STEAM PURITY CHALLENGES IN GEOTHERMAL POWER PLANTS: A CASE OF OLKARIA IAU POWER PLANT

Edwin Wafula[1] and Melissa Nkapiani[1]

[1]KenGen, P.O Box 785-20117, Naivasha, Kenya

ewwafula@kengen.co.ke

Keywords: *Olkaria, geothermal, steam, purity.*

ABSTRACT

Steam purity refers to the amount of contaminants (solids, liquids or gases) that are present in steam, as opposed to steam quality which is a measure of the amount of moisture in steam. Steam purity is determined by a combination of factors including the chemistry of the produced geothermal fluid, the separation pressure(s), mechanical carry-over rate during the separation process and the effectiveness of passive and active steam washing processes. The Olkaria geothermal project currently has four conventional power plants; Olkaria I, Olkaria II, Olkaria IAU and Olkaria IV and wellhead units all generating a total of 533.3 MW. The construction of the 140 MW Olkaria V power plant is on course after its ground breaking in April, 2017.

The Olkaria I Additional Unit (Olkaria 1AU) power plant was commissioned in December 2014. The power plant hosts two condensing turbines each generating 70 MW of electricity. Sometime between February and March of 2015, numerous trips began affecting the Olkaria IAU power plant, with subsequent signs of wet steam and brine carry over being noticed in the steam lines. The first drain port analysis program for Olkaria I AU Unit IV and V was conducted between 27th February and 3rd March after water was observed in the steam line. Sampling was carried out for the drain ports from separator stations SE1, SE2, SE3, SN3, OW 32 and OW 35 to the scrubber at the power plant. A second drain port sampling and analysis program was initiated from 20th June to 21st June 2015. Also included in the sampling program were drain port samples from OW 727 separator station that supplies the Olkaria II power plant. The sampled condensate drain ports for SE1, SE2, SE3, SN3, OW 32 and OW 35 reported high concentrations of dissolved components. From the analysis, there was a carry- over of separated water into the steam phase. A root cause analysis was done to determine the cause of this brine carryover. A comparison was done with the purity tests carried out at the Eburru wellhead plant between 2012 and 2016 and in 2017.

1. INTRODUCTION

1.1 Background

Steam purity refers to the amount of contaminants (solids, liquids or gases) that are present in steam, as opposed to steam quality which is a measure of the amount of moisture in steam. Steam purity is determined by a combination of factors including the chemistry of the produced geothermal fluid, the separation pressure(s), mechanical carry-over rate during the separation process and the effectiveness of passive and active steam washing processes. Steam purity can be a significant factor in maintaining plant reliability, availability and efficiency in geothermal power plants. Poor steam purity and quality can result in steam turbine and steam handling equipment damage from both erosion and corrosion. This can lead to unexpected plant outages and expensive repairs. Accurate monitoring of steam purity is therefore essential to understand the risk and mitigation of steam path damage due to poor steam purity in a particular plant.

1.2 Olkaria setting

The Olkaria geothermal project currently has four power plants; Olkaria I, Olkaria II, Olkaria IAU, Olkaria IV and wellhead units all generating a total of 533.3 MW. The power plants are single flash systems being supplied with steam from production wells located in the Olkaria East, Olkaria North East and Olkaria domes fields. The Olkaria geothermal system is a two phase system and steam to the turbines is obtained after separation from cyclone separators. The Olkaria 1AU power plant was commissioned in December 2014. The power plant hosts two condensing turbines each generating 70 MW of electricity. As with many geothermal power plants, the Olkaria IAU plant has monitoring mechanisms to ensure that the quality of steam is good. The Olkaria power plants have digital provisions for monitoring impurities in steam as well as physical sampling at specified points. Olkaria IAU steam line is supplied with steam from the Olkaria East field, controlled by around six separator stations. These are labelled SE1, SE2, SE3, SN3, OW 32 and OW 35. With the exception of the latter two, the other separator stations are common stations and receive two phase fluids from at least four production wells each. The steam lines delivering steam from the separator stations have drain ports along the line to get rid of steam condensate that occurs along the steam line. The first sets of the drain ports near the separator station are the first line of defense against water (brine) carry over and they should remove this carry over such that at the drains ports near the power plant, only steam condensate with no dissolved components is obtained. Sometime between February and March 2015, numerous trips began affecting the Olkaria IAU power plant, with subsequent signs of wet steam and possibilities of brine carry over being noticed in the steam lines. The wetness became abundant, so much so that the scrubber tank had to be emptied periodically. This moist steam and brine laded steam lines brought operational challenges to this power plant. A geochemical assessment was therefore necessary to establish the steam purity and quality as well as the source of the brine carryover.

