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Development of the Neutralization 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 also Unit 5 (19 MWe, a binary plant) in the year 2004. The thermal water of most of the production wells is slightly alkaline, but 5 wells have produced distinctly acidic water, with pH values between 2.3 to 3.2. Since February of 2000 (in well PGM-19) and October of 2001 (in PGM-07), acid neutralization systems have been used successfully, which has allowed these wells to supply steam to the generating units. Experience has indicated that, with the deep injection of an appropriate dosage and concentration of sodium hydroxide, it is possible to incorporate wells with acidic fluids into production with no corrosion and at a reasonable cost.

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 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°C and is water-dominated.

The Miravalles geothermal field has been producing since 1994. 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 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. 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.

Normally, two or three production wells supply two-phase fluid 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. Most of these fluids are passed through Unit 5 (binary plant) to generate 19 MWe.

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 (México); WHU - Wellhead Unit; and BOT – build-operate-transfer.

To meet the steam supply requirements of the power plants, it has been necessary to utilize two wells (PGM-07 and PGM-19) that were not used previously because they produce acid fluids. This required the development and installation of systems to neutralize the acidity, and now there are 2 neutralization systems in continuous operation at the Miravalles geothermal field. The improvements in the neutralization system and the economic benefit from the acid wells are described in the following sections.

2. PHYSICAL AND CHEMICAL CHARACTERISTICS OF WELLS PGM-07 AND PGM-19

Most of the wells of the Miravalles Geothermal Field produce sodium-chloride type waters, with pH about 5.7, reservoir silica at about 430 ppm and a tendency to deposit carbonate scale in the wellbore. However, among the 53 wells already drilled, five (PGM-02, PGM-06, PGM-07, PGM-19 and PGM-64) have been found to produce acid fluids with a pH between 2.3 to 3.2. These five wells are located in the northeastern part of the field, which suggests the possible existence of an acid aquifer of some extent (see Figure 1). All of these wells except for PGM-64 have been tested on a preliminary basis to study the possibility of commercial operation by using a downhole acid neutralization system, and wells PGM-19 (since February 2000) and PGM-07 (since October 2001) have been used successfully for production. The completion profiles and related information about wells PGM-07 and PGM-19 are shown as Figures 2 and 3, respectively.

