UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensásvegur 9,
IS-108 Reykjavík, Iceland

30th Anniversary Workshop
August 26-27, 2008

TWENTY FIVE YEARS OF PRODUCTION HISTORY AT THE MOMOTOMBO GEOTHERMAL FIELD, NICARAGUA

Enrique A. Porras M.
ORMAT Momotombo Power Company
Centro FINARCA detrás antiguo SANDY'S Carretera a Masaya,
Módulos 10 y 11, Managua
NICARAGUA
eporras@ormat.com

ABSTRACT

The Momotombo geothermal field in Nicaragua is a good example of field management how revitalizing and improving steam production of the field succeeded after improper operation of the field for years. This paper presents the production history of the field from 1983 to 2008. Till 1999 the geothermal system of Momotombo suffered from over-exploitation that induced excessive flashing and intrusion of cold water in the reservoir resulting in a drastic decline of electricity generation and brine was discharged into Lake Managua. In 1999 ORMAT took over the concession for 15 years, invested more than US$ 45 million to drill four production wells, installed a 7 MWe bottoming unit, and implemented a full reinjection. Today, the Momotombo geothermal field can produce 32 MWe of its 77 MWe installed capacity. The geophysical studies and reservoir modelling show that even with an intensive well maintenance program more steam cannot be produced from the present concession area. To supply steam to the second steam turbine of 35 MW additional wells have to be drilled outside the boundaries of the present concession. ORMAT has proposed to make the necessary investment if the concession area is increased and its term is extended beyond the 6 remaining years to enable recovery of the additional investment.

1. INTRODUCTION

Nicaragua is endowed with the largest geothermal potential of the Central American countries due to the presence of the Marrabios range along the Pacific coast. Geothermal surveys started in Nicaragua in 1966. An exploration program in the western part of the country was carried out in the early 70's that led to the selection of ten geothermal areas (Figure 1): Momotombo, San Jacinto, El Hoyo, Granada-Masaya-Nandaime, Cosiguina, Casita - San Cristóbal, El Ñajo, Chiletepe-Managua, Masaya-Tipitapa and Ometepe with an estimated power potential in the order of 1100 MWe

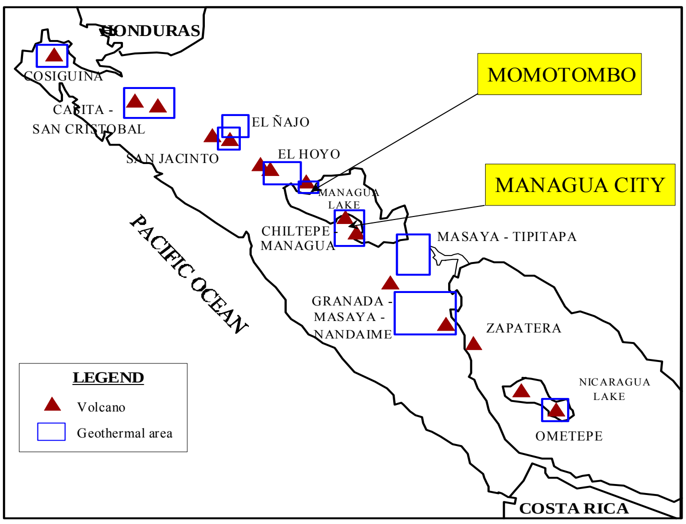

FIGURE 1: Location map of the geothermal areas in Nicaragua

(Porras, 2005). Currently, Momotombo and San Jacinto are the only geothermal areas producing steam for power generation with an installed capacity of 77 and 10 MWe, respectively.

2. EXPLOITATION HISTORY

Electricity generation using geothermal steam began in 1983 when a 35 MWe condensing type unit was commissioned in Momotombo. Between 1983 and 1989, five shallow wells were drilled and started producing steam and water mixture. These wells are MT9, MT12, MT20, MT23 and MT27. Separated water from wells MT9, MT23 and MT27 (Figure 2) were connected to the reinjection system, and consequently an average of 20% of the produced brine was reinjected back into the reservoir during this period with four reinjection wells. Power output started decreasing from the end of 1986 (Figure 3) when well MT9 stopped discharging because of a casing collapse.