1.3 Factors affecting steam purity

Richardson et. al. (2013) have discussed several factors that might affect steam purity in geothermal power plants. One of the major factors that influences the construction of geothermal power plants is the chemistry of the geothermal fluid. Characteristics of the geothermal fluid such as the pH, dissolved solutes like chloride and silica and the non-condensable gases determine the design of the plants. Very acidic fluids or very high levels of non-condensable gases may cause the operation of these plants to be difficult.

Hjartarson (2012) has reported problems of chloride pitting in geothermal plants.

The other aspect that could influence the quality of steam is the separator efficiency. The cyclone separator, the kind of which is used in Olkaria is designed to be about 99.9 % efficient. This is to ensure that there is near complete separation of brine and steam from two phase fluids. If this does not happen, then there is bound to be carry-over of liquid into the steam line and subsequent entry into the turbines. The non-volatile components in the brine like chloride will corrode and deposit in turbine blades causing a lot of inefficiency. Most power plants operate with steam separators located at several locations far away from the generator house. This is the case in Olkaria. One of the things that happens in these conditions is the condensation of steam that happens along the steam lines. The longer the steam lines are, the more condensation is expected. Condensate drain ports are usually constructed along several sections of the steam pipes to drain way any excessive condensate. If this condensate drain systems are not efficient, then it's expected that some steam quality issues might develop.

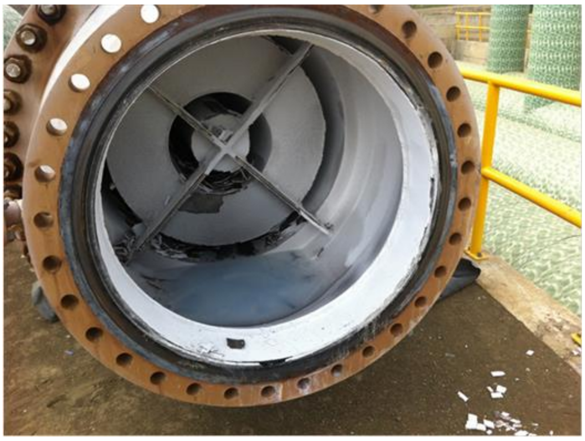

Figure 1: Scaling and brine carryover at Olkaria 1AU Pressure let down station silencer.

1.3 Impacts of steam purity

One of the notable impacts of poor steam quality and purity is the deposition that occurs either within the steam line or in turbine parts and blades. Mechanical blockage can also occur as a result of this deposition. Deposits could cause blockages at sensitive locations usually with severe consequences. For example, even small deposits on the stem of a turbine check valve can interfere with its function. In the event of a turbine trip, a malfunctioning check valve may lead to continued steam flow, an over speed event, and destruction of the turbine. Also, deposits on stationary parts, if thick and strong enough, may impede blade movement, presenting a particular risk of mechanical damage to small blades.

The presence of non-volatile components like chloride, carryover of low pH fluid and high moisture content in steam have been known to cause serious corrosion problems in geothermal power plants. In most cases Corrosion fatigue and Stress corrosion cracking cause extensive pitting of blades leads to significant loss of stage efficiency or, in extreme cases, weaken component integrity to the point of failure. Pitting and localized corrosion are unlikely to originate during turbine operation due to the absence of oxygen in the liquid films on the turbine surfaces during operation. Rather, pitting results from corrosive deposits absorbing moist air during turbine shutdown. Corrosion Fatigue and Stress Corrosion Cracking of turbine components have been consistently identified among the main causes of turbine unavailability. IAPWS, (2013).

