Presented at "Short Course on Geothermal Development and Geothermal Wells",
organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 11-17, 2012.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

LaGeo S.A. de C.V.

IRON METERS FOR PRODUCTION WELLS AT THE MIRAVALLES GEOTHERMAL FIELD

Paul Moya and Rodrigo Mora
Instituto Costarricense de Electricidad
P.O. Box 10032-1000, San José,
COSTA RICA
PMoya@ice.go.cr, RomoraS@ice.go.cr

ABSTRACT

At the Miravalles geothermal field there are wells that produce acid fluids, which have been successfully utilized by treating the acidity using a neutralization system. The system continuously adds sodium hydroxide (NaOH) through a capillary tubing string that reaches the production zones of the wells, to neutralize the acid fluids. Conditions inside the wells can lead to failure of the capillary tubing, causing the neutralization system to operate improperly. This situation is very difficult to detect from the surface, unless an iron meter is installed as part of the neutralization system. When the capillary tubing breaks, fluids are neutralized in only part of the wellbore, causing corrosion inside the well. An iron meter can detect, under these conditions, the amount of iron that enters the brine, which serves as an indirect signal that corrosion has increased due to the broken capillary tubing, even when pH readings are within the normal operating range.

The need to have an indirect indicator of a capillary tubing failure has led to the installation of iron meters as a part of the neutralization systems. The first digital equipment and sampling methods used did not work well. Field tests, analysis of the results, modifications and corrections to the sampler have resulted in important improvements in the instrumentation. A description of the iron meters utilized in the geothermal wells and the improvements made in the sampling methods are described in this document.

This paper was published in the Proceedings of the World Geothermal Congress held in Bali, Indonesia during April, 25-30, 2010.

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 south western slope of the Miravalles volcano. The present field extends over an area of more than 21 km^2; and about 16 km^2 are dedicated to production while 5 km^2 to injection. The temperature of the water-dominated geothermal reservoir is about 240^{0}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 MWe; 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, the Costa Rican Institute of Electricity (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 the wellhead unit was transferred to a new location at the south eastern part of the field.

Two temporary 5 MW wellhead plants came on line (1996 and 1997) as part of an agreement between ICE and the Federal Commission of Electricity of Mexico (CFE). These two temporary units were disassembled in April 1998 and 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, Unit 5, a 19 MW binary plant, increased the total installed capacity at Miravalles to 163 MW (Table 1). The history of growth of capacity at the field is shown in Figure 1 and its corresponding generation 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	

