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Miravalles PGM-29 Wellhead Unit, Guanacaste, Costa Rica: Technical and Environmental Performance Assessment

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ABSTRACT

Wellhead power plants have played an important role in the development of the Miravalles field in Costa Rica. Wellhead units were being considered during the well-drilling phase to provide on-site power and to allow well testing under realistic flow conditions. Within one year of the startup of the 55 MW single-flash Unit 1 in 1994, the first of three wellhead units was installed and put into operation. This 5 MW unit, originally designated Wellhead Unit 1, took advantage of excess steam that was available prior to the installation of the second 55 MW unit.

This paper covers the history of wellhead units at Miravalles. It focuses on the motivation for and the performance assessment of Wellhead Unit 1 throughout its operating lifetime from its original location in the north sector of the field about 800 m north-northeast of Units 1 and 2 to its current location in the southeastern sector at well PGM-29, about 2.3 km east-southeast of Unit 5. The unit now carries the designation, PGM-29 Wellhead Unit.

A brief overview of the current Miravalles operation including a layout of the field showing the locations of power units, wells, satellite separator stations, and gathering and reinjection system pipelines is included in a companion paper in these Proceedings; Moya and DiPippo (2010).

This paper provides detailed information on the subject wellhead unit beginning with the motivation for the unit, its field position, and the means of geofluid supply, along with some performance data including electrical generation, as well as capacity and load factors, for each location where the unit has operated.

The unique design aspects of the plant are presented and discussed. The performance of the wellhead unit is given in terms of its thermodynamic design and its actual operating conditions. The processes followed by the steam in the plant are shown in state-point diagrams; state-point property tables are given for design and typical operating conditions; actual performance data are analyzed in terms of power generation, parasitic power requirements, utilization efficiency, specific steam consumption, and specific brine consumption. The results of the present-day operation are viewed in terms of the knowledge gained from production and reinjection at the southern part of the field that has been used mainly as the injection zone for the other power plants.

The operation is markedly different for the two different locations, since in the first location the unit was fed steam directly from a satellite separator, whereas in the current location it is connected to one well that is equipped with a cyclone separator. Thus both steam and brine flows are now directly associated with its operation. Although it is difficult to isolate the effects of one small 5 MW unit among four other larger units that now total 163 MW, several possible impacts including acid rain, air pollution, and pollution of ground waters are examined.

1. INTRODUCTION

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 km^2; about 16 km^2 are dedicated to production and 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, 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 began generating power in a new location in the southeastern part of the field where it continues its operation. In 1996 and 1997, 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 temporary units were disassembled in April 1998 and 1999 and returned to CFE. Unit 2, the second 55 MW plant, started production in August 1998 and in March 2000, Unit 3, a private 29 MW single-flash plant started delivering electricity to the national grid; Moya and Yock (2007). Finally, in 2004 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 the increase in energy production at the geothermal filed is shown in **Figure 2**.

Table 1: Power units at the Miravalles geothermal field.

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	

Abbreviations: ICE-Instituto Costarricense de Electricidad,; CFE-Comisión Federal de Electricidad (Mexico); WHU-Wellhead Unit; and BOT-build-operate-transfer.

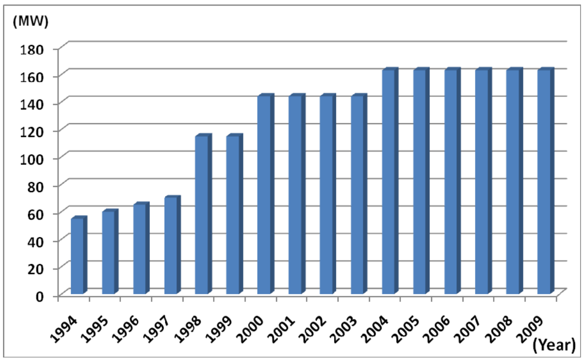

Figure 1: Geothermal installed capacity (1994 – 2009).

