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Steam Purity Challenges in Geothermal Power Plants: A Case Study of Olkaria IAU

Melissa Nailantei Nkapiani

Kenya Electricity Generating Company (KENGEN),

P.O. Box 785, Naivasha- Kenya

mnkapiani@kengen.co.ke

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ABSTRACT

Steam chemistry in geothermal power plants is a product of the chemistry of the fluid that is extracted from the geothermal reservoir for use in the power plant. The fluid chemistry can vary significantly from field to field, and also between wells in the same field. It can also change over time within the same well as fluid is extracted. The differences in fluid chemistry can result in significant changes in steam quality especially due to moisture carry over. It is therefore necessary that steam quality monitoring is done on a continuous basis.

Olkaria geothermal project currently has four power plants; Olkaria I, Olkaria II, Olkaria IAU and Olkaria IV all generating a total of 430MWe. Sometime in 2016, following installation of the pressure let down station, numerous trips began affecting Olkaria IAU power plant, with subsequent signs of wet steam and possibilities of brine carry over being noticed in the steam lines. Steam condensate samples reported high concentrations of dissolved chloride and silica. Condensate drain ports sampling and analysis program was carried out from separator stations SE1, SE2 and SE3 along the steam line towards the scrubber at the power plant, to ascertain the root cause. The sampled condensate drain ports reported high concentrations of dissolved chemical components in the steam line from SE1 and SE3 separator stations indicating carry over of separated water to the steam phase.

Further analysis of the steam gathering system indicated pressure build up at OW 13 hot reinjection well serving SE1 and SE3 separator stations. The well has since been quenched to lower wellhead pressure and allow for disposal of separated brine.

1. Introduction

KenGen owns and operates four conventional geothermal power plants and fifteen wellhead units that generate about 533 MWe. All the geothermal power plants are the single flash condensing type with an evaporative cooling system. Steam purity is an important aspect for direct steam and flash plants as the geothermal steam interacts with the steam turbine directly. Geothermal power plants design recommends steam purity of 99.90% so as to prevent damage to power plant components during operation, Richardson et al., (2013). Contaminants can however be present in the steam, affecting its overall quality. Sources of contaminants in the steam includes brine carry over from steam separators and volatility of chemical components dissolved in the geothermal fluid, IAPWS, (2013). Contaminants can be found in both saturated and supersaturated steam. The most vulnerable components in the steam path are mostly areas where expansion and cooling of the steam occurs. The negative effects of steam impurities on the power plants components is pitting, corrosion fatigue and stress corrosion cracking. Richardson et al., (2013)

Steam quality therefore, is a significant factor in maintaining plant reliability, availability and efficiency in geothermal power plants. Continuous monitoring of steam purity is therefore essential in maintaining the power plant operation and to detect changes in steam purity that need intervention.

In the Olkaria geothermal project, Steam quality monitoring is done continuously for all the power plants. Steam condensate samples are collected daily from all the plants and chemical analysis done in the geochemistry laboratory. The parameters monitored include conductivity, total dissolved solids, pH, chloride and silica.

This report assesses the performance of the Olkaria IAU power plant in relation to steam chemistry.

2. Contaminants affecting Steam Purity in Geothermal Plants

Steam chemistry in geothermal power plants is a product of the fluid that is extracted from the geothermal reservoir for use in the power plant. The fluid chemistry can vary significantly from field to field, and also between wells in the same field. Fluid chemistry can also change over time within the same well as fluid is extracted. The differences in fluid chemistry can result in significant changes in steam quality mainly due to moisture carryover. Richardson et al., (2013). It is therefore necessary that steam quality monitoring is done on a continuous basis.

