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Operational Considerations in the Process of Exploitation at the Miravalles and Pailas Geothermal Fields: 20 Years of Field Operation

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ABSTRACT

In the early 90s, a group of people from ICE, from Miravalles volcano zone, Guanacaste, formed a working group designed to operate productive fronts of what it would be someday the Miravalles Geothermal Field. This team will be known later under the name of Field Operation. Miravalles Geothermal Field started in 1994, while Pailas in 2011. Nowdays, Miravalles has an installed capacity of 163 MWe, while Pailas produces about 35 MWe. Field Operation has given logistical support during the explotation phase. This paper describes experiences of general activities related to the operation of Geothermal Fields in Costa Rica for 20 years of operation, as aspects of interaction between fluids, ascending fluid (vapor, liquid, biphasic), direct quantification fluids equipment (steam and brine), operation of neutral wells (inhibition system), operation of acid wells (neutralization system), aspects of binari units, operational logistics Separator Stations (improvements), subsystems optimization: elimination of drainage in systems with downward slope and upslope, among other.

1. INTRODUCTION

An essential part of the development of these geothermal complexes is related to operational success. At the beginning of the Decade of the 1990s, a group of officials from the ICE, in the area of the Miravalles volcano, Guanacaste, formed a team to operate productive fronts of what one day would be the Miravalles geothermal complex. This team would be known later with the name of the Field Operation Department.

Exploitation of geothermal energy began in Costa Rica in 1994 with the installation of a power plant of 55 MWe in the Miravalles zone (Figure 1). By 2003, the installed capacity increased to about 163 MWe with the integration of new units, and it has kept so until nowadays. Furthermore, a new geothermal field was developed in Las Pailas zone in 2011(Figure 1). The production of Pailas field begins with the installation of a binary plant of 35 MWe (42 MWe gross). By the moment, there are two geothermal fields in exploitation phase, Miravalles and Pailas. However, there are more interest zones, some of them are being researched (Table 1).

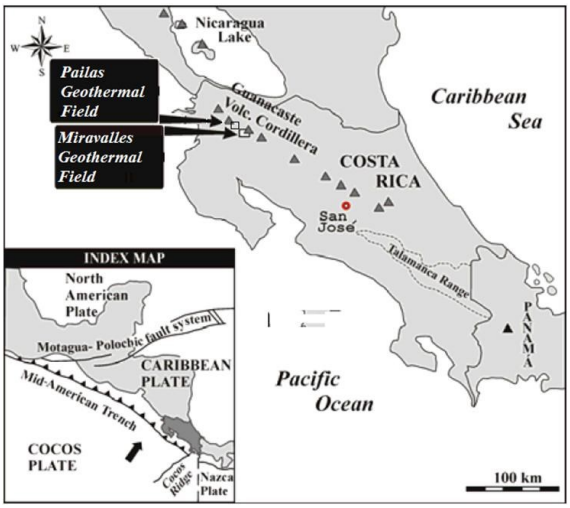


Figure 1: Location map showing Costa Rica and two Geothermal Fields: Miravalles and Pailas.

The complexity of the Miravalles geothermal field generated important challenges to the Field Operation team. Biphasic systems of flows of high pressure and temperature, separation systems of phases, distribution system of pipes, systems of inhibition of calcium carbonates, among many others, distributed in more than 21 km^2, as well as the control of all the associated parameters, are part of the developments of the Field Operation Department.

In Miravalles, the current capacity installed is around of 160 MWe (Table 2), thus remaining for an extended period of time. The generating behavior annually is shown in Figure 2. There have been changes in the mass ratios, pressure drops in the system, cooled fronts, among others. Wells have been closed and new ones have been opened and integrated, in order to maintain the productive capacity of the field. The quantity of wells is shown in Table 3.

Table 1. Geothermoelectric capacity installable in Costa Rica (in MWe).

