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
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STIMULATING WELLS – THE EXPERIENCE IN THE MOMOTOMBO GEOTHERMAL FIELD, NICARAGUA

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ABSTRACT

The Momotombo geothermal reservoir has been developed for twenty nine years. Two condensing type units of 35 MWe each were commissioned in 1983 and 1989 respectively. Steam production was doubled in 1989 and since then production wells show marked changes in flow rates, fluid chemistry and specific enthalpies of produced fluids. These changes are mainly attributed to reservoir pressure decline because of excessive fluid production and cooling of reservoir due to intrusion of colder and carbonated waters. By 1999, when the power plant output dropped to 8 MWe, an international tender was issued for the rehabilitation of the project under a 15 year concession. Ormat won the tender and undertook to drill additional wells, work over of existing wells, implement a full reinjection, install a bottoming OEC unit and apply all available technology such as acid jobs and calcite scale inhibition in order to maintain the maximum power output that the reservoir can handle. As for now, the plant is producing about 30 MWe gross supported by an intensive well maintenance program that includes at least one acid job every two years and calcium inhibition system installed in seven out of eleven producer wells. Acid jobs have been crucial for keeping a stable power output in Momotombo since 2000. Top acid jobs and spotting acid through drill pipe, coil tubing and macaroni tubing have been carried out in Momotombo. ORMAT has designed and built its own blending unit for acid stimulation jobs. More than fourteen acid jobs have been carried out in Momotombo using different service companies, methodologies, types of acids and recipes.

1. INTRODUCTION

The Momotombo geothermal field is located on the north-western shore of Lake Managua, Nicaragua and on the south-western slope of the active Momotombo Volcano. The field was initially developed by the Nicaraguan National Institute of Energy (INE) and Nicaraguan Electric Company (ENEL) that led to the commissioning of a 70 MWe (2 x 35 MWe) plant capacity in 1983 (first 35 MWe Unit) and 1989. ORMAT Momotombo Power Company (OMPC) then continued with the development and exploitation of the field in 1999. To date, the plant capacity is 77 MWe after commissioning of a 7 MWe OEC Unit in 2003. There are 47 wells drilled in the field in an area of about 2 km^2. There are three permeable horizons at Momotombo: a shallow permeable layer between 200 and 700 meters below sea level (m b.s.l.) and the other two layers located at around 700 to 1,500 m b.s.l., and 1,500 to 2,000 m b.s.l. Figure 1 below shows the location of the wells in Momotombo geothermal field, twenty wells have been connected to the steam gathering system in different periods.