2. METHODOLOGY

One of the methods that have been applied in the improvement of steam purity and quality is the use of moisture removal systems. These include condensate drain ports, demisters and scrubbers. The Olkaria IAU has condensate drain ports distributed along the steam pipelines. Once the suspected case of brine carry over or lack thereof was noticed, the first action was to confirm that the drain ports were in good working conditions. The drain ports are designed such that once an overflow is sensed within the pipeline, an opening mechanism is triggered and the excess condensate is drained off. However, in cases where there is just more than the condensate, then this ports can be overwhelmed and water will find itself to the generating unit. The first drain port analysis program for Olkaria I AU Unit IV and V was conducted between 27th Feb and 3rd March after water was observed in the steam line. Sampling was carried out for the drain ports from separator stations SE1, SE2, SE3, SN3, OW 32 and OW 35 along the steam line towards the scrubber at the power plant. Subsequently, following installation of pressure let down station at Olkaria 1AU power plant, there were signs of scaling at the pressure let down station. There was therefore need for an evaluation of the steam purity from the various separator stations delivering steam to the plant. A second drain port sampling and analysis program was initiated between 20th June and 21st June 2015. Also included in the sampling were drain port samples from OW 727 separator station in Olkaria II power plant. These were collected to serve as control points for Olkaria 1AU evaluation. Sampling of the drain ports was done based on procedures described by SKM, (2003). The diagram below indicates a general layout of the condensate drain ports relative to the position of the cyclone separator stations and the scrubber.

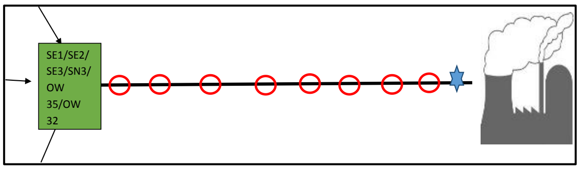

Figure 2: General layout of the condensate drain ports

The drain ports samples were analyzed for pH, TDS, Chloride, Silica and sodium using methods described by Pang and Armansson (2006) for analyzing low concentration of chloride and silica using a UV-Vis spectrophotometer and Sodium using the flame photometer. Additional analysis was done according to standard methods for geothermal fluid analysis as described by Armansson and Ólafsson (2000). The concentrations were reported in mg/kg in time series plots to see how the concentrations varied with time. A total of 54 drain ports were sampled over this period. The analysis was compared against the standard steam purity requirements from Power engineers, (2014) shown in table 1 below.

Table 1: Steam Purity Standards

Analyte	Standard steam inlet purity recommendation	Standard steam inlet purity limit requirement
Na	<0.1	<1
Fe	<0.1	<1
Cl	<0.1	<1
SiO_2	<0.1	<1
pH	>5.5	>5.5
Steam wetness	<0.01%	<0.1%

3. RESULTS AND DISCUSSIONS

This study presents the results of the condensate drain port sampling and analysis over the period where signs of brine carry over was noticed. The concentration of dissolved constituents in the drain ports samples is the best indicator of steam purity. For an ideal steam cleaning mechanism, the drain ports near the separator should indicate high concentration of dissolved components if carry- over from the separator exists. The concentration of these dissolved solutes should decline between the production separator and the power plant inlet as any brine carryover and steam condensate along the steam line is removed by the drain ports SKM, (2003). The concentrations of SiO_2 and sodium were monitored to see how that changed from port to port. It's expected that steam condensate is very low in this species, at least according to theory, and that any anomalously high concentrations of these parameters will be due to brine incursion into the steam line after separation.

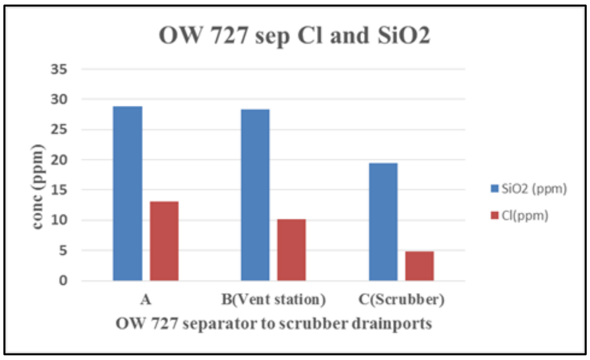

Figure 3: OW 727 Chloride and silica concentrations

The figure 3 indicates the results as observed in the drain ports for OW 727 separator station. Chloride and silica concentration for the drain ports samples are observed to decline as the steam approaches the turbine inlet as indicated in figure 3 above. The Total dissolved solutes and the reported pH values also decline as the steam approaches the power plant. The Cl is less than 5ppm as the steam approaches the scrubber unit, this showing a functional cleaning mechanism and steam that is within recommended standards.