Area	*Capacity that can be fed by the reserves (MWe)*			*Priority*
	Single Flash	**Dual Flash**	**Average**	
Miravalles	164	213	189	I
Rincón de la Vieja (Las Pailas)	137	177	157	
Irazú - Turrialba	101	130	116	II
Tenorio	97	123	110	
Platanar	97	122	110	
Poás	90	116	103	
Barva	85	109	97	
Fortuna	61	77	69	III
Orosi - Cacao	33	41	37	
Seven other areas*	---	---	---	IV
Total	865	1108	987	

*: Caño Negro, Liberia, S. Jorge, Tilarán, Puerto Viejo, San José and Tigra
From: Cataldi, R. and Mainieri, A. Geothermal Ranking and Resource Assessment of Costa Rica. Dirección Planificación-Recursos Geotérmicos, San José, Costa Rica. Pp. 6.

Table 2. Installed capacity in Miravalles Geothermal Field.

Unit	*Power (MWe)*	*Type*	*Start-up date*	*Final date*	*Belongs to*
Unit 1 (Miravalles 1)	55	SF	March, 1994		ICE
WHU-1	5	BP	January, 1995 December 2006	July, 2006	ICE
WHU-2	5	BP	September, 1996	August, 1998	CFE
WHU-3	5	BP	February, 1997	January, 1999	CFE
Unit 2 (Miravalles 2)	55	SF	August, 1998		ICE
Unit 3 (Miravalles 3)	29	SF	February, 2000		GG
Unit 5 (Miravalles 5)	19	ORC	November, 2003		ICE
Total	**163**				

SF = Single flash
BP = Backpressure
GG = Geoenergía de Guanacaste Ltda., in a BOT system (Build-operate-transfer)
ORC = Organic Rankine Cycle. It is a binary plant
ICE = Instituto Costarricense de Electricidad
CFE = Comisión Federal de Electricidad (México)
WHU = Wellhead Unit. The WHU-1 changed the position during 2006 to other zone

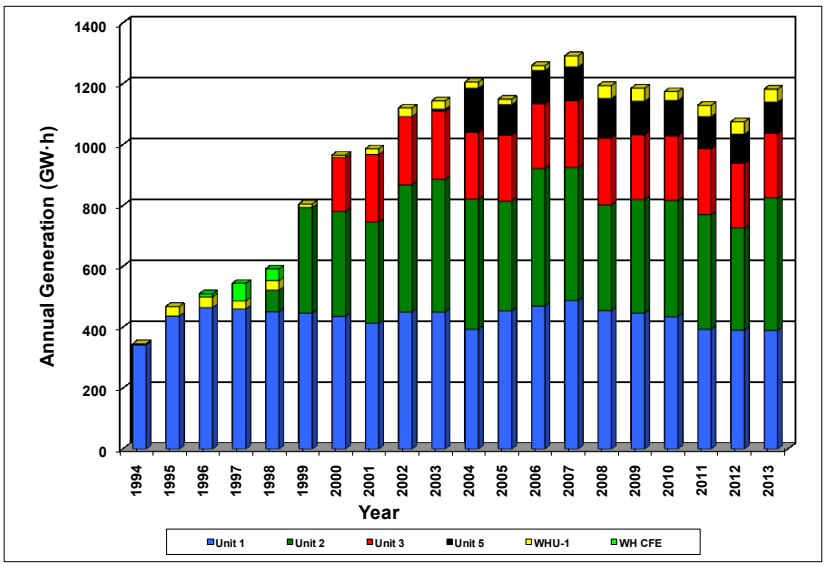


Figure 2: Energy production at Miravalles Geothermal Field (1994-2013).

Table 3. Quantity and type of wells in the Miravalles and Pailas Geothermal Fields.

Well Type	*Number of wells according Geothermal Field**	
	Miravalles	**Pailas**
Producers	30	7
Injectors	17	8
Observers	2	4
No usable	3	0
Total	**52**	**19**

* Area: 21 km^2 Miravalles, 10 km^2 Pailas

Works related to the second stage of the Miravalles Complex, Generating Unit 2 (Miravalles 2, installed capacity of 55 MW) were carried out between 1997 and 1998. By this time, Field Operation was already a consolidated group in knowledge, experience and logistics; therefore, taking responsibility for the activities related to the commissioning of this second stage.

The third stage of the Miravalles Complex began in 1999, with construction and the start-up (already at the beginning of the year 2000), of the Generating Unit 3 (Miravalles 3, with an installed capacity of 27.5 MW), which is administered in the form of BOT (build - operate - transfer), by a private company. However, the operational control of the productive sites associated with that unit is in charge of Field Operation, therefore, good performance and high factor of Unit 3 plant is due, in large part, to the work of Field Operation in the supply of geothermal fluids.

