Rehabilitation of the Aluto Pilot Geothermal Power Plant – An overview

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SUMMARY

The Aluto Pilot Geothermal Power Plant was commissioned in late 1998 but stopped operation after a very short period due to various technical problems. Failure of the heat exchanger tubes caused the premature shutdown of the OEC unit after about a year of operation. A number of resource related problems also caused reduction in net the power output of the GCCU which was eventually shut down in 2002.

The rehabilitation of the plant began in early 2006 which encompassed overhaul of the wellhead valves, inspection of the steam turbine rotor and bearings, testing and identifying failed tubes of the OEC heat exchangers and rectifying plant PLC control system.

Significant work was carried out during 2006 and 2007 which resulted in the GCCU unit becoming operational in June 2007.

Further additional rehabilitation works and on-going monitoring are required to bring the plant back to full safe and reliable.

1. INTRODUCTION AND BACKGROUND

The Aluto geothermal field is located in the lakes district region of Ethiopia, about 200km south of the capital Addis Ababa. Access to the site is along the main southern high way leading to Kenya.

The Aluto Langano Geothermal Pilot Plant is the first geothermal plant to be built in Ethiopia. The power plant is owned and operated by the state power company, Ethiopian Electric Power Corporation (EEPCO). The plant is composed of two units, the geothermal combined cycle unit (GCCU), which uses the geothermal steam from the hotter wells (LA3 and LA6); and the Ormat Energy Converter (OEC unit) which uses steam from the lower temperature wells (LA4 & LA8) and brine from all four wells. The objectives of the pilot plant were to test the Aluto resource, identify any resource or plant-related issues that could affect the further development of geothermal power at Aluto, allow EEPCo personnel to gain operation and maintenance experience with a geothermal power plant, and to provide power to the national grid. The project was also designed to act as a catalyst for the development of larger follow-on geothermal plants in the area.

Although the production wells were drilled during the early 1980's, as exploration wells, the decision to build a geothermal pilot plant was made more than a decade later in the mid 1990's. During the exploration program, a total of six wells were drilled on the Aluto volcano of which five were found to be productive.

Ormat Industries Ltd of Israel built and installed the power plant under a turnkey contract from early 1997 until the mid-1998. EEPCo assumed formal responsibility for the operation and maintenance of both the plant and well field after commissioning in the middle of 1998.

The designed power output of the pilot plant was 8.52 MWe (gross) and 7.28 MWe (net). Shortly after commissioning, the resource and plant began experiencing problems that eventually led to its shutdown in 2002.

In 2005, EEPCo issued an international tender for the rehabilitation of the Aluto plant and wellfield that was won by Geothermal Development Associates of USA. The primary objectives of the contract was to investigate the reported problems and carry out repairs on the plant, wellfield, gathering system, transmission line, remote control system and provide training for EEPCO personnel. Any additional failure discovered during the rehabilitation was to be given as a recommendation. The rehabilitation contract was implemented beginning in February 2006 through June 2007 when the GCCU unit was put back into operation.

2. PROBLEMS IDENTIFIED

A number of problems were identified during the initial operation of the plant and subsequent to its shut down in 2002 which formed the contract terms of reference for the rehabilitation work. These problems can be generally classified into two groups: those relating to the resource and those relating to the plant/steamfield.

Resource related problems:

- Wells unable to deliver steam at design pressure
- Solid emission from some of the production wells
- Mineral deposition down hole and is surface fluid gathering system

Plant/ steamfield related problems

- Leakage of wellhead valves
- Steam turbine bearing wear and high bearing temperature
- Heat exchangers' tube failure
- Cooling tower fan problems
- Operational difficulties with plant control & monitoring software
- Transmission line problems

Figure 1 The Aluto Pilot Geothermal Power Plant

3. REHABILITATION WORK PERFORMED

3.2 Resource related rehabilitation works

Low operating pressure of wells LA3 & LA6

The most serious problem observed during the initial operation of the plant was that the operating pressure of wells LA-3 and LA-6 became significantly lower that the design inlet pressure of the steam turbine. Subsequent well testing performed by GDA as part of this contract also showed that the wells are unable to sustain the operating pressure that the turbine was originally designed for. To address this problem, it was necessary to review the original turbine design and do some re-engineering to allow the turbine to operate at lower steam inlet pressures. After thorough review of the characteristics of the wells, a recommendation was made to remove the first two stages of the turbine blades, thereby enabling the turbine to operate with reduced inlet pressure. This measure of removing some of the stages (de-staging) would allow the wells to operate reliably, although at a slight reduction in power generated from the steam turbine.

