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Maintenance and Operational Experience Gained By Operating the Aluto Langano Geothermal Pilot Power Plant

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ABSTRACT

Ethiopia is well endowed with geothermal resources, and current exploration is believed to have studied only a fraction of the ultimate potential. The potential prospective areas are distributed along the Ethiopian Rift valley system which runs in a northeast direction along the entire length of Ethiopia. To begin to realize this potential, in 1998, the Ethiopian Electric Power Corporation (EEPCO) constructed the Aluto Langano geothermal pilot power plant (8.5 MW gross) consisting of two Ormat generating units, one an OEC (Ormat Energy Converter) and the other a GCCU (Geothermal Combined Cycle Unit consisting of a back pressure steam turbine exhausting to an OEC bottoming cycle unit) - each designed to have similar power outputs.

The power plant operated satisfactorily for a short period of time right after commissioning before a number of problems arose that severely affected its availability and the power output level.

Repair and maintenance of the Aluto Langano GCCU has been completed and the unit was put back into normal operation in July 2007. During the original operational period of the pilot plant and after its recent rehabilitation, experience gained in operation and maintenance will ultimately be used to develop and harness the huge geothermal energy reserve exists in the rift valley region of Ethiopia.

In the coming five years it is planned to expand the Aluto Langano geothermal field in two phases.

1. INTRODUCTION AND BACKGROUND

The Aluto Langano geothermal field is located in the Ethiopian main Rift valley, Lakes District, some 200 km south of the capital Addis Ababa, which is one of the principal sectors of the East African Rift system. In this field detailed geological, geochemical and geophysical surveys were carried out during the late 1970's and early of 1980s. The result of the studies indicated that a high temperature underground fluid exists with an evidence of long time residence occupied by high temperature rocks. Six deep exploratory wells were drilled at Aluto out of which four wells were successful to supply a geothermal fluid to the power plant.

The ALuto Langano Geothermal pilot plant was built, commissioned and put into operation in 1998 to demonstrate the potential of geothermal energy in Ethiopia under a turnkey contract with Ormat International. The power plant is composed of two generating units; the geothermal Combined Cycle Unit (GCCU), and the Ormat Energy Converter (OEC). Combined, they had a design output of 8.5 MW. The two high pressure wells LA-3 and LA-6 are feeding the geo fluid to the conventional steam turbine of the GCCU. The exhaust steam coming out of the steam turbine is delivered to a heat exchanger which, in turn, boils a binary fluid to drive the organic binary turbine.

After its commissioning, the power plant operated for a relatively short period of time before a number of problems arose that severely affected the availability and power output level, ultimately leading to the shutdown of the power plant. These problems occurred underground, within the surface (fluid handling) equipment, and in the power plant itself. After a number of years, EEPCO issued an international tender to rehabilitate the power plant and put it back into operation.

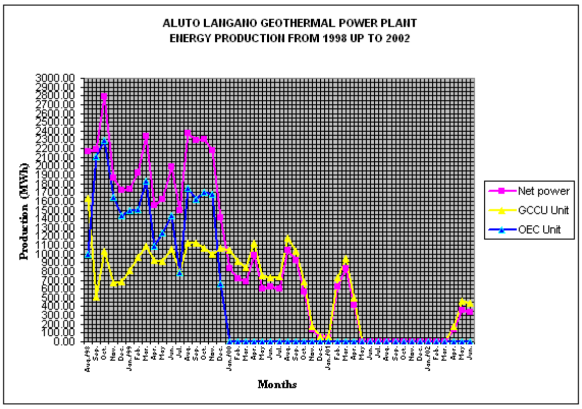

Figure 1: Chart of Energy production before the failure of the pilot plant

Subsequently, EEPCO engaged the services of a geothermal consultant, Geothermal Development Associates, to do the analysis of the problems and carry out the necessary repairs on the units to put it back into operation. Work carried out as part of the power plant rehabilitation includes:

- Reconditioning of the GCCU steam turbine has been completed and the unit is put back in operation. This included re-engineering of the steam turbine to enable it operates at lower steam pressures, upgrading the power plant automation system (PLC) and improving the lubrication system of the steam turbine.
- Repair and maintenance (servicing and/or overhaul) of the wellhead valves has been completed.
- Flow tests, go-devil runs, and down-hole pressure and temperature measurements to confirm the causes of the output declines were undertaken. The result of the tests indicated that the two high pressure wells are in good condition and are

currently supplying the geothermal fluid to the GCCU unit.