In 2005, the Generating Unit 5 (Miravalles 5) entered into operation, with a nominal output of 17 MW. This unit has a different technology to the other previously installed; a binary cycle unit, which takes the temperature of the flow of hot reinjection and transfer it through a heat exchanger to a working fluid, pentane, which vaporizes and moves the turbines.

At the beginning of the year 2007, the Wellhead (WHU-1) began its production in a new location, away from the central area of the Miravalles Complex, in an independent sector from the point of view of the main site. It produces 5 MW and being an isolated system, the processes are independent.

Under policies of energy growth and expansion of the fields related to geothermal energy, in 2011, the production of the Pailas Generating Unit began. This Unit works with binary technology, similar to that used in Generating Unit 5 (Miravalles 5). The Pailas Generating Unit has a nominal generation of 35 MW net (42 MW gross). Field Operation was responsible team in the start-up and operation of all systems of the Pailas complex. The experience and knowledge acquired during years were decisive in the excellent results obtained.

Pailas has a different context to Miravalles. The commercial development began from May, 2011.The energy produced annually is displayed in Figure 3. Several wells were drilled with directional technology, giving good results.

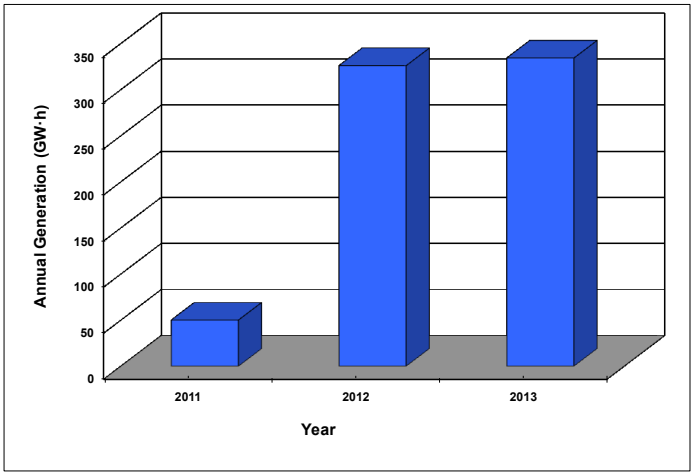


Figure 3: Energy production in Pailas Geothermal Field (2011-2013). The field produces from May 2011; however, the generation accounting begins in November 2011 in plant (production phase).

In this field was implemented the concept of "square" (small quadrant), which contains two, three or four wells with directional drilling. This reduces costs of surface pipe connection; land used, and allows the underground access to not permissible sites as national parks.

The installed unit is of binary type, with two modules. This unit operates with steam and brine. It has only one separation station, which provides approximately 85 kg/s of steam and 400 kg/s of liquid. The distribution of wells is shown in Table 3. Even with the short time of operation, some changes in wells have been displayed; recent studies displayed the arrival of injection in few days, but

in small quantities (Torres, 2014). Two wells have been affected directly; however, another well was drilled and joined last year, which gave support to the production.

The geothermal utilization in the country is only for electrical energy production (Mainieri, 2005). Although there are some swimming pools that use natural geothermal water.

2. OPERATIONS OF GEOTHERMAL FIELDS WITH BIPHASIC FLUIDS, STEAM AND BRINE

The operations associated with two-phase systems are generally more complex. Internal phenomena of transfer of mass and energy between the two fluids make these systems more unstable, and therefore, more robust in terms of design-build. There must be separation systems (separation stations) and biphasic lines must not have ascending slopes very steep (in terms of angle and length); preferably they must be horizontal or descending slopes.

The geothermal fields Miravalles and Pailas produced fluids in two phases. The first of the two fields to be developed was Miravalles (1994). In the beginning, the works were realized in coordination with foreign consultancies, both at level of process starting and in normal operational conditions. The heating and pressurization lines were carried out slowly, checking the process state of the sections of pipe and the behavior of fluids; several drains and vents were used to control the heating and pressurization rate.

Once reached the right conditions, proceeded in a first stage, with the activities of cleaning of pipes. Drains and vents were closed, flow conditions were adjusted to ensure necessary drag speeds, and the system remained in operation during prolonged periods of time (over 4 hours).