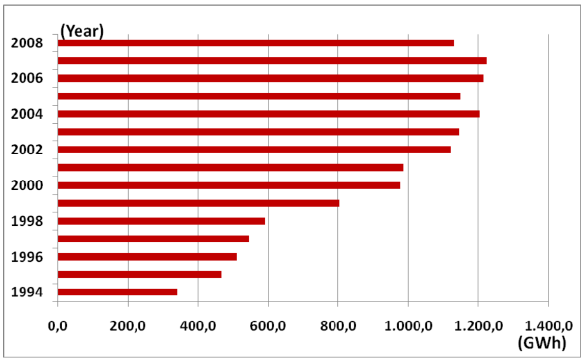

Figure 2: Geothermal generation (1994 – 2008).

Figure 3 shows the mass flow rate since production began at the Miravalles geothermal field. 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 steady or slowly growing since 1994, a condition that has allowed meeting 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 southwestern sectors. With these quantities of steam and brine the total generation reaches around 150 MW.

As indicated in **Table 1**, the Wellhead Unit was commissioned in early 1995, that is, less than a year from the beginning of production of Unit 1 (55 MW) at the Miravalles geothermal field. Back then, it was decided that the best location for the Wellhead Unit was in the neighborhood of Satellite Separation Station No.1 (Satellite 1). At this location, the Wellhead Unit took advantage of the steam of two spare wells - PGM-31 at first and later PGM-65 - and also of the separated steam coming from Satellite 1 and going to steam Collector Pipeline No.1 to produce 5 MW. This location was very convenient to the geothermal development in Miravalles while there was enough steam to supply the main units (Units 1 and 2) and also the Wellhead Unit.

At this location, ICE benefitted from the Wellhead Unit between 1995 and 2006, even when the unit only produced energy for half of the year, i.e., only during the dry season. The spare steam began to decrease through the years and it was thought best to change the location of the Wellhead Unit in order to obtain generation from it all year long.

The facts that: a) the Wellhead Unit was operating only during the dry season (from January to June), b) there was no spare steam in the center of the field, and c) the available steam could be better utilized if it was sent to the main units motivated the thought to move the Wellhead Unit to a new location.

Since in the past, there had been a Wellhead Unit at the PGM-29 site and well PGM-29 had the necessary conditions to supply steam to a Wellhead Unit, ICE decided to move it to this new location during the second half of 2006. The geothermal reservoir conditions around PGM-29 seem to be somewhat different from the rest of the field; namely, the noncondensable gases are higher than the average value in the rest of the field.

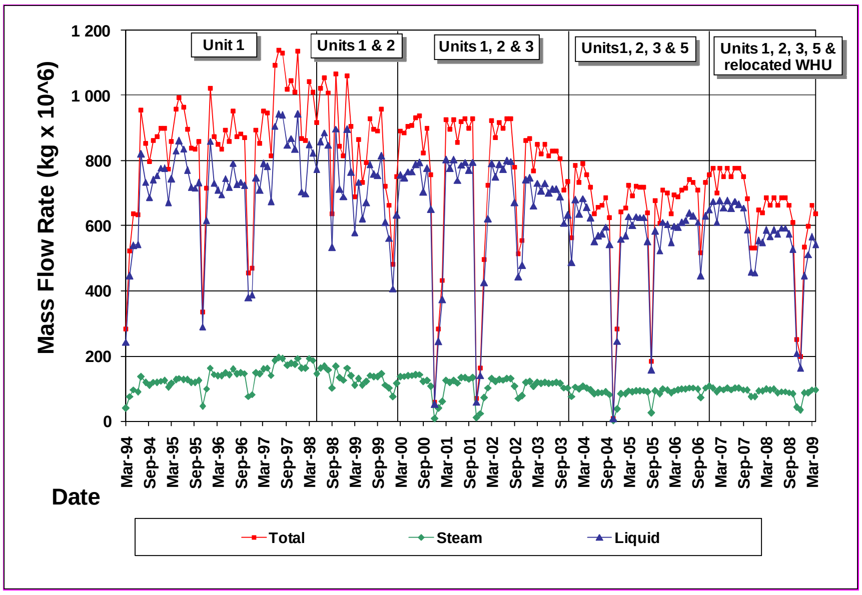

Figure 3: Monthly mass flow rates at Miravalles field.