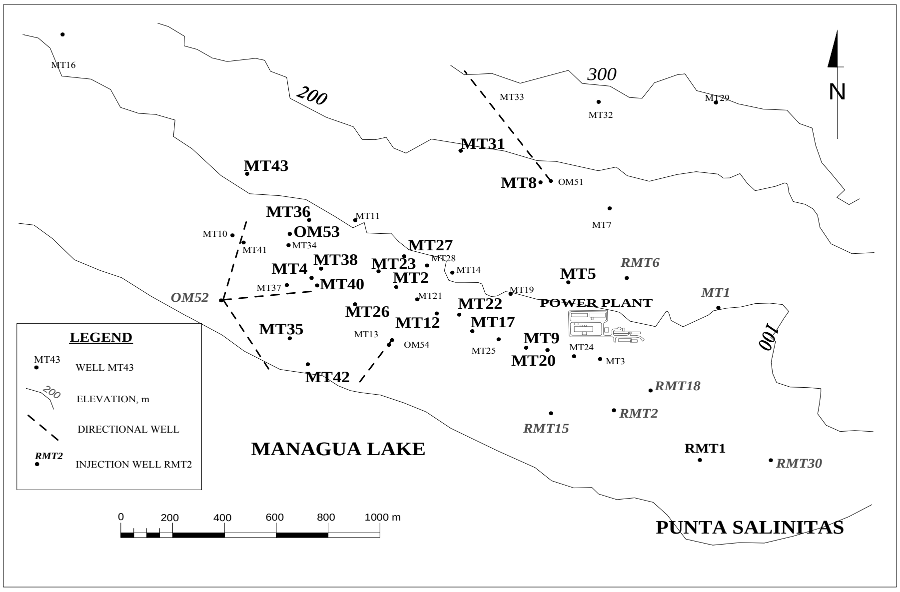

FIGURE 2: Location map of wells

2.1 Over exploitation of the field

Even though reservoir engineering studies suggested that the field was not capable of sustaining 70 MWe by only shallow production wells (DAL SpA, 1989), the second 35 MWe condensing type unit was installed and commissioned in March 1989 when additional six shallow wells were online for this unit without any new reinjection well. Among others, over-exploitation of the reservoir and a lack of