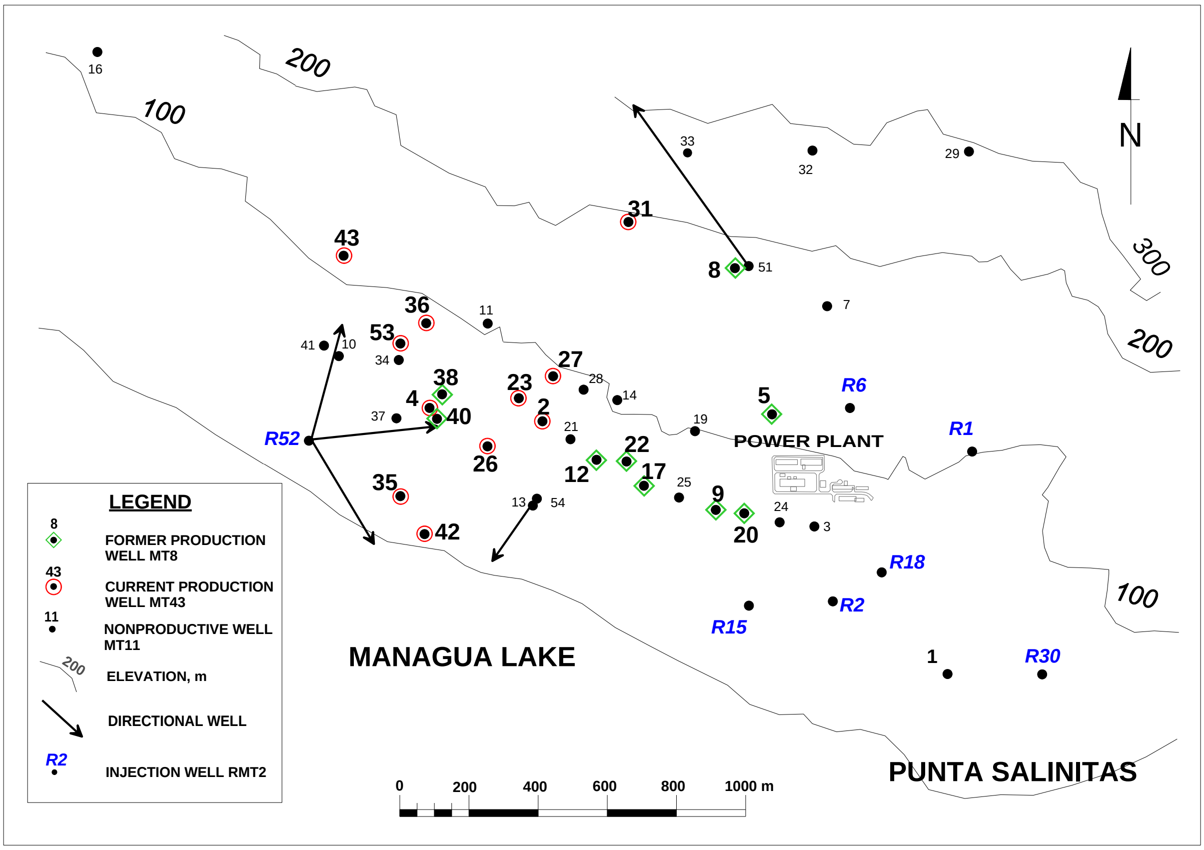

FIGURE 1: Location of the Momotombo geothermal field

2. FIELD PERFORMANCE HISTORY

Figure 2 shows power generation history of the Momotombo geothermal field, from commissioning of the first condensing type unit (35 MWe) in 1983 until present. It is clearly seen non-stability that resulted from numerous difficulties related with power plant operation and resource management. A gradual generation decline started in 1991 related with enthalpy loss of most of the producer wells. By 1996 most of the shallow and intermediate wells develop calcite scaling plugs. By 1999, a minimal power output of 9 MWe was reached.

As a result of an international bid, in March 1997 ORMAT signed a 15-year Concession and PPA contract with ENEL (Nicaragua National Power Company), to rehabilitate the Momotombo Geothermal Power Plant. From 2000 to 2006 a parallel program of well workovers and new drilling was carried out, preceded with surface exploration studies and revision of existing production history and reservoir conceptual model. A substantial gain in power production in the year 2000 resulted from cleaning calcite plugs out of existing wells in the centre well field. Drilling of new and deep wells OM51 to OM54 in 2001-2002 only added about 8 MWe to the total generation. In 2002 Ormat made a strategic decision in its field development, by installing the 7 MWe binary unit. Calcite scaling problems continued to persist in many of the shallower wells, requiring a calcite inhibitor system in 7 out of 11 production wells. Acidizing units were employed in and after 2003. These acid jobs allowed for continued operation of wells that had a tendency to flash and scale into formation. Additionally Ormat was able to stimulate feedzones previously clogged by drilling mud; in particular at the Eastern well field where 100 % brine injection takes place since 2003. Among recent resource studies undertaken, a tracer experiment in 2002 to 2003 may explain rapid loss in enthalpies observed in most production wells after 1991. As to be expected chemical breakthrough times are fastest in the shallow and intermediate depth wells while slower in deeper wells, suggesting that there is a direct connection between the East well field and production wells, most likely by fractures. The Eastern well field seems to act as a constant pressure boundary, which is unfortunately cold. It is then located close to well RMT18 due to its reversed temperatures at depth (Porras and Bjornsson, 2010).