The recommendation to remove the stages was also based on other practical issues. For example during the rehabilitation work, visual inspection of the first and second stages showed that they would have required major repairs or outright replacement with new components. The de-staging process is reversible and if the operating pressure of future new wells reaches and maintains the original design pressure, the removed stages can be reinstated.

Solid emission from wells:

Some of the production wells were reported as emitting solids into the fluid gathering system resulting in blockage of the piping and parts of the plant. Most of the wells only discharge solids during the initial opening; however, well LA8 tends to produce sand & debris even during normal operation. In order to resolve this problem, two solutions are proposed. The first is to design & implement an operational procedure that will ensure that wells are vented to atmospheric discharge vessels (silencers) during initial opening until the flow stabilizes and become clear of solids. The second solution is to install strainers on the wells that continuously discharge solids.

Mineral deposition:

Due to the reported blockage in some wells and the suspected decline in flow, detail investigation of the condition of the well bores was carried out using go-devil tool and sinker bars to determine the open diameters and current total depths of the wells. The sinker bar/go-devil logging in well LA-4 conclusively showed that the well has a major scale deposition with the greatest restriction near a depth of 1000 m. The sinker bar/go-devil logging in LA-8 discovered a major blockage of uncertain nature at a depth of 700 m. LA-3 had little or no loss of total depth but LA-6 had lost some total depth. It was determined that the thick scale recovered from go-devils in LA-4 would explain a large reduction in the output. The recovered fragments of scale from LA4, along with the depth and shape of the reduction in diameter, strongly suggest that this scale is carbonate scale that formed as a result of flashing of the liquid in the wellbore. A major blockage of uncertain nature was also observed at 1,461.7 m in LA-7. As this is a reinjection well, it is not known how this blockage will impact the well's ability to accept fluid. Well work-overs have been proposed for those wells with blockage.

3.2 Plant and steamfield related works

Rehabilitation of the steam turbine

The major repair work undertaken involved the work done to rectify the problems on the GCCU steam turbine. During inspection of the turbine rotor, in addition to the repairs defined in the rehabilitation contract, significant damage to the rotating blades, seal hub and shaft journal area were observed. Damages to the rotor shaft and bearing were also noted. Subsequently, a recommendation to repair the turbine blades and the hub was made to EEPCo.

There was heavy corrosion and deposits on parts of the rotor blades (Figure 2), with severe corrosion appearing on the first and second stage. There was shroud damage to all of the stages. Additionally, the interstage drains were clogged and filled with a hard deposit. The drains were cleared of the deposition and cleaned.

There was very little scale deposited on the first stage nozzles, where it normally is found. A soft scale was found in the first stage rotating blades and it was deposited along the outer section of the blades, near the shrouds. The scale was soft and easily removed and appeared to have been dry when deposited, rather than deposited by contaminated liquid. The deposited amount was enough to significantly affect the steam flow and turbine power output.

Figure 2 Corrosion of the turbine blades

A section of the rotor labyrinth steam seal appeared to have been damaged due to wear from contact with a heavy scale deposit or a foreign object (Figure 3). However, there was no corresponding wear on the mating stationary labyrinth seal.

Other than the aforementioned damage, the rest of the turbine appeared to be in reasonably good condition and the design and build quality was good.

Figure 3 Worn rotor labyrinth steam seal

Figure 4 Corroded shroud bands

The stationary labyrinth steam seals were generally in excellent condition. There was no sign of rubbing between the rotating blades and nozzle assemblies and no sign of rubbing at the blade shroud area.

