ONLINE STEAM PURITY ANALYSIS FOR GEOTHERMAL POWER GENERATION

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ABSTRACT

Steam purity can have a major impact on steam turbine performance and reliability. Online steam purity monitoring is considered standard practice in thermal and nuclear power plants with steam turbines to enable the rapid identification of out of specification steam purity that could lead to turbine damage. Steam purity is not routinely monitored in real time in geothermal power plants for a variety of reasons including the difficulty of conditioning samples for analysis with online instrumentation. This is as a result of high levels of non-condensable gases that interfere with analysis techniques, as well as concerns as to whether a steam sample is representative of the bulk steam flow due to the two-phase nature of many geothermal steam supplies. Operators may also have concerns about what actions they have available to them to improve steam purity should it be found to be insufficient.

This paper describes the considerations to be taken into account when developing online steam purity monitoring systems for geothermal power plants. A case study demonstrating some of the benefits of geothermal steam purity monitoring is also discussed.

1. INTRODUCTION

Steam purity refers to the amount of solid, liquid, or vaporous contamination in the steam. High (or good) steam purity refers to steam with a low level of contamination, while low or poor steam purity indicates steam with elevated levels of contamination. Steam purity should not be confused with steam quality. Steam quality is a measure of the amount of moisture in the steam. It is expressed as the weight of dry steam in a mixture of steam and water droplets.

The purity of steam used in geothermal power plants can have a significant impact on both the short term and long term performance of the power plant, particularly the steam turbine (flash plants) and heat exchangers (binary plants) **(Richardson, Addison and Thompson, Steam Purity Considerations in Geothermal Power Generation 2013)**.

Even the high purity steam can contain sufficient contaminants to result in deposition onto steam turbine surfaces in the phase transition zone (PTZ) of the turbine (Addison and Dooley 2015). Contaminants in steam such as sodium and chloride ions are either dissolved in water droplets entrained in saturated steam, or solubilized in superheated steam. At concentrations greater than 2 µg/L (sodium) and silica 10 µg/L (silica), deposition onto steam turbine surfaces is likely. These deposits can result in problems for any steam turbine through:

- A reduction of the flow passing ability (“swallowing capacity”) of the turbine and a change in the effective steam flow profile on the turbine blades. These changes result in a reduction in steam flow and reduced turbine efficiency and consequently power output of the turbine.
- Corrosion in the offline environment due to the reaction of turbine deposits with oxygen and moisture. This then allows pitting damage in the turbine to occur that can result in stress corrosion cracking and corrosion fatigue failures. Both these corrosion mechanisms initiate from pitting damage and then propagate as cracking when the turbine is in service.
- Corrosion in the online environment due to the presence of corrosive fluids, either as under deposit corrosion or corrosive condensate (Richardson, Addison and Lawson, Chemistry Challenges in Geothermal Power Generation 2015).
- Solid particle erosion (SPE) due to the release of deposits (e.g. silica) on upstream surfaces in a geothermal steam turbine resulting in SPE of downstream components (Richardson, Addison and Thompson, Steam Purity Considerations in Geothermal Power Generation 2013).

In the case of geothermal turbines operating on saturated steam, the primary source of contaminants that can result in deposition and corrosion in a steam turbine is brine carryover from the separator vessels. This situation can be compounded by ineffective moisture removal systems (MRS) (Arifien, Zarrouk and Kurniawan 2015) downstream of the separator vessels combined with low drain pot efficiency and ineffective steam sampling and analysis systems (Morris and Mroczek 2015).

1.1 Factors Affecting Steam Purity

Many factors can affect steam purity within a geothermal power plant, the significance of these factors can vary from power plant to power plant as local conditions and plant designs vary. Broadly the major factors are:

- Fluid chemistry;
- Separator efficiency;
- Moisture removal;
- Separation pressure;
- Operating conditions; and,
- Washing system efficiency and condensation.

Changes in any of these factors can result in changes in steam purity at a geothermal power plant. With many geothermal power pants operating as base-load power plants, and significant plant modifications and new production wells generally spaced years apart, there can be expectations that steam purity does not change significantly. However changes in steam purity can happen unexpectedly as a result of changes to the factors listed above, for instance damage to a separator or moisture removal system, or load swings due to plant or network constraints.

Understanding the purity of the steam delivered to a steam turbine is important if the risks to the turbine are to be effectively managed and maintenance and inspection routines optimized. To determine the steam purity, it needs to be measured, this can be done either periodically (typically grab sampling) or continuously (online instrumentation), with advantages and disadvantages to each approach.

1.2 Grab Sampling

When steam purity is measured periodically, the grab sampling method is usually utilised.

Grab sampling refers to the practice of collecting a discrete sample for analysis in a laboratory (either on site or remote). Grab samples may be collected periodically (e.g. weekly or monthly) and/or when it is deemed necessary to determine steam purity e.g. as a result of an operating change. Grab sampling is relatively simple to undertake, only requiring basic sampling equipment and procedures. Where grab sampling takes place relatively infrequently (less than weekly), it can be cost effective to outsource the analysis of the samples to an external laboratory, negating to the need for an onsite laboratory, analysis equipment and laboratory staff.

A major disadvantage of the grab sampling is that steam purity is only measured at a given point in time. While steam purity may appear suitable at the time of sampling, steam purity transients are often missed. Grab samples are also usually collected during normal power plant operation, and as such steam purity is often not measured during non-standard operating conditions. This can result in “best case” steam purity being measured; while poor steam purity events go unnoticed.