2. PGM-29 WELLHEAD UNIT CHARACTERISTICS

The wellhead unit is a simple design in keeping with its transportable nature. In its original location, it received steam directly from the steam mains from Satellite 1, whereas in its current location, it is fed steam separated from the adjacent cyclone separator at well PGM-29. The schematic layout for the present situation is shown in **Figures 4** and **5**. **Figures 6** and **7** are site photographs for the original and present locations.

The plant consists of a back-pressure steam turbine with a top-mounted diffuser through which the spent steam is exhausted to the atmosphere. There is a moisture remover between the separator and the turbine inlet. The separated liquid from the well could be sent to injection wells PGM-28, -35 or -59. Currently, the separated liquid is injected in well PGM-35, approximately 530 meters west of PGM-29. The schematic flow diagram is shown in **Figure 8**. The main characteristics of the turbine are given in **Table 2**.

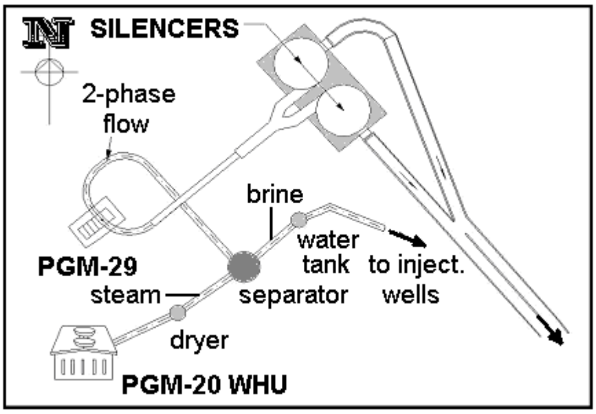

Figure 4: PGM-29 Wellhead Unit gathering system.

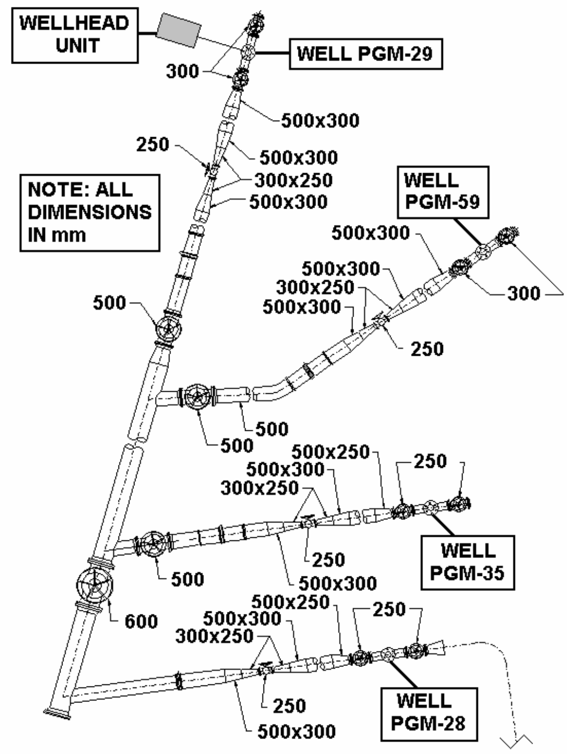

Figure 5: Piping arrangements for reinjection of separated brine at wellhead unit.

Figure 6: Original location of Wellhead Unit now at PGM-29. Photo by R. DiPippo.

Figure 7: Wellhead Unit PGM-29. Photo by P. Moya.

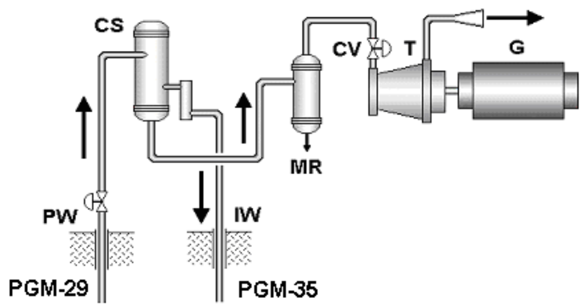

Figure 8: Schematic flow diagram for wellhead unit PGM-29.

Well PGM-29, such us most of Miravalles wells, has a down-hole dosing system in which calcite inhibiter is injected below the flash point to prevent the deposition of calcite.