Contaminants found in geothermal steam include Silica, Boron, Chloride, Sodium, Carbon Dioxide, Hydrogen Sulphide and Hydrogen. Among these, Silica, Chloride and Hydrogen Sulphide pose the highest risk to geothermal plants according to Richardson et al., (2013). The presence of these contaminants in steam is dependent on separator efficiency and the volatility of the individual contaminant. Poor separator efficiency may lead to brine carry over; that is, droplets of brine can be carried into the steam after separation. The semi volatile contaminants can be present in the steam even with high separator efficiency. Silica and chloride are subject to volatile transport and may be present in steam with or without brine carry over. Silica present in steam may deposit in high pressure nozzles in the turbine, reducing turbine blade efficiency. Silica deposited in blades can also be dislodged causing solid particle erosion in the process. Chloride in steam causes pitting corrosion and stress corrosion cracking in the wet stages of the geothermal power plant. Paglianti et al., (1996). Sodium is not subject to volatility like silica or chloride. Therefore its presence in steam could indicate brine carry over at the separator station. Sodium can combine with chloride ion and hydroxide ion to form caustic contaminants or deposition of chloride salt. Sodium chloride can dissociate into Na^+ and Cl^- ions and these two ions can recombine with OH^- and H^+ to form NaOH and HCl respectively. HCl causes stress cracking of carbon steel.

Hydrogen sulphide and carbon dioxide are gases forming part of the non-condensable gases in the steam and their extraction from the system can be difficult. Carbon dioxide poses design and operational challenge as this forms part of the non-condensable gases that needs to be ejected from the condenser during the operation of the power plant. Hydrogen sulphide however in the presence of moisture can lead to corrosion of steel. Trofimov et al., (1997). The set industry standard allowable concentrations for some of these contaminants are shown in Table 1 below.

TABLE 1. Recommended industry standard for steam purity of condensing turbines

Items		Recommended values	Limit values
Steam wetness		≦ 0.01 %	≦ 0.1 %
Total dissolved solids	(TDS)	≦ 0.5 ppm	≦ 5 ppm
pH	(at 25°C)	≧ 5.5	≧ 5.0
Chloride ions	(Cl^-)	≦ 0.1 ppm	≦ 1 ppm
Sulfate ions	(SO_4^{2-})	≦ 0.1 ppm	≦ 1 ppm
Sulfide ions	(S^{2-})	≦ 0.1 ppm	≦ 1 ppm
Carbonate ions	(CO_3^{2-})	≦ 0.1 ppm	≦ 1 ppm
Sodium ions	(Na^+)	≦ 0.1 ppm	≦ 1 ppm
Potassium ions	(K^+)	≦ 0.1 ppm	≦ 1 ppm
Calcium ions	(Ca^{2+})	≦ 0.1 ppm	≦ 1 ppm
Fluoride ions	(F^-)	≦ 0.01 ppm	≦ 0.1 ppm
Arsenic	(As)	≦ 0.1 ppm	≦ 1 ppm
Ammonia	(NH_3)	≦ 0.1 ppm	≦ 1 ppm
Silica	(SiO_2)	≦ 0.1 ppm	≦ 1 ppm
Total Iron	(Fe)	≦ 0.1 ppm	≦ 1 ppm
Oxygen	(O_2)	≦ 0.01 ppm	≦ 0.1 ppm

Source Power engineers, (2014)

3. Steam Quality Monitoring

3.1 Olkaria IAU geothermal power plant

Olkaria 1AU power plant was commissioned in December 2014. The power plant hosts two condensing turbines each generating 70 MW. The steam turbines are designed to take pure saturated steam to generate power and therefore high separation efficiency is necessary. The power plant gets steam from 20 production wells located in the East field of the greater Olkaria geothermal area. Cyclone separator stations namely OW 35A, OW 718, OW 32, SE1, SE2, SE3 and SN3 as shown in Figure 1, separate steam from water at designed separation pressures of between 10 to 11 bar. The location of the separator stations is such that it can serve groups of wells that are near to each other.