Subsequent to this time line of operation was withdrawal (cooling and depressurization activities), which consisted in the opening of drains and vents, and the removal of the fluid. The pipe was left in such condition during the night and the next day started again with the activities of pressurization - warming.

This cycle was repeated every day until the criteria defined for cleaning were achieved. Usually any alloy or aluminum sheets were placed in the discharge zone for the purpose of accounting for the impacts per unit of area once completed cleanup activities. The steam lines were the most critical by their relation to the turbines of the generating units.

Achieved the goals of clean lines, it began with the start-up and operation of the systems. Pipes and surface structures were connected in the final configuration to be pressured-heated, reaching the optimal operating conditions of pressure and flow. Some examples are shown in Figure 4.



(a) **(b)** **(c)**

Figure 4: Commissioning of systems (pressurization – warming): a) operations producing wells b) operations unions – divisions c) operations Wellhead Unit (WHU-1).

The start-up tests were performed, to verify functionality, as well as the operating conditions of producing wells, acceptance capacity of injecting wells, behavior of the lines (deviations, ruptures of brackets, sudden movements, among others), separation efficiency in separation stations, condition of the lagoons, pipeline of cold injection, atmospheric emissions.

2.1 Biphasic Ascending Flow

The first unit (Unit 1 in Miravalles, 1994) should be fed with the steam flow necessary to achieve a production of 55 MWe, at a pressure of approximately 6 bar pressure gauge. To do this, three separation stations were designed, each fed by several producing wells: Separation Station 1(wells PGM-01, PGM-05, PGM-10, PGM-11 and PGM-31), Separation Station 2 (wells PGM-03, PGM-17 and PGM-46) and Separation Station 3 (wells PGM-12, PGM-20 and PGM-21). The Separation Stations 1 and 2 had cases of ascending biphasic flow.

The well PGM-11 (Separation Station 1) sent the biphasic fluids to a high area called "Plazoleta"(small Separation Station). In the “Plazoleta” the steam and brine were separated. The steam was sent to the Separation Station 1 through a descending line and the brine to the hot Reinjection well PGM-02 (Nietzen, 2015).

The well PGM 05 (Separation Station 2) represented the most critical case; the angle of the upslope was the highest; the biphasic fluid in its totality was sent to the Station.

The biphasic line of the well PGM-46 (Separator Station 2) also had an upward angle. The integration of the fluids began with the stabilized well toward atmospheric discharge (silencer).

Pressurization - warming of the line were in a conventional form (checking previously that the pipeline was completely empty); however, the cut-off valve on the joint of the biphasic line of the Separation Station (or “Plazoleta” in the case of the PGM-11) must be closed.

With line pressure greater than a bar with respect to the pressure of the biphasic collector, valve of the union was open slowly, so that the fluid were incorporated under controlled conditions, and verifying the behavior of the line (sudden movements). The operation ended once reached the limit of valve opening (before sudden movements).

Some important aspects were considered: Some important aspects were considered: the lines had to be incorporated immediately posterior to the pressurization - heating of the ascending line, and the restriction of the well was in the union, not necessarily in the well valve. The wells in these cases remained on a restricted condition.

2.2 Brine in Ascending Order (Without the Use of Drains)

With the development of the Pailas geothermal field (2011), arises the need to inject the brine to a high area, using pumping systems installed in the unit.

During the first stage of the warm-up period, there were movements in some sections in the pipe. These movements started from the opening of the valve in the derivation of the ascending flow and were manifested as a shock wave towards the upper zones, until to reach to the square-wells of injection.

The mass of steam that is obtained when the liquid goes from a high pressure (approximately 10 bar upstream of the valve in the bypass) to an atmospheric pressure, is mobilized quickly toward the highlands.

The steam has a high speed, favored by the configuration of the ascending line. This rapid movement can cause an accelerated warming-pressurization of the system. Once the temperature has stabilized in the area of step, the systems tend to stabilize, and comes with a "normal", increasing periodically the opening of the valve in the bypass. It is important to keep the valve restricted in the square-wells, in the area of injection; to conserve the pressurization controlled (Nietzen, 2014).

