MAINTENANCE OF OLKARIA 1 ADDITIONAL UNITS (AU) POWER PLANT, KENYA

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ABSTRACT

Operating a geothermal power plant is a continuous process where equipment has to be maintained for reliability. In 2015, Kenya, which is currently the eighth largest geothermal producer in the world, commissioned the 280MW geothermal expansion project. This project consists of two power plants which are Olkaria 1 Additional Units (AU) and Olkaria IV. Olkaria 1 AU has two generating sets each rated 75.26MWe. The plant started commercial operation in January 2015 and since then it has faced several maintenance issues ranging from corrosion, silica scaling, slug flow and erosion. These issues have affected plant efficiency thus decline in overall plant availability due to unwarranted stoppages considering that this is a base load plant. This paper will describe the operation of the Olkaria 1 AU geothermal power plant, maintenance issues and corrective actions undertaken since commercial operation. These include deflected main steam lines due to slug flow, cracked circulating water glass reinforced polyester pipe, clogged pressure and flow control valves and carryover causing scrubber faults. However, these issues have and are being quickly addressed in a view of reliably powering the country. This has been attributed to dedicated and skilled maintenance staff both at the steam field and power plant, redundancy of plant equipment and applying the planned maintenance concept in their activities.

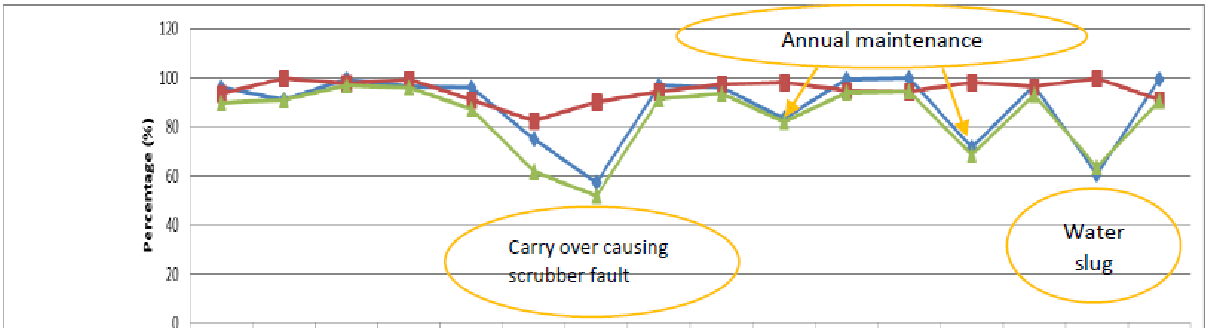
1. INTRODUCTION

Olkaria 1 AU is one of the newest geothermal installations in Kenya. It has two main units namely Unit 4 and Unit 5 with a total installed capacity of 140MW. The power plant was built in stages. Unit 4 was commissioned in October 2014 while Unit 5 in January 2015. Commercial operationalization of the plant began in January 2015 and since then staff operating and maintaining this power plant have ensured best engineering practices are followed. This power plant has various systems which include steam gathering, circulating water, waste water treatment, chemical dosing, service and potable water, HVAC, compressed air, firefighting, steam turbine and generator, electrical and power evacuation.

Figure 1: Olkaria 1 Additional Units aerial view

1.1 Problems encountered

Since commissioning, the plant has encountered maintenance issues ranging from corrosion, silica scaling, slug flow, discolouration and erosion. This is influenced by factors such as fluid chemistry, environment and weather. These issues have led to reduction in efficiency and thus decline in plant performance and availability as shown in Figure 2. For example, carry over from separators due to unreceptive hot reinjection Well no. 13 led to plant trips due to high condensate levels in the scrubber. This also contributed to water slug causing deflection of main steam line support structures.



	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April
Station Availability Factor	95.87	91.04	99.23	96.51	95.88	75.12	57.33	96.86	96.03	83.43	99.29	100	71.56	96.83	60.57	99.39
Station Utilisation Factor	93.44	99.76	97.53	99.34	90.77	82.56	90.03	94.13	97.42	98.24	94.74	94.54	98.26	96.27	100	91.03
Overall Plant Load Factor	89.58	90.81	96.79	96.11	87.03	62.02	51.62	91.18	93.55	81.96	94.06	94.54	68.51	93.22	63.56	90.48

Figure 2: Station availability factor

The geothermal fluid in the Olkaria reservoir is a complex mixture of salts of sulphates and carbonates which tends to continuously vary the geothermal water PH. The varying PH has varying effects with regard to corrosion. The geothermal plumes and hydrogen sulphide gas corrode outdoor structures because after oxidation, it is converted into Sulphuric acid which is very corrosive. Heavy downpour has altered the loose soil in Olkaria leading to siltation, runoff and erosion.