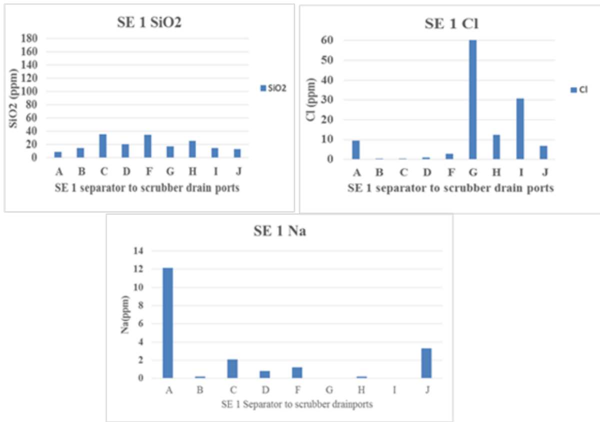

Figure 4: SiO_2, Cl and Na concentrations in drain ports from SE1

Figure 4 above shows the concentration of Silica, chloride and Sodium for drain ports samples collected along SE 1 Separator station. The sodium concentration declines from the first drain port towards the scrubber, from an initial concentration of 12.14 ppm to a value of 3.29 ppm. The Cl and silica concentrations do not show a general trend although the Chloride concentrations are relatively low. The Chloride concentrations from the previous report generally compare to the current values, but still the concentrations are above the recommended limits. Based on the sodium concentrations of < 1ppm, the SE1 separator has minimal carryover of brine.

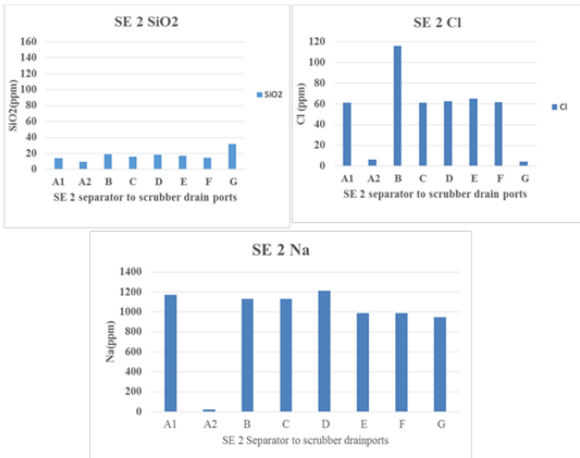

Figure 5: SiO_2, Cl and Na concentrations in drain ports from SE2

Figure 5 above shows the chloride, silica and sodium concentration for drain port samples from SE 2 separator station towards the power plant. The sodium concentrations in the drain ports samples are anomalously high with values of about 900 to 1200 ppm. The chloride concentrations are also high reporting values of up to 120 ppm. Such anomalously high values could be as a result of a lot of brine carryover from the production separator. From the analysis, there is a carry- over of separated water into the steam phase. The reason could be that steam separation is not 99.9% efficient and that the cleaning mechanism of the drain port is also inefficient, such that even the drain ports near the scrubber are registering concentrations >1ppm recommended industry standard.

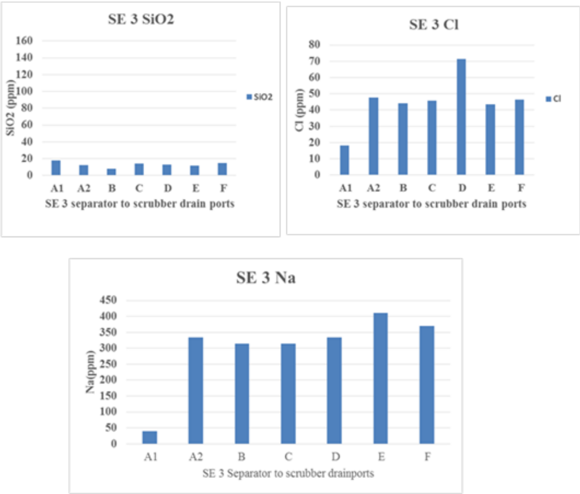

Figure 6: SiO_2**, Cl and Na concentrations from drain ports from SE3**

Figure 6 shows the concentration of silica, chloride and sodium for drain ports along SE 3 separator station. The sodium concentrations are also high as reported for SE2 separator station with values ranging between 300 to 400 ppm. The chloride concentrations are also considerably high with values of up to 70 ppm. This is indicative of brine carry over from the separator station.