3. THERMODYNAMIC ANALYSIS AND TECHNICAL PERFORMANCE

The thermodynamic process diagram is the same as for a typical single-flash unit and is depicted in **Figure 9**. In this case the spent steam from the turbine is not condensed but merely discharged at slightly above atmospheric pressure. The average thermodynamic state-point properties are shown in **Tables 3a** and **3b** for the two locations of the wellhead unit. These data correspond to average operating conditions, excluding unreliable data.

The recent history of power generation for the unit in its current location is given in **Table 4**; accurate data for the earlier years are not available. The table includes the average monthly power generation, the turbine isentropic efficiency (where reliable data was available), and the specific steam consumption. The average power over the two-year period is 4.83 +/- 0.30 MW, the average turbine efficiency is 0.921 +/- 0.022, and the average steam consumption is 4.07 +/- 0.09 (kg/s)/MW. The unit has operated at a 96% capacity factor and a 92.2% load factor. The utilization efficiency based on the exergy of the separated steam is 30.2%; however, based on the exergy of the total produced geofluid from PGM-29, it is only 14.3%. The unit is performing at its rated power with little variation month to month.

Table 2. Technical specifications and performance.

Item, Units	WHU at Original Location	WHU at PGM-29
Plant		
Start-up/ shut-down	1995-2006	2007--
Type	Direct-steam/atmospheric exhaust	Single-flash/atmospheric exhaust
Rating, MW	5	5
Net power, MW	5	5
Resource temp., °C	240	230
Turbine		
No. cylinders	1	1
No. flows	1	1
No. stages	4	4
Inlet press., kPa	590	770
Inlet temp., °C	158.1	169
Exhaust press., kPa	99.1	99.1
Steam mass flow, kg/s	20.14	19.96
Last-stage blade ht., mm	116	116
Speed, rpm	3600	3600
Condenser: None		
Noncondensable gas removal system: None		
Plant performance		
Specific steam consumption, (kg/s)/MW	4.03	4.07
Utilization efficiency, %	32.6(1)	30.2(1)

(1)Dead-state temperature = 21.7°C

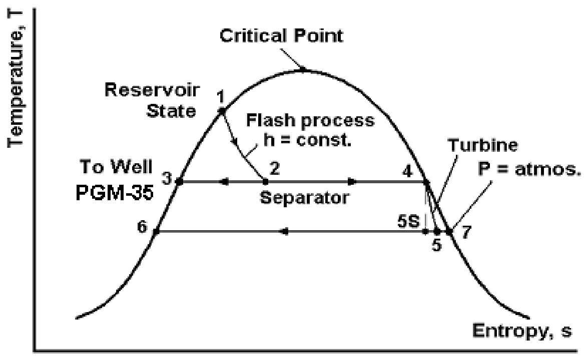

Figure 9: Temperature-entropy process diagram.

Table 3a. Thermodynamic state properties: WHU at original location (operational average Jan. '95–Jun. '06).

State	P, kPa	h, kJ/kg	x
1	3344.0	1037.32	0
2	631.5	1037.32	0.191
3	631.5	679.11	0
4	631.5	2757.71	1
5s	99.1	2445.23	0.898
5	99.1	2528.40	0.935
6	99.1	416.44	0
7	99.1	2674.55	1

Table 3b. Thermodynamic state properties: WHU at PGM-29 (operational average Jan. '07–Jan. '09).

State	P, kPa	h, kJ/kg	x
1	2795.0	990.12	0
2	770.5	990.12	0.134
3	770.5	714.20	0
4	770.5	2766.40	1
5s	99.1	108.41	0.887
5	99.1	2511.20	0.928
6	99.1	416.44	0
7	99.1	2674.55	1

Table 4. Performance results for WHU at PGM-29 (operational average Jan. '07–Jan. '09).