1.2 Scope of maintenance

The power plant and steam gathering systems are headed by 2 Chief Engineers who report to their respective managers. On a normal day, the plant is manned by a total of 27 staff. Out of these, 15 maintain the steam field and 10 maintain the power plant. The systems that are maintained are 2 double flow steam turbines, 16 cooling tower fans, 36 geothermal wells, several control valves and pumps and 30 kilometres steam pipelines. The team employ a blend of corrective and planned preventive maintenance. Annual inspection of the steam field and power plant components is conducted and was last undertaken in January 2016. This involved turbine and auxiliary equipment overhaul and steam line inspection and repairs.

2. THE GEOTHERMAL RESOURCE

Olkaria 1 AU is located in the Kenya Rift Valley, about 120km from Nairobi. It forms part of the Greater Olkaria geothermal field which is a major volcanic complex characterised by numerous rhyolitic domes (Axelsson. *et al., 2012)*. The geothermal fluid in the Olkaria reservoir is a complex mixture of salts of sulphates and carbonates. The power plant has 26 production wells which were drilled between March 2009 and March 2012 averaging 3000m in depth and enthalpies of 2300kJ/kg. The plant also utilizes 3 (three) 600m shallow depth cold reinjection wells and 7 (seven) hot reinjection wells ranging from 900m to 1700m.

3. COMMISSIONING OF THE POWER PLANT

The power plant, which was part of the 280MW geothermal power turnkey project, was commissioned by HE President Paul Kagame of the Republic of Rwanda in the presence of Kenya's President HE Uhuru Kenyatta on 19th February 2015. It was financed by a loan from Japan and was constructed by a consortium of Toyota Tsusho Corporation (Japan) and Hyundai Engineering (South Korea), and the two turbines supplied by Toshiba Corporation (Japan). Prior to handing over, performance and reliability tests were done with the guaranteed parameters as shown in Figure 3. These tests verified that the units can be operated in accordance with KenGens' dispatch requirements for a continuous period of 30 days without maintenance intervention. The reliability run tests also included 72 hours continuous operation at not less than 95% of the unit rated capacity.

Condition	Steam mass flow (Tonnes/ hour)	Net plant output (kW)	Net plant steam rate (kg/kWh)
Nominal Continuous Rating (NCR)	1064	143720	7.404

Figure 3: Olkaria 1AU commissioning guaranteed parameters

4. STEAM FLOW DIAGRAM

Saturated steam at 10 to 14 barg and 98% dryness is obtained from production wells. The mixture is separated at 10 barg in the separators and then flows through a pressure let down station. Any excess steam is vented via the vent station pressure control system that is designed to handle 1046 tonnes/hr. This station contains pressure control valves which perform adiabatic expansion of the saturated steam while maintaining an upstream steam field pressure of 9 to 10 bar and downstream pressure of 4.2 barg. This expansion converts steam from saturated to superheat. Since the turbine utilizes saturated steam, the steam is de-superheated using water to temperatures of about 152.8°C.