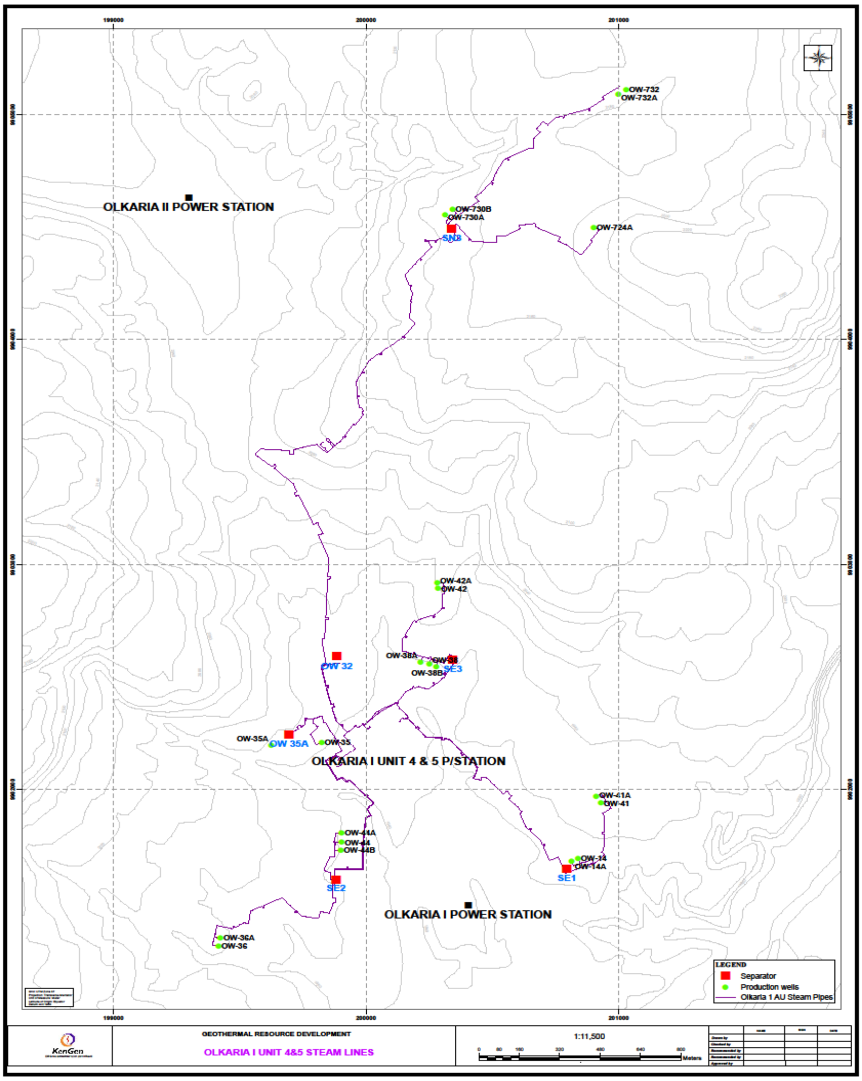
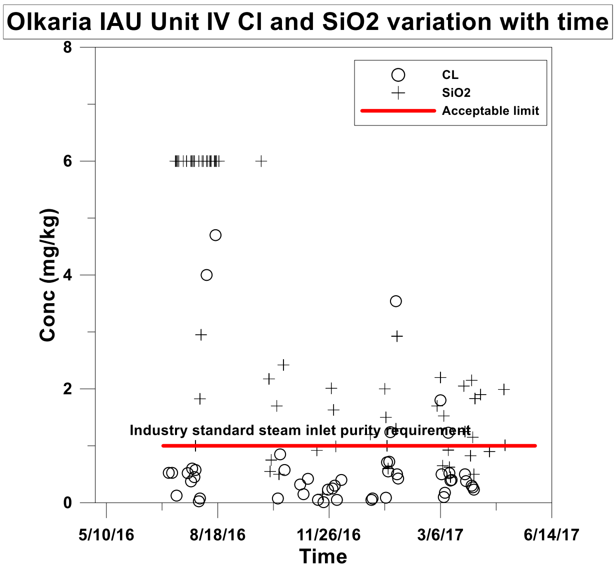


Figure 1: Steam gathering layout for Olkaria 1AU

Two stage steam washing has been done in Olkaria IAU steamline to minimize risks of turbine damage resulting from volatile transport of contaminants. Steam quality monitoring is done as a continuous process to evaluate the quality of the steam to prevent possible turbine damage.