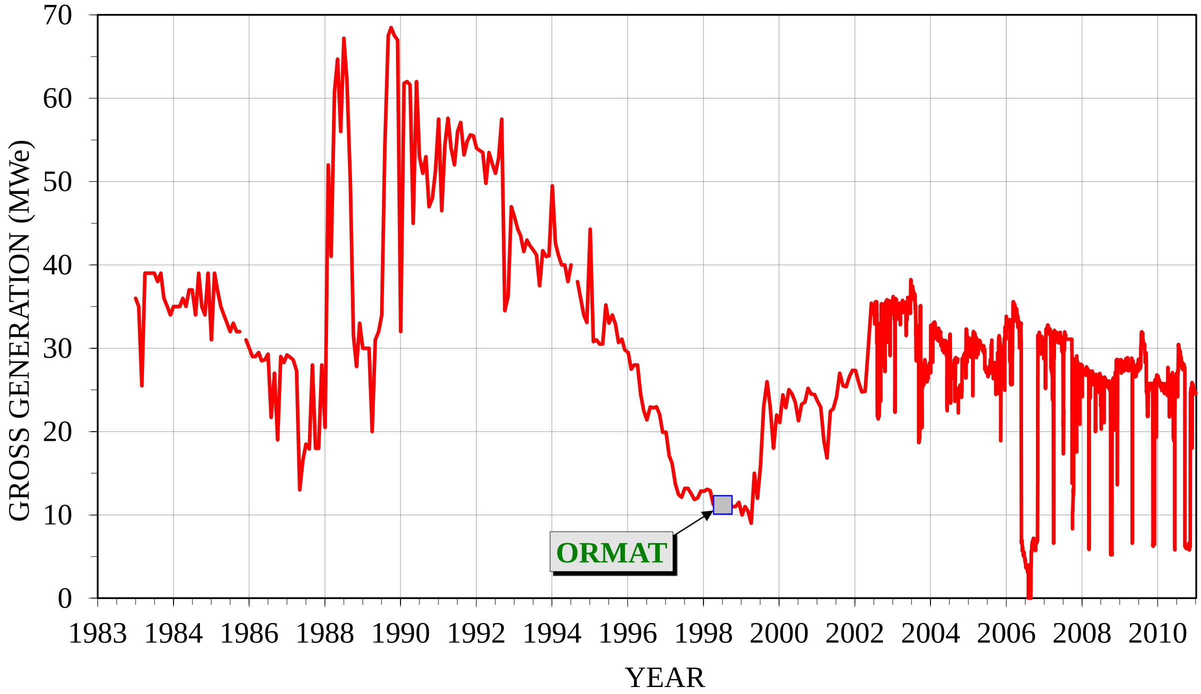

FIGURE 2: Gross generation history of the Momotombo Geothermal Field

3. ACID STIMULATION OF THE MOMOTOMBO WELLS

Different acid stimulation campaigns have taken place in Momotombo since 2002 using different methodologies, type of acids and service companies. Table 1 shows a summary of all acid jobs performed at the Momotombo Geothermal Field.

3.1 The Schlumberger experience

Schlumberger carried out the first campaign of acid treatments in three of producer wells (MT4, 35 and 42). They carried out solubility tests on drill cuttings of the selected wells. Test results suggested that an HCl + HF solution was the best option for dissolving the mineral scale formed within wellbore and formation.

The acid was pumped through a 2 3/8" coiled tubing with scale blaster (Figure 3). By using high velocity acid injection, the abrasive effect of such way of injection ensures a much better cleaning of the casing walls. By spotting the acid at the right pay zone of the well, a better penetration of the acid is obtained. From all acid jobs performed in Momotombo, the ones carried out by Schlumberger had the highest costs due to imported chemicals and high technology of the coil tubing unit used.

The procedure applied by Schlumberger consisted of three main stages: *the cleaning of the production casing* with the coiled tubing + Scale Blaster using either water or acid. A second stage is the *Matrix Stimulation* itself by using the recommended acid. Divergent material was used to spot the acid on at exact depth of payzone to be stimulated. Schlumberger applied a third stage called Post-Flow, in this stage to displace the main acid inside the formation. At the end of the acid stimulation operation fresh water is pumped.

TABLE 1: Summary of acid jobs performed at the Momotombo Geothermal Field

Well Name	Well Type	Date	Preflush Vol (m^3)	Main Treat Vol (m^3)	Postflush Vol (m^3)	Type of Injection	Service Company
MT42	Producer	24/07/2002	>200	140.3	96.7	Top Job	Schlumberber
MT35	Producer	29/07/2002	>200	37.7	8	Coil Tubing+Scale Blaster	Schlumberber
MT42	Producer	04/08/2002	>200	50	50	Coil Tubing+Scale Blaster	Schlumberber
MT35	Producer	15/02/2004	>200	69.2	>200	Top Job	ORMAT
		14/07/2006	64	184	220	Drilling string	BJ Services + ORMAT
MT42	Producer	02/10/2003	>200	69.2	210	Top Job	ORMAT
		02/09/2004	>200	69.2	210	Top Job	ORMAT
		19/07/2006	>200	155	133	Top Job	BJ Services + ORMAT
		14/01/2009	>200	87	210	Top Job	ORMAT
		15/11/2009	120	40	210	Spot through macarroni pipe	ORMAT
RMT30	Injector	05/08/2006	64	184	220	Drilling string	BJ Services + ORMAT
RMT18	Injector	11/09/2006	93.1	99	165	Top Job	BJ Services + ORMAT
MT27	Producer	17/09/2006	149	149	540	Drilling string	BJ Services + ORMAT
OM53	Producer	08/10/2006	84	84	80	Top Job	BJ Services + ORMAT
MT31	Producer	20/10/2006	95	74	133	Top Job	BJ Services + ORMAT