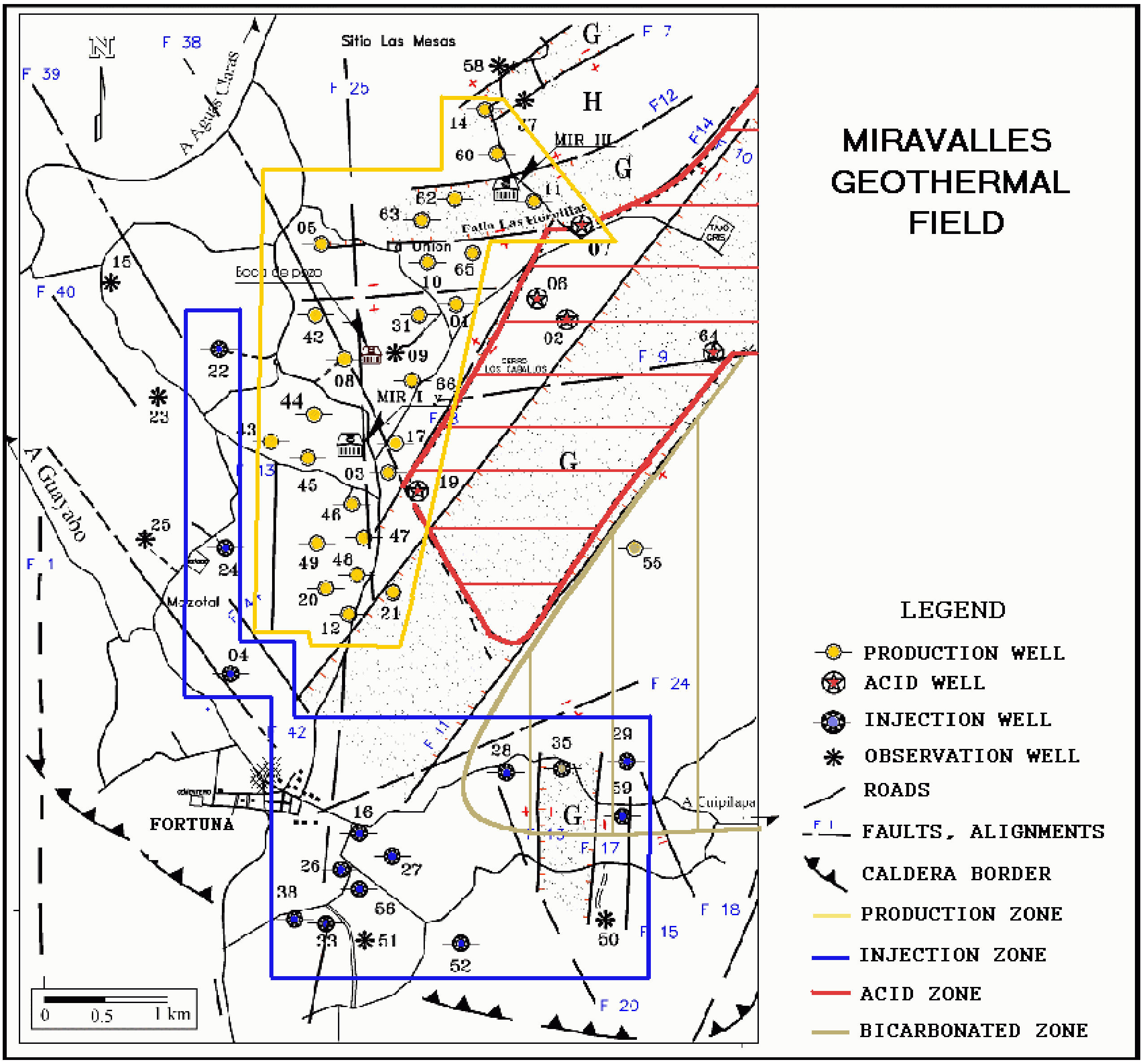

Figure 1: Location of production wells at the Miravalles Geothermal Field

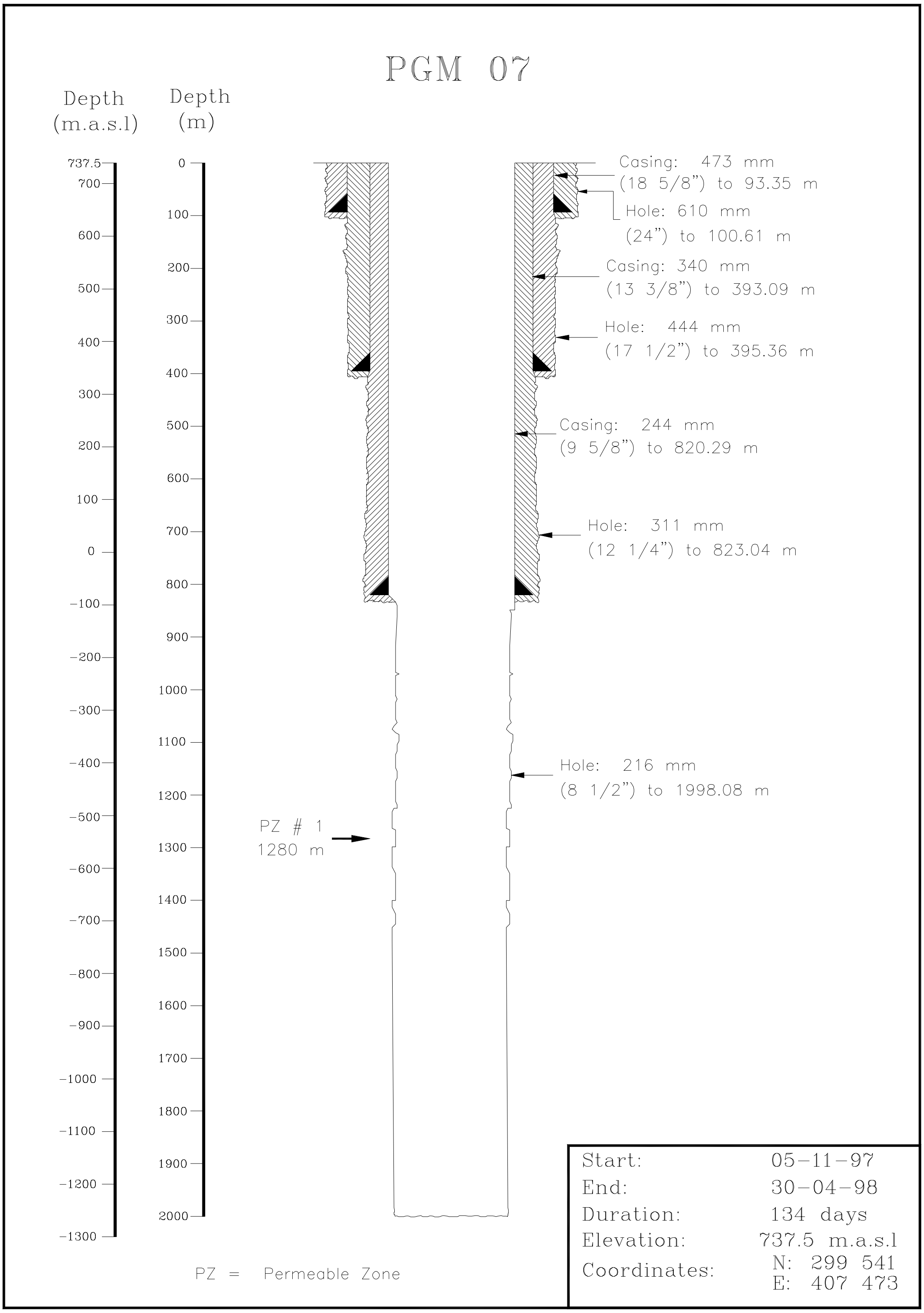

Figure 2: PGM-07 Well Completion Profile

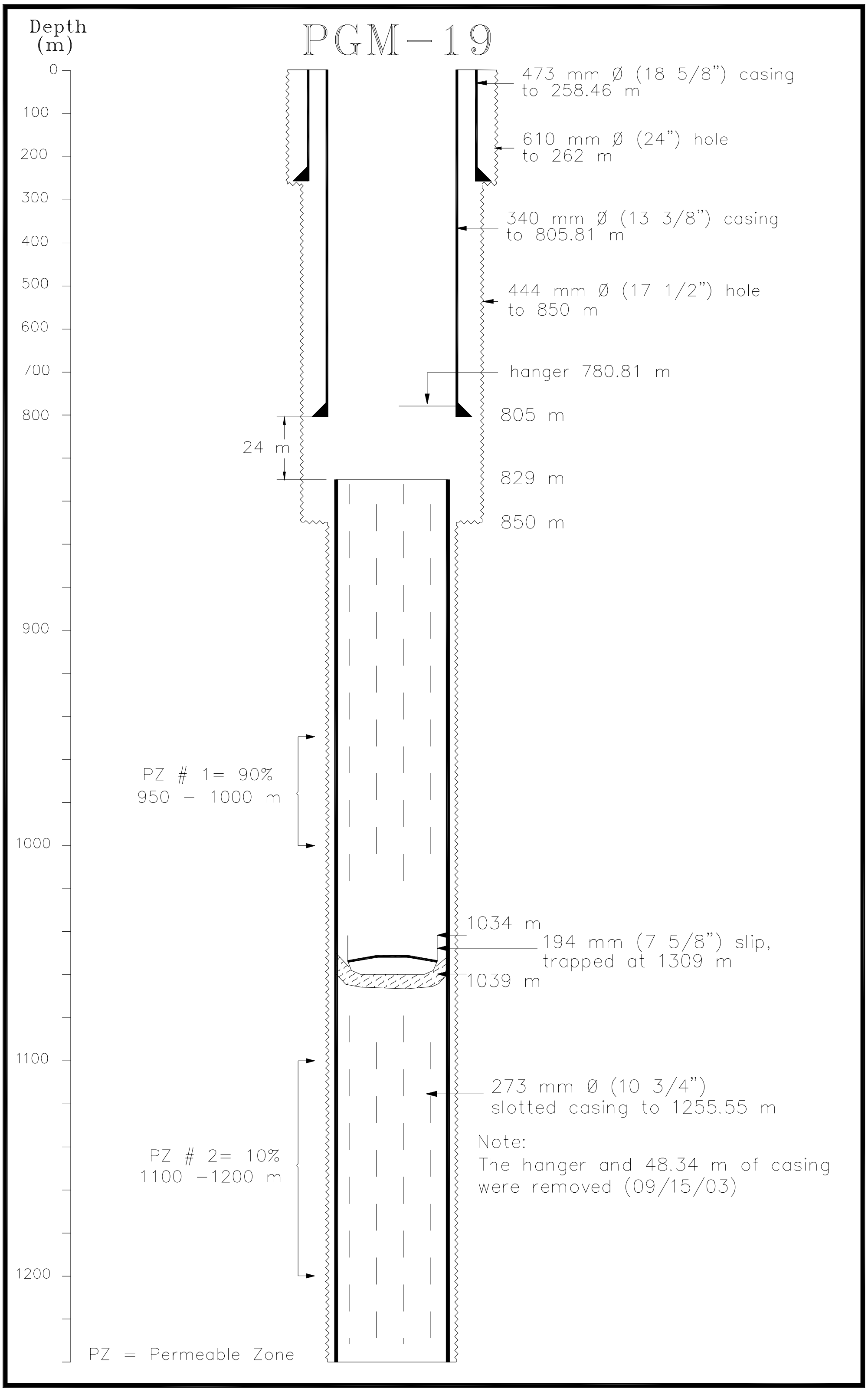

Figure 3: PGM-19 Well Completion Profile

Table 2 shows fluid chemical data from wells PGM-07 (after 5 months of production) and PGM-19 (after 13 months of production), along with the pH-neutral production wells PGM-11 and PGM-17 (after 7 years of production). As the table illustrates, the four wells are chemically quite similar, their main differences being in the concentrations of sulfate, magnesium, pH and bicarbonate. Other chemical variations, such as those of calcium and chloride, are characteristic of the Miravalles field and depend on well location and the influence of (re-)injected water. Temperature variations of about 15ºC among northern (hotter) and southern (cooler) wells are a function of well location with respect to the heat source. The chemical characteristics of the wells listed in Table 2 have remained constant until the present (March 2004).

The relatively high magnesium concentration at the acid wells can be attributed to disassociation of chlorite-group minerals in an acidic environment, while the most important characteristic of the acid wells is sulfur content and its relationship to pH. The acidic aquifer is confined to the eastern sector of the field, and is believed to be the result of magmatic gases rising from deeper levels into a pre-existing portion of the reservoir. This hypothesis is supported by the evolutionary trend of the fluids in wells PGM-07 and PGM-19, in which the sulfate content has decreased from 300 and 400 ppm to 225 and 217 ppm respectively, the pH has increased from 2.3 and 3.2 to nearly 4, and the magnesium content has tended to decrease as the natural pH of the fluids increases.

3. OPERATION OF THE NEUTRALIZATION SYSTEM

The commercial exploitation period at wells PGM-07 and PGM-19 has shown that the downhole neutralization systems are working properly (Figure 4). They have achieved their goals, which are to raise the pH at depth and to protect the well casings and surface installations. Table 3 shows typical monitoring data from the neutralization systems, and illustrates how the stabilized pH values lead to low iron corrosion values, and therefore favorable operating conditions.