The steam inlet to Unit IV and Unit V turbines does not meet the recommended industrial standard of steam purity as depicted in figure 2 and 3 below. Unit IV has reported chloride concentrations of < 1 mg/kg but high silica values of more than 5 mg/kg. Unit V has predominantly registered high concentrations of chloride and silica which could be indicative of brine carry over from separator stations serving this unit.

Olkaria 1AU power plant operators have also observed increased water levels at Unit IV and V scrubbers. This then necessitated drain port sampling and analysis to ascertain the source of the carry over.



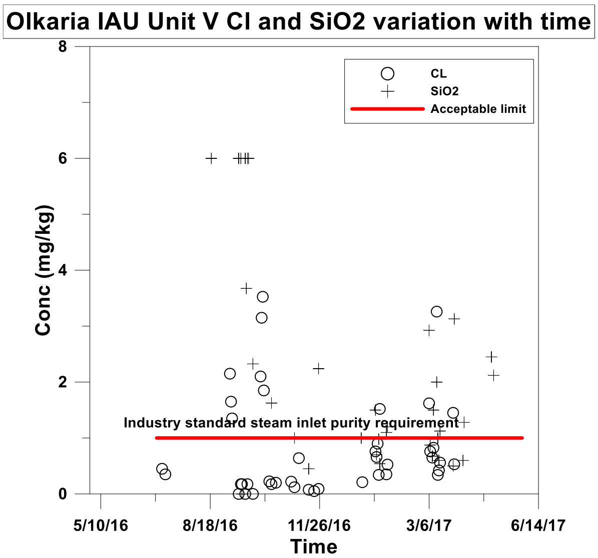


Figure 2: Olkaria IAU Unit Iv and V steam condensate Cl and SiO2 variation with time

3.2 Olkaria IAU condensate drain port sampling and analysis

In the ideal case, 100% steam separation should occur at the separator station. However this may not be the case and sometimes traces of brine can be carried over into the steam. The steam lines delivering steam from the separator stations have drain ports along the line to get rid of steam condensate that forms along the steam line. The sets of drain ports near the separator station are the first line of defense against water (brine) carry over and they should remove any carry over such that at the drains ports near the power plant, only steam condensate with no dissolved components is obtained.

At times, when 100% separation is not occurring, traces of water from the two phase fluid will be carried into the steam. This can be detected by analysis of water discharged at the drain ports. Components in the two phase fluid partition either in the steam phase or the liquid phase. SiO_2, Na, Cl preferentially partition into the water phase while gases partition into the steam phase. Analysis of Na, Cl or SiO_2 could therefore help detect if there is carry over of brine at the separation stage or from the separator to the steam line.

Following installation of the pressure let down station at Olkaria 1AU power plant in 2016, there were signs of scaling at the pressure let down station. There was therefore need for an evaluation of the steam quality from the various separator stations delivering steam to the plant. This was to assess and mitigate possible turbine damage which could result from brine carry over to steam phase.

Table 2 below gives a summary of the wells connected to specific separator stations, separation pressures, total mass flows for each separator stations and brine disposal wells specific to each separator station.

TABLE 2. A summary of Olkaria IAU steamfield

Separator stations	Wells connected	Separation pressure (bar)	Mass flow (T/hr)	Hot Reinjection well
SE1	OW-14 OW-14A OW-41 OW-41A	11.6	230	OW 13/ OW 17
SE 2	OW-36 OW-36A OW-44 OW-44A OW-44B	11.5	286	OW 7
SE 3	OW-38 OW-38A OW-38B OW-42 OW-42A	11.3	431	OW 13/OW 17

4.0 Results and Discussion

Condensate drain port sampling and analysis was therefore conducted in June 2016. Condensate samples from drain ports of separator stations SE1, SE2 and SE3 were sampled and analyzed for pH, TDS, Chloride, Silica and Sodium. Drain ports were sampled from the separator stations to the power plant interface.