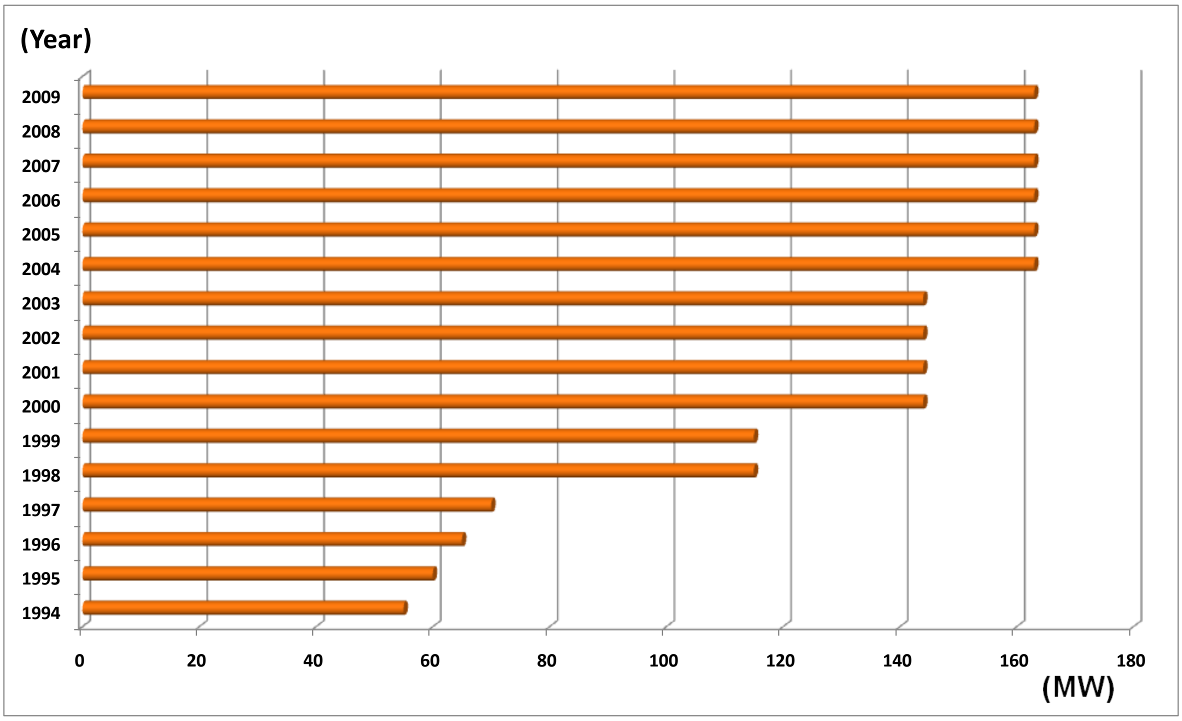

FIGURE 1: Geothermal installed capacity (1994 – 2009)

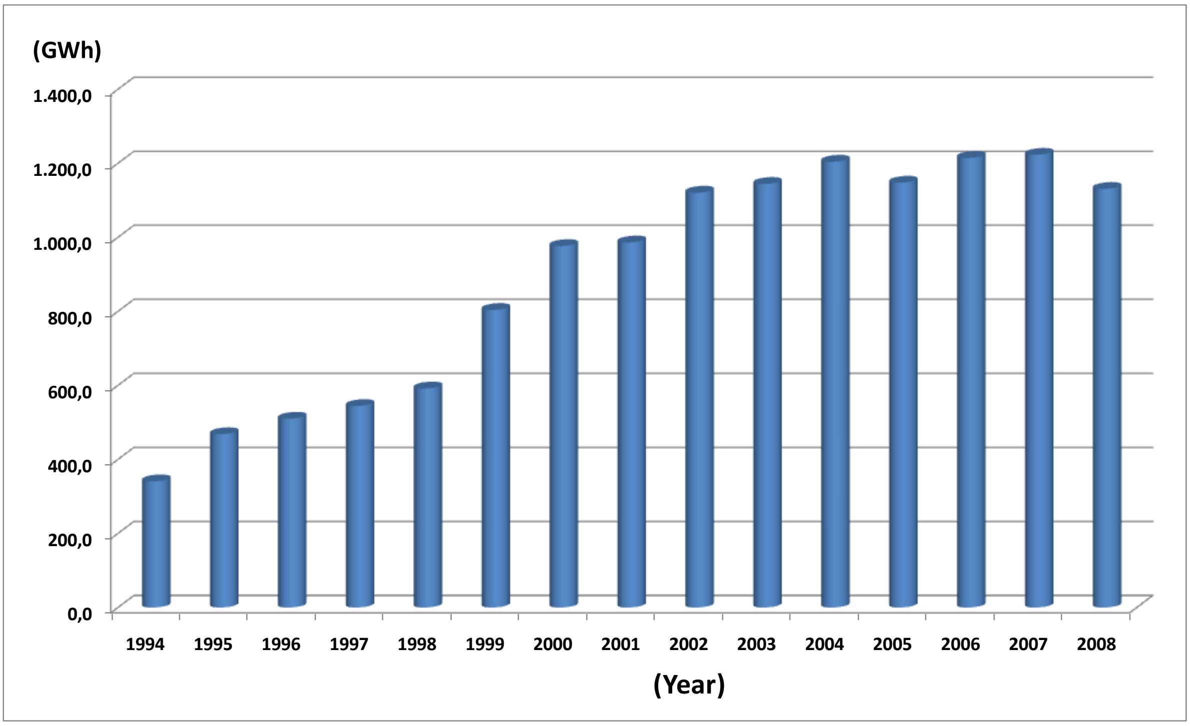

FIGURE 2: Geothermal generation in GWh (1994 – 2008)

Figure 3 shows the cumulative mass since production began at the Miravalles geothermal filed. In this figure the steam is represented by the green curve, the brine by the blue line and the sum of both is shown by the red curve. It can be seen that the steam supply has been slowly growing since 1994, a condition that has allowed the geothermal field to meet the steam demand coming from the generating units. Incremental production increases have accompanied each of the new units coming on line. 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 south western sectors. With these quantities of steam and brine the total generation reaches around 150 MW.