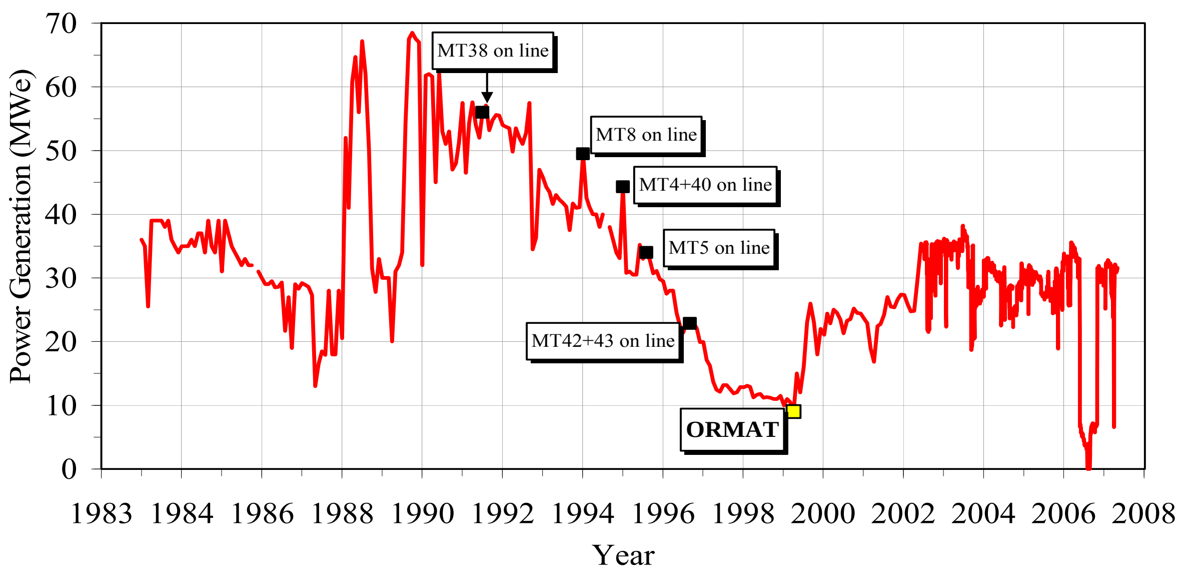

FIGURE 3: Power generation history of Momotombo geothermal field, Nicaragua

a proper field development strategy, resulted in a fast decline of the power output from 69 MWe in 1990 down to 9 MWe in 1999. Such a quick decrease of power output promoted drilling of four makeup wells and work over for one well. Furthermore, two existing wells were investigated and found to be productive. They were connected to the steam gathering system. These operations resulted in recovery of steam production. All these wells were on line between 1992 and 1997. In spite of these additional wells, decrease of output still remained. Wellbore surveys in 1996 and 1997 revealed that most of the shallow wells located in the central part of the well field were damaged by scaling, and other shallow wells in the eastern part were suffering from cooling. In 1999, the output dropped down to about 8 MWe when only 7 wells were producing (Figure 3). These wells have deep feed zones (800 and 2000 m b.s.l.) except MT27 (300 m b.s.l.) (Figure 2).

The results of the over-exploitation of the field and lack of reinjection of separated brine to the reservoir are described in the following sections.

2.2 Cooling of main feed zones

Figure 4 shows the histories of specific enthalpy of the produced fluid (solid red line) and total flow rate (open circles) for wells MT20 and MT12. We can see that both wells produced high-enthalpy fluid for most of the time. However, a quick decrease in enthalpy started in both wells in 1997 and 1996, respectively, when they failed to produce at the required separator pressure due to low temperature at feed zones.

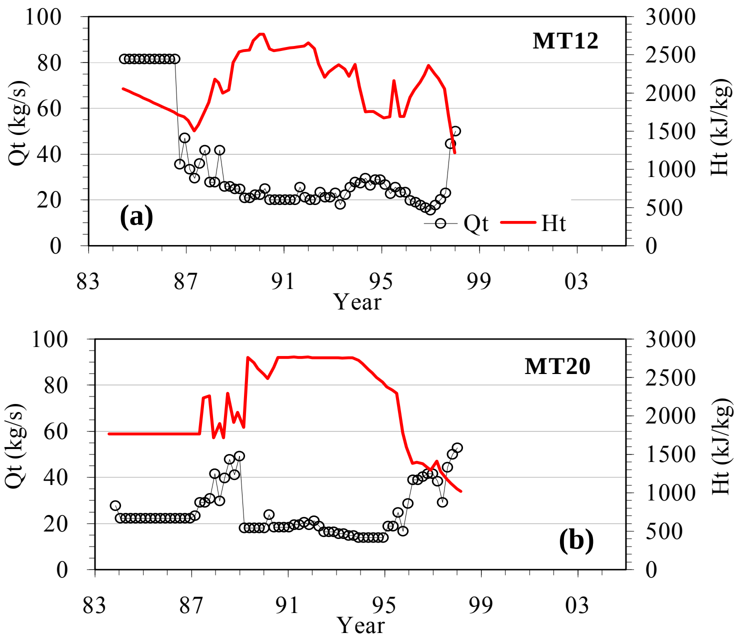

FIGURE 4: Production history of wells MT12 and MT20

2.3 Calcite scale within wellbore

Figure 5a shows a picture of wellbore MT35 at about 862 m depth taken with a down hole video (DHV). It is clearly shows calcite scale deposit on the surface of the wellbore and how it clogged the wellbore and thus reducing production rate of this well, which also failed to discharge at required separator pressure.