2.3 Inhibition and Neutralization

Before starting with the exploitation of the geothermal resource (1994), was implemented the systems of inhibition of calcium carbonates.

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 and Nietzen, 2012). The diagram of the systems is shown in the Figure 5.

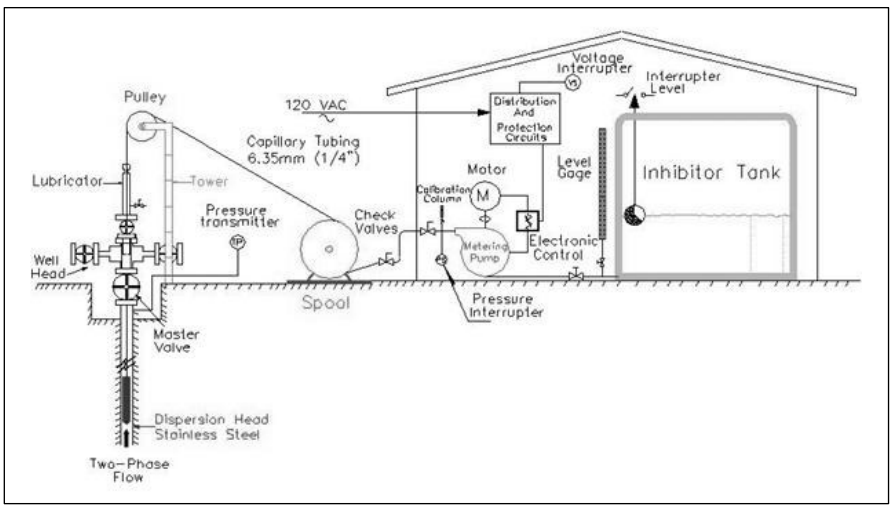


Figure 5: The calcium carbonate inhibition system (neutral geothermal well).

The diluted inhibitor is stored in the tank located at each well. There is a sensor that it is activated when the level is low. The inhibitor is injected into production well by action of the system pump, through to capillary tubing to the boiling point of the well (between 1000 to 1400 meters, depending on the well). The capillary tubing is connected to the injected head and the weigh bar which helps system stability. The capillary length is between 1100 to 1500 meters and the material is alloy 316L, but it is also used incoloy 825 alloy in some cases (Figure 6).

There is a plant of dilution to store pure inhibitor and the diluted, as well as also the different dilutions at different concentrations. From the Plant of dilution, the inhibitor is distributed to the different wells, using a cistern.

There is an acid sodium-chloride-sulphate aquifer (Na-Cl-SO4) at the Miravalles geothermal field. Therefore, the fluids have a sodium-chloride sulphate composition and they are located in the northeast sector of the field. The pH ranges between 2.3 and 3.2 and then it is necessary to carry on chemical treatment to avoid corrosion inside the well and surface equipment.

In 1999, Miravalles professionals developed the design of what would become one of the first acid wells exploited around the world. Field Operation took the responsibility for the control of this process, developing it and refining it successfully over time. This technology placed Costa Rica (ICE) as a leader in the development of technological solutions.



(a) (b) (c)

Figure 6: Parts of Inhibition System and Neutralization System: a) towers b) spool truck c) views of drum, capillary tubing, tower.

There are four acid wells situated in this zone: PGM-02 (integrated since March 2006), PGM-06 (has not been integrated), PGM-07 (integrated since October 2001) and PGM-19 (integrated since February 2000 until March 2011). It was required the implementation of neutralization systems to neutralize the acidity, and nowadays there are 2 neutralization systems in continuous operation.

The fluids from these wells are highly corrosive unless treated previously. The materials and equipment in contact with the fluids (pipes, casing, capillary tube, separators, others) must be protected. The aim of neutralization system is to protect the production casing as well as all surface equipment from the corrosion. It injects a neutralizing fluid (like caustic soda, NaOH) inside the well through the capillary tube (1000 m depth, approximately). Three pumps are used and the neutralizer is stored in tanks. The Figure 7 shows the overall diagram about the neutralization system applied in the most of the wells.