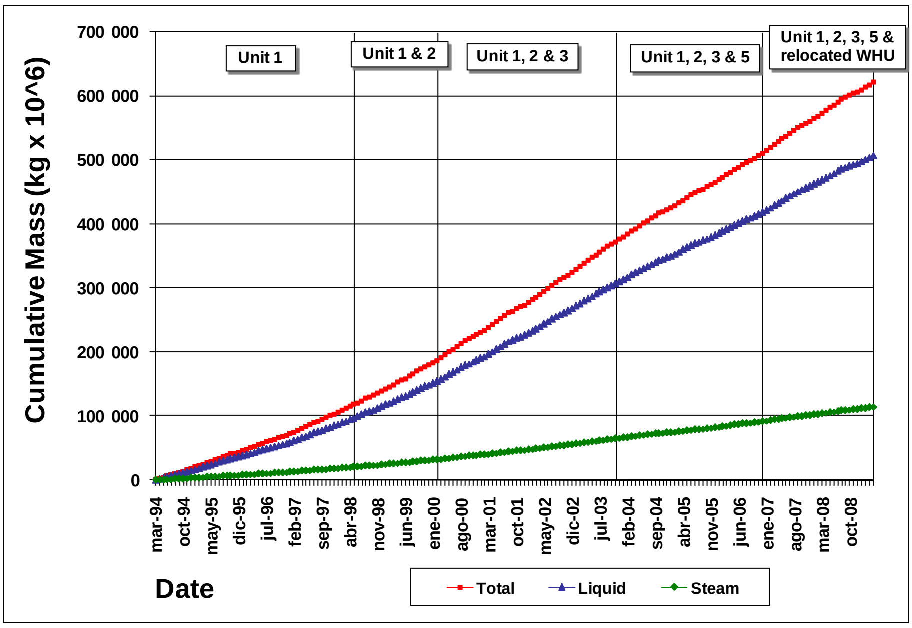

FIGURE 3: Cumulative mass at the Miravalles geothermal field

To meet the steam supply requirements of the power plants, it has been necessary to utilize three wells that produce acid fluids: PGM-02, PGM-07 and PGM-19 (Figure 4).

The incorporation of these three wells has required the implementation of systems to neutralize the acidity, and there are now 3 neutralization systems in continuous operation at the Miravalles geothermal field. As part of the neutralization system, an iron meter device has been utilized to monitor the behaviour of the neutralization system at the surface.

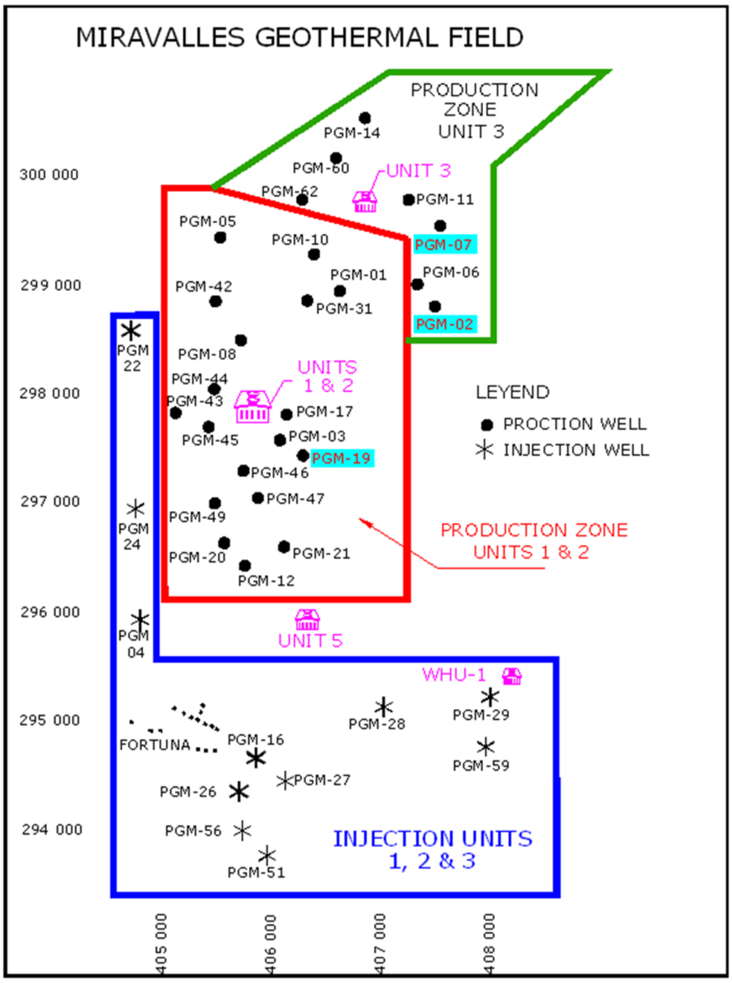

FIGURE 4: Location of wells PGM-02, PGM-07 and PGM-19

2. IRON METERS

Conditions inside the wells can cause the capillary tubing to break, which in turn causes the neutralization system to operate improperly. This situation is very difficult to detect from the surface, unless an iron meter is installed as part of the neutralization system. When the capillary tubing breaks, the fluids are neutralized in only part of the wellbore, and increased corrosion occurs in the unprotected part the well. An iron meter can detect, under these conditions, the amount of iron that enters the brine, which serves as an indirect signal that corrosion has increased due to the broken capillary tubing, even with pH readings that are within the normal operating range.

