Q/K) was evaluated for each production well using the Watch computer program (Arnórsson et al., 1982; Bjarnason, 1994) and it was found that the pre-flashed reservoir fluids of neutral pH are below saturation levels. Arnórsson (1989) discussed two mechanisms by which calcium carbonate minerals can be formed from geothermal fluids. The first process occurs through hydrolysis, the second through boiling. In both mechanisms, the important parameters that govern the deposition of calcite include P_{CO2} (fugacity or partial pressure of dissolved CO₂), pH, temperature, salinity and Ca²⁺ content.

Table 1: Units at the Miravalles geothermal field.

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	

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

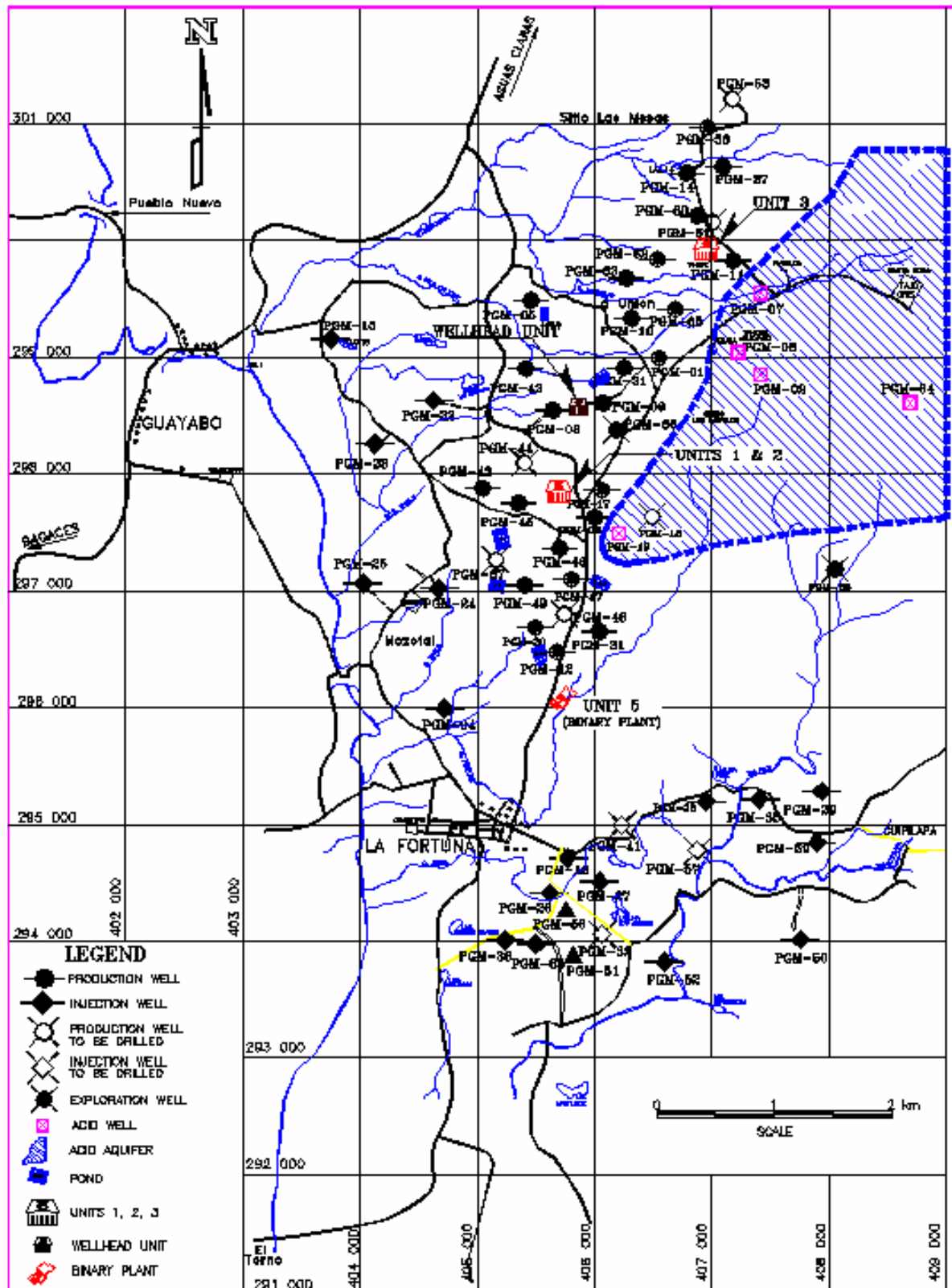


Figure 1: Location of production wells at the Miravalles Geothermal Field.

In Miravalles, the second process of calcite precipitation (boiling) is the mechanism that affects the output of the production wells; this is supported by the fact that calcite deposition has occurred on the downhole capillary tubing near the flashing zone. 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 are ascending to the wellhead, the fluid tends to become supersaturated with calcite and hence there is a high potential for calcite to be deposited (Moya and Yock, 2001).