- Installing data loggers to enable records of wellhead pressure and temperature under static and dynamic condition. This has helped EEPCO personnel to understand the way the wells respond under dynamic flow condition.

- Analysis and investigation of corroded OEC heat exchanger tubes to determine the root cause of the tube failures. The result of the tests indicated brine carry-over, with traces of chloride, was the root causes of the tube failure. Based on the results obtained it was decided to replace all the heat exchanger tubes (over 2,000 tubes) with higher quality duplex stainless steel. Modification work is currently underway to install a duplex filtering system to remove any debris and solid carryover to the heat exchangers in order to maintain fluid quality.

2. IDENTIFIED PROBLEMS RELATED TO THE STEAM FIELD AND THE POWER PLANT

Some of the problems that were identified that relate to the steam field and the power plant are:

1. Solid deposition in the well bore and surface equipment
2. Well output decline
3. Difficulty of operating the two high enthalpy, wells LA-3 and LA-6 in parallel
4. Journal bearing failure of the steam turbine
5. Worn-out steam turbine shaft on the drive-end side
6. Tube leaks in the OEC heat exchangers
7. Frequent failure of the cooling fan shafts

2.1 Solid Depositions in the Wellbore and Surface Equipment

Liquid dominated geothermal reservoirs are hydrothermal reservoirs that contain circulating liquids which transport the thermal energy of the hot rock with dissolved minerals near to the surface by natural fluid circulation. The fluid comes from such reservoirs may form scale that deposits in the well bore and fluid carrying surface equipment, particularly after boiling and brine separation. Therefore the brine scaling potential, corrosiveness, non-condensable gas (NCG) and hydrogen sulfide (H_2S) content are the four major chemical characteristics that have to be studied and addressed in the geothermal power plant design.

The schematic diagram showing common locations of solid depositions (Teso Merga report, 2001, UNU- GTP) shows in Figure 2.

The geothermal reservoir that feeds the well bore contains a variety of dissolved minerals and gases. Tests and downhole logs conducted on the Aluto Langano geothermal field wells indicated that well LA-4 exhibited calcite scale depositions. This well was drilled in 1983 to a depth of 2062 m in the outflow zone of Wonji fault. The logging result of May 2006 indicated that a go-devil of 3 in diameter stopped at a depth of 1085 m and a 4 ½ in go-devil stopped at a depth of 1050 m while logging fragments of white soft pieces, resembling calcium carbonate, were recovered from both go-devils.