ICE implemented the operation of the first iron meter with the commissioning of well PGM-19 in 1999. Later, ICE installed two more iron meters, at well PGM-07 (in 2001) and at well PGM-02 (in 2008). In these ten years (1999-2009), several modifications and improvements have been made in the method of sampling the brine and also in the instrument utilized for this purpose.

So far, all the iron meters utilized at the Miravalles geothermal field use a colorimetric analysis technique. The equipment processes the sample and the reagents to form a colored end-solution whose absorbance is proportional to the iron concentration.

The main inconvenience with these types of instruments has been that it is difficult to obtain the sample under the conditions required. Normally, the sample of brine is collected near the wellhead at around 165 ^{0}C, which is a very high temperature for the instrument; also the brine contains impurities that complicate the operation of the instrument.

2.1 Iron Meter in Well PGM-19

The iron meter utilized at well PGM-19 was the Continuous Flow Analyzer from Rosemount Analytical Inc., which has a detection range of 0 to 20 ppm of iron. This instrument was bought by

ICE through a local representative of the USA company in Costa Rica. The characteristics of the continuous flow analyzer, which was installed by ICE personnel, are shown in Table 2 and Figures 5a and 5b.

TABLE 2: Characteristics of Continuous Flow Analyzer – Rosemount Analytical

Dimensions	45.7 cm wide x 71.1 cm high x 38.1 deep
Weight	57 kg without reagents and 80 kg with reagents
Electrical connections	115 V, 60 Hz
Sample requirements	10 – 15 mL/minute, pressure less than 10 psig, temperature 32^0 – 122 ^{0}F, filtered to 10 micros
Environmental requirements	50^0 – 104^0F, 10 – 80 % humidity
Pump	Peristaltic
Colorimeter	Single channel output
Interference filter	One narrow band interference filter
Flow cell	One constant volume flow through cell
Outputs	a) 0 – 5 VAC, b) 4 – 20 mA

The flow analyzer was installed next to the wellhead in a small provisional house to protect the equipment from both the weather and the impacts of normal well operation, as suggested by the representative of the company that provided the meter. Additionally, ICE bought and installed for this instrument a system to process the brine sample from the well; this system consists of a small heat exchanger and a filter device, designed by the company that sold the instrument (Figure 6). The system design was based on the initial data from the operation of the well.

Unfortunately, it was not possible to obtain good results from this arrangement because the heat exchanger was not able to cool the sample to the temperature required by the instrument, and also because the pipes of the apparatus were too small, leading to continuous blockages. Additionally, the hose arrangement into the instrument required a complex system of measurements where the mixture of the reagents was involved. There were also troubles in setting the correct adjustments to perform the colorimetric analysis.

FIGURE 5a: Continuous flow analyzer from Rosemount Analytical Inc. Photo by P. Moya

Due to all these problems in handling the sample, it was decided to relocate the instrument inside the main small house, where it would be better protected from the weather, and to install a new heat exchanger built by ICE. The new spiral-type heat exchanger (Figure 7) successfully reduced the final temperature of the sample, but it created some other problems, because the sample now had to travel a longer distance to reach the heat exchanger, and sediment (sand) caused obstructions in this new line. There was no consistency in the results due to these problems; two very different results might be obtained under similar sampling conditions. Many adjustments suggested by the company representative were made, including calibration for 1, 5, 10 and 20 ppm, and also the inclusion of a filter upstream of the instrument. These improvements did not work too well; there continued to be inconsistency between measurements and also obstructions in the filter. Several tests were carried out over many months, but it was not possible to obtain good results, and therefore, the instrument was not utilized any longer.