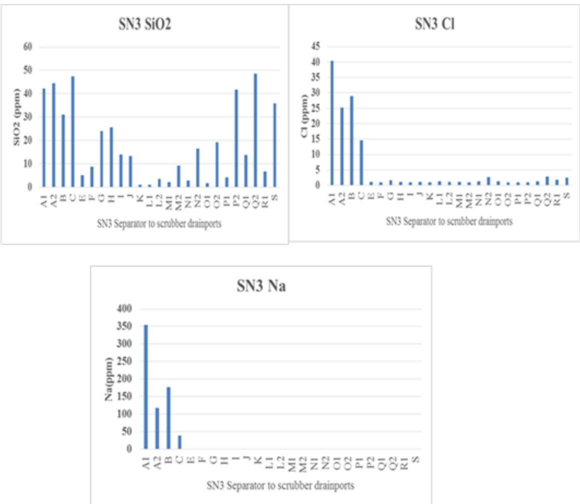

Figure 7: SiO_2**, Cl and Na concentrations in drain ports from SN3**

Figure 7 shows the concentration of chloride, silica and sodium for drain ports samples along SN3 separator station. The Sodium and chloride concentration are high in the first drain ports but decline as they approach the scrubber. The first drain port has a value of 40 ppm and 350 ppm and decline to values of 2.45 and 0.2 ppm for Cl and Na respectively at the last drain port. This compares with expected drain port cleaning mechanism as observed in the control data from OW 727 separator station. Therefore the drain port cleaning mechanism has been able to mitigate against the moisture carry over from the production separator.

Steam quality monitoring in Eburru was carried out once a week from late 2012 to August 2016. Steam quality monitoring during this period indicated a carryover of water into the turbine. The plant was then shut due to frequent trips and corrosion at the turbine blades. The graphs below show the concentration of SiO_2 and Cl in steam condensate samples measured over time from late 2012 to August 2016. (Kamunya, 2016).

Figure 8: Turbine Corrosion in Eburru Plant

According to Kamunya, 2016, for the most part of this period, the concentrations of silica and Chloride was below 1ppm. There were times the concentrations were above acceptable limits reporting values of > 1ppm. This necessitated a turbine blade replacement as well as replacement of the separator with a bigger sized separator.

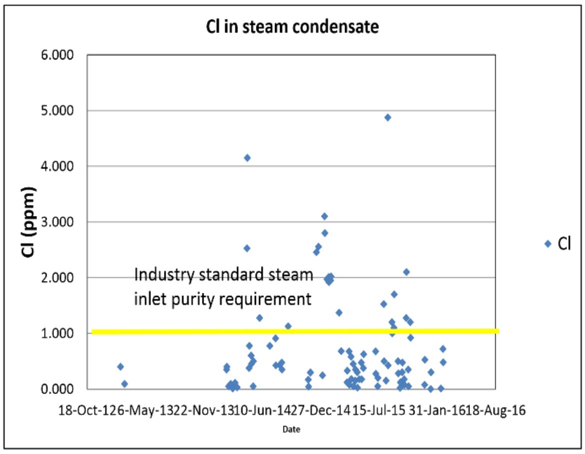

Figure 9: Cl in condensate from Eburru strainer sample

Steam quality monitoring was then done to assess the efficiency of the new separator system. Three sets of condensate drain ports samples and steam condensate samples were obtained on 26th July 2017 on an hour interval and samples obtained analysed for pH, Cl and SiO_2.

Figure 10 and 11 below show the values of Chloride and silica measured in the samples from the condensate drain ports close to the separator (CDP 1) to the steam condensate (strainer) point.