1.3 Online Monitoring

Online monitoring of steam purity is standard practice in fossil and nuclear power plants. Several international guidelines are available for steam monitoring system design and selection (IAPWS 2015), (VGB 2012), (EPRI 2007) based on fossil and nuclear plants.

While the purity of steam in geothermal power plants can be expected to be significantly lower than the steam from fossil and nuclear plants (making turbines more susceptible to corrosion and scaling/deposition risks), effective online monitoring of steam purity is uncommon in geothermal power plants world-wide. The authors believe that there are several reasons for this, and these are discussed in section 3 of this paper.

The use of online steam purity monitoring provides several very important advantages over grab sampling. Online monitoring can provide continuous real time steam purity data, allowing transient steam purity conditions to be identified, and actions taken where required. This is extremely important where a change in steam purity could place the integrity of the steam turbine at risk. The recording of continuous data also provides information that can analysed in relation to post event investigations, for example where turbine deposition is observed, continuous monitoring data can inform whether the deposition is a result of the plants “normal” level of steam purity, or if it has been a result of transient conditions. Continuous monitoring of steam purity can also be used to rapidly optimise plant processes (e.g. steam washing systems) by providing rapid feedback on the impact of process changes on steam purity – without the need for the collection of grab samples and the delays associated with laboratory analysis.

Online monitoring has been undertaken by some geothermal power plant operators (e.g. Mercury, Energy Development Corporation). These online geothermal steam purity monitoring systems vary in the parameters tested for from a single parameter (e.g. sodium) to multiple parameters (e.g. silica, gas content, pH and conductivity after cation exchange (CACE)) (Taguchi, Makimoto and Ishii 2010). Some online monitoring systems provide real-time, continuous data, while others operate as a high frequency automated grab sampling and analysis system. This distinction can be very important depending on the frequency of analysis in the later design.

There are many factors to be considered when designing a steam purity monitoring system for a geothermal plant to ensure that the system produces representative, reliable and useful information for the plant operator. These factors are considered in the following sections of this paper.

2. SAMPLING

Acquiring a steam sample for analysis that is representative of the bulk steam can be a challenge in many power plants, but can be particularly challenging in geothermal systems where the steam is often at saturation temperature and flowing through relatively large diameter piping designed to allow the formation and collection of a condensate film on the pipe internal surfaces. The presence of moisture in the steam flow can present challenges to representative sampling as the concentration of contaminants can vary significantly (by orders of magnitude) between the liquid (water) and gas (steam) phases due to solubility differences. In attempting to sample representatively consideration must also be given to the potential presence of pipe-wall condensate, which may not be able to be effectively sampled.

2.1 Sample Location

The selection of the steam sampling location can have a significant influence over the success of a steam monitoring program (whether online or via grab sampling). If the sampling location is inappropriate, representative steam sampling may not be possible. There are several factors to consider when selecting a steam sampling location:

- Proximity to the steam turbine
- Location of steam scrubbing systems (if present)
- Expected moisture content of steam
- Proximity to flow disturbances
- Geometry of the pipework

To ensure that any steam sampled is representative of the steam reporting to the turbine, the sample should be collected as close to the turbine inlet as is practicable. It is essential that the sampling location is downstream of any steam cleaning/scrubbing equipment. These considerations ensure that the steam purity does not materially change between the sampling location and the steam turbine.

The sampling location should also be located where the moisture content of the steam is low, often immediately downstream of the final steam scrubber or demister. Sampling where the moisture content is low increases the likelihood of a representative steam sample. The sample point should also be located away from flow disturbances such as bends, valves, changes in pipe diameter etc. Reducing flow disturbances increases the likelihood of a representative sample where the steam flow contains more than one phase (eg moisture or solid particles). For power plants utilising saturated steam the authors prioritize low moisture content over an avoidance of flow disturbances for instance by sampling at the outlet of the final scrubber or demister. Ideally the sample point will be located in a vertical pipe with downward flow for saturated steam sampling.

2.2 Isokinetic Sampling

Isokinetic sampling is recommended for saturated steam to ensure the collection of the most representative sample possible where multiphase flow is likely (eg with saturated or wet steam). Isokinetic sampling involves collecting the sample such that the steam velocity in the sampling nozzle is at the same velocity as the bulk steam flow at a given steam flow condition (normally at full load conditions). This reduces the likelihood that the collected sample will be either over or under-represented with more dense components of the steam flow such as moisture droplets. The concept of isokinetic sampling is explained well in (Jonas, et al. 1991).

For geothermal power plants utilising dry steam, the use of isokinetic sampling may not be necessary, however it can be of benefit if particulate impurities are present (eg corrosion products or formation material).

2.3 Sampling System Design

Sampling system design for geothermal steam is similar to that required in fossil and nuclear power systems. Sampling line runs should be kept as short as practicable with a continuous downward slope and analysis should take place as close as practicable to the sampling location. Fluid velocities should also be maintained at approximately 2m/s to minimise the settling of any solids that may be present in the steam sample (e.g. corrosion products). The use of strainers may be required to protect instrumentation from solid particles (e.g. corrosion products), therefore a sampling point should be located upstream of any strainers to allow for sampling of solids, total iron etc. All sample system components must be constructed from corrosion resistant material; 316 SS is typically utilised.