FIGURE 5b: Continuous flow analyzer from Rosemount Analytical Inc. Photo by P. Moya

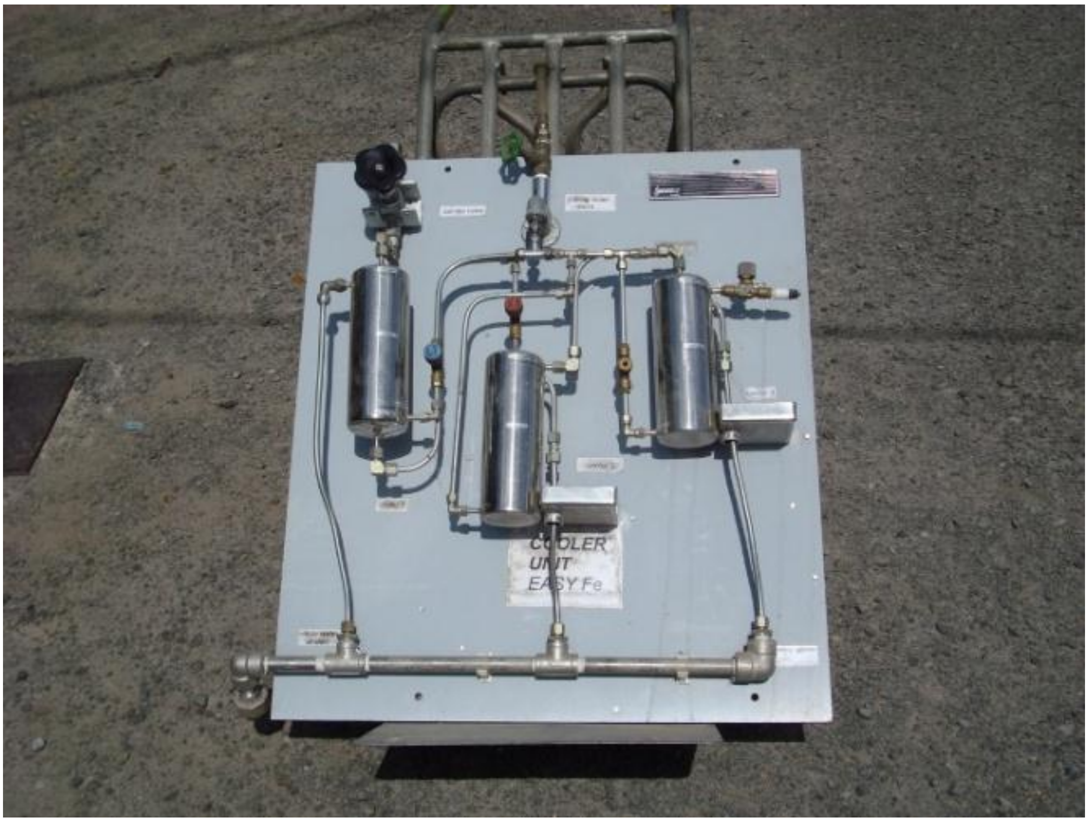

FIGURE 6: System to process the brine sample. Photo by P. Moya

2.2 Iron Meter in Well PGM-07

With the commissioning of well PGM-07 in 2001, ICE bought new iron metering equipment, called EASY from Seibold. The characteristics of this equipment are shown in Table 3.

This instrument was also supplied by a local representative of the company, and it was installed by ICE personnel. The instrument used the heat exchanger built by ICE for the previous instrument in well PGM-19.

FIGURE 7: Spiral-type heat exchanger. Photo by P. Moya

The behaviour of this instrument was a bit better than the previous one, but still there were inaccurate measurement results and obstructions in the pipes. A set of instructions provided by the supplier were followed to improve the operation of the instrument, but unfortunately the results were ambiguous. The final recommendation from the company to ICE was to consider a site visit from one of their experts from Austria, but a very high cost for ICE. After analyzing their proposal, it was not accepted.

2.3 Iron Meter in Well PGM-02

In 2006 a new acid well (PGM-02) was connected to the gathering system. To avoid problems with the samples and the instruments, several efforts were made to improve the way the sample is collected as well as the instrumentation itself. A photograph of the instrument (called Composer by Seibold) is shown in Figure 8, and Table 4 presents its characteristics.

TABLE 3: Characteristics of EASY – Seibold

Dimensions	70 cm wide x 80 cm high x 25 cm deep
Weight	25 kg
Electrical connections	110 – 120 V, 60 Hz
Sample requirements	Pressure 0.25 – 0.5 bar, temperature 40 ^{0}C maximum
Environmental requirements	5 – 40 ^{0}C, 10 – 80 % maximum humidity
Measuring method	Photometrical or potentiometrical (ISE)
Measuring cycle	Free Programmable
Measuring range	0 – 20 ppm Fe
Outputs	0/4 – 20 mA
Switch contacts	2 x P-controlled (minimum, maximum), 1 x alarm contact
Indication	20 character alphanumerical LCD, 3 LEDs for contact state

FIGURE 8: Composer by Seibold. Photo by P. Moya

As part of the process of procuring the equipment, a training course for ICE`s personnel was requested, as well as commissioning of the equipment by an expert from Seibold.