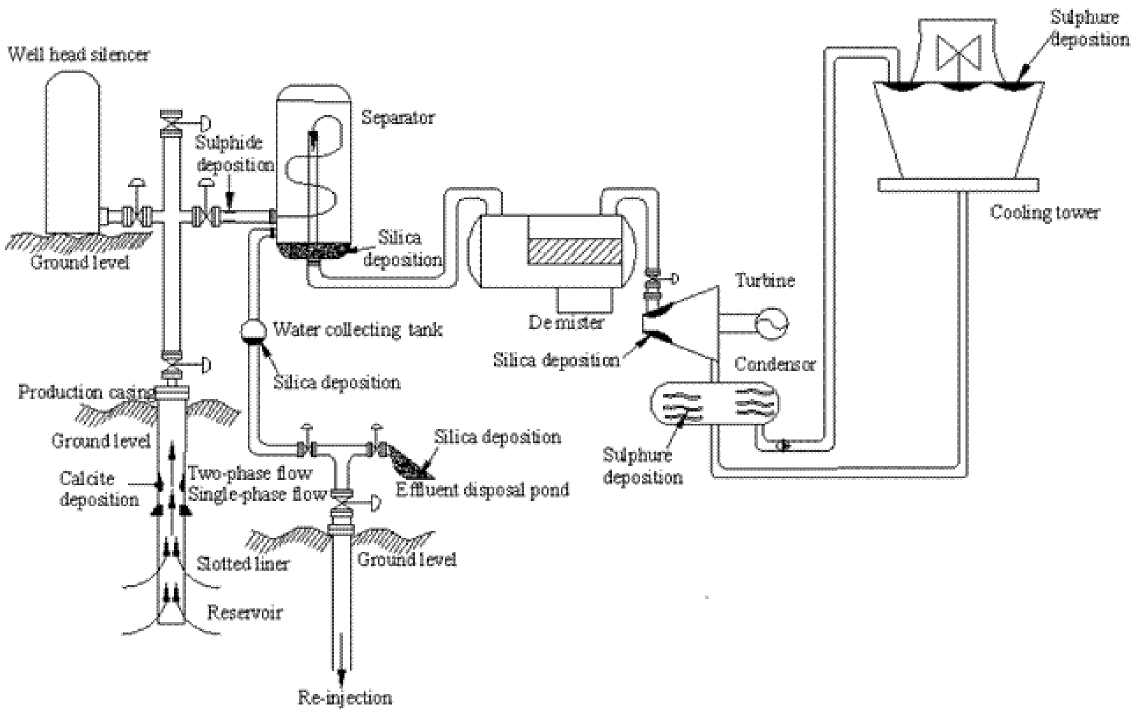

Figure 2: Flow diagram showing common locations of solid depositions

The blockage observed in well LA-4 has also significantly reduced the flow from this well. Subsequently, a well work over was recommended to remove the obstruction and bring the well back into normal flow. It is expected that, within a six month time period, the well work over will be completed and the well will come back into normal operation.

3. RECOMMISSIONING OF THE GEOTHERMAL COMBINED CYCLE UNIT (GCCU)

During early operation following commissioning the GCCU, it was observed that when well LA-6 was opened and the flow from both LA-6 and LA-3 wells was joined, the LA-3 wellhead pressure increased while the flow of LA-3 dropped sharply. This indicates that when the two wells operate together, LA-3 was unable to flow sufficient steam at higher system pressure to maintain a stable flow to the unit. This issue was discussed in detail with the Consultant and it was believed that the production pressure of the wells was not sufficient to spin the multi-stage steam turbine.

Destaging of the steam turbine, to enable operation of the GCCU at a lower inlet pressure, was suggested by PB Power in its final report prepared in 2000. According to PB Power, by de-staging the GCCU unit and removing turbine stages, the design steam inlet pressure would be lowered. This would match the stable production pressure of the wells to the turbine's capacity.

The predicted performance of the GCCU unit was as follows (from the original PB POWER design):

Table 1:

Steam Pressure inlet (bar) to the demister		Steam Flow Rate (t/h)	Power output
Design data before de-staging	12.0	29.0	4.0
	10.0	24.05	3.25
	7.5	18.1	2.3
	5.0	12.15	1.35
With first stage removed	7.0	26.8	2.9
	6.0	23.0	2.5
	5.0	19.2	2.1
Removal of the first two stages	5.0	29.0	2.6
Actual performance of the steam turbine after removal of the first two stages	5.14	~29.0	3.05

Based on the above and the actual flow tests conducted by the rehabilitation consultant (Geothermal Development Associates - GDA), it was recommended to remove the first two stages of the rotor. The modification of the turbine rotor was implemented by shipping it to Conhagen workshop in Texas, USA, as there were no workshops available locally who could do the de-staging. De-staging of the GCCU unit was performed successfully and the unit was put back into normal operation in June 2007.

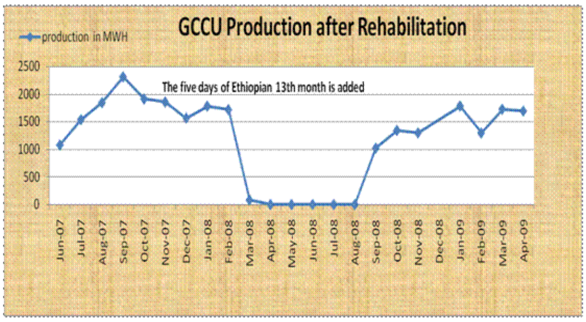

Figure 3: Plot of GCCU unit Energy Production

Note: The unit was out of operation during the period of April to August due to a reduction gear box failure (RG)

During the course of its operation after the rehabilitation, routine vibration measurements revealed a gradual increase in the vibration levels nearly 9 months after the start of operation. It was later discovered that the root cause of the vibration was related to loosening of the inertial masses on the pinion gear of the speed reduction gearbox. From the month of March to August 2008 the unit was out of operation in order to rectify the problem with the reduction gear box (RG). The purpose of the RG is to couple and reduce speed of the high speed steam turbine to match that of the synchronous generator.