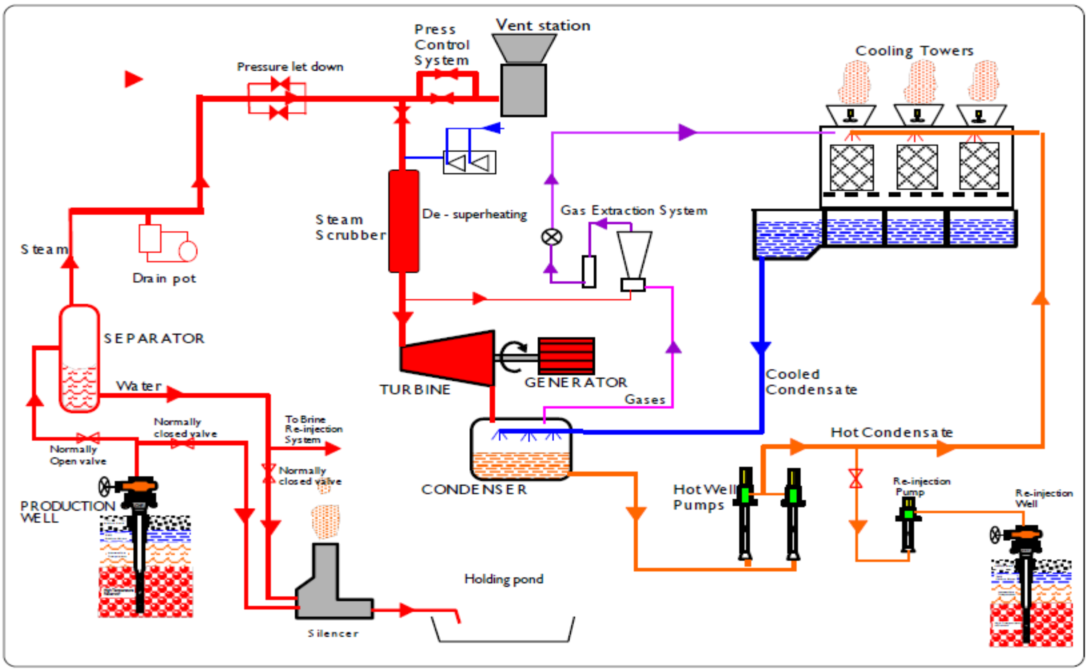


Figure 4: Power plant flow diagram

The steam is admitted through the scrubber where impurities are separated to meet the 90% turbine inlet condition while dryness is increased from 98% to 99.98%. For 99.8% dryness, sodium, silica and chloride are <1.0ppm while for 99.98% dryness, sodium, silica and chloride are <0.1ppm. TDS for both cases are <5.0ppm and <0.5ppm respectively.

The clean and purified steam is then admitted to the steam turbine at 4.2barg, 152.8°C and at a rate of 7.4kg/kWh. This steam is also provided for the gas removal system ejectors and the turbine gland seal system. The steam turbine exhaust is 40.13°C at 75mbara. Cooled condensate from the cooling tower at 23°C is utilized in the condenser thus resulting in a cooling range of 17°C. Excess hot or cold condensate is re-injected into the wells.

5. POWER PLANT COMPONENTS

The power plant components discussed include wells, steam field pipework, pressure let down station, vent valves and silencers**,** steam traps, scrubber, steam turbine nozzles, cooling towers, pipes and outdoor structures.

5.1 Wells

The power plant has 26 production wells which were drilled between March 2009 and March 2012 averaging 3000m in depth and high enthalpies of 2300kJ/kg. The plant also utilizes 3 (three) 600m shallow depth cold reinjection wells and 6 (six) hot reinjection wells ranging from 900m to 1700m. Currently, the wellhead pressures range between 10 to 14 barg as opposed to the pre–pressure let down station pressures of 6 to 9 barg. Maintenance of these wells is majorly done on master, working and side valves. To prevent catastrophic failures, they are stroked, greased and gland packings replaced.

5.2 Pressure let down station

Olkaria 1AU wells have high enthalpies of above 2300kJ/kg and were tapped into a very high silica environment. This posed a silica scaling problem when the geothermal fluid came to the surface and pressure drops occurred. To minimize this problem, KenGen installed a pressure let down station between 29th May and 14th June 2015 so as to operate the wells at high pressures. It was preferred because at the time, it was least cost intensive and would be used on a temporary basis as other options are considered in future.

Prior to installation of this station, the wellhead pressures ranged from 6 to 9 barg while the separation pressures were 5.5 barg to give a turbine inlet pressure of 4.2 barg. After installation, the wellhead pressures ranged between 10 to 14 barg while the separation pressures are 10 barg to give a turbine inlet pressure of 4.2 barg. The station has special pressure control valves that carry out adiabatic expansion of the steam and maintain a high upstream steam field pressure and the desired downstream pressure at the plant. Maintenance is mainly carried out on stuck pressure control valves which are Fisher and Rotork type.

Figure 5: Pressure control valves

5.3 Steam pipework

The steam pipework is 30 km long. Maintenance is carried out by a team of 20 Steam field staff. The steam pipe work contains gate valves, flow control valves, emergency dump valves, condensate drain ports and vents. So as to ensure continuous operation, weekly routine checks are carried out.