Other problems found in producer and reinjection wells were mechanical damages. For example,

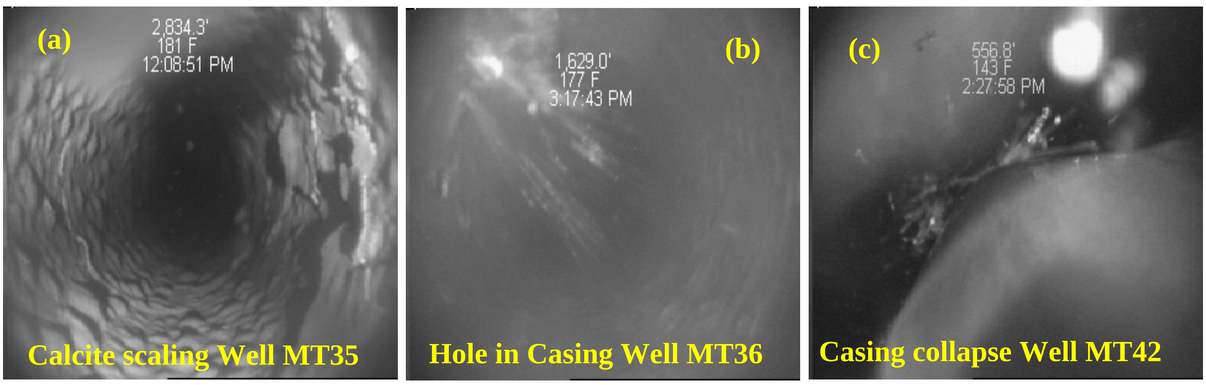

FIGURE 5: Different mechanical problems found in Momotombo wells through a down hole camera survey

Figure 5b shows a picture at about 514 m depth within the production casing of well MT36 where cold shallow groundwater flowing into the well through a hole can be clearly seen. Inflow of such cold fluid into the production well decreases the enthalpy of the produced fluid and results in reducing steam production and unstable discharging.

Figure 5c shows a picture taken at 168 m deep in well MT42. A casing collapse is also found in this picture. Such failures are commonly due to an inadequate cementing job during drilling.

3. REHABILITATION OF MOMOTOMBO BY ORMAT

As a result of an international bid, ORMAT signed a 15-year concession and power purchase agreement (PPA) contract with Nicaraguan Electric Company (ENEL) in March 1997 to exploit the Momotombo field and manage the power plant for improving reservoir management and increasing the power output. Since then, the installed capacity of the plant has increased to 77 MWe and currently it produces between 30 and 35 MWe supported by intensive well maintenances (Figure 6). In July 1999, ORMAT started to manage the Momotombo geothermal field and power plant, right after a power output recovery program started which is described in the next section together with results.

3.1 Geophysical survey

An integrated geophysical exploration program was executed in 2000 to define production target areas and specific drilling targets using integrated suite of geophysical methods that included: self potential, gravimetry, aeromagnetics, microearthquake monitoring, review of existing resistivity data, remote sensing data including aerial photo, LandSat and RadarSat images, and temperature survey at 1 m depth. As a result, two target areas were chosen and recommended; one area was located within the well field, and the other area was identified in the surrounding exploration concession.