Table 2: Chemical composition of the fluids

Well	PGM-07	PGM-19	PGM-11	PGM-17
Date	Mar-02	Mar-02	Jul-01	Jul-01
sampling pres.(bar m)	0,94	0,94	0,94	0,94
Cond. (µS/cm)	12680	12890	12398	14018
pH	***7,40****	***7,18****	***8,16***	***8,01***
Na+ (ppm)	2567	2587	2487	2785
K+ (ppm)	324	321	289	334
Ca++ (ppm)	34	42	68	91
Mg++ (ppm)	***1,53***	***3,85***	***0,19***	***0,09***
Li+ (ppm)	6,05	5,05	5,47	5,28
Rb+ (ppm)	0,96	1,00	0,82	1,01
Cs+ (ppm)	0,71	0,71	0,51	0,55
Al Tot (ppm)	0,30	0,34	0,66	0,41
Fe Tot (ppm)	0,16	0,12	< 0.05	< 0.05
Cl^- (ppm)	4123	4077	4088	4655
$SO_4^=$ (ppm)	***225***	***217***	***50***	***50***
HCO_3^- (ppm)	***12,1***	***1,8***	***65,3***	***22,3***
F^- (ppm)	2,25	2,3	1,96	1,60
B (ppm)	70	67	64	72
H_2S (ppm)	1,00	1,45	0,70	0,67
NH_3 (ppm)	3,6	4,8	1,1	1,45
As (ppm)	10,6	11,05	9,65	10,37
SiO_2 mon. (ppm)	664	555	606	530
T.D.S. (ppm)	8300	8050	7860	8925
gases in steam (%)	1,5	0,8	1,4	0,3
T Measured (°C)	245	230	242	235
Enthalpy (KJ/Kg)	1450	1000	1100	1015

* neutralized values

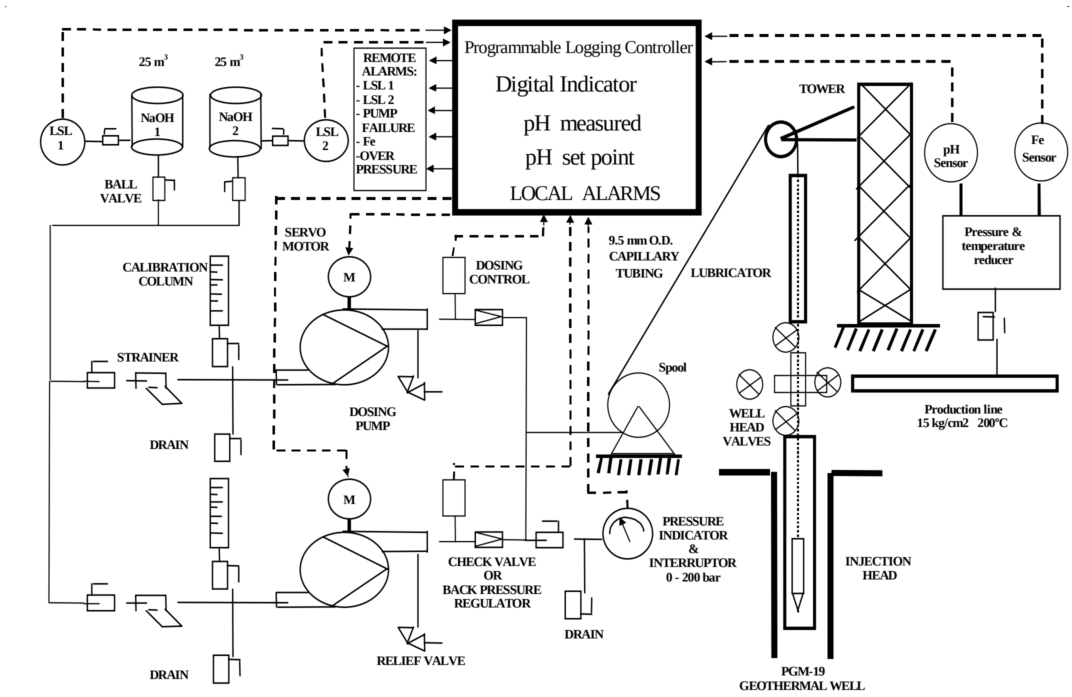

Figure 4: Miravalles geothermal field. Fluid Neutralization System

Table 3: Neutralization Monitoring Data.

Well	Data	Sample #	Ca^{+2} ppm	Cl^{-} ppm	Relation Ca/Cl*3000	pH	Fe ppm	SO_4^{-2} ppm	Dose ppm NaOH
PGM-07	4-May-04	86025	33	3573	27.7	6.62	0.39	355	65
	4-May-04	86026	33	3538	28.0	6.59	0.41	347	65
	4-May-04	86027	34	3542	28.8	6.57	0.44	348	65
		Average	33	3551	27.8	6.59	0.41	350	65
PGM-19	2-Mar-04	84228	43	3909	33.0	6.57	0.22	472	30
	2-Mar-04	84229	43	3916	32.9	5.72	2.09	527	30
	2-Mar-04	84230	42	3938	32.0	5.70	2.20	556	30
		Average	43	3921	32.6	6.00	1.50	518	30

The first acid-well neutralization tests at the Miravalles geothermal field (Sánchez, 1997, Sánchez & et 2000) established that raising the fluid pH creates oversaturation which may cause deposition of solid phases within the well and at the surface. Figure 5 illustrates that anhydrite ($CaSO_4$) is oversaturated when the pH is greater than 3.5 at temperatures greater than 220ºC. Indeed, the main problem with acid neutralization has been the formation of anhydrite and a complex of amorphous silica. Both are found at depth, and the silica is also found at the surface. As a result, after nearly six months of production it is necessary to perform a mechanical cleanout to restore lost productivity caused by scaling inside of the production casing. Figure 6 shows the different types of deposits formed as a result of production from the acid wells.