Month-Year	Avg. Power MW	Turbine Efficiency	Spec. Steam Cons. (kg/s)/MW
Jan-07	5.0389	na	3.938
Feb-07	4.8464	na	4.018
Mar-07	4.5529	na	4.303
Apr-07	4.4437	na	4.360
May-07	4.2310	na	4.384
Jun-07	4.1950	na	4.460
Jul-07	4.3981	na	4.254
Aug-07	4.8385	na	4.233
Sep-07	4.9507	na	4.047
Oct-07	4.7668	na	4.150
Nov-07	4.6147	na	4.302
Dec-07	4.5677	na	4.301
Jan-08	4.4216	0.9129	4.336
Feb-08	4.7834	0.9169	4.142
Mar-08	5.1012	0.9722	3.980
Apr-08	5.1467	0.9673	3.983
May-08	5.0984	0.9234	4.034
Jun-08	5.0538	0.8944	4.133
Jul-08	5.2357	0.9126	4.020
Aug-08	5.1419	0.9167	4.016
Sep-08	5.0233	0.9110	4.038
Oct-08	5.0419	0.9119	4.015
Nov-08	5.0583	0.9075	4.027
Dec-08	5.0874	0.9004	4.123
Jan-09	5.0355	0.9236	4.001

4. PGM-29 WHU ENVIRONMENTAL ASPECTS

The history of ICE's environmental policy is given in a companion paper in these Proceedings; Moya and DiPippo (2010). Here the results of environmental monitoring in the area of the PGM-29 Wellhead Unit will be described.

As a general status of the environmental impact of all power units at Miravalles, an annual report is prepared; Guido (2008). The most recent report covering activities up to December 2008 indicates that there are no significant environmental impacts due to the commercial exploitation of the Miravalles geothermal field. This conclusion is drawn from the recent results on the various control parameters as measured at a large number of stations located inside and outside the production zone. **Figure 10** shows the location of these stations.

As can be seen in the figure, there are 23 stations for water quality control, 7 stations for the air quality control, and 8 stations for the evolution of rain pH control.

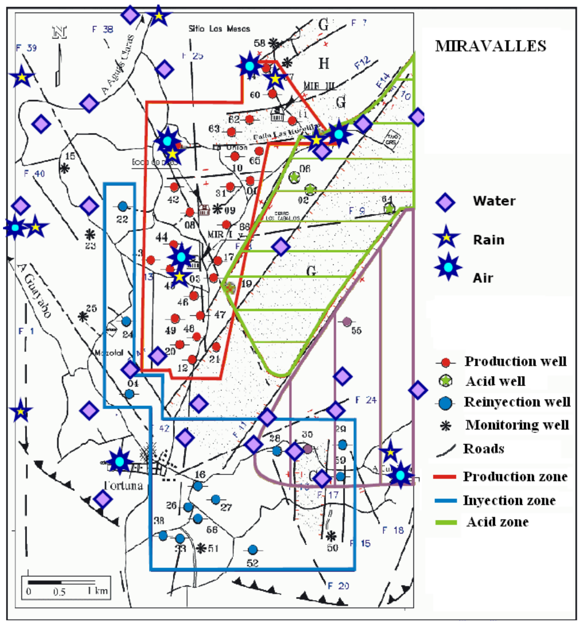

Figure 10: Environmental stations at Miravalles.

The results from the closest stations to the PGM-29 Wellhead Unit for water quality control, air quality control, and the evolution of rain pH control are shown in **Figures 11**, **12** and **13**, respectively. **Figure 11** shows that the pH, the Cl^- and the conductivities have been stable since 1991 (three years prior the commissioning of the first unit at Miravalles). It can be seen in **Figure 12** that the amounts of H_2S and CO_2 emissions have been very low since year 2000. These emissions have remained the same even though the generation has varied between 976 and 1,214 GWh.

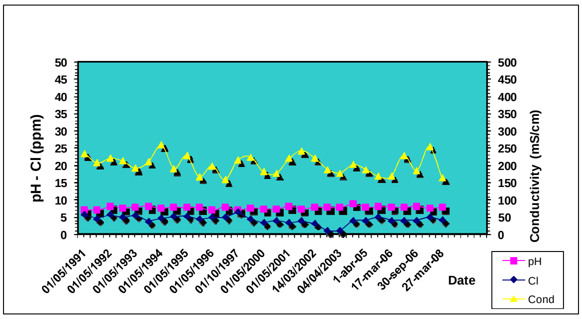

Figure 11: Quebrada Peje - Water quality control station at the Miravalles field.