Figure 5 Worn turbine rotor shaft

An investigation was conducted to decide whether it would be better to repair the rotor in Ethiopia or send it overseas. Several facilities in Addis Ababa were visited and the Ethiopian Airlines (EA) shop appeared to be an excellent and well-equipped facility and a strong candidate for a local repairs. However, the EA shop repairs damaged shafts by a plating process and the maximum thickness they could plate was 1 mm. Unfortunately, the scoring on the shaft was too deep to be repaired in their shop.

The decision to repair the shaft in Addis was further complicated because the rotor must be disassembled for repair, and drawings relating to or experience with this particular rotor design were not available. The needed turbine drawings were not provided as part of the original plant contract.

GDA's recommendation was that the rotor be shipped to Conhagen in Texas, USA, where identical turbines from other US geothermal plants are routinely repaired.

The steps in the rotor repair were described as follows: Cleaning and inspection using magnetic particle or other non-destructive examination methods, rotor disassembly, repair the shaft journal bearing area, repair or replace the damaged rotary steam seal section, repair turbine blades and shrouds as necessary, re-assemble rotor components and coupling in original locations, rebalance so that the final result meets or exceeds required specifications.

Wellhead valve repairs

The wellhead valves at Aluto had been in service ever since the wells were drilled and completed in the early 80's. Major problems observed included, severe corrosion of the valve stem (Figure 6), corrosion and in some instances jamming of the gate-segment assembly, erosion and wear of the body-seats, damage of the valve gland and bearings. Despite these problems, the valve bodies were in very good condition. It was decided that the most cost-effective solution was to procure valve spare parts and carry out maintenance of the valves in stead of buying new wellhead valves, which has a long lead times. Accordingly, sufficient parts to service most of the 10" and 2" wellhead valves at the project site were purchased and the maintenance was carried out. After completing repair, each valve was pressure tested (Figure 7) to the applicable pressure to ensure that the repair work was satisfactory. The reconditioned valves were subsequently installed on the geothermal wells.

Figurer 6 Corroded stem of a wellhead valve

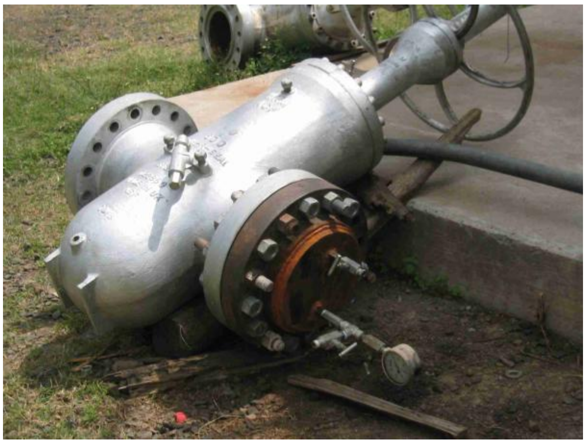

Figure 7 Hydrostatic pressure testing of reconditioned valve

Repairs to Heat Exchanger Tubes

The OEC was taken out of service in 1999 due to vaporizer tube leaks. EEPCo reported a total of twenty (20) leaking tubes.

The vessel is a shell and tube heat exchanger with approximately 1,641 tubes of welded 316L stainless steel and 20 mm (¾") OD by 0.035" wall thickness (20 gages) dimensions. The tube length is approximately 11.6 m (38').

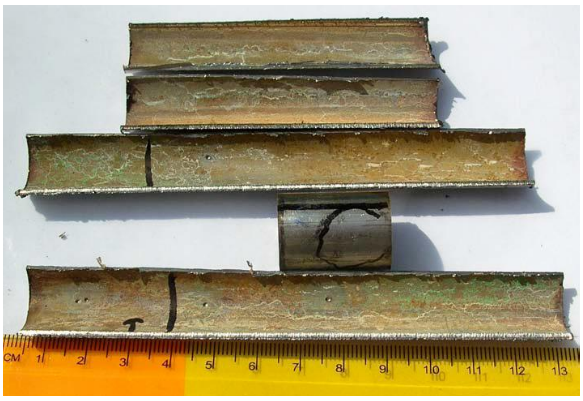

Figure 8 Pitting corrosion of vaporizer tubes

GDA was tasked with identifying the cause of the leaks, repairing existing leaks and, if possible, putting the unit into operation and making recommendations for a long-term solution.