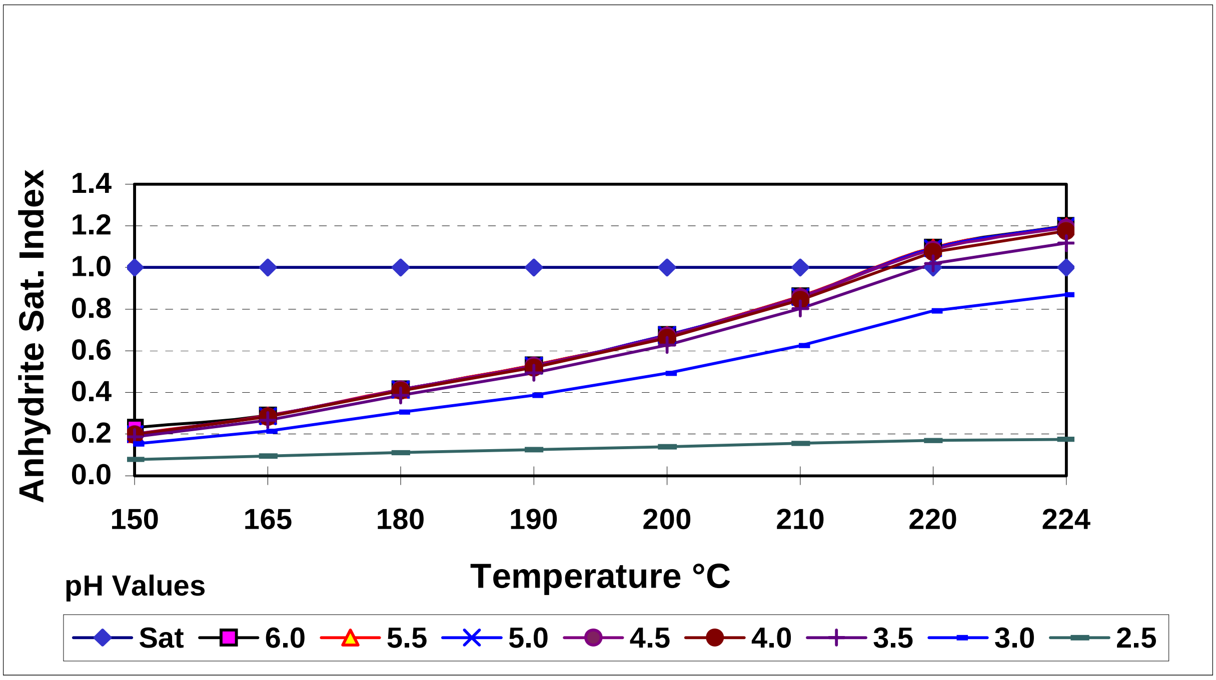

Figure 5: Anhydrite Saturation Index, Temperature and pH

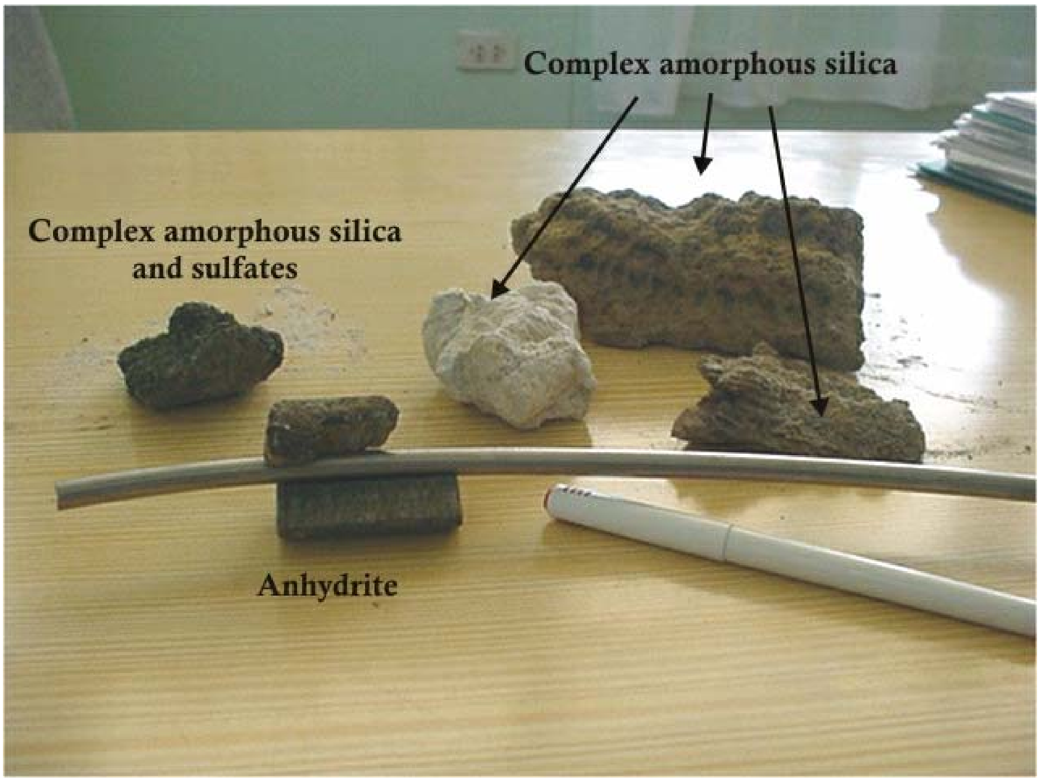

Figure 6: Different types of scale deposits formed as a by-product of neutralization