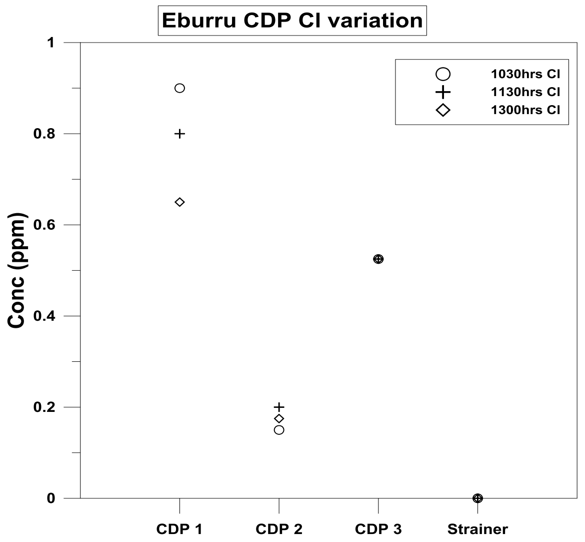

Figure 10: Chloride concentration in CDP samples from Eburru

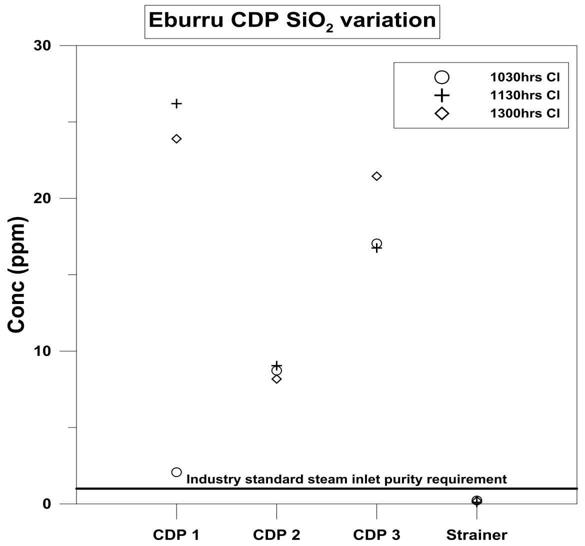

Figure 11: SiO_2 concentration in CDP samples from Eburru

Chloride concentrations show a general decline from the first drain ports towards the turbine inlet (strainer). The first condensate drain port had a concentration of 0.9 ppm for Cl and 26.2 ppm for silica. These concentrations then decline to 0 ppm and 0.225ppm for Cl and SiO_2 at the strainer point. The Cl concentration for CDP 1, 2, 3 and strainer point meet the set industry standard steam purity requirement. However, the SiO_2 values for CDP 1, 2 and 3 record values above set standard of 1 ppm. For all the three set of samples, the Cl and SiO_2 concentrations at the strainer point meet the industry standard steam purity requirement for condensing turbines. Figure 12 and 13 below show impact of steam purity on plant parts, with silica deposits in the turbine blades and steam valve affecting the efficiency of the plant.

Figure 12: Turbine blades with silica deposits on nozzles from Olkaria II

Figure 13: Steam valve with silica scales

4. CONCLUSION

Steam purity refers to the amount of contaminants (solids, liquids or gases) that are present in steam, as opposed to steam quality which is a measure of the amount of moisture in steam. Poor steam purity and quality can result in steam turbine and steam handling equipment damage from both erosion and a variety of corrosion mechanisms which can lead to unexpected plant outages and expensive repairs. Sometime between February and March 2015, numerous trips began affecting the Olkaria IAU power plant, with subsequent signs of wet steam and possibilities of brine carry over being noticed in the steam lines. Sampling and analysis of drain ports from separator stations SE1, SE2, SE3, SN3, OW 32 and OW 35 was done to confirm the concentrations of SiO_2, Cl and Na as indicators of brine carry over. The sampled condensate drain ports for SE1, SE2, SE3, SN3, OW 32 and OW 35 steam pipeline network to power station interface reported high concentrations of dissolved components. From the analysis, there was a carry-over of separated water into the steam phase. After isolation of the separators and root cause analysis, the carryover had arisen from physical blockage of one of the separator stations by debris from a damaged well. This was isolated and resolved.

ACKNOWLEDGEMENTS

The authors would like to thank the staff of Olkaria geochemistry Laboratory for their participation in filed sampling and laboratory analysis. We would also like to thank the management of the Kenya Electricity Generating Company (KenGen) for allowing us to publish this paper.

REFERENCES

Ármansson, H., and Ólafsson, M.: Collection of geothermal fluids for chemical analysis. ÍSOR – Iceland

GeoSurvey, Reykjavík, report ISOR-2006/101, 17 pp. (2000)

Hjartarson, S., Saevarsdottir, G., Palsson, H., Ingason, K., Palsson, B., Harvey, W.: Utilization of chloride bearing superheated steam. Proc. 37th Workshop on Geothermal Reservoir Engineering, Stanford University, California, USA (2012)

IAPWS: Technical guidance document; steam purity for turbine operation (2013)

Richardson, I., Addison, S. and Thompson, G.: steam purity considerations in geothermal power generation. Research Gate. Presented at the New Zealand geothermal workshop (2013)

SKM: Olkaria II geothermal power station steam field manual (2003).

Pang Z., and Ármansson, H. (editors): Analytical procedures and quality assurance for geothermal water chemistry. UNU-GTP, Iceland (2006).

Power Engineers: Olkaria I condensate sampling Report (2014).

Kamunya, K.M.: Eburru power station steam quality monitoring. Kenya Electricity Generating Company Ltd., internal report. (2016)