Detailed information on sampling system design from fossil and nuclear power systems can be found in the literature.

2.4 Sampling Issues

Several issues can interfere with representative steam sample collection in geothermal power plants. The first and most challenging issue is collecting a representative sample which is discussed above. However other issues result from the high gas content of geothermal steam as well as the low steam pressures in some geothermal plants.

When geothermal steam is condensed for collection the volumetric ratio of non-condensable gas to liquid increases significantly (the volume of gas may exceed the volume of condensed steam). This can make it difficult to measure flow rates through standard metering equipment and also makes the untreated sample unsuitable for use in online instrumentation due to the interferences in analytical methods caused by the presence of hydrogen sulfide. As such geothermal steam with high gas content can be difficult to sample without suitable sample venting arrangements to separate non-condensable gas from the condensed steam followed by active degassing methods to remove any remaining dissolved gases (this is usually easily managed when undertaking manual grab sampling, but can be particularly problematic for online analysis).

The low steam pressures used in some geothermal power plants can also present sampling challenges. Where steam pressures are particularly low it can be difficult to obtain isokinetic sample flows through sampling and conditioning equipment. To minimise the challenges presented by low steam pressures sampling and conditioning equipment should be designed with the minimum pressure drop that can reasonably be achieved. Careful selection of sample line sizing, geometry, fittings, and sample cooling systems are required to minimise low sample pressure issues.

2.5 Grab Sampling Capability

Where online steam purity monitoring is undertaken, consideration should be made for the need for grab samples to be undertaken from time to time. Grab sample requirements may dictate that several samples locations are designed into an online monitoring system, eg a sample point upstream of a degassing system for gas sampling, and another sample point downstream of degassing for condensate sampling.

3. CONDITIONING

Sample conditioning involves preparing the collected steam sample for analysis, typically by adjusting the sample temperature, pressure and flow rate to the conditions necessary for analysis and to ensure safe handling. In geothermal applications sample conditioning also includes removing gases from the sample (such as hydrogen sulfide and carbon dioxide) that can interfere with the analysis process. The main components of the sample conditioning system are described below, however additional components (such as flow meters etc) may also be included in a well-designed system as required by the site conditions.

3.1 Primary Cooling

Sample conditioning typically begins with the first stage of temperature control (primary cooling), where the steam sample is condensed and the temperature reduced to a safe level for both personnel and equipment. Primary cooling is typically achieved with a coil in shell heat exchanger, although coil in coil, and plate and frame heat exchangers are also known to be used in geothermal applications and other types of heat exchangers may also find application here. The choice of heat exchanger is typically dependent on sampling conditions and available services at a given power plant. Gas blanketing can be an issue in primary coolers used for geothermal steam, and as such heat exchanger selection and installation should take this into consideration with manual gas venting capabilities installed if required.

3.2 Pressure Control

Pressure control is required to reduce the sample pressure to a level that is low enough such that it does not damage the degassing system and instrumentation, but remains high enough to ensure adequate sample flow to the instrumentation. Pressure control is usually undertaken downstream of the primary cooler via a pressure reduction valve. Pressure drop should be minimised upstream of the primary cooler as flashing of liquid in the steam sample may result in the deposition of minerals that can foul the sampling and conditioning equipment, while also altering the composition of the sample, resulting in an under-reporting of impurity levels. Pressure reduction may be undertaken with a dedicated pressure reduction valve, a throttled valve, orifice plant or other means as is suitable to achieve the required pressure reduction. In low pressure steam systems (<2barg) it is likely that pressure reduction will not be required.

3.3 Degassing

Degassing of the sample is required to reduce interference of the analysis processes from the dissolved gases often found in geothermal steam. Carbon dioxide and hydrogen sulfide can interfere with sodium analysis undertaken with ion specific electrodes by depressing the pH of the steam sample. Silica analysis by the heteropoly blue method (colorimetric analysis) is very sensitive to the presence of hydrogen sulfide, and as such if silica is to be analysed by this method, a very high level of hydrogen sulfide removal is required. There are three main methods known to be in use for removing dissolved gasses from geothermal steam for online analysis. These are:

- Active gas sparging, with either an inert gas (batch degassing) or air (continuous degassing);
- Passive degassing with air to remove dissolved gasses and;
- The use of gas exchange membranes to remove dissolved gases from the condensed steam.

All of these methods involve utilising the equilibrium of gas partial pressures (Henry’s Law) to draw gas out of the steam sample with the active gas sparging and passive degassing methods both dropping the sample pressure to atmospheric pressure. In the case of gas exchange membranes the majority of the sample pressure remains leading to a more compact installation set up. Vacuum degassing has been used to degas geothermal steam samples for laboratory analysis however its use in on-line steam analysis systems is not known to the authors, which the exception of when it is used in combination with a gas exchange membrane. The pressure drop involved in a direct vacuum degassing system would likely require the use of a batch degassing system rather than a continuous degassing system. Other degassing methods (such as re-boiling) are not known to be in use on geothermal applications by the authors, a re-boiler system would also result in a pressure drop issues that would need to be addressed.