4. PRODUCTION FROM WELLS PGM-07 AND PGM-19

As mentioned above, well PGM-07 has been producing since October 2001 and well PGM-19 since February 2000; the production histories of these two wells can be seen in Figures 7 and 8. Well PGM-07 has flowed almost constantly during its production period, but well PGM-19 has been closed several times. Mechanical problems at the two wells have included loss of the downhole dispersion head, rupture of the capillary tubing, pump problems, and scaling inside the borehole, to mention the most important ones.

Despite these difficulties, the investment in the two wells is being recovered within a short period of time. This can be illustrated by comparing expenses and income. Expenses include the initial capital investment, the drilling cost, the separation station (pipes, separator and water tank), the consumption of NaOH, and operation and maintenance costs (including mechanical cleaning, fishing jobs to recover the dispersion head and the capillary tubing, etc.). Income is based on the value of the steam delivered to the geothermal plant (not the revenue that ICE receives for selling the electricity generated). Figures 9 and 10 show the Expense curve, the Income curve and the Profit curve for these two wells from the time they started production up until December, 2003. The difference between the Expense curve and the Income curve gives the Profit curve. When the Profit curve crosses from negative to positive, all the investments in the well have been recovered, and from that point on a gain is obtained from producing the well. These figures show that well PGM-19 had already paid for itself by November, 2002 and that well PGM-07 has been paid for since May, 2003.

5. NEW STUDIES

New studies have been conducted in order to optimize the value of the pH to control the corrosion better and reduce scale formation. An agreement between NEDO (New Energy Development Organization, Japan) and ICE has allowed studies to be carried out to determine the rate of corrosion and scale formation, utilizing different values of pH in well PGM-07. Figure 11 shows the various pH values that have made it possible to operate well PGM-07 without a mechanical cleanout for more than a year. These results are already very positive, because they indicate that the frequency of mechanical well cleanouts can be reduced in the future, making the operation and maintenance of the acid wells less expensive (in the past, around 2 cleanouts per year were required for each well).

At present, an optimization of the pH value in well PGM-19 is being performed, because the chemical conditions of the wells PGM-07 and PGM-19 are not identical. The pH value at well PGM-19 has been reduced to five, and the results are being observed.

In addition, silica inhibitors from two chemical companies will be tested in well PGM-07 in the near future. During the first phase of the test, the silica inhibitor will be injected at the wellhead in order to observe the stability and efficiency of the product. If good results are obtained during the first phase, then, in the second phase, the injection of the silica inhibitors will take place downhole, mixing them with the NaOH.