FIGURE 3: Scale blaster

3.2 ORMAT Acid Unit

Repeat acid stimulation jobs were also conducted by OMPC local staff in wells MT42 and MT35 (2003/2004). In February 17th 2003 well MT42 failed to flow due to calcite scale in the feed zone. Due to high cost of service companies for performing acid jobs, ORMAT decided to design and build its own acid stimulation unit (Figure 4). Total storage capacity of the unit is 131,100 litres with all needed manifolds, pumps and metering devices important for blending HCl and HF acids. This unit is not only for blending the chemicals but for carrying out Bull Head Acid Jobs (Top Job) on wells that had not completely lost their injectivity. The unit was tested on well MT42 (October 2003) and it has been used in all subsequent acid jobs performed in Momotombo. In some cases, the unit has been connected to service companies' high pressure pumps to perform acid jobs at high injection rates and pumping pressures.

ORMAT designed procedures and recipes for the acid stimulation treatment of well MT42 in October 27th 2003. The proposed acid treatment was designed to remove scale from within the wellbore and at the pay zones. It was assumed that the feed zone fractures were mostly plugged with scale due to flashing outside the wellbore. This was the principal target of the acid treatment. The proposed treatment consisted of cooling the well prior the injection of the main acid, and then injecting the main acid by bull head injection. The main acid contained corrosion inhibitor in the needed amount for protecting the casing from the acid at a temperature of 230°C. As a final step of the acid stimulation, fresh water was pumped into the well in order to displace the main acid inside the formation. Injection tests and PTS logs, or temperature surveys, are needed before and after the acid stimulation in order to know if the acid job has been successful or not.

FIGURE 4: ORMAT acid stimulation unit

3.3 The BJ Services experience

From June 15th to November 5th 2006 ORMAT carried out an acid stimulation and work over campaign on seven Momotombo wells to improve their productivities and injectivities. In this campaign, ORMAT invested several millions of dollars in order to increase the power output of the Momotombo Field. In only six months, five acid jobs were completed on production wells (MT35, 42, 27, 53 and 31) and two in injection wells (RMT30 and 18), in parallel, workovers were completed in wells MT35, RMT30 and MT27. For this job, the Santa Barbara drilling company and BJ Services were hired to perform the work over and acid jobs respectively. BJ was also in charge of the cementing jobs needed during the work overs.

Table 2 summarizes the volumes of fluids injected in the wells where acid jobs were completed. Acid treatments were designed by BJ Services and ORMAT, all jobs carried out on the above mentioned wells, except MT42, followed this design but using different ways to pump the acid (through the drill pipe and top jobs). Wells MT35, 27 and RMT30 used the drill pipe, wells MT42, 53, 31 and 18 were top jobs. As an example of the procedure applied on the wells enlisted in Table 2, see the description of the acid job performed in well MT35, which is as follows:

Well MT35:
A couple of acid stimulations had been previously carried out before 2006 by ORMAT crew and acid blending unit. A matrix acid stimulation was conducted in June 2002 by Schlumberger using a 2-3/8 in Coil Tubing Unit (CTU) (see Table 1). There was no significant improvement in well output after the acidizing operation, although the well registered a faster pressure recovery after shut-in. In fact, the output decline continued thereafter after the acid treatment. The total mass flow was down to around 68 t/h by November 2002. Analysis of the post-acid Pressure Build-Up (PBU) test in July 2002 showed a negative skin (s=-6.0) that indicates the absence of wellbore or formation damage (currently, we know that the problem of the well is a shallow feed zone at about 900 m deep that produces fluid reached in calcite, then a calcite inhibition system was installed after performing the acid job in 2006). The continue decline in output (total mass flow was at 38 t/h or ~2 MWe) by January 2004, prompted the necessity of conducting another acid stimulation in February 2004. The acid treatment design employed a smaller volume HCl mainflush that was injected at the wellhead. Again, there was no positive improvement attained after the acidizing operation.