The behavior of the pH in the rain can be observed in **Figure 13**. The pH has mainly ranged between 4 and 7 since June 1987 to date. This indicates that the generation at the Miravalles geothermal field has not modified the value of the pH values. The same variation of the pH values in the rain took place before the first unit was commissioned in 1994.

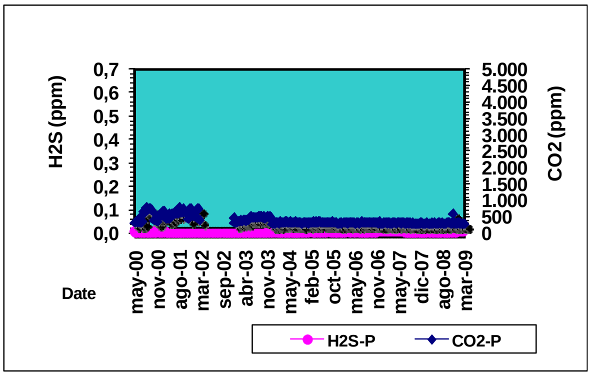

Figure 12: Cuipilapa - Air quality control station at the Miravalles field.

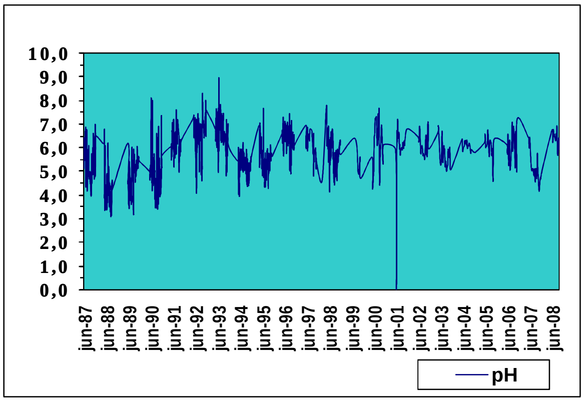

Figure 13: Cuipilapa - Evolution of rain pH at control station at the Miravalles field.

As mentioned, besides these three stations, there are more environmental control stations around the Miravalles geothermal field. Basically all of them show the same behavior, that is, there is no alteration of the pattern before and after generation started at the Miravalles geothermal field. Furthermore there is no evidence that the PGM-29 Wellhead Unit has created any negative impact on the environment due to its operation.

6. CONCLUSIONS AND DISCUSSION

ICE developed the Miravalles Geothermal field in just one decade (1994-2004). The initial installed capacity was 55 MW and 10 years later the capacity was already 163 MW. The generation associated with this installed capacity represents around 15% of the total energy generation in the country. The geothermal load factors are the highest ones of all energies in the country.

The new location of the wellhead unit has allowed the operation of this unit all year around and it has, at the same time, saved steam to be utilized by the main units in the center of the field. The decision to move the unit has improved the field management since there is less fluid extraction from the main production zone and at the same time, a new injection zone has been incorporated in order to divert the injected brine into the geothermal reservoir.

The average power over the two-year period is 4.83 MW, the average turbine efficiency is 0.921, and the average steam consumption is 4.07 (kg/s)/MW. The unit has operated at a 96% capacity factor and a 92.2% load factor. The utilization efficiency based on the exergy of the separated steam is 30.2%; however, based on the exergy of the total produced geofluid from PGM-29, it is only 14.3%. The unit is performing at its rated power with little variation month to month.

The composition of the superficial waters has not been affected significantly in the neighborhood of the Miravalles geothermal field due to the geothermal activities. The behavior of the air quality (CO_2 and H_2S) as well as the pH values in the rain has been constant prior to and after the commissioning of the geothermal plants. The contribution of the PGM-29 Wellhead Unit to the overall environmental impact of the Miravalles power complex is very small since it involves the consumption and discharge of only some 20 kg/s of steam.

Therefore, the geothermal activities have not generated a significant environmental impact at the Miravalles geothermal field. Rather, the development of this field has contributed to a rapid reforestation as well as an improvement in the economic and social activities of the surrounding towns.

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