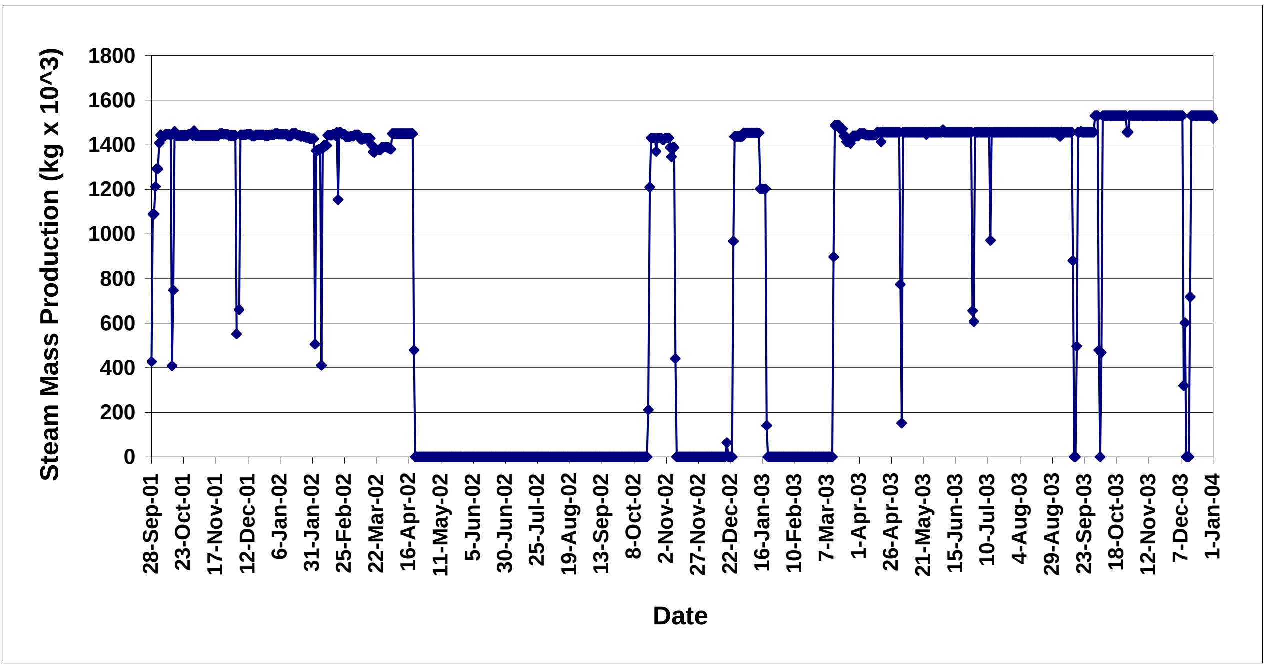

Figure 7: Production History of Well PGM-07

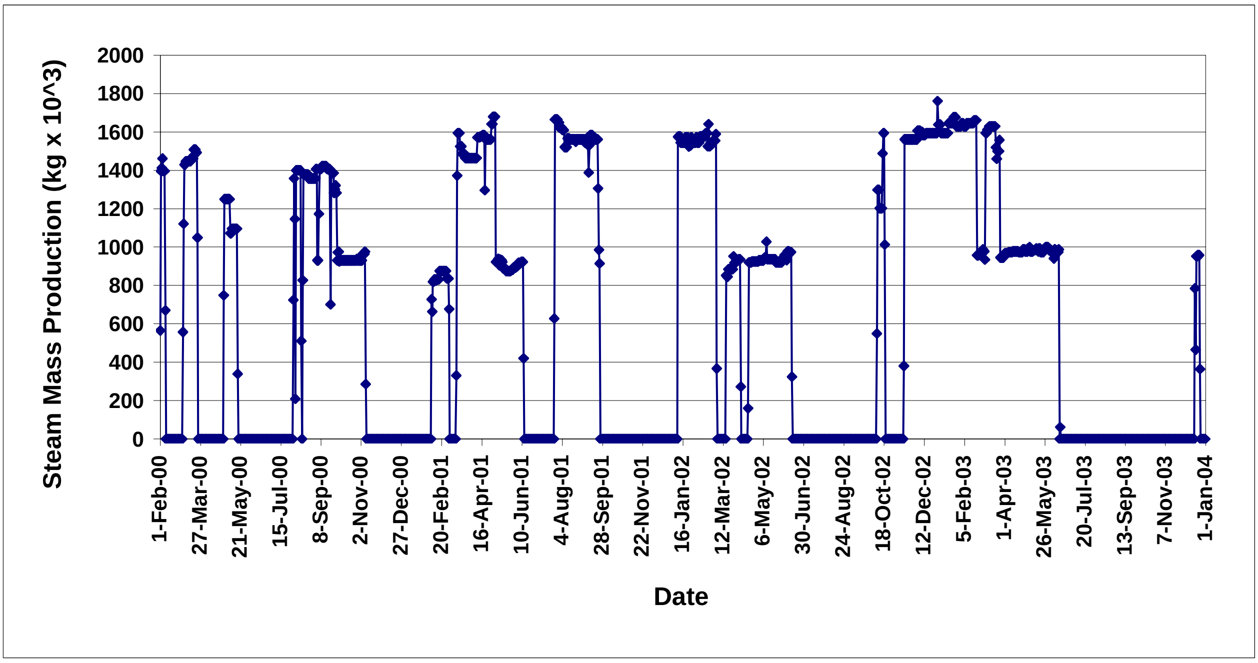

Figure 8: Production History of Well PGM-19

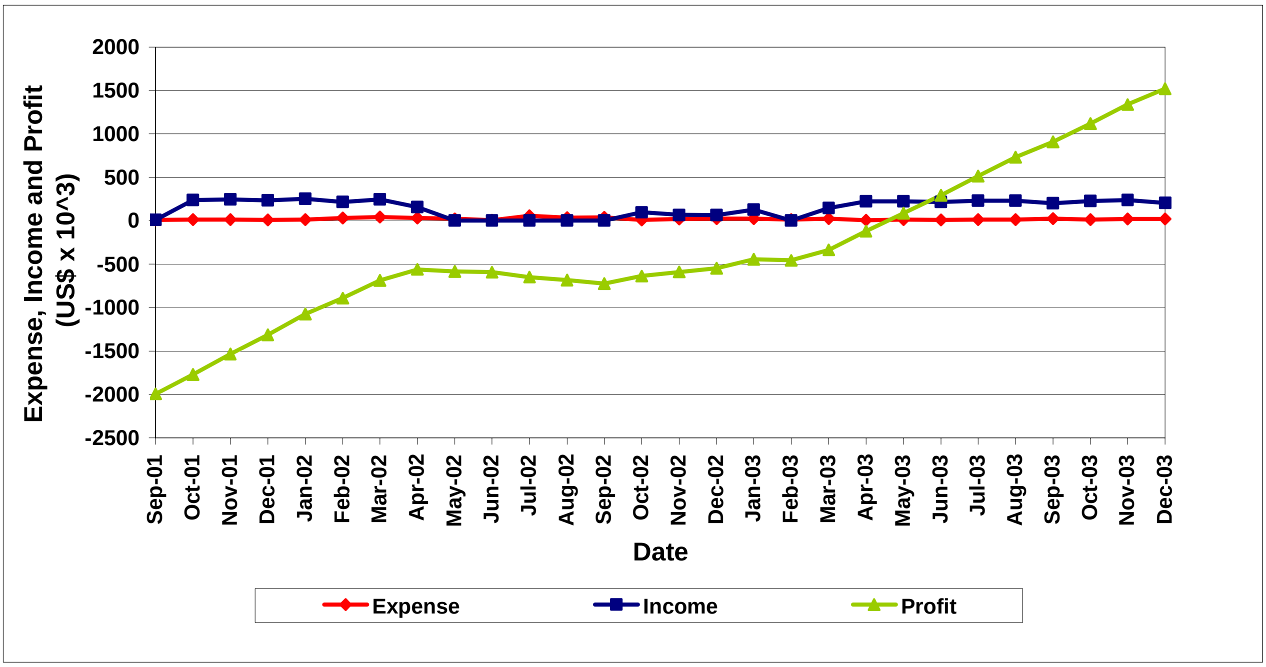

Figure 9: Expense, Income and Profit curves of well PGM-07

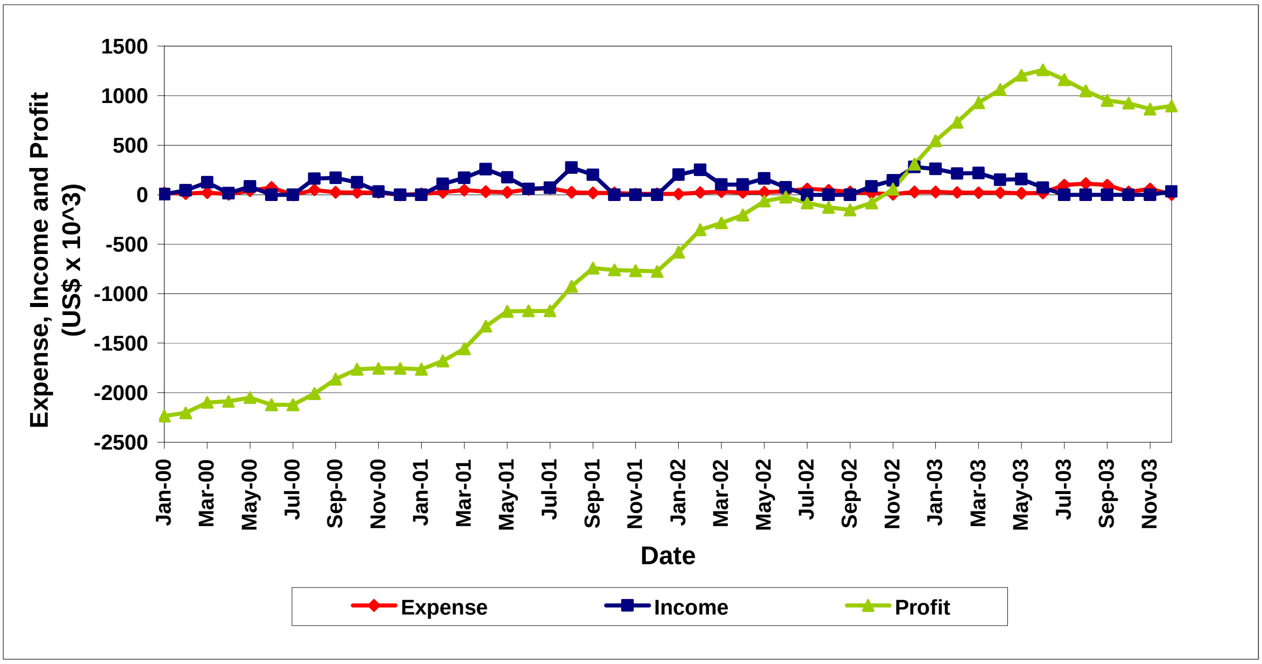

Figure 10: Expense, Income and Profit curves of well PGM-19

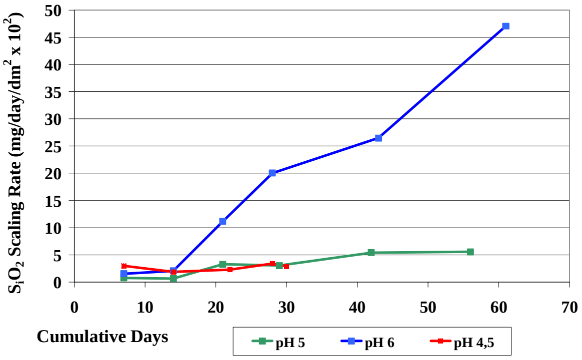

Figure 11: Channel SiO_2 scaling rates at different pH values in PGM-07

6. FINAL REMARKS

1. Currently there are 2 acid neutralization systems working 24 hours a day at the Miravalles Geothermal Field. They have allowed a continuous supply of steam to be delivered to the gathering system from the acid wells PGM-07 and PGM-19.

2. The chemical differences between the neutral and acidic aquifers are the result of the influence of deep gases that have entered the acidic aquifer. This phenomenon took place after the formation of the reservoir, and insufficient time has passed for the acidity to be neutralized in the reservoir by natural processes.

3. During exploitation of the acidic aquifer thus far, the well fluid pH before neutralization has shifted from 2.3 (in PGM-07) and 3.2 (in PGM-19) to 4.0.

4. The neutralization system has worked properly; that is, it has raised the pH at depth to protect the well casings and surface installations.

5. The scaling process that takes place in connection with neutralization produces anhydrite and an amorphous silica complex. New studies have been conducted in order to optimize the value of the pH to control the corrosion better and reduce the formation of these deposits. Silica inhibitors from two chemical companies are going to be tested in well PGM-07 in the near future.

6. The operation of the neutralization systems has allowed the recovery of the initial capital investment in well PGM-07 (in July, 2003) and in PGM-19 (in January, 2003).

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