5.4 Vent station valves

The vent valves are ball butterfly (Fisher) type and are designed to handle a total of 1046 T/hr of steam. Maintenance at this station is mainly carried out on the valves, condensate drain ports and diffusers. The valves are stroked and calibrated while condensate drain ports and diffusers unblocked and cleaned. The Figure 6 below shows pictures of a clogged flow control valve and diffuser taken during the plant annual inspection in January this year.

Figure 6: Clogged vent valve and diffuser

5.5 Steam traps

Low point drains are provided on the main steam pipes for start-up operation and to prevent slug flow. Cleaning is done by the steam field maintenance team on weekly basis by the Steam field maintenance team.

5.6 Slug flow

Slug flow is intermittent flow caused by a moving liquid bubble mass being pushed by a gaseous mass. In March 2016, this phenomenon occurred in Unit 4 resulting in deflection of steam line support structures as shown in Figure 7. The damaged structures were repaired and reinforced. To avoid such scenarios in future, it was resolved that frequent monitoring of clogged steam drains must be undertaken so as to unblock them before starting up the plant.

Figure 7: Deflected main steam line supports

5.7 Scrubber

The steam scrubbers provide 99.98% dry steam to the turbine. They are cyclonic separator type and have less than 0.1 barg pressure drop at rated conditions. They are equipped with a waste condensate vessel where the condensate separated is collected temporarily before being discharged to the cooling tower through spargers. The discharge is enabled by drain valves. Carryover from the separators due to an unreceptive hot reinjection well led to frequent clogging of these drain valves thus initiating turbine trips due to high condensate levels in the scrubber. Scale pellets were cleaned from the drain valves. In November 2014 Unit 4 and Unit 5 scrubbers developed internal abnormal noises leading to cracks in the vortex tube and smoothing sleeve weld seam. This was considered a design failure which was rectified by the EPC contractor.

Figure 8: Steam scrubber and internal repairs

5.8 Steam turbine nozzles

This turbine is a tandem-compound single cylinder double flow exhaust type as shown in Figure 9. The rated power of one unit is 75.3MW at the conditions of 4.8 bar abs/150.3°C steam for IP steam and 1.14 bar abs/103.3°C steam for LP steam.

Figure 9: Steam turbine inspection

The turbine has supervisory and monitoring instruments for temperature, speed, eccentricity, differential expansion and vibration thus enhancing condition based monitoring and maintenance. The turbine also has lead ways which decreases the condensed steam in the turbine which wears the turbine blades. During commissioning steam pressure drops between the 1^{st} and 2^{nd} stage steam turbine nozzles were experienced leading to onsite nozzle clearance enlargement by Toshiba. At end of defect liability inspection, the turbine was disassembled and scaling found in the 1^{st} stage nozzles as shown in Figure 10. This was attributed to the unreceptive hot reinjection Well 13 leading to carry over from the separators into the plant. The scaling was cleaning and the turbine reassembled.

Figure 10: 1st stage stationary nozzle silica scaling

5.9 Cooling towers

Olkaria 1AU has two cooling towers. They are counter flow induced draft type with 8 cells per tower. The inlet water flow rate is 17520m³/h with a wet bulb temperature of 18°C including recirculation. Cooling tower water is regularly treated, generally with biocide and dispersants, to prevent the growth of harmful bacteria, minimize corrosion, and inhibit the build-up of scale on the fill. The plant uses condensate as make up water which can cause scaling. The internals are film fills designed for a maximum TSS <150ppm. During annual inspection, the films fills were disintegrated as there were many loose sheets, large holes in the pack randomly distributed throughout the cells due to failure of the adhesive that binds each individual sheet into blocks. The spray nozzles were clogged.

The nozzles and pipes were cleaned. The film packs used by the EPC contractor were substandard and will be replaced in due course.

Figure 11: Deposit of foreign material in the cooling tower GRP pipe

5.10 Pipes

Olkaria 1AU uses glass reinforced plastics (GRP) in the outdoor circulating water system. GRP is preferred because it is high corrosion and abrasion resistant, has a leak tight system for maximum loss free flow and also is cheaper compared to stainless steel. Olkaria generally has soils with near zero cohesion. This normally requires stricter considerations when compacting or an operation environment where the moisture content of the pipe surrounding is controlled and monitored on continuous basis. The 2000mm GRP return pipe from Unit 5 cooling tower to condenser developed cracks which was noted after water from a faulty scrubber drain sipped into the hotwell pit area.