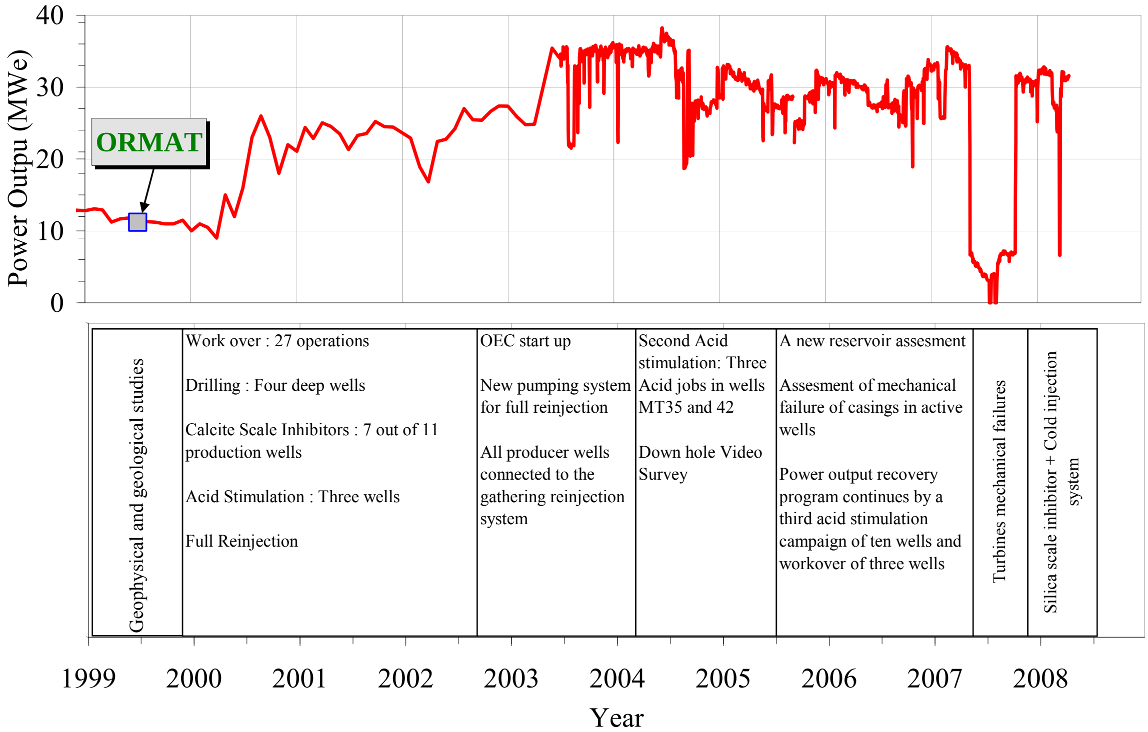

FIGURE 6: Gross power output generation from 1999 to 2008

3.2 Drilling of four deep wells

Four deep wells were drilled by ORMAT between 2001 and 2002, following the geophysical study results. A total length of 7097 m was drilled from which well OM53 resulted to be commercially productive and has become the best steam producer of the field. Another well, OM52, is now used as a brine injector.

Geophysical studies suggest deep drilling targets (deeper than 2500 m) for production wells. Of the four wells drilled by ORMAT, none except OM52 (> 2800 m) did reach 2100 m. The deep targets are still considered promising for steam production in order to increase the current power output up to the current installed capacity of 77 MWe. ORMAT is willing to invest in new studies and drillings only if concession term is extended beyond the remaining six years.

3.3 First work over campaign

Parallel to the drilling deep wells, ORMAT carried out a work over program on selected wells. This program included deepening, mechanical cleaning of calcite scale, running new liners, cementing and fishing jobs. A total of twenty seven operations in eleven wells were carried out. An increase of 15.4 MWe in power output was the result of the work over program (Figure 6).

3.4 Calcite scale inhibitors

Due to the high risks and costs of the mechanical cleanings, it was decided to install calcite scale inhibition systems in seven out of eleven producer wells. The inhibition system has been working continuously with high efficiency for the last seven years.

3.5 First acid stimulation campaign

Cleaning and acid stimulation were carried out between June 15th and July 7th 2002 using a 2 ⅜" coiled tubing and scale blaster. The cleaning operation was conducted by Schlumberger in wells MT4, 35 and 42. These three wells were identified to be suffering from calcite scale within wellbore and formation, as well as from formation damage due to drilling mud. As a result, an increase of 4 MWe was achieved with this acid stimulation campaign (Figure 6).

3.6 Commissioning of an ORMAT Energy Converter (OEC)

A 7 MW ORMAT Energy Converter (OEC) unit was installed in October 2002 at the Momotombo geothermal field. The decision to install this unit was taken after a 6 six months field test with the brine from producer wells (Kaplan, 2004). The test results showed that brine temperatures could be dropped down to 100°C without changes to heat exchange capacity due to silica scaling on heat exchange pipes. However, reinjecting heat depleted brine of 100°C after installing the OEC unit was a concern from the viewpoint of reservoir management. Therefore, a tracer test was carried out in the field for quantitative evaluation of connectivity among wells. On January 2003 four different tracer materials were pumped into the reinjection wells. Water samples were collected at all the production wells. The test results suggested that reinjection wells RMT2 and RMT6 effectively support reservoir pressure with only limited thermal cooling on production zone. Reinjection well RMT18 has a better communication with the production zone compared with the previous two reinjection wells. Finally, the excellent connection between reinjection well RMT15 and the production zone was confirmed, thus it was concluded that this well could cause marked cooling in the Momotombo reservoir. As a result of the tracer test, a new reinjection strategy was adopted. A limited amount of injection fluids went into well RMT15, maximizing reinjection both in RMT2 and RMT18. Two old wells (MT1 and MT30) located in the eastern part of the field were connected to the reinjection system in order to increase injection capacity of the well field.