3. SCALING INHIBITOR AND CAPILLARY TUBING TEST

Several anti-scaling chemicals have been tested at the Miravalles geothermal field. In order to compare results and to avoid unexpected events, which could be caused by variations in the thermal and production conditions, all of these tests were carried out in well PGM-11. This well was drilled during 1984-1985 and is located in the northern part of the field. It is 1,454 meters deep and has two main feed zones that have been identified. The first zone is from 850-1,050 m deep and the second is at 1,440 m. The mass flow rate is approximately 56 kg/s and non-condensable gases are approximately 1% w/w. Before the mechanical cleanouts carried out in 1987, a major calcite deposit was found between 650 and 920 m depth. The first test, performed in May 1989, utilized an inhibitor called Sequion 40-30. This product is an organic-phosphate chemical and it was injected to 1,050 m depth by simply hanging a 6.35 mm OD Alloy 825 capillary tubing in the well. The operation was stopped after two days due to scale deposits that blocked the capillary tubing. Chemical analysis of this material showed a high phosphorous content and low Cr, Mn, Ni and Fe contents. This deposit was probably formed by a reaction of the Sequion 40-30 with the inner part of the capillary tubing at high temperature.

In June 1990, a second test was conducted, also in well PGM-11. This time, Nalco 1340, an aqueous polyacrylate, was used as the inhibitor and was injected to 1,000 m depth using 6.35 mm OD ASTM A-269 type 316-L capillary tubing. The operation was stopped after three months due to scale deposits that blocked the capillary tubing. Chemical analysis of the material showed a high content of sulphur (38%), iron (40%) and chrome (14%). This deposit was probably formed by the reaction of a sulfur impurity and the capillary tubing.

In 1992, a third test was conducted in PGM-11, this time using Nalco 1340, Sequion 40-30 and Exxon Chemical Surflo as inhibitors. The last product is an aqueous poly maleic anhydride solution. Two capillary tubings were used in this test: ASTM A-269 type 316 and Incoloy 825. Using Nalco 1340 inhibitor and the ASTM A-269 type 316 capillary tubing provided the best technical and economic results.

Before the commissioning of Unit 1 in 1994, Nalco Co. improved its chemical product and produced the Nalco 1340 HP without sulfur impurities, with a pH near 4.1. The previous deposition caused by Nalco 1340 (sulfur, iron and chrome) was avoided with new this product.

During the first year of production at Miravalles, several problems occurred with the tubing in well PGM-31, and it was necessary to replace the SS 316-L with Incoloy 825, which provided good results that have continued until the present.

By 1997, a new product was utilized at the Miravalles geothermal field. This time it was Aquaquest 305 from Henkel, which is an aqueous Na-polyacrylate solution with a pH of 7.5-9.0. The inhibition results were good, but it presented two operational problems. The first occurred when the product was diluted with water and some bacteria grew with time, clogging the capillary tubing. The second was caused by the antibacterial product used by Henkel to inhibit the bacterial growth. The product had a high phosphorus content that reacted with the SS 316-L capillary tubing, producing a solid that plugged the tubing.

The last improvement from Nalco Company was Nalco 1340 HP Plus. This product has a 100% higher concentration of the active ingredient, and it is currently the one used at the Miravalles geothermal field.

4. INHIBITION SYSTEM VERSUS MECHANICAL CLEANOUTS

The cost of the inhibition system has been estimated, taking into account the expenses during the first 10 years of operation (Figure 2). The cost has been divided into three subgroups: field, plant and auxiliary equipment costs. The sum of these three costs equals the total cost. All the activities related to the implementation (Figure 3), operation (Figure 4) and maintenance (Figure 5) of the inhibition system are included in the total cost. In order to estimate the cost for the field, it has been assumed that there will be five 7 MWe wells, operating continuously to supply steam to a 35 MWe plant.

Table 2 indicates the costs for the field (considering five geothermal wells), plant and auxiliary equipment. This table shows that the total cost is around \$3,367,000 and that the cost per year is close to \$205,365.

Table 2: Cost of the Inhibition System

Cost Category	Total Annual Cost
Field	\$82,430
Plant	\$77,790
Equipment	\$45,145
Total	\$205,365

The main purpose of the inhibition system is to extend the life of the well, maximize the production time of the well and reduce the frequency of mechanical cleanouts. If there were no inhibition system in place, the wells at Miravalles would produce for approximately 3 months (worst case), during which time each well's production rate would decrease until the well is unable to supply steam to the plant. At this point, a drilling rig would have to be installed to clean out the well, removing the calcium carbonate deposits near the flash point inside the borehole (near 1,000 m depth). At Miravalles, in order to clean a well and put it back in production, no fewer than 15 days are required. To simulate the loss in production due to the formation of calcium carbonate deposits near the flashing zone, it was assumed that each production well would produce at its maximum flow rate during half of its production period. During the other half, the flow rate would decrease by 1% of the total flow in a given time period.