Several adjustments were necessary, including specific ones to calibrate the instrument to the brine samples on site. Once this was achieved, ICE personnel were trained by an expert in the operation and maintenance of this type of instrument. The training course included the correct management of the reagents utilized in the colorimetric analysis. All these efforts led to good results from the device, which utilized the new sampling arrangement, in which the brine sample is collected for measurement of both iron concentration and pH. The modifications and improvements incorporated in this sampling arrangement are described in the next section.

3. SAMPLING ARRANGMENT

As mentioned before, a new sampling arrangement was implemented. Since there was the need to collect a sample to estimate the pH of the brine, it was considered to take the brine sample for both purposes, that is, to measure both the iron content and the pH value of the brine.

Initially, the system collected the sample through a 3/8-inch capillary tubing leading from the wellhead to the heat exchanger (about 60 meters away). Inside the heat exchanger was a 3/8 capillary tubing coil in a receptacle where fresh water would continuously flow to cool the sample. Once the sample was cooled down, it was sent to the measurement equipment (iron and pH), then guided to a drain to dispose of the brine.

The system was in operation for several months, but with many maintenance and operational problems. There was no confidence in the results, and obstructions occurred in various places (valves, capillary tubing, heat exchanger, accessories, etc.). In addition, there was minor silica deposition inside the capillary tubing that affected the results. Due to all these problems, it was necessary to improve the current sampling system to obtain better results from the instruments and also to reduce the cost of maintenance and operation.

One of the improvements was to install an extra receptacle between the heat exchanger and the measurement instruments to cause the sample to flash. A small receptacle was built and installed three meters above ground level (Figure 9); this allowed reduction of the pressure on the sample and collection of the sediments. The sediments were sent to a drain, and the clean sample was sent by gravity to the instrument. These sampling arrangements improved the results, but there were still some problems to solve, and therefore, another sampling method was implemented.

TABLE 4: Characteristics of COMPOSER – Seibold

Measuring application	Iron ($Fe^{2+/3+}$)
Measuring range	0.1 – 20 mg/l $Fe^{2+/3+}$
Accuracy	Better than +/- 3% (based on full scale)
Measuring method	Colorimetric
Measuring interval	Continuous, programmable, external start
Calibration	Not required
Environmental Temperature	+3 ^{0}C - +25 ^{0}C, ambient temperature
Sample temperature	+3 ^{0}C - +50 ^{0}C (recommended 20 ^{0}C, maximum 50 ^{0}C)
Humidity	Maximum 70% RH, no condensation
Sample pressure	0 – 0.5 bar
Sample Inlet	6/4 mm hose
Sample Drain	Unpressurised, free falling, 6/4 mm hose
Fresh water	6/4 mm hose
Cabinet size	746 x 600 x 373 mm (HxBxD)
Weight	+/- 70 kg
Power supply	110 V AC, 50 – 60 Hz.
Power Consumption	50 VA maximum
Input	Photometer
Output	Analog: 4 – 20 mA (serial interface, RS232C, optional
Switch contacts	2 switch contacts (min/max), 1 alarm contact
Controller	Independent proportional (P) controller (min, max) with adjustable time basis, setpoint W, prop part Xp and hysteresis
Display	20-character alphanumerical LCD, 3 contact LEDs min/max/alarm, 2 operational lamps
Operation	Four button keyboard, main switch

In this case, the diameter of the tubing conducting the sample from the wellhead was increased to 13 mm, and the receptacle used to flash the sample was placed very near the wellhead, in order to prevent obstructions. The pre-flash reduces the pressure and precipitates the solids present in the sample. The sample is then sent to the heat exchanger, which has larger (13 mm diameter) and straighter pipes, facilitating cleaning and maintenance. The sample is cooled by the heat exchanger which uses fresh water, and then sent by gravity to the instrument at a temperature between 30 and 40 ^{0}C to be analyzed (Figure 10).

This new sampling system has been installed at the three acid wells (PGM-02, PGM-07 and PGM-19). The pH is being continuously measured at all three wells, but iron content is being measured only in wells PGM-02 and PGM 19, because the EASY instrument from Seibold (Figure 11), which had been used at PGM-07, is currently out of order. Fortunately, this well has become a neutral producer, and the absence of the instrument to monitor iron content is not critical.