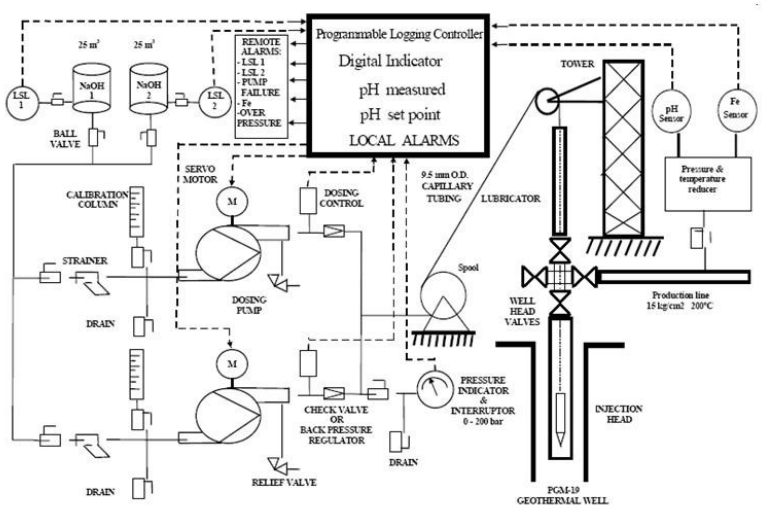


Figure 7: Neutralization System.

The manual sampling system is not continuous; each hour an operator takes a sample from the open channel of the well, waits for cooling and measures the pH and the concentration of Fe with tests and digital pH-meter; also, the same operator controls several variables of the neutralization system (percent of pumping, flow, pumping pressure, system energy, work of the pumps, water supplied, others). If the well is out of control (example pH too low or too high), the operator reacts immediately to avoid the corrosion or scaling in the well.

The neutralization system of the acid wells kept the pH value around 7. However, there were problems of scaling in the casing with this value of pH. The production of the well decreased in the time and a mechanical intervention was inevitable (costs of the intervention, the reduction of production and time without production). Then it was necessary to change the value of pH for minimize the silica scaling. This value is between 5.5 and 6.0. For values lower than 5.5 corrosion problems will be significant (damage in casing, pipes and superficial stations, with associate costs, and possible loss of the well). Contrary case, for values higher than 6.0 the scaling problems will be significant (loss in production, cost of mechanical intervention and cost to keep the well out of the production) (Nietzen, 2007).

2.4 Separation Logic

With the evolution of the Miravalles Field (integration of new units) was necessary to increase in number the Separations Stations. Currently there are seven main Separation Stations in Miravalles and one in Pailas (Figure 8). The logistics of separation is

practically the same. The biphasic flow from wells is bifurcated into two separators. By cyclonic effect, the steam is separated and sent to Condensing Units. Moreover, the brine is sent to Hot Injection (to areas of interest) and a part is used in the Binary Unit 5.



(a) (b)

Figure 8: Separation Stations: (a) Separation Station 7 in Miravalles b) Separation Station Pailas.

In the Separation Stations are mainly controlled two variables: pressure and liquid level. The pressure has three security systems:

- Automatic action. The automatic system measures pressure continuously; if the pressure is increased to values greater than are defined in the set point, then a relief valve opens automatically to stabilize pressure in the station.
- Safety valve. If the automatic system fails, then a safety valve is actuated in the event of overpressure. The valve is a mechanical, with a device type spring which is compressed according to the force exerted by the steam.
- Rupture discs. If the two previous systems fail (not be operated in case of overpressure), a few disks installed in the secondary discharge line break at a given pressure of design.

Generally, the set point pressure in the Separation Stations is around 7 bar m, although the operating pressure is less than (6 bar m or less than that).

The level is controlled by automatic systems. In the configuration of each station there are two tanks of water level, where this parameter is controlled:

- Automatic action 1. The automatic system measures the level continuously; if the level increases to values greater than are defined in the set-point, the leave valve opens automatically to stabilize at the station level.
- Automatic Action 2. If the previous action gives no results, then the steam shut-off valve is activated, closing the flow to the units. This prevents the brine reaches the Steam Unit, what would cause a forced retirement. It is best to isolate only one station that remove an entire unit.
- Automatic Action 3. When there is a low level, the injection valve is actuated, trying to keep the level in a band of established values. There may be loss of steam and instability of Reinjection by a low level line. Long ago, the control valve operated continuously, trying to "follow" the level of the tanks, causing instability and continuous maintenance. With the definition of level bands, these disadvantages have been minimized.