3.4 Secondary Cooling

Secondary cooling is used to cool (or in some cases heat) the steam sample as close as possible to the ideal temperature for analysis (often 25˚C). Temperature can have a significant influence on the analysis results, even where temperature compensation algorithms are used. Silica analysis can be particularly temperature sensitive in geothermal applications where an integral sample heater is not included in the silica analyser. Sodium by ion specific electrode and pH can also be sensitive to the sample temperature, particularly where sample temperatures exceed 30˚C. Secondary cooling often utilises a coil in shell heat exchanger and are set up as isothermal baths – with a heater/chiller unit used to control the cooling water temperature. Secondary cooling is usually undertaken as close as possible to the analytical instrumentation, to minimise temperature variation as a result of ambient conditions in the analysis area.

3.5 Protection Equipment

The sampling conditioning system also includes protection devices to reduce risks to both personnel and equipment. Thermal shut-off valves (TSV) are used to cut off the sample flow in the event of high sample temperatures (usually a result of a cooler failure or loss of cooling water flow). TSVs are used to protect instrumentation from hot fluids and also reduce the risk to personnel working near the instrumentation. TSVs may be located after either the primary or secondary cooler depending on the system configuration. It is recommended that in geothermal sampling systems the TSV is located between the primary cooler and the degassing system, such that the degassing system and instrumentation is protected.

Sample strainers or filters may also be used to prevent solid particles (such as corrosion products) from reporting to instrumentation. Where strainers or filters are used in is important that samples that will be analysed for material that may be solid (such as iron) are collected upstream of the strainer. Strainers should be designed for ease of maintenance as strainers can block quickly where particle levels are elevated such as during plant or system start-up. For geothermal sampling systems it is recommended that strainers are located between the primary cooler and the degassing system, such that the degassing system and instrumentation is protected.

4. ANALYSIS

Selecting the parameters to be analysed in an on-line steam monitoring system requires an assessment of the steam purity risks likely to be faced at a given geothermal power plant. The steam purity risks can vary significantly between geothermal power plants, however the most common contaminant risks that can be readily measured online are described below. Fortunately most common steam purity issues can be monitored with a small complement of analysers as shown in Figure 1.

Figure 1: Steam Purity analysers at the Nga Awa Purua Geothermal Power Plant. Sodium, Silica, Conductivity and CACE shown.

Silica

High pressure flash plants (>10bar(a) separation pressure) have the potential for the presence of significant concentrations of semi-volatile contaminants to be dissolved in the steam. The contaminant of most concern in this instance is likely to be silica which is a commonly reported as a significant issue for geothermal steam turbines. The amount of silica that can be expected to be dissolved in the steam is a function of reservoir fluid temperature which controls the amount of silica in the produced fluids, and the separation pressure which affects both the volatility and the subsequent concentration of silica in the separated geothermal steam. The impact of reservoir temperature to the separation pressure is shown in Figure 2, which is shown for a silica saturation index of 1.0 for a first-stage flash. The volatile silica concentration that can be expected in the steam as a function of the reservoir temperature is shown in Figure 3. This is calculated from the silica concentration of the geothermal fluid (governed by the reservoir temperature) and the corresponding separation pressure which determines the distribution coefficient of the silica between the liquid and vapour phases (K_D). It can also be seen from Figure 3 that geothermal flash plants operating with reservoir temperatures of >280˚C (separation pressures >10 bar(a)) are at risk of silica scaling when utilising steam turbines. This is due to the likelihood of the steam supply being fully or super-saturated with silica. It is recommended that steam washing systems are considered for geothermal power plants operating at these higher pressures.