Once the heat of the produced brine has been converted to electricity in the bottoming unit, ORMAT will have fulfilled one of its commitments to environment which is to reinject 100% of the produced brine. This is an important part of the field management scheme that ORMAT started to implement in 1999 after taking over the project.

3.7 Second acid stimulation campaign

Soon after the OEC came on line, the maximum power output was attained (38 MWe, Figure 6). However, months later some producer wells showed scale problems such as MT42 and MT35. The second acid stimulation campaign took place in 2004, but ORMAT designed and built its own acid mixing and pumping unit for this project. Then, well MT42 was stimulated twice and MT35 once. This resulted in a power output recovery of 2 MWe which was contributed solely by well MT42.

3.8 Work over and the third acid stimulation campaign (2006)

Ten wells were identified from the analysis of production data; produced fluid chemistry and DHV survey carried out in 2005 to have both mechanical and scaling problems. Two wells, MT42 and MT36, had casing collapse and broken casing. Other wells were selected for deeper redrilling (MT35 and MT27) and acid stimulation (MT35, 18, 30, 27, 42, 53 and 31). The results were an increase in production rate of steam 60 t/h and brine 200 t/h that was equivalent to 8 MWe.

3.9 Silica scale inhibition

After operating for about one year, silica scale and deposition started to occur in the OEC´s heat exchangers. Silica concentration of the brine sent to the flash vessels is approximately 650 ppm. This level of silica becomes over saturated as the brine temperature drops from 148 to 109ºC through the OEC heat exchangers. Under these conditions, silica is over saturated approximately 1.4 times and silica scale can occur in the heat exchangers tubes. Furthermore, silica scale was observed in the outlet section of the preheater and vaporizers, and flow rate of brine through the OEC was reduced together with power output. As a first countermeasure, preheaters and vaporizers were cleaned six times with HF acid solution between 2004 and 2007. Time intervals for cleaning became shorter with time. Hence, it was decided to run a six months test with the Geosperse 5110 to control silica scaling and injection lines to wells. Amorphous silica and co-precipitated silica scales have been effectively controlled using this chemical after six months of testing. Figure 7 shows flowrate of brine (blue solid dots) and power generation history (red solid dots) of the OEC. The figure shows that both values become stable after the inhibitor started to be pumped at the entrance of the OEC in January 2008. The feed rate of chemicals has been kept to 4 ppm for brine at a flow rate of about 1000 t/h. The chemical injection system is composed of a chemical metering pump, stainless steel injection quill and ¼" capillary tubing has been used as injection system.

Scale control performance has been monitored since the beginning of the test by using retractable deposition coupons at the inlet of OEC and the farthest injection well from the inhibitor injection point. Deposition coupons were weekly inspected, measured, and weighted in order to detect any changes with time and to compare with the operational activities of the OEC.

4. CONCLUSIONS

1) From 1983 to 1999 the geothermal system of Momotombo suffered overexploitation that induced excessive flashing and intrusion of cold water in the reservoir. This resulted in a significant decline of steam production as well as electricity generation and clogging of the injection wells and the improper management of the reinjection system which led to the discharge of the brine into Lake Managua.