In general, the control loops of the variables in the Separation Stations are not complicated. There are PLC, hydraulic and pneumatic systems, actuators, butterfly valves, mechanical systems for overpressure, among others, in order to maintain the conditions of separation within the established limits

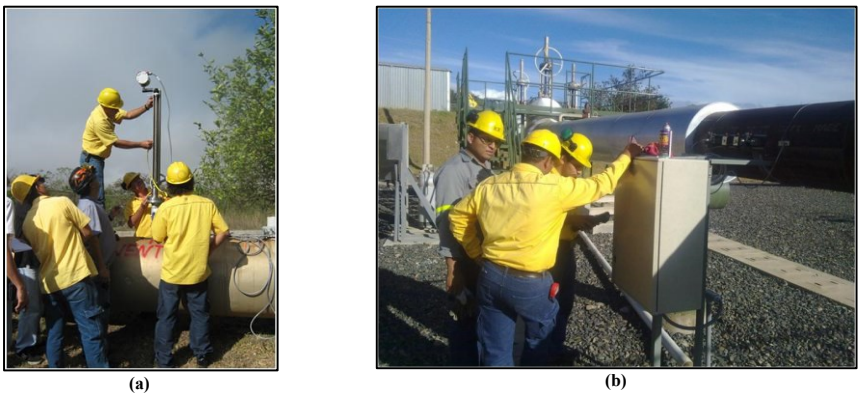
2.5 Fluid Measurement Technologies

For the measurement of steam are venturis installed at each Separation Station of Miravalles, which continuously record the data in the system. On the other hand, it is implemented a methodology of testing, based on a direct measurement, using a gauge of technology vortex (Figure 9). These measurements are not continuous; they are made at set periods of time, and serve to verify the measurement in the venturi. The equipments are pseudo-portable.

In a valve of 50.4 mm (2 "), is inserted a probe, which records speed, pressure and temperature, calculating with them steam mass flow. This equipment has good reliability (less than 1% error).

Ultrasonic equipment is used for the brine flow measurement. This measurement is not continuous. The operators should be located with the equipment in the water pipe of each separation station to take measurements at an interval of time, also, in the brine pipe of each injection well (Figure 9). The data are processed later (Nietzen, 2010). The method error is around 2 %.

In the coming developments, dual systems will be implemented in order to give greater reliability to flow measurements. With this, two enhancements are proposed: reliability for estimates of process efficiencies in the Units, and verification continues of the flow provided by the reservoir; any anomaly in the flow would be detected immediately.



(a) (b)

Figure 9: Technologies used in measurement flow at Miravalles and Pailas : a) Vortex Technology, a probe is incorporated into the steam line through a valve of 50.4 mm (2 ") b) Ultrasonic Technology, noninvasive method for brine measurement.

3. FINAL REMARKS

In Costa Rica, all steps related to geothermal developments are implemented, starting with research, following with drilling, design, construction, commissioning, operation and monitoring - maintenance of the reservoir. The results have been successful, two geothermal fields are producing energy.

Several activities take place during the operational phase, related with direct interventions of wells, where several working groups are involved. The interventions are performed according to a specific objective. Examples include mechanical intervention of the well (cleaning, physical repair, searching for other productive areas) and chemical cleaning (by accumulation of material, scaling, both in the casing well as in the formation) (Figure 10).



Figure 10: Chemical Cleaning of wells.

Improved designs - processes are applied continuously. With them, the reaction time is minimized, costs are reducing, fluids delivered to the different units are optimized, and aspects of occupational safety and environmental impact are also considered in the steps of continuous improvement (Figure 11).

The team of Field Operation has been characterized by possessing a flexible organizational structure, in days, roles, timetables, multifunctional activities (officials who possess the skills to operate the entire process, not officers specialized in sub-processes), due in part to the changing of the site condition as well as the same culture of group. This structure is observed in leading companies around the world, which react efficiently with changes in the environment (Figure 12).

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Figure 11: Improving applied towers. The new towers in Pailas have two levels: the higher is needed in the case to require chemical treatments, and the lower is for the incorporation of measurement elements. Operating times are reduced by some intervention, and safety aspects are improved.



Figure 12: Field Operation Team, 2014.