A tube failure analysis was carried out by Jonas, Inc. (Jonas, Inc. laboratories, Wilmington, Delaware, USA) on two leaking tubes. The major finding of this analysis was that the root cause of the pitting was the use of wrong tubing material, 316L austenitic stainless steel, which seemed to be not suitable for the chemistry of the Aluto wells. It also found that the tube leaks were caused by tube ID pitting (Figure 8), which occurred during the initial service of the heat exchanger. There may be additional pitting due to six years of unprotected layup. The pitting was more concentrated at the bottom part of the tubes where there was a liquid layer of condensed steam. It was expected that pits were present on the ID of most of the heat exchanger tubes. Jonas concluded that, with the same composition of steam and operating conditions, the pitting will continue and the heat exchanger will be unusable within a few years and, therefore, total replacement of the tubes would be necessary.

PowerChem, of Minden, Nevada, USA, carried out a second analysis. PowerChem's final report provided a number of recommendations that related to operator training in order to improve the steam quality, testing and startup procedures, etc. as well as implementation of a corrosion mitigation treatment program. The practicality/feasibility of isolating (by plugging) the failed tubes and putting the unit into operation, as a temporary solution, was extensively investigated. However, successive pressure tests on the plugged tubes proved to be unsuccessful due to discovery of more leaky tubes after each pressure test. It was then decided that the failed tubes on the vaporizer and the first two passes of the preheater would be replaced with more corrosion resistant tube material – 2205 Duplex stainless steel.

Other Rehabilitation Works performed

Various additional tasks and reviews were carried out during the rehabilitation phase. A number of recommendations on well work-over, establishing a plant and resource monitoring program, staffing and training, and spare parts were submitted. Some of the major additional works performed include the following:

- Investigating the problems and putting the plant automation system (Programmable Logic Control) back into operation by supplying the necessary hardware and carrying out required software programming.
- Repairing the Fiber Optic communication link between the plant and the Adami Tulu substation by supplying additional Fiber Optic cable,
- Investigating the problem with the cooling tower fans and undertaking the necessary repair, including supply of parts and the proposal of long-term solutions, and
- Inspecting and reviewing the design of the 15 kV transmission line between the power plant and the substation and providing recommendations to enable reliable operation.

4. FUTURE WORK

A number of follow-on tasks are required to be implemented to complete the rehabilitation work and ensure long-term reliable operation of the plant and resource. Some of these follow-on tasks include:

- Work-over of wells which have blockage in the wellbore
- Implement chemical inhibition system for those wells with chemical deposition
- Implement resource (reservoir & geochemical) monitoring program and a plant performance monitoring program

5. CONCLUSION AND RECOMMENDATIONS

Geothermal energy can play an important role in the energy mix of Ethiopia. Geothermal power is capable of providing a base load to supplement the existing heavily hydro-based power generation system. Unlike hydro power plants, geothermal power also has the benefit of not being affected by drought patterns.

Based on the experience gained during the rehabilitation work, the following observations and recommendations can be made:

1. The Aluto plant is a relatively complex plant to operate and maintain when compared to back pressure or even condensing flash plants of similar size. When it is operating, it makes efficient use of the thermal energy from the Aluto resource. Due to its complexity, it requires oversight and maintenance by an experienced team of plant and resource specialists.
2. In order to expand the use of geothermal energy in Ethiopia, training of Ethiopian personnel in the various aspects of plant and wellfield operations and maintenance should be an ongoing process.
3. An experienced geoscientist, responsible for

the long-term operability of the wellfield, including resource monitoring, scaling monitoring and mitigation, and implementation of well work-over of the Aluto wellfield should either be hired or seconded to EEPCo from GSE.

4. Successful operation of a geothermal plant requires adequate and timely supply of tools, equipment and consumables, therefore a well-organized spare parts procurement and storage/retrieval system must be put in place.

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