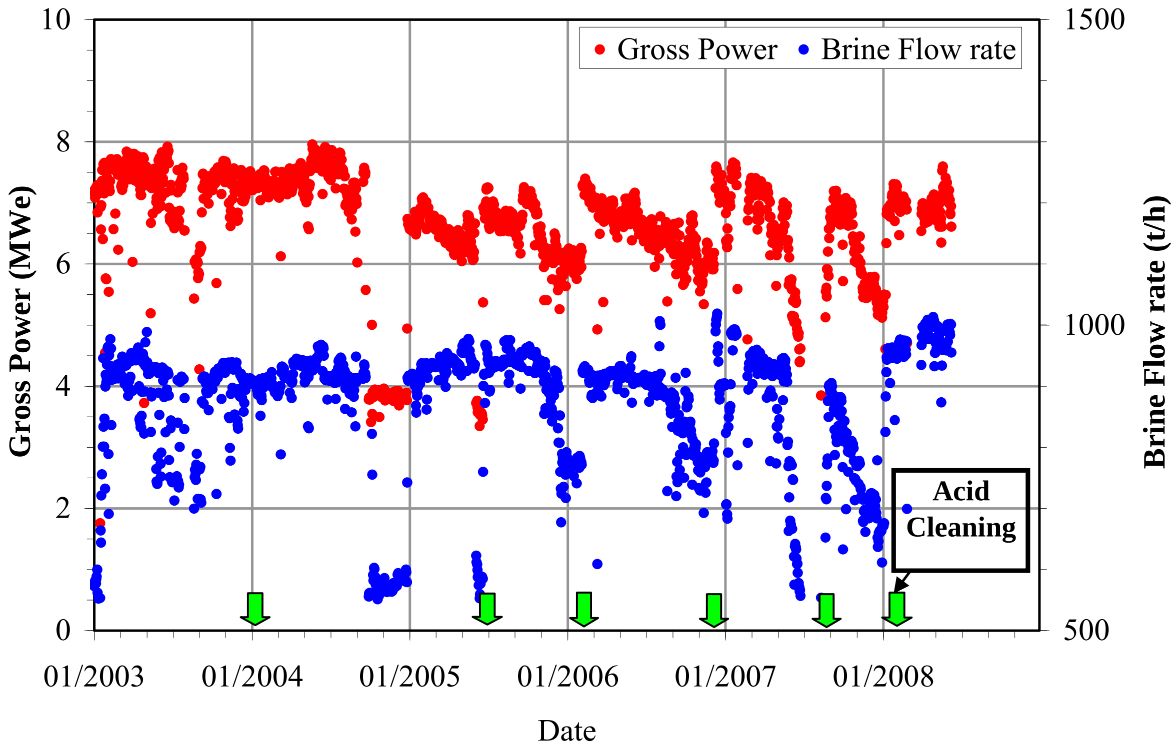

FIGURE 7: Brine flow rate and gross power generation histories of the OEC Unit

2) Since ORMAT took over the Momotombo geothermal field and power plant, most of the problems that ORMAT inherited from the past operations have been solved by applying all available technologies for exploiting the resource under a sustainable environmentally responsible scheme including full reinjection.

3) Production records, geophysical studies and reservoir modelling show that in spite of ORMAT's more than US$ 45 Million investment, the area presently allocated to the geothermal reservoir of Momotombo can not supply steam for more than 32 MWe of power output (23-24 MWe net from one 35 MWe steam turbine and 6-7 MWe from the ORMAT bottom unit).

4) To supply steam to the second steam turbine of 35 MW additional wells have to be drilled outside the boundaries of the present concession. ORMAT has proposed to make the necessary investment if the concession area is increased and its term is extended beyond the 6 remaining years to enable recovery of the additional investment.

REFERENCES

DAL SpA, 1989: *Campo Geotérmico de Momotombo: Optimización del sistema Campo-Planta. Informe final*. DAL SpA, report for INE (Nicaraguan Institute of Energy), 342 pp.

Kaplan, U., 2004: Geothermal cold brine injection two years experience in the Momotombo Field, Nicaragua. *Geothermal Resources Council, Transactions*, 28, 59-64.

Porras, E., 2005: *Development of numerical model of the Momotombo geothermal field, Nicaragua.* Kyushu University, Fukuoka, Japan, PhD thesis, 207 pp.

Zúñiga, A., 2005: Nicaragua country update. *Proceedings of the World Geothermal Congress 2005, Antalya, Turkey*, 5 pp.