4. IRON CONTENT AND PH MEASUREMENTS

With the implementation of the latest sampling system and the utilization of the instrument called Composer by Seibold, it was possible to obtain precise, continuous measurements of the iron content of the brine. The Composer iron measurements have matched very well the measurements obtained by the traditional colorimetric analysis method (Figure 12), which are made hourly in each of the wells, even when the different instruments have worked properly.

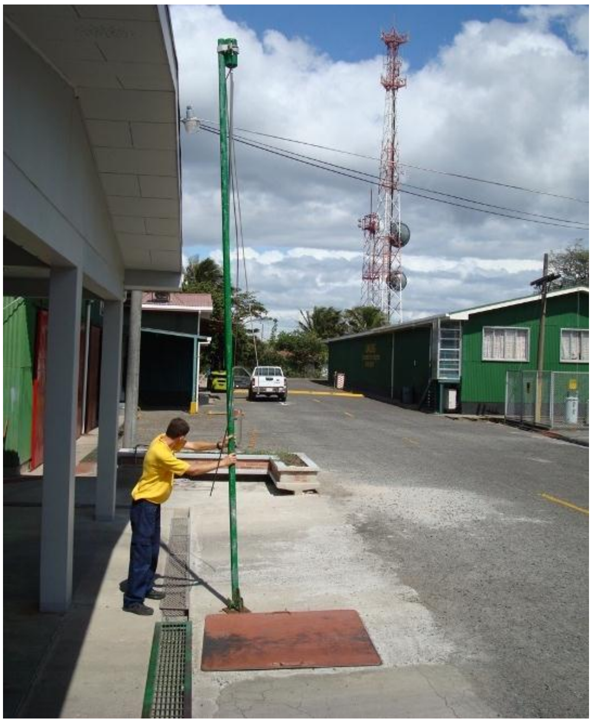

FIGURE 9: Recipient three meters above ground. Photo by P. Moya

FIGURE 10: Sampler system. Photo by P. Moya

The pH measurements are also taken manually every hour, using a common pH meter (Figure 13). The pH values recorded continuously by a pH instrument (Figure 14) match the values measured by the pH meter.

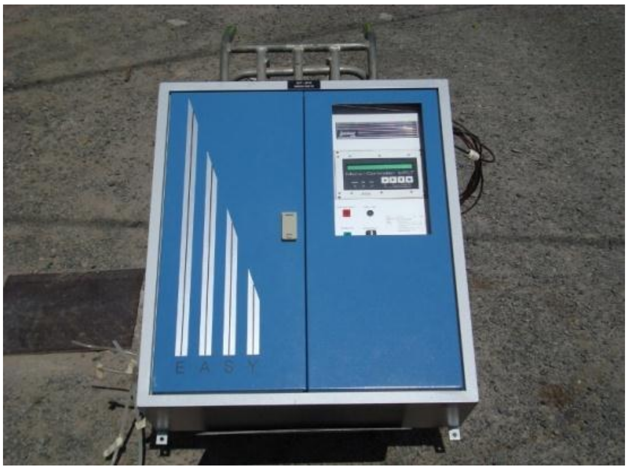

FIGURE 11: EASY from Seibold. Photo by P. Moya

FIGURE 12: Colorimetric traditional method. Photo by P. Moya

5. FINAL REMARKS

ICE implemented the operation of the first iron meter with the commissioning of well PGM-19 in 1999. Later, ICE installed two other iron meters at wells PGM-07 (in 2001) and PGM-02 (in 2008).

All the iron meters utilized at the Miravalles geothermal field use a colorimetric analysis technique. The equipment processes the sample and the reagents to form a colored end-solution which has an absorbance that is proportional to iron concentration.

The main inconvenience of these types of instruments has been difficulty in obtaining a sample under the conditions required by the instrument. Normally, the brine sample is collected near the wellhead at around 165 ^{0}C, which is a very high temperature for the instrument; also the brine contains impurities which impact the operation of the instrument.