Extensive investigation on the cause of the gearbox problem was carried out. Information was also obtained on experience with gearboxes at similar geothermal power plants (such as the Puna, Hawaii plant). A repair strategy was developed and the gearbox pinion was sent to the Ethiopian Airlines workshop for reconditioning. Ethiopian Airlines reconditioned the RG and carried out dynamic balancing to acceptable industry standards. The RG was subsequently taken to the power plant, installed and the unit restarted and put back into operation in August 2008.

4. TUBE LEAK OF THE HEAT EXCHANGER OF THE OEC UNIT

The Ormat Enegy Converter (OEC) is an organic turbine that uses N-Pentane as a working fluid. The two medium-enthalpy wells, LA-4 and LA-8, are the primary energy source to boil the organic fluid in the tube and shell heat exchangers. The OEC unit is comprised of a one pass vaporizer and four stages of pre-heaters; the heat exchanger tubes were made of 316L and duplex stainless steel except for the first and second passes of the preheater which were made of carbon steel.

Approximately one year following the original commissioning of the OEC unit, in December 1999, a pentane leak was observed through the non condensable gas (NCG) vent and caused the stoppage of the OEC unit. The results of investigations carried out subsequently indicated that pentane had leaked into the geothermal fluid stream due to vaporizer tube failure.

During the recent rehabilitation of the Aluto plant, in order to investigate the root causes of the tube failures, samples of the failed tubes and other relevant materials were sent to a metallurgical testing company in the USA to carry out a failure analysis. The company, Jonas Inc., conducted metallurgical analysis of the tube material and compatibility of the chemistry of the geothermal fluid with that of the tube materials.

Table 2: Results of tube inspection

Tube	Number of pits per foot on ID	Pit Depths (mm)	Pit Diameter (mm)
1	12	0.2 to 0.9	0.2 to 1
2	23	0.2 to 0.9	0.2 to 1
1	8	0.2 to 0.9	0.2 to 1

The result of Jonas' investigation indicated that localized pitting inside the tubes was due to high concentrations of corrosive impurities carried into the heat exchanger by brine carry-over during the initial operation of the plant. Jonas concluded that the heat exchanger material was not compatible with the chemistry of the Aluto wells. It further indicated that if the heat exchangers were operated under the same conditions, further damage would occur to the heat exchanger tubes. The recommendation was to replace the existing heat exchanger tubes with a more resistant grade 2205 Duplex Stainless Steel.

5. EXPERIENCE GAINED

1. Experience gained in refurbishment of wellhead master valves and bleed lines is very important. This included experience with the assembly and disassembly of master valves, hydrostatic testing, acquisition of spare parts, use of specialized tools and equipment, and local manufacture of some valve parts.

2. The knowledge acquired in steam field resource management and wellhead equipment operation would ultimately be used for Aluto expansion and other geothermal prospects.

3. Experience was gained with the operation of a new, digital, Kuster K-10 tool for down hole pressure and temperature logging.

4. Knowledge was acquired in the use of wellhead data loggers and interpretation of the logged data.

5. Experiences was gained with the refurbishment of cooling tower fans, specifically, in vertical shaft alignment, and correct tensioning of the torque transmission belt, which will be used to resolve problems that may arise with the cooling system.

6. Knowledge was acquired in updating the power plant automation system. This familiarized plant personnel with the operation of the programmable logic controller (PLC), Supervisory Control Acquire Data Acquisition (SCADA) system and Human Machine Interfacing (HMI) of the power plant.

6. CONCLUSION

As described above, Ethiopia is endowed with considerable geothermal resource potential. But, up to now, only a tiny fraction of this enormous resource has been used. The success with the re-commissioning of the Aluto plant will now pave the way for future expansion of power generation at Aluto and at other geothermal prospects.

Bringing the Aluto Langano geothermal power plant back into operation has been a high priority for EEPCO in order to maximize the return on the capital invested in the project, provide power to the national grid system, and demonstrates that geothermal power from Aluto site as well as from other fields can reliably meet the future electricity demand in Ethiopia.

Expansion of the Aluto Langano geothermal site to larger-scale power generation is in the pipe line and the experience gained in operation and maintenance of the existing pilot plant will ultimately be used for larger scale development.

Close monitoring of the resource (reservoir performance, fluid chemistry and steam quality) and performance of the power plant will ensure the reliable operation of the pilot plant as well as provide useful operational data that can be used for future power plants in the country.

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