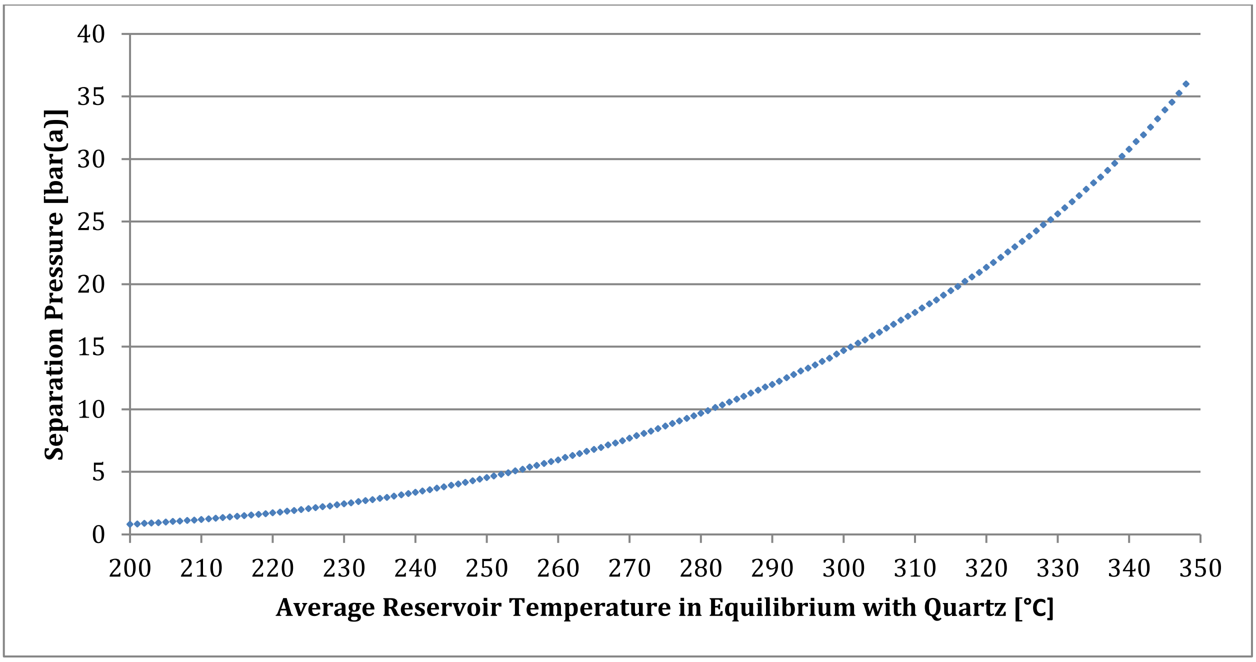

Figure 2: Graph showing the separation pressure vs. the average reservoir temperature of the produced fluids for a silica saturation index of 1.0. Quartz solubility taken from (Fournier and Potter, A Revised and Expanded Silica (Quartz) Geothermometer 1982), amorphous silica solubility taken from (Fournier, Solubility of Silica in Hydrothermal Solutions: Practical Applications 1989) and (Fournier and Marshall, Calculation of Amorphous Silica Solubilities at 25 to 300C and Apparent Hydration Numbers in Aqueous Salt Solutions Using the COncept of Effective Density of Water 1983).

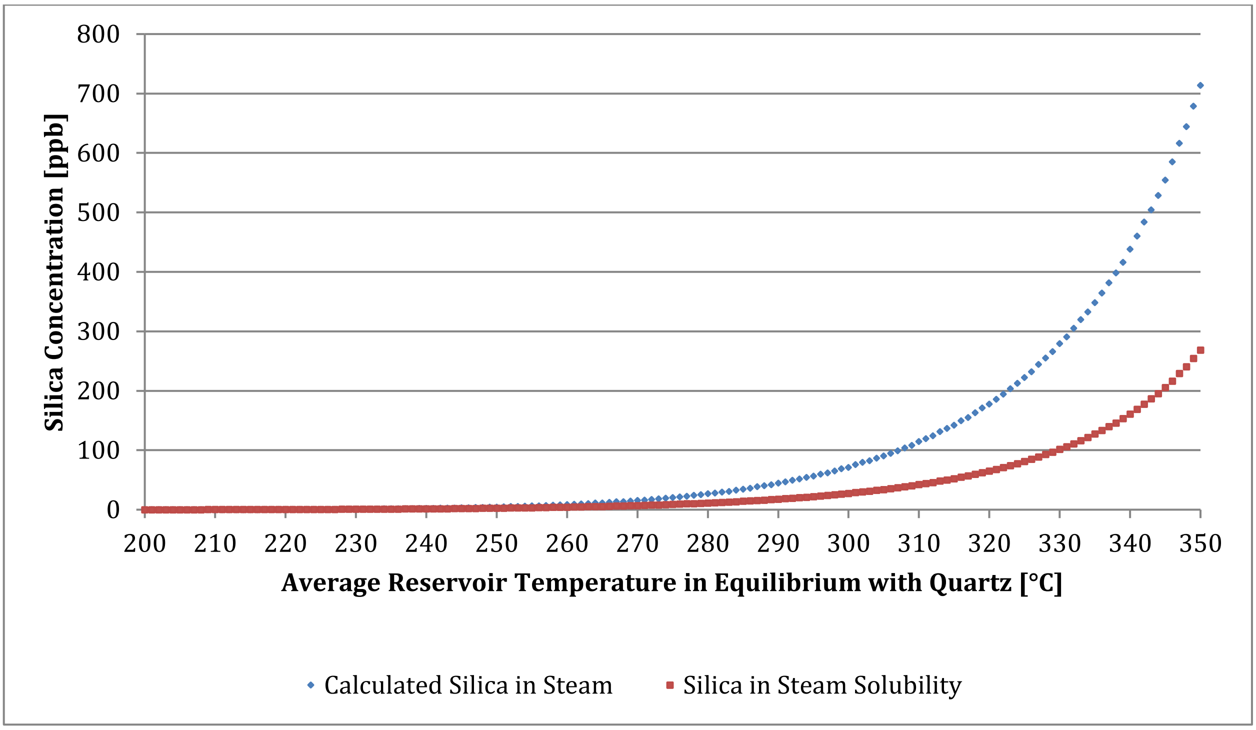

Figure 3: Calculated silica concentration in steam calculated using K_D values from (Povarov 2006) for a given average reservoir temperature and a separation pressure that results in a pure amorphous silica saturation index of 1.0, as per Figure 2. Silica in steam solubility from (James 1986)

Silica scaling is most prevalent on the 1st stage stationary blades on geothermal steam turbines. In the case of saturated steam this is due to evaporation of the liquid films on the turbine surfaces, leading to super-saturation and subsequent deposition. Where superheated steam is supplied to the turbine, deposition is likely due to solid particles of silica in the steam – as the pressure of the superheated steam is reduced, the solubility of silica in the steam is reduced, which can lead to super-saturation and the formation of silica particles. There is typically sufficient moisture in the steam by the 2nd stage stationary blades that silica deposition is significantly reduced from the 1st stage – if present at all.

As such it is recommended that silica is analysed in the steam of geothermal power plants operating at high separation pressures with steam turbines.

Analysers designed for online analysis applications in power plants typically utilise the hetero-poly blue method of colorimetric analysis. This method is highly sensitive the hydrogen sulfide, as such highly effective sample degassing is essential for reliable operation. Some instruments contain an integral sample heater to maintain a stable, elevated sample temperature which can accelerate analysis times while minimising variability due to changes in sample temperature. When utilising instruments without a sample heater it is recommended that sample temperature is tightly controlled – for instance with an isothermal bath.