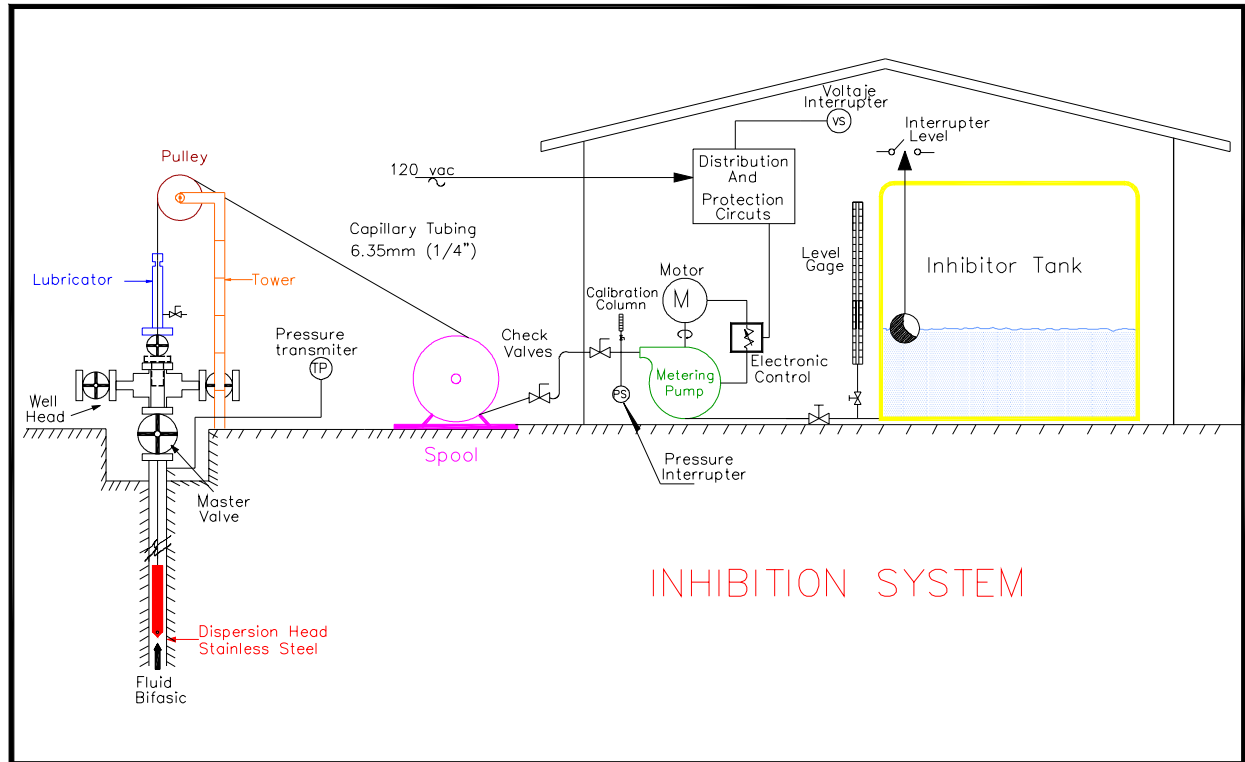


Figure 2: Inhibition System, Miravalles Geothermal Field.



Figure 3: Inhibition System. Dispersion Head.



Figure 4: Inhibition System. Tower.



Figure 5: Inhibition System. Dilution Plant.

The costs associated with the mechanical cleanout are related to the installation and operation of the drill rig, the well production decline, and the generation lost during the 15 days of the cleanout.

It was considered that the 5 production wells would need a mechanical cleanout once a year, in order to make a comparison with the utilization of the inhibition system. As Table 3 indicates, the implementation, operation and maintenance of 5 calcium carbonate inhibition systems (one for each production well) is only 7.6% as expensive as performing five mechanical cleanouts of the production wells in a one year period.

Table 3: Cost of Mechanical Cleanouts.

Item	Cost /year
Cleanouts	\$731,325
Lost generation	\$2,635,187
Total	\$2,708,319

4. FINAL REMARKS

The inhibition systems at the Miravalles Geothermal Field operate 24 hours a day. These systems have allowed a constant supply of steam to the installed units, with little or no deposition of calcium carbonate inside the production wells during the first ten years of commercial operation.

The formation of calcium carbonate inside the wells at the Miravalles Field is caused by boiling; this is supported by the fact that calcite has deposited on the capillary tubing near the flashing zone.

The inhibitor controls at the Miravalles field have been implemented successfully. This has been proven by the fact that there have been few mechanical cleanouts and the outputs of the production wells have been almost constant during the period of exploitation.

The optimal inhibitor dosage was initially estimated to be 3 ppm. When exploitation began at the Miravalles field, the dosage was increased to 4 ppm, but since then it has been decreasing, and now the dosage is between 0.5 and 2.5 ppm. In most wells the dosage varies between 0.5 to 1.0 ppm.

Under normal conditions, about 27,550 kg/month of diluted inhibitor at 10.5% v/v (equivalent to 12% w/w) must be delivered to the field to feed the tanks at the well sites. Therefore, about 330,478 kg of diluted inhibitor are needed each year to operate the Miravalles geothermal field.

It is less expensive to implement, operate and maintain 5 calcium carbonate inhibition systems than to carry out 5 mechanical cleanouts (one in each well) in a one-year period. The inhibition systems represent only a 7.6% of the total cost associated with the mechanical cleanouts in the production wells.

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