Table 3 below gives a summary of chemical analysis results for Olkaria IAU drain ports from separator stations SE1, SE2 and SE3

TABLE 3: A summary of Olkaria 1AU drain ports sampling results are indicated in the table below

Separator station	Separation pressure(barg)	Drain ports	pH	TDS (mg/kg)	High Cl^- (mg/kg)	Low Cl (mg/kg)	Na^+ (mg/kg)
SE1		A	7.02	12.7		9.13	12.14
		B	7.27	3.21		14.98	0.21
		C	7.08	40.8		35.7	2.10
		D	6.83	6.23		20.63	0.82
		E	5	10.6		34.98	1.24
		G	5.23	17.6		16.88	0
		H	6.14	5.61		25.4	0.21
		I	6.23	5.37		14.98	1.21
		J	6.54	6.88		32.66	3.29
SE2		A	7.06	5.13		0	16
		B	6.77	90.6		17.65	2
		C	7.84	115.5		20.375	5.8
		D	7.67	22.35		6.975	20
		F	7.45	5.05		1.625	1.2
		G	6.9	8.535		0.2	1.2
		H	7.1	4.22		0.4	1.8
		I	7.16	3.73		0.275	1.2
		J	7.14	4.54		0.9	1
		A1	6.48	14.8		10.25	0.8
		A2	7.77	82.95		10.225	11.2
		B1	7.28	77.8		15.375	9.8

Separator station	Separation pressure(barg)	Drain ports	pH	TDS (mg/kg)	High Cl^- (mg/kg)	Low Cl (mg/kg)	Na^+ (mg/kg)
SE3		B2	7.45	120		19.35	19.2
		C	6.95	135.5		20.25	20
		D	6.84	112.5			17.8
		E	6.47	63.6		12.75	11.6
		F	6.66	23.6		4.075	2.4

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 then decline between the 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).

Figure 6 shows the concentration of dissolved chloride and sodium in steam condensate for drain ports from separator stations SE1, SE2 and SE3 to power plant interface.

4.1 SE1, SE2 and SE3 Separator stations

Figure 3 shows the concentration of chloride and sodium of drain ports samples collected along SE1, SE2 and SE3 steam line.