FIGURE 13: pH meter. Photo by P. Moya

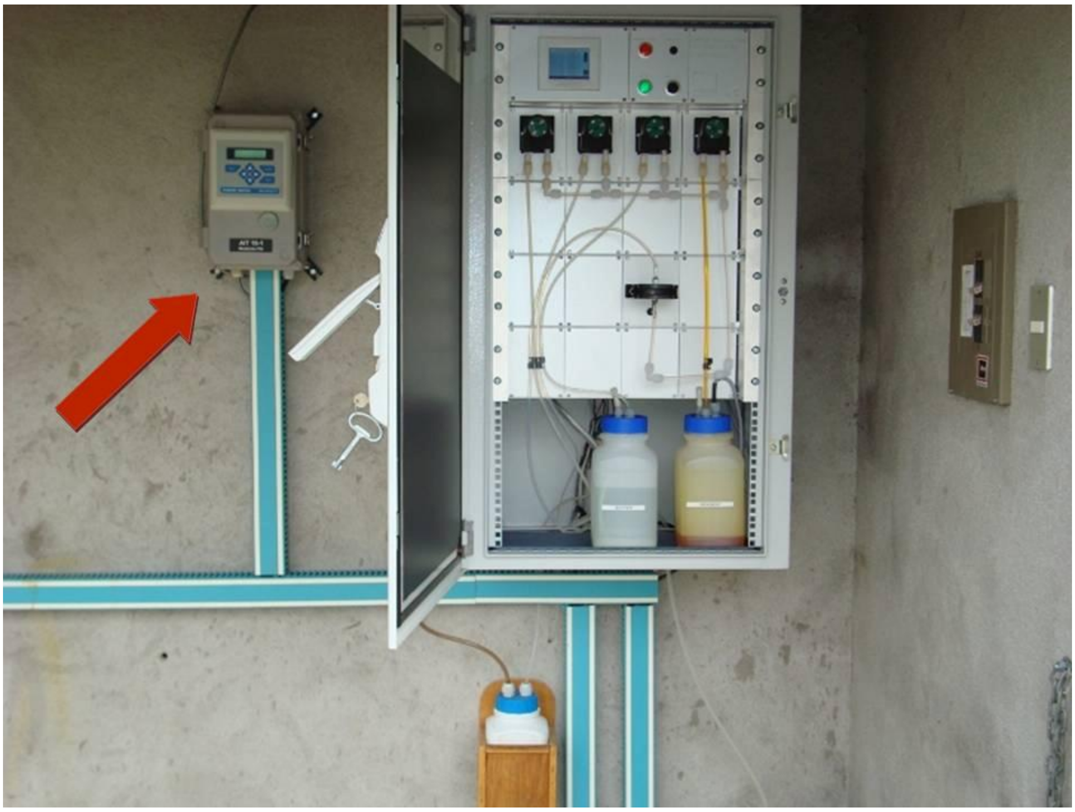

FIGURE 14: pH instrument for continuously record pH values. Photo by P. Moya

The iron meters utilized at the Miravalles geothermal field were the Continuous Flow Analyzer from Rosemount Analytical, another called EASY from Seibold, and finally the one called Composer also from Seibold. The only iron meter that is being used nowadays is the Composer; hopefully the other iron meter from Seibold (EASY) may be repaired and used in well PGM-07 when required.

The need to have an indirect indicator of a capillary tubing failure has led to the installation of iron meters as a part of the neutralization systems. The first digital equipment and sampling methods used did not work well.

Because there was the need to collect a sample to estimate the pH of the brine, it was decided to take the brine sample for both purposes; that is, to measure both the iron content and the pH value of the brine. Several changes were made to develop a sampler system that would pre-flash the sample, eliminate the solids and sediments, and cool down the sample before sending it to the pH and iron measurement instruments.
Field tests, analysis of the results, modifications and corrections to the sampler have allowed for an important improvement in the results of these instruments. It took several years for ICE´s personnel to obtain confidence in the results coming from the iron meter instruments.

ACNOWLEDGEMENTS

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

REFERENCES

Moya, P., 2006: Costa Rican geothermal energy development, 1994-2006. *Proceedings of the "Workshop for Decision Makers on Geothermal Projects in Central America", organized by UNU-GTP and La Geo in San Salvador, El Salvador*, 14 pp.

Moya, P., Nietzen, F. and Sánchez, E., 2005: Development of the neutralization system for production wells at the Miravalles Geothermal Field. *Proceedings World Geothermal Congress 2005, Antalya, Turkey*, 10 pp.

Rosemount Analytical Inc., 1997: *Continuous Flow Analyzers*: *Instruction manual*. P7N 51-Chemp, Irvine, CA, USA.

Seibold, 2008: *Composer Iron Analyzer: Operating instructions manual*. A-1110, Wien, Austria.

Seibold, 1998: *Easy Iron Analyzer: Instruction Manual*. A-1020 Wien, Austria.