TABLE 2: Volumes of fluid pumped during acid jobs performed in 2006

Well Name	Well Type	Preflush Vol (m^3)	Main Treat Vol (m^3)	Postflush Vol (m^3)
MT35	Producer	64	184	220
MT42	Producer	-	155	133
MT27	Producer	149	149	540
OM53	Producer	84	84	80
MT31	Producer	95	74	133
RMT30	Injector	64	184	220
RMT18	Injector	93.1	99	165

Downhole surveys conducted in March 2004, after the second acid job, revealed that the 1-1/4" sinker bar was not able to pass through at 1005 m that would suggest significant obstruction and possibly complete isolation of the entire production horizon at the bottom (slotted liner at 1130-1290 m). A downhole video log (DHV) was conducted in the well in May 2005 to establish the nature of the blockage at 580 m and assess the condition of the production casing preparatory to a workover operation. The downhole video log confirmed the presence of mineral (calcite) deposits throughout the casing but the tool however, was not able to penetrate below 865 meters due to the stripped off calcite scales that accumulated at this depth. Since January 2004 the well was shut in waiting for mechanical cleaning.

The acid treatment program implemented in this well, called for the dissolution of the mineral deposits (calcite), within and around the wellbore as well as at the feedzones (~1200 to 1290 m), and acid soluble minerals within the formation to enhance its permeability and recover and improve its production capacity. A total aggregate payzone thickness of around 90 m was programmed for acid stimulation. The problem of isolating the "thief zone" was address by increasing the freshwater injection into the backside (annulus) to create additional head in order to suppress the acid from entering the unwanted zone. The acid job was performed after the drilling rig finished the work over operation, the drill string was then lowered to the targeted payzone (~1200-1,290 m) and the acid was pumped right away.

The MT42 spotted acid case

A different procedure was applied for the acid job performed in well MT42 in November 2009 (see Table 1). In this case, the acid job program consisted on spotting 40 m^3 of HCl at 1300 meters where an obstruction was tagged with sinker bar. It was concluded that the obstruction was calcite scaling that the only way to dissolve it was by spotting the acid right on top of the upper part of the obstruction. The operation consisted on lowering a macaroni tube and then pumping the acid after cooling the well by injecting enough water to cool down the well and reduce the risk of corrosion. The macaroni tube had to pass through a casing collapse at 168 m (based on DHV survey ran in 2005). The injection of the acid was done by steps since chemical reaction of the scale and the HCl produced CO_2 gas that came out of the well increasing well head pressure and discharging the water column above the obstruction. After pumping the total amount on HCl on three steps, the well was discharged to the atmosphere for about 2 hours suggesting that the operation was successful. Figure 5 shows pictures during the acid job operation. Pumping rate through the tube was between 0.5 and 2 BPM (barrels per minute), pumping pressure came up to 2000 psig at the beginning of the acid injection, but then pressure was released to less than 500 psig.

As a result of this last acid job in MT42, the well was online until September 2011 when it failed to produce probably due to another calcite scaling plug formed within the wellbore. Another acid job will take place soon in order to recover MT42 production.

FIGURE 5: Pictures taken during the acid job, November 2009, in well MT42

4. CONCLUSIONS

As part of the costly well field management of the Momotombo geothermal field, acid jobs have become a very important component. Fluid production from producer wells has been recovered by applying different techniques and recipes of acid stimulation. HCl at different concentrations have been successfully used for dissolving calcite scaling. Other type of acid such as HF have been pumped in Momotombo wells to dissolve silica scale (injection wells) and other silica based products found on permeable zones of producer and injection wells.

Selecting the right type of acid is crucial for the success of an acid job; this acid must be first tested by checking dissolubility on drilling cutting from depth near pay zones to be treated. Previously to the acid pumping operation, the well should be cooled down as much as possible in order to reduce the risk of corrosion, even though corrosion inhibitor is added in the blended product.

High cost of acid job operations can be reduced by selecting the right volume and type of chemical to be pumped in the well. This can be done by analyzing all available data of the well to be acidized. Previous reservoir estimations of skin effect, location of the main pay zones, thickness of the payzones and gain estimations on power output/injectivity after performing the acid job will help to do an economical assessment of the acid stimulation. Cost of blending process during the acid job can be reduced by build own blending units with the right material and storage capacity. Combination of an own blending unit with pumping service companies can reduce the total cost of an acid job by 40%. However, if high pressure pumping is not needed for the acid job, Services Company won’t be needed and total cost of an acid job will be reduced to the minimum cost that will be basically the cost of chemicals and work power.

ORMAT has successfully applied technologies and experience to reduce the cost of acid jobs performed in Momotombo wells. Right now, ORMAT is able to run bull head acid jobs by using its own blending acid unit at a very low cost.

REFERENCES

Porras, E., and Bjornsson, G., 2010: The Momotombo reservoir performance upon 27 years of exploitation. *Proceedings World Geothermal Congress 2010, Bali, Indonesia,* 5 pp. Website: http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0638.pdf