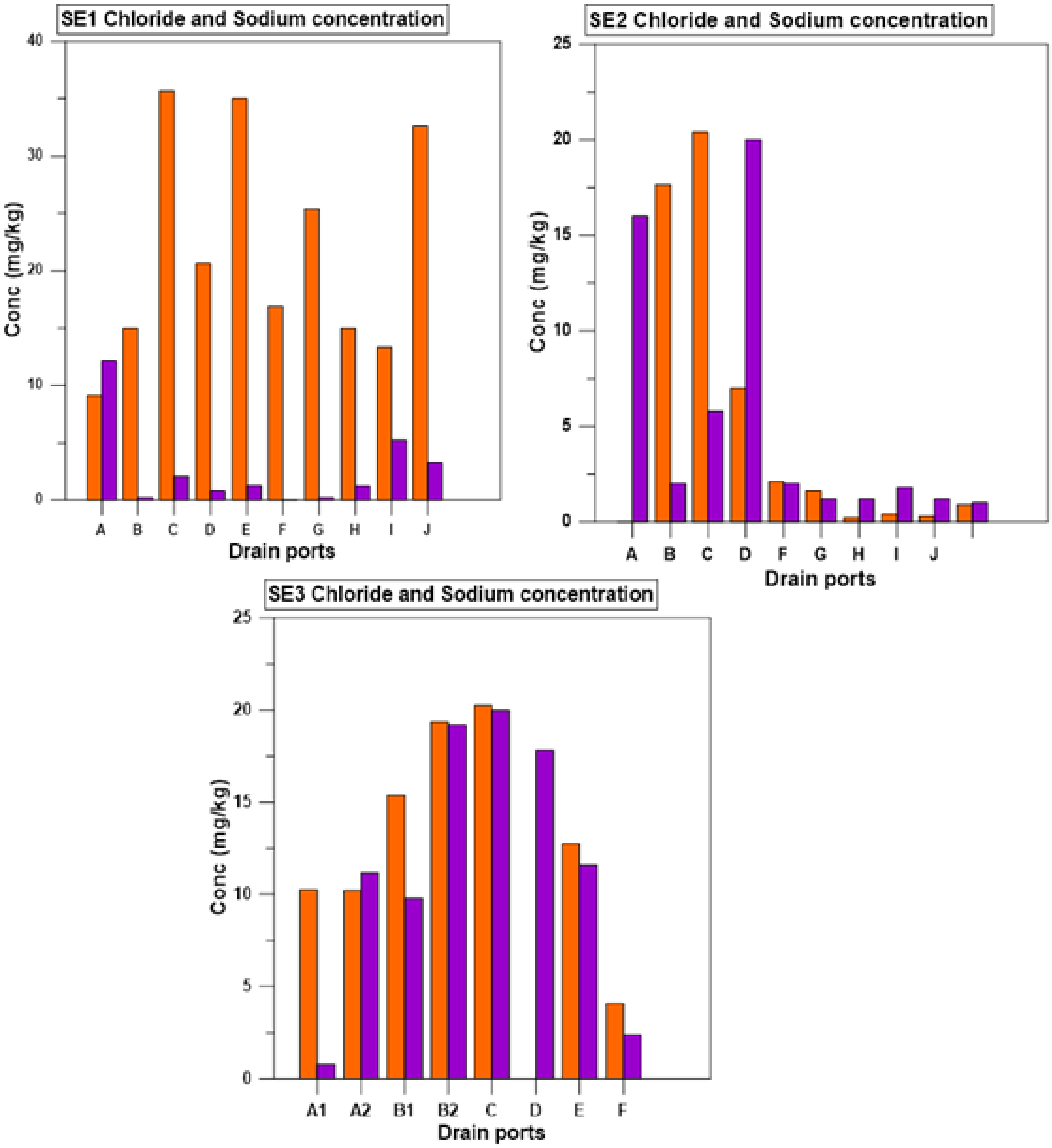


Figure 3: Chloride and Sodium concentrations in SE1, SE2 and SE3 separator stations

From the chemical analysis, Separator stations SE1 and SE3 steam pipeline network reported high concentrations of dissolved chemical components. The chloride and sodium concentrations along SE1 and SE3 steam line do not show a general decline. These separator stations have the last drain ports recording concentration of > 4 mg/kg chloride and > 2 mg/kg sodium against recommended standard limit of ≥ 1 mg/kg chloride and ≥ 1 mg/kg sodium. Power engineers, (2014). This is Indicative of carry-over of separated water to the steam line. This could be as a result of inefficiencies in separation or poor steam cleaning mechanism. SE2 separator station reports high concentration of dissolved constituent in the drain ports closest to separator station but then the concentrations decline as steam approaches the scrubber recording concentration of 0.9 mg/kg chloride and 1 mg/kg sodium. This is indicative of efficient drain port cleaning mechanism and minimal brine carry over to steam line.

5.0 Conclusion

A summary was prepared to indicate the order of the separator station from those with the highest amount of brine carry over to those with minimal brine carry over.

Separator station	Comment
SE 3	Extremely high brine carry over
SE 1	Extremely high brine carry over
SE 2	Minimal brine carry over

It was then appropriate to isolate and assess the separation effectiveness, the reasons for brine carry over and drain ports steam cleaning mechanism of SE3 and SE1 separator stations. This then necessitated shut in of wells serving the two separator stations and inspection of separator units and brine disposal wells serving the two separator stations. Upon inspection of the SE1 and SE2 separator stations, debris was found to have clogged the brine line, preventing separated water to flow to reinjection well. Wellhead pressure monitoring of OW 13 reinjection well indicated a pressure build up in the well, therefore resulting to a kick back of separated brine back to the separator unit and then to the steam line. OW 13 was then shut and separated brine from SE1 and SE3 separator stations redirected to OW 17. The well was then quenched to decrease wellhead pressure. This is currently a maintenance process to monitor any signs of "kicking" from the well.

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