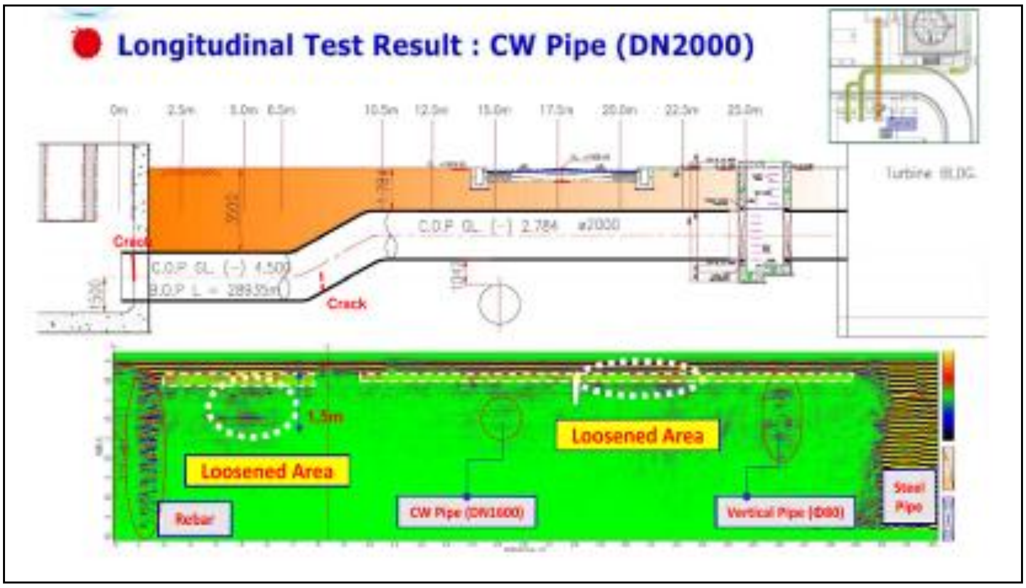


Figure 22: GRP longitudinal test results

The GRP pipe sand bedding was washed out causing pipe differential settlement. To ascertain the effect of the leakage on the general area, Geophysical surveys, ground penetration and electrical resistivity tests were done as shown in Figure 12. These tests confirmed poor consolidation as a result of the water ingress and grout injection was the available remedy for reinforcement of the sand bedding of pipe and the general area. This was done using low pressurized mortar. KenGen is considering encasing the GRP pipes in concrete and in other areas, using stainless steel pipes in ducts.

5.11 Outdoor steel structures

There is a general deterioration and discolouration of majority of the plant items around the cooling tower such as brackets, piping, U-bolts, fasteners, embedded plates and earthing connections. Care should be taken in selecting grades of stainless steel to avoid galvanic corrosion when in contact with carbon steel. The defective items are currently being replaced with grades 316 SS stainless steel.

6. EFFECTIVE OPERATION AND MAINTENANCE ENABLERS

For the effective operation and maintenance of Olkaria 1 AU, the power plant was designed and constructed in a manner that facilitates routine, periodic and forced outage maintenance. This includes adequate provision of facilities such as equipment withdrawal spaces, access ladders, stairs and platform, crane access and lifting point and laydown areas. Isolating facilities are also provided to allow the safe and efficient maintenance of all items of the power plant.

For the cooling tower system, water is regularly treated, generally with biocide and dispersants, to prevent the growth of harmful bacteria, minimize corrosion, and inhibit the build-up of scale on the fill. The distributed control system (DCS) is used by operators in controlling and monitoring field equipment. SAP computerised maintenance management tool is used to help manage maintenance tasks.

The maintenance team in the power plant procured turbine maintenance tools as they were not part of the mandatory spares provided by the EPC contractor such as hydraulic wrenches and jacks. These tools have necessitated efficient turbine overhaul. So as to have a skilled workforce, the EPC contractor operated the plant for six months prior to handover to KenGen thus offering on the job training to all power plant staff.

7. CONCLUSIONS

Olkaria 1 AU has been in commercial operation for the past 1½ years. It has faced maintenance issues ranging from corrosion, silica scaling, slug flow and erosion which have affected efficiency thus reducing plant availability. However, these issues have and are being quickly addressed in a view of reliably powering the country. This has been attributed to dedicated and skilled maintenance staff both at the steam field and power plant, redundancy of plant equipment and applying the planned maintenance concept in their activities.

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Axelsson, G. et al: Consultancy services for geothermal resource optimization study of the greater Olkaria geothermal field, *Draft Report*: Feasibility of additional units, (2012).