Silica measurement instruments used in geothermal steam applications should have a detection limit of less than 10µg/kg (and preferably <2µg/kg). Silica concentrations in geothermal steam can vary significantly between plants, however in general a silica analyser that can measure accurately and reliably between 10µg/kg and 200µg/kg should be suitable for most geothermal steam applications.

Sodium

Sodium, as sodium chloride or other sodium salts is typically found in significant concentrations in geothermal brines (usually with significant concentrations of chloride). Sodium compounds have very limited volatility in steam at the temperatures and pressures found in conventional geothermal systems, as such sodium is often considered non-volatile in geothermal steam systems. As such the presence of sodium in steam is a sign of brine carry-over into the steam combined with ineffective moisture removal. This makes sodium a useful parameter to measure for the determination of brine carry-over rates. With knowledge of the brine chemistry and the sodium concentration in the steam, the concentration of many other impurities in the steam can be estimated.

The simplest method for measuring sodium concentrations in steam continuously is likely to be with ion specific electrodes (ISE). ISE based sodium analysers are commonly used in fossil power plant applications and are also used successfully in geothermal applications in New Zealand. With detection limits below 5µg/kg, ISE sodium analysers are able detect even minor levels of brine carryover. The presence of acidic gases (CO_2, H_2S) can interfere with ISE due to pH depressions, so sample degassing is typically required.

Flame photometers have also been used to measure sodium concentrations in condensed geothermal steam samples (Angcoy, et al. 2008). Flame photometers may be less sensitive to dissolved gas levels, although maintenance requirements and detection limits can be higher than ISE instruments.

pH

Measuring the pH of geothermal steam can be useful in different ways, even where pH may not be the primary concern. Measuring the pH of the geothermal steam can be a relatively straight forward way to detect the presence of acidic species (such as HCl) that are routinely found in dry steam geothermal systems. In these instances pH can be used to measure the presence of acidic species, as well as the effectiveness of any scrubbing measures that are employed by measuring the pH both upstream and downstream of the scrubbing system. pH is also a useful tool for measuring the effectiveness of the degassing system used to condition the sample.

Measuring the pH of the condensed geothermal can be undertaken with the standard pH monitoring equipment utilised in thermal power plants. pH monitoring equipment is considered to be generally reliable and easy to operate and maintain. The authors see the most appropriate use for pH monitoring on degassed steam (where both the presence of acidic species and degassing performance can be measured), although there may be specific applications where users may need to measure the pH of the steam prior to degassing.

Conductivity and CACE

Conductivity and Conductivity after Cation Exchange (CACE) can provide a non-specific measure of contaminants in steam. As conductivity and CACE are not specific to any particular contaminant (and will only indicate electrically conductive contaminants such as dissolved salts) their use in geothermal steam monitoring may be limited to detecting significant changes in steam purity such as significant brine carryover. The utility of conductivity and CACE may also be limited in geothermal applications where background conductivity levels in geothermal steam are very high (especially in high pressure plants), as the high background level can mask changes in steam purity and consumption of the cation exchange resin in the CACE instrumentation is high. Conductivity and CACE measurement may find use in low pressure geothermal steam systems where background conductivity levels are low. Conductivity measurement may find use in plants at risk of acid chloride transport, as acid salts are significantly more conductive than their equivalent neutral salts (in this case CACE would not be appropriate). Conductivity and CACE may also find use in tuning wash water systems as a general measure of steam purity – however it is recommended that specific contaminants of interest (e.g. silica, sodium) are also measured during any such tuning.

Conductivity and CACE instruments are typically very reliable and require very little maintenance, making them especially suitable for plants within minimal staff.

5. CASE STUDY – KAWERAU GEOTHERMAL POWER PLANT

The Kawerau Geothermal Power Plant (KGL) does not have dedicated laboratory facilities or staff, as such samples collected for chemical analysis are sent to an external laboratory. For a steam purity monitoring system to be successful at KGL it would need to be reliable, easy to operate and have low maintenance requirements.

The system would be required to record all data on the Distributed Control System and data historian systems to allow remote monitoring of both the steam purity data and the instrument status.

5.1 System Requirements

5.1.1 Continuous Monitoring

Continuous, real-time monitoring was desired for the KGL plant to ensure that transient changes in steam purity were captured. Deposition on the steam turbine at KGL had been observed previously, however the steam purity data available from the grab sampling program was not sufficient to determine if the deposition was a result of discrete steam purity events, or a result of the “normal” level of steam purity at the plant.

Intermittent grab sampling can be used to build up a picture of the general level of steam purity at a power plant, however transients are often undetected. This is a result of a grab sample only indicating the steam purity at a given moment of time, for instance weekly tests of steam purity (particularly if taken on the same day of the week at the same time) can miss changes in steam purity that may occur during changes in operating conditions such as valve positioning or generation set-points.

5.1.2 Sodium Analysis

Sodium makes up a significant proportion of the dissolved solids in the geothermal fluid at Kawerau and is also essentially non-volatile under the typical geothermal power plant operating conditions, including at KGL with a separation pressure of 13 bar(a).

This makes sodium a very useful tracer for measuring any brine carryover from the separation and scrubbing system. The use of sodium measurement also allows for the estimation of the concentration of other non-volatile contaminants that are likely to be in the steam (based on brine carryover).

5.1.3 Silica Analysis

Silica has been observed to be the major foulant of the KGL steam turbine during routine turbine inspections. The high concentration of silica in the geothermal brine at KGL and the moderate separation pressure (13 bara) also suggest that moderate silica concentrations can be expected in the steam in the absence of brine carry-over.

Online silica analysis, coupled with online sodium analysis can be used to determine the amount of silica dissolved in the steam, compared to the amount of silica present as a result of brine carryover. The measurement of silica will also enable rapid optimization of the KGL wash water system.

5.1.4 Conductivity Analysis

The monitoring of electrical conductivity of the steam can provide an indication of the total dissolved solids present with the steam. Conductivity measurement is a simple and cost effective means of providing extra information during a steam purity excursion, for instance the electrical conductivity would be expected to increase during a brine carryover event (along with sodium and silica measurement). An increase in electrical conductivity coupled with an increase in silica, but no increase in sodium measurement, would indicate an increase in semi-volatile contaminants within the steam that is not a result of brine-carryover.

Conductivity after cation exchange (CACE) can provide a more sensitive measurement than specific conductivity as the cations present in the steam sample are removed (such as ammonia). This increase in sensitivity can be used to identify small changes in steam purity that may otherwise be masked by high background conductivity readings.

5.2 Results

Results from the KGL steam purity monitoring system have been consistent with laboratory analysis of the steam samples (sodium by atomic absorption spectroscopy and silica by ICP-MS), indicating that the system is producing accurate results. Sodium and conductivity readings have proven to be very stable under stable operating conditions, while silica results have proven to be temperature sensitive. Stable silica results have required a stable sample temperature to minimise variability in the results (temperature affects the reaction speed of the colorimetric silica method). As such good sample temperature control (±1˚C) is required for high quality online silica analysis if the silica analyser does not contain an internal sample heater.

5.2.1 Online Data

Data from the KGL steam purity monitoring system is immediately available in the plant Distributed Control Systems (DCS) as well the plants data historian. This allows both operators at the plant and off site support personnel to access the steam purity data in real time. The benefits of the real time data include the ability to respond immediately to changes in the steam purity that may be the result of a change in any of the factors that affect steam purity.

5.2.2 Brine Carry-over

The use of continuous steam purity monitoring at KGL was essential in confirming ongoing, low level brine carry-over in the LP steam system as shown in Figure 4. The provision of continuous, high resolution steam purity data was essential in not only filling in the data void between grab samples, but also confirming the carry-over in the face of grab sample variability. The grab sample variability was compounded by the concentration of contaminants in the LP steam being close to the detection limits of the laboratory analysis techniques.

The steam purity data was then used to explain the formation of deposits that were observed on the LP turbine at KGL during a routine borescope inspection. As the data enabled confirmation that the turbine deposits were a result of brine carryover, it was possible to determine the likely composition of the deposits, and their likely impact on the turbine materials without removing the turbine casing to collect a physical sample of the deposit for analysis.

In this case the data provided by the steam purity monitoring system was important in confirming that deposition was occurring within the steam turbine even though steam purity was within the recommended range. The use of the steam purity monitoring system is enabling the development of stricter steam purity guidelines (to avoid turbine deposition) that can be monitored by the plant operator.

5.2.3 Change in Operating Conditions

The KGL steam purity monitoring system has also been used to identify unexpected changes in steam purity that would have otherwise gone undetected. During a plant upset condition it was noted that the LP steam purity declined as shown in Figure 5. The conductivity and the silica concentration of the steam increased, while the sodium concentration remained relatively unchanged, indicating that the issue was not related to brine carryover. Further investigation revealed that the change in steam purity was related to the status of the acid dosing system – when the acid dosing system was turned off the steam purity appeared to decline. Once the acid dosing was restored the conductivity and silica levels in the LP steam returned to normal. Investigations are continuing into why the acid dosing system is having such a significant impact on LP steam purity.

Without continuous steam purity monitoring it is highly unlikely that this change in steam purity would have been otherwise identified. This example highlighted the benefits if continuous monitoring, as it is often impractical to test steam purity under every possible operating scenario using grab sample analysis.

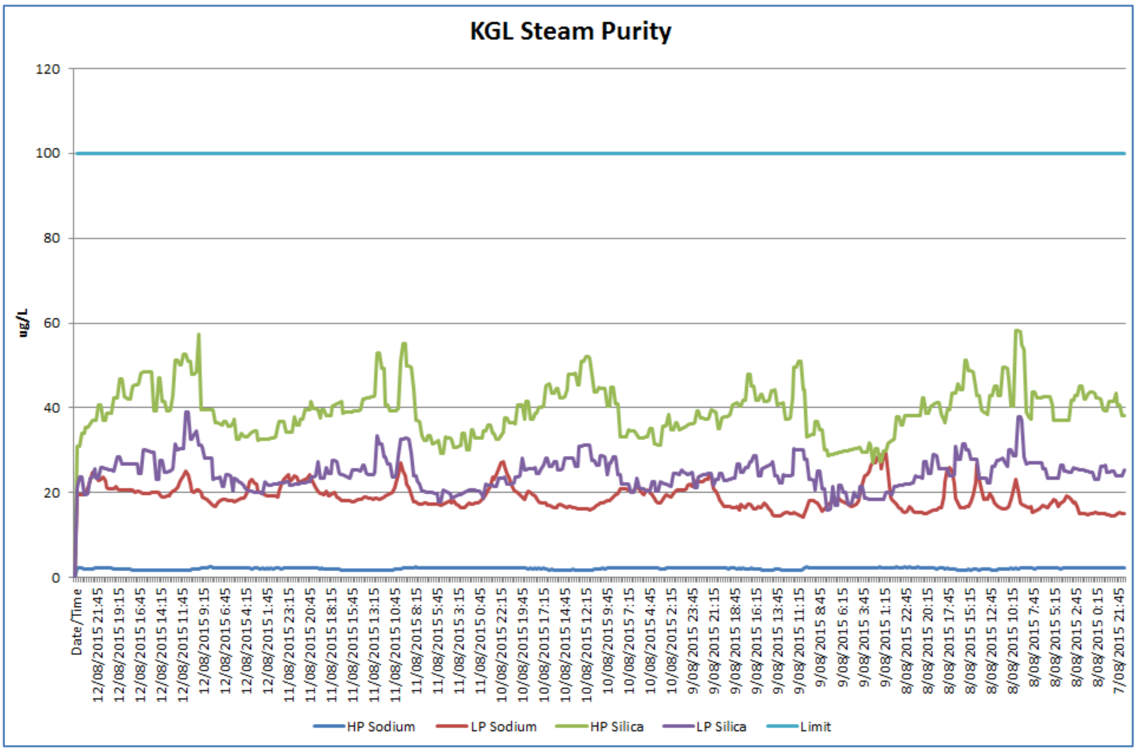

Figure 4: KGL Steam purity during normal operation. Note the elevated level of Sodium in the LP steam, while within the steam purity guidelines this was still enough to cause deposition on the turbine

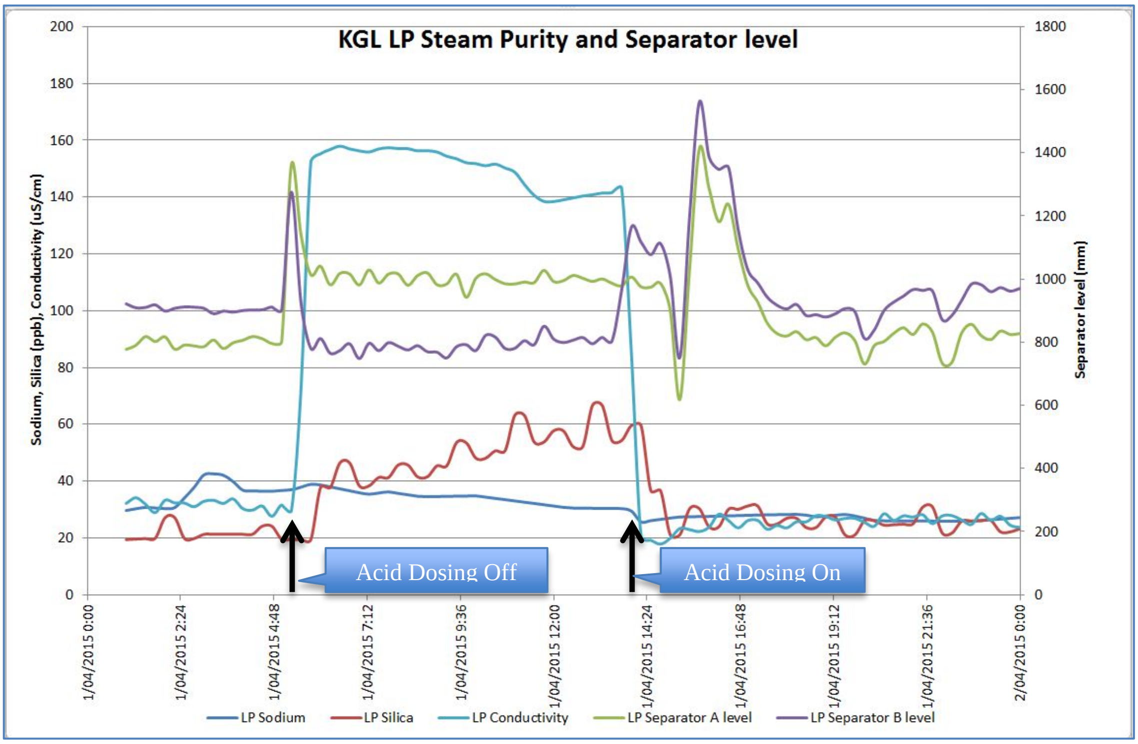

Figure 5: KGL LP steam purity during separator level changes, note the increase in silica and conductivity in the steam. The change in steam purity was determined to be a result of the acid dosing system shutting down.

6. CONCLUSIONS

Steam purity has a significant impact on the performance and reliability of geothermal power plants. Online steam purity monitoring can be used to determine steam purity as steam is delivered to the turbine, enabling rapid identification of out of specification steam chemistry and process upsets that may result in damage to the steam turbine. The use of online steam purity monitoring can assist plant operators in avoiding steam turbine damage, and identify the cause of steam purity changes and excursions.

Implementing successful steam purity monitoring in geothermal power plants has several challenges in addition to those faced by thermal plants. These challenges can be overcome with informed analysis of the steam purity challenges and considerations at a given power plant and careful design of the monitoring system.

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