# STEAM PURITY CONSIDERATIONS IN GEOTHERMAL POWER GENERATION

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**Keywords:** *Geothermal, Steam Purity, Steam Turbine, Erosion, Corrosion*

## 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), and mechanical carry-over rate of 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 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. Accurate monitoring of steam purity is essential to understand the risk and mitigation of steam path damage due to poor steam purity in a particular plant.

Determining steam purity in geothermal steam plants can be a challenging endeavour. Saturated steam, low pressures and the presence of gases such as carbon dioxide and hydrogen sulphide make representative sampling and analysis of steam samples less than straight forward. These challenges must be overcome regardless of whether sampling is undertaken by manual grab sampling and laboratory analysis or continuous online monitoring. Where steam purity is poor, options are available to improve steam purity such as steam washing systems and secondary moisture separation.

This paper presents some examples of damage that can result from poor steam purity in geothermal power plants, while also discussing options to both monitor and improve geothermal steam purity.

## 1. INTRODUCTION

Contaminants responsible for poor steam purity may be present in both saturated and superheated steam as solids, liquids and gasses, some contaminants may also be dissolved in the steam itself.

Contaminants often found in geothermal steam used for power generation include, among others, silica, boron, chloride, sodium, carbon dioxide, hydrogen sulphide, hydrogen and particulate matter (formation material and corrosion products). Of these contaminants silica, sodium, chloride and hydrogen sulphide often pose the greatest risk to steam plant integrity and reliability. Particulate matter contributes to erosion of steam plant components and in severe cases can cause significant turbine damage. The presence of hydrogen in steam can contribute to hydrogen embrittlement and cracking of steels as well as stress corrosion cracking, although these effects may be less significant than the effects of hydrogen sulphide in geothermal power plants. Other non-condensible gases present in steam, such as carbon dioxide and ammonia may present challenges to power plant design and operation, however they are not usually a cause of significant steam plant damage.

As the solubility of silica in the fluid is exceeded, usually through a reduction in pressure (steam) or from evaporation of silica-laden moisture, the presence of silica in steam can lead to deposition of silica on steam-touched surfaces. Silica deposits in steam turbines may result in decreases in turbine efficiency and capacity as flow through the stationary nozzles becomes restricted (Takayama, 2000). Heavy silica deposits can also contribute to erosion of the turbine as deposits detach from surfaces and flow through the turbine. Silica is subject to volatile transport in steam generating systems and, like chloride, can be found in both dry and saturated geothermal steam.

The presence of chloride in steam can result in corrosion of the steam handling plant (piping, separators, scrubbers etc.) while also posing a significant risk to steam turbines (Hirtz, 1990). Chloride contamination of steam contributes to stress corrosion cracking, corrosion fatigue and pitting of steam turbines (EPRI, 1999). Chloride is subject to volatile transport in steam generating systems and can be expected to be found in both dry and saturated geothermal steam.

The presence of sodium in steam can result in corrosion of the steam handling plant and steam turbines. Sodium deposits (as sodium chloride or sodium hydroxide) can contribute to stress corrosion cracking of steam turbine components (EPRI, 1999) and other steam plant equipment fabricated from stainless steels. Sodium compounds are not subject to any significant volatile transport under the pressures typically found in geothermal power plants, as such the presence of sodium in steam is usually the result of brine carryover with the steam.

Sodium chloride and sodium hydroxide are perhaps the most frequently found corrosive agents affecting the steam turbine blade path. The introduction of caustic contaminants into the water/steam cycle is attributed to the ingress of common salt (NaCl) into the system and the dissociation of this compound into sodium (Na) and chloride (Cl) ions, which can then recombine with ions of hydroxide (OH) and hydrogen (H) to form caustic sodium hydroxide and hydrochloric acid (HCl) (Saunders, 2001).

The presence of hydrogen sulphide in geothermal steam has corrosion implications for steam plant including both corrosion of carbon steel steam piping and sulphide stress corrosion cracking of steam turbine components (Takaku, 2004).

The design, materials of construction, as well as the required operating duty and expected life of the power plant all dictate the requirements for the desired level of steam purity in a geothermal power plant. The steam turbine (if used) will usually be the principal determinant of the required steam purity; alternately the steam-touched heat exchangers in a binary plant can be the determining factor.

## 2. FACTORS AFFECTING STEAM PURITY

The challenges in attaining the desired steam purity specification can vary between different geothermal power plants based on both the power plant design and the nature of the geothermal fluid that is utilised. As the design of the power plant influences both the required level of steam purity and the ability to achieve a given level of steam purity; it is essential that steam purity is considered during the design phase. This is to minimise operational issues associated with poor steam purity. The common factors that influence steam purity in geothermal power plants are shown in Figure 1 and described below.

### 2.1 Geothermal Fluid Chemistry

The nature of the steam source is perhaps the most significant determinant of steam purity in a geothermal power plant. Geothermal power plants utilising geothermal fluid from both vapour dominated and liquid dominated fields have reported steam purity issues (Van der Mast, 1986). Chloride contamination of steam has been reported as a common issue in vapour dominated geothermal fields producing dry steam and very low moisture steam (Hjartarson 2012). Silica contamination of steam is a common issue in geothermal power plants, and can be particularly severe in plants operating with geothermal fluids from high temperature reservoirs, especially if these plants are operating with relatively high pressure steam. Power plants operating with very saline brine such as that found in the Salton Sea, USA, geothermal field are likely to have high levels of chloride and sodium in steam even at low or moderate levels of brine carryover.

### 2.2 Volatility of Contaminants

The volatility of contaminants has a significant influence on observed steam purity in a geothermal power plant. Highly volatile contaminants that are present in geothermal steam (such as carbon dioxide, ammonia and hydrogen sulphide) can be impractical to remove from the steam flow. As these contaminants are gases under power plant operating conditions they do not deposit or form scales on steam plant, however hydrogen sulphide can contribute to corrosion of steel in the presence of moisture (wet steam).

Semi-volatile contaminants such as chloride, boron and silica may be present in geothermal steam without any moisture or brine carry-over. The vaporous carry-over of chloride, boron and silica is strongly influenced by pressure in two phase systems (flash plants) and also by fluid pH, which may increase volatile carry-over of semi-volatile contaminants in power plants using brine pH modification for scale control. Semi-volatile contaminants can be removed from the steam flow through condensation and the use of steam washing systems both of which are described below.

For example, as shown in Figure 2 the estimated $K_d$ (distribution co-efficient) for silica is approximately $3x10^{-4}$ for silica at 25 bar. For a geothermal fluid containing 1000mg/L silica the calculated vaporous carry-over of silica is:

$1000mg/L \times 3x10^{-4} = 0.3mg/L = 300\mu g/L\ SiO_2$ in steam

$300\mu g/L\ SiO_2$ in steam is above the recommended value for silica in steam from several geothermal steam turbine manufacturers. If this system also experiences mechanical (brine) carry-over then the level of silica in steam will be significantly escalated.

Contaminants which have very low volatility such as sodium and calcium are generally only present in saturated geothermal steam when there are brine droplets entrained in the steam flow. Low volatility contaminants can be removed from steam flows with effective moisture removal systems.

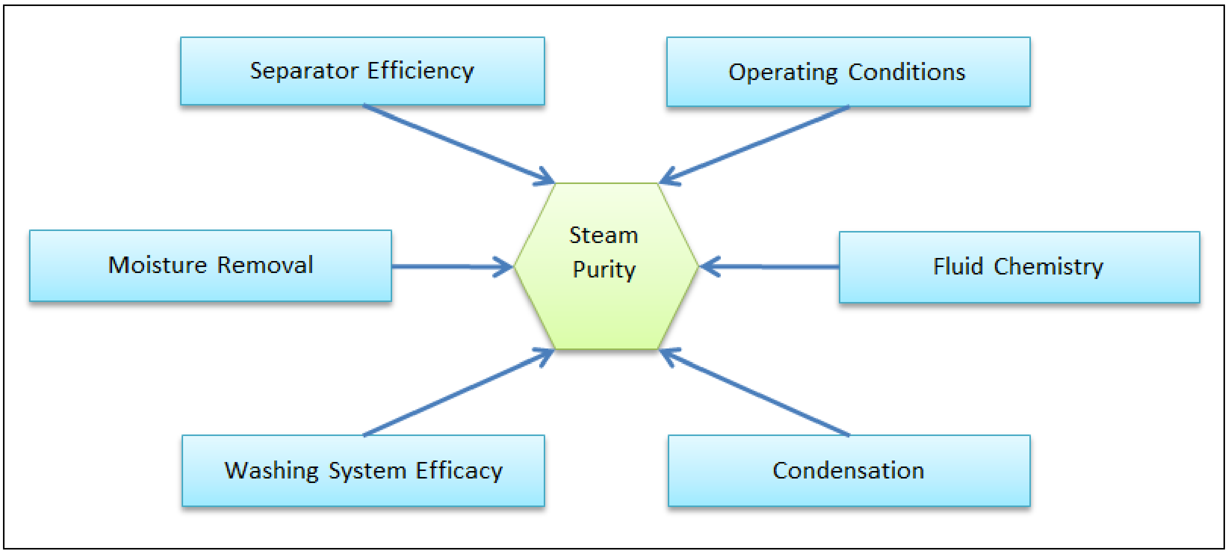


**Figure 1. Factors influencing steam purity**

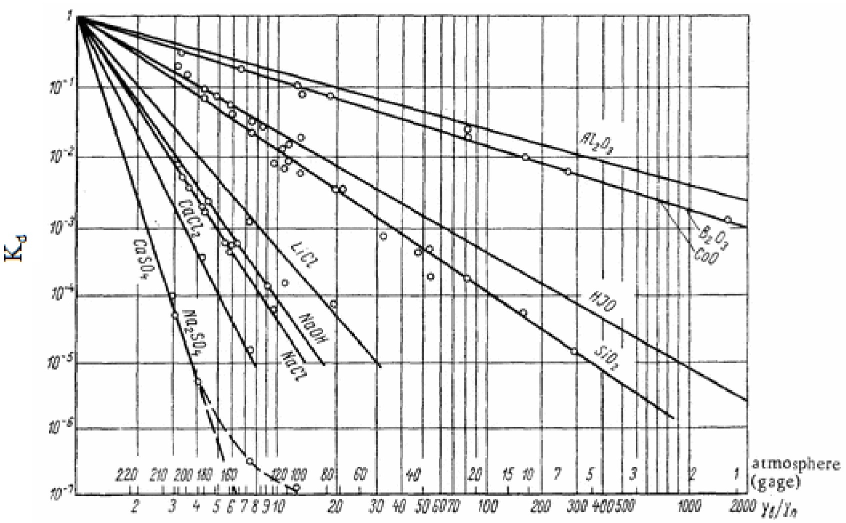


**Figure 2. Distribution co-efficients between water and steam of a selection of contaminants as a function of pressure. Note, $K_d=C_v/C_l$ (Modified From Styrikovich and Martynova, 1963)**

### 2.3 Separator Efficiency

For geothermal power plants utilising saturated steam the steam separator performance has a significant impact on the resulting steam purity. Brine that becomes entrained in the steam flow contains all but the most volatile contaminants that make up the brine composition. As previously mentioned the presence of these contaminants in the steam can result in severe damage to the power plant steam path.

A steam separator operating at 99.90% moisture removal will supply steam containing 0.1% brine (by mass). As such, species present in the geothermal brine will also be present in the steam at 0.1% of their concentration in the brine (ignoring volatile transport). For a geothermal fluid containing 2000mg/L of dissolved solids, the steam delivered from such as separator will contain 2mg/L of dissolved solids (again ignoring volatile transport). Geothermal steam containing 2mg/L of dissolved solids does not meet the steam purity specifications required by many steam turbine manufacturers. This highlights the importance of highly effective steam separators (>99.9% moisture removal) in achieving acceptable steam purity in a geothermal power plant.

### 2.4 Condensation

Condensation of steam occurs as heat is lost from the steam during transit from steam separators to its point of use (steam turbine or heat exchanger). As condensate is formed in the steam piping, semi-volatile contaminants that are present in the steam will partition in the condensate preferentially. If the condensate is removed from the steam flow through a series of drainpots (drop pots) along the steamline, this can lead to an improvement in steam purity. Power plants utlising longer steam pipes or scrubbing lines, particularly those using steam field separators are likely to experience significantly more condensation during steam transmission than plants utilising steam separators located at the power plant and the resulting shorter steam pipes.

### 2.5 Steam Washing System Efficiency

Steam washing systems can be used to improve steam purity. Steam washing systems at geothermal power plants usually involve the injection of water (wash water) into the steam flow which is followed by a moisture removal system. This method can be used to remove semi-volatile contaminants from the steam, as these contaminants will partition preferentially into the aqueous phase. A steam washing system may be used where natural condensation and moisture removal alone are not sufficient to produce the required steam purity. This may be the case in fields with particularly contaminated steam, or where steam separation takes place at the power plant, giving a much shorter steam pipe for condensation to occur when compared to a plant utilising steam that is separated in the field. In the case of steam contaminated with hydrochloric acid, sodium hydroxide may be added to the wash water to assist in its removal while also neutralising the resulting liquid prior to its removal through a moisture removal device.

### 2.6 Moisture Removal

Moisture removal systems play a key role in maximising steam purity in power plants utilising saturated steam. As low and semi volatile contaminants are concentrated in the aqueous phase, the removal of this phase from the steam also removes a significant amount of these contaminants. Moisture removal systems such as steam scrubbers, purifiers, demisters and condensate drop pots are generally used as a "polishing" step following steam separators while also removing condensation that has occurred during the steam transmission process.

## 3. IMPACTS OF STEAM PURITY

### 3.1 Corrosion of Steam Handling Equipment

Poor purity can lead to excessive corrosion of steam handling systems. The presence of HCl in wet steam can result in very rapid corrosion of carbon steel. The presence of $H_2S$ in wet steam contributes to the corrosion of carbon steel, however the resulting iron sulphide layers can minimise further corrosion of the parent metal. The presence of oxygen in the steam (via a wash water system) can significantly increase corrosion of steam handling equipment where hydrogen sulphide is present in the steam. It is suspected that this accelerated corrosion is due to the alternating REDOX potential caused by the continuous presence of hydrogen sulphide in the steam combined with the injection of oxygenated water through the wash water system. Corrosion of steam handling equipment has consequences for the useable life of both the steam handling equipment being affected by the corrosion and also for downstream equipment that is impacted by corrosion product transport such as steam strainers (blockages) and steam turbines (erosion and deposition).

**Figure 3. Corrosion damage on a geothermal steam pipe downstream of a wash water injection station. At this plant the wash water is oxygenated, while the steam contains hydrogen sulphide.**

**Figure 4. Corrosion product deposition within a high pressure steam strainer.**

**Figure 5. Iron sulphide deposition on steam turbine nozzles – the iron sulphides result from the corrosion of the steam path due to the presence of $H_2S$ and moisture.**

### 3.2 Steam Turbine Damage

Steam purity can have a significant impact on the reliability, efficiency and useable life of a steam turbine. Poor steam purity can result in erosion and corrosion related efficiency loss and failures of steam turbines.

The presence of deposit-forming material such as silica in the steam can result in significant deposits of the material in the steam turbine if the saturation level is exceeded. The solubility of silica in steam is pressure-dependant and, as the steam pressure drops, the solubility of silica decreases. This can result in silica deposits forming in the low pressure stages of a steam turbine. In geothermal power plants operating with saturated steam with elevated levels of silica, silica deposits often form at the turbine inlet and the high pressure stages of the turbine. This occurs as silica-laden moisture in the steam evaporates as the steam pressure drops, leaving behind the silica that is less soluble in the steam than it is in the aqueous phase. The formation of silica deposits in the turbine can result in reduced turbine output and efficiency as the cross section available for steam flow is reduced and the turbine surface profiles change.

Very severe silica deposition found in the high pressure stages and nozzles of the turbine can also result in solid particle erosion (SPE) of the steam turbine, as silica deposits form and detach from the turbine surface. The released solid silica flows through the turbine where it impacts on the turbine surfaces, resulting in erosion of turbine materials, i.e. thinning of the stationary blade trailing edges as shown in Figure 6. Solid particle erosion of turbine blades and nozzles results in reduced turbine efficiency and, if severe enough, requires the replacement of the damaged components. Several geothermal power plants utilise online turbine washing systems to remove silica deposits from the turbine inlet and high pressure stages. These systems can be effective at restoring lost turbine performance due to the silica deposition, however the silica deposits are washed through the turbine and contribute to solid particle erosion of turbine components.

**Figure 6. Solid particle erosion on HP and IP turbine nozzles as a result of heavy silica deposition and resultant transport through the turbine.**

**Figure 7. Severe silica deposits on a turbine casing (HP)**

**Figure 8. Metal loss suffered from a steam turbine due to hard silica deposits becoming wedged between the turbine rotor and casing.**

The presence of corrodents such as sodium, chloride and sulphate in steam can result in severe corrosion of steam turbine components. Online corrosion of steam turbine components may result from severe steam purity issues. However, corrosion during turbine shutdown periods may be experienced as a result of even minor excursions in steam purity. Offline corrosion of steam turbines often results when deposits of corrodents are exposed to wet, oxygenated conditions which results in corrosion pits developing (EPRI, 2009). Offline corrosion of steam turbines can be mitigated with the use of dehumidification systems (EPRI, 2009).

**Figure 9. Corrosion of a turbine rotor seal – note the silica deposition on the rotor blades.**

### 3.3 Heat Exchanger Fouling

Poor steam purity may result in the corrosion and fouling of heat exchangers in binary cycle geothermal power plants. While heat exchangers are generally considered more robust than steam turbines, excessive deposition within a heat exchanger can reduce heat transfer, increase pressure drop and result in a decline in power plant output until the heat exchanger is cleaned. Corrosion of the heat exchanger may result in leaks developing and either a loss of or contamination of the motive fluid – both of which are likely to result in a decrease in plant output until the heat exchanger is repaired.

### 3.4 Steam Path Maintenance and Repair

In order to assess the condition of the turbine steam path it is necessary to remove any deposits and carry out non-destructive testing (NDT) to detect cracks in steam path components. High stress areas such as blade roots, aerofoils and rotor discs are particularly susceptible to micro cracking. Blast cleaning with the appropriate media such as aluminium oxide or glass beads has been successfully used in the past to remove deposition. Therefore it is recommended that blast cleaning and NDT is part of every major outage scope to ascertain the condition of the steam path and identify any defect which may affect the operational life of the asset.

Defects found in vulnerable areas of the steam path have been successfully repaired by Inconel overlay welding or material inserts manufactured from Martensitic stainless steels. These repairs have been predominantly carried out in critical areas, including pressure seal faces and casing split faces. Stationary blades with eroded trailing edges have been built up through welding, or welding an insert, and re-profiling the blade. Due to the steam purity condition geothermal steam turbines are usually inspected every two to four years, often requiring major repairs and extensive outages.

## 4. MEASUREMENT OF STEAM PURITY

### 4.1 Frequency of Monitoring

Monitoring the levels of steam purity allows conditions that may adversely affect the steam turbine to be identified and corrective actions commenced. The more frequent the sampling, the more likely adverse conditions are to be identified, allowing corrective action to be taken in a timely manner. Infrequent sampling may lead to significant turbine damage as a result of adverse conditions going unnoticed as shown in Figure 10. The ability to sample both during normal station operation (base-load) and during departures from standard operating conditions (unit load swings, start-up, shut down, production well changes etc.) is highly valuable. Steam purity conditions can vary widely during non-standard operating conditions (e.g. increased carryover during load changes).

There are numerous parameters that may be analysed when determining steam purity, however monitoring of all potential parameters on a frequent basis is both time consuming and costly. For these reasons a selection of key parameters are usually identified and monitored frequently (preferably continuously) as reliable indicators of steam purity, while other parameters may be measured less frequently to provide more detailed steam purity information and confirmatory checks. Sodium is a common steam purity measurement as it can be used as a measure of brine carry-over in geothermal flash plants. Other common steam purity measurements include silica and chloride, depending on the nature of the steam purity issues experienced by the particular power plant.

### 4.2 Sampling of Saturated Steam

Representative sampling is necessary if steam sampling and analysis results are to reflect actual steam purity. Representative sampling of superheated steam without particulate impurities is relatively straightforward. Representative sampling for multi-phase systems such as saturated steam or steam with particulate matter entrained can be challenging. There are several methods for sampling multiphase steam systems described in the literature; the most appropriate method may be power plant-specific, depending on the individual characteristics of each plant.

### 4.3 Sample Conditioning

Conditioning of steam samples is required for analysis to be successful. Sample conditioning involves preparing the sample for analysis by controlling the sample temperature, pressure and flow rate. Sample conditioning is required for both manual (grab) sample collection as well as for online (continuous) analysis. The analysis of geothermal steam may also require that the steam is adequately degassed, as the dissolved gases often present in geothermal steam ($CO_2$, $H_2S$) may interfere with some analysis methods commonly used for the continuous monitoring of steam purity (such as colorimetric silica analysis and sodium analysis by ion selective electrode).

## 5. IMPROVING STEAM PURITY

Options are available to improve steam purity, where steam purity at a geothermal power plant is inadequate for reliable and efficient operation of the plant. Steam purity can be improved by addressing the factors that influence steam purity as described in section 2. The particular factors to be addressed may vary from plant to plant depending on the nature of the steam purity issues. Some examples of measures to improve steam purity are described below.

### 5.1 Separator Design

The performance of the steam separation system has a major impact on steam purity – as this is the point where brine can become entrained in the steam flow. High performance separators can reduce or even remove the need for other steam purity improvement measures where volatile contaminants are not problematic (such as some low pressure saturated steam systems). Several types of steam separators are used in geothermal power plants including horizontal steam separators with separation furniture, vertical steam separators with steam separation furniture and vertical cyclone separators (without steam separation furniture). The choice of separator design can be influenced by fluid chemistry, fluid composition and cost requirements. Steam separators are expensive components, however they have the largest influence on steam purity of any component in the steam handling system of a geothermal power plant utilising two phase fluid. As such a well-designed, maintained and operated steam separator is essential to achieving high purity geothermal steam. A comprehensive overview of the variety of separators used in geothermal power plants is provided by Jung (1989).

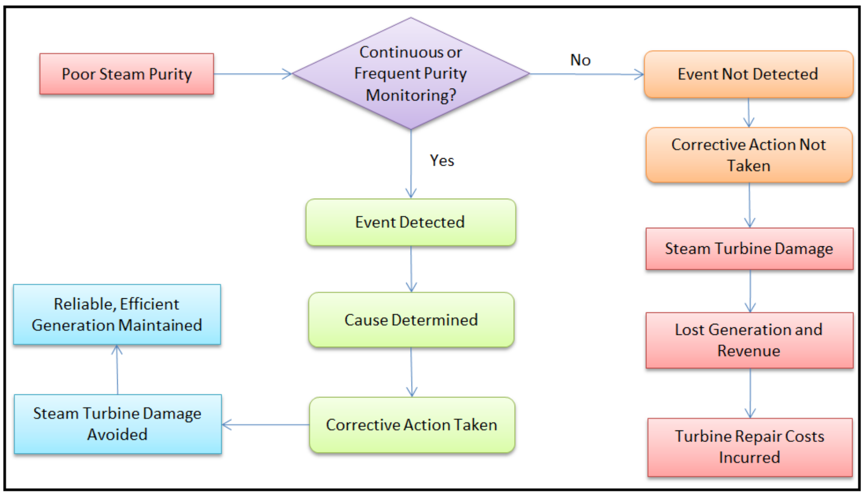


**Figure 10. Potential steam purity monitoring outcomes.**

### 5.2 Steam Washing Systems

Steam washing systems are utilised in many geothermal power plants to improve steam purity. Steam washing systems generally consist of one or more water injection nozzles where water is sprayed into the steam flow, followed by a moisture removal system (condensate pots, scrubbers or demisters) to remove the wash water and any condensed steam. Steam washing systems remove some usable heat from the steam (depending on wash water temperature and flow rate), resulting in the need for a slightly higher steam flow to maintain electrical generation.

Steam washing systems can be used to remove contaminants with a wide range of volatilities and are particularly common for the removal of both volatile chloride as well as entrained brine. In steam washing systems utilised for the removal of volatile chloride (HCl), sodium hydroxide (NaOH) may be added to the wash water. The addition of NaOH assists in the removal of chloride through the decrease in the partitioning coefficient of NaCl compared to HCl as shown below. The addition of NaOH also assists in reducing corrosion in the wash water/condensate-touched surfaces by neutralising any dissolved HCl.

$$HCl + NaOH \rightarrow NaCl \quad (1)$$

At 25bar operating pressure:

$K_d$ HCl ~ 1.88 (Calculated from Palmer, 2004)

$K_d$ NaCl ~ $1x10^{-5}$ (Estimated from EPRI, 2001)

$K_d$ NaOH ~ $1x10^{-6}$ (Estimated from EPRI, 2001)

Steam washing systems utilised to assist in the removal of entrained brine in the steam flow do so by increasing the size and mass of the brine droplets. Increasing the size and mass of the brine droplets makes them easier to remove through moisture removal systems such as drop pots and demisters. The same process can be used to assist in the removal of particulate matter/suspended solids from steam.

Steam washing systems can also be used to remove semi-volatile contaminants such as silica. The partitioning coefficient of silica indicates that the majority of silica in a two phase steam-water system is going to be present in the water phase, so by adding water to the steam, the silica will preferentially partition into the water phase and the water can then be removed by a moisture removal system. This results in a lower concentration of silica in the remaining steam as shown below.

This calculation of the potential effectiveness of a steam wash system is shown only to provide an example of how effective a steam washing system can be at removing semi-volatile contaminants (in this case silica) from a steam flow.

Using the conditions described in the example in section 2.2:

Pressure = 25 bar,

$K_d \sim 3x10^{-4}$

Steam = 300µg/kg $SiO_2$ ($C_v$ = 300 µg/kg)

And assuming:

Wash water = 0 µg/kg $SiO_2$

Wash water flow rate = 1% of steam flow such that;

$100C_v + C_l = 30{,}000$µg $SiO_2$

$C_l = 30{,}000 – 100C_v$

Then using $K_d = C_v/C_l$

$C_v = K_dC_l$

$C_v = 3x10^{-4} \text{ x } (30{,}000 – 100C_v)$

$C_v = 9 - 0.03C_v$

$1.03C_v = 9$

$C_v$ = 8.74 µg/kg $SiO_2$

$C_l$ = 29,126 µg/kg $SiO_2$

In this example the steam washing system has reduced the silica concentration in steam from 300µg/kg to less than 9µg/kg. A concentration of 9µg/kg $SiO_2$ in steam is considered acceptable for admission to steam turbines by a variety of international steam purity guidelines.

Note: These calculations assume that equilibrium is reached between the vapour and liquid phases.

It should be noted that incorrect operation of wash water systems can adversely affect steam purity if more contaminants are added through the wash water than removed by the moisture removal system. Incorrect selection of the wash water supply is a common cause of steam washing systems failing to improve steam purity and may also result in increased plant damage, such as when oxygenated water is used in systems utilising $H_2S$-laden steam.

### 5.3 Long Pipe Runs and Removal of Insulation

Long steam pipe runs and the removal of steam pipe insulation has also been observed to improve steam purity (Morris, 2001) i.e. development of scrubbing lines. Long pipe runs result in greater heat loss from the steam, as does the removal of steam pipe insulation, and as a result of this heat loss, a small proportion of the steam is condensed and becomes unavailable for generation. This process has a similar effect to the use of a steam washing system and depends on the agglomeration of moisture droplets for the removal of brine carry-over and on the partitioning coefficients of semi-volatile contaminants for contaminant removal. Effective removal of the condensate from the steam flow via a moisture removal system is required.

### 5.4 Moisture Removal

Improving moisture removal from saturated steam flows can enhance steam purity through the removal of both entrained brine (from separator carry-over) and condensate (resulting from heat loss during steam transmission). As steam is condensed in the steam handling systems the condensate will contain a higher proportion of contaminants with a partitioning coefficient <1 as described above. Moisture removal can be enhanced through addition of moisture removal equipment (drop pots, scrubbers and demisters) or enhancement of existing moisture removal systems. Enhancing the performance of existing moisture removal systems may require re-engineering of the systems which can incur significant costs. One observed method of improving moisture removal systems is the use of the boundary layer condensate drain pot (Jung, 1996) which essentially involves larger diameter steam piping immediately upstream of drop pots. This reduces steam velocities and turbulence in the section of pipe, reducing the amount of moisture entrained in the steam flow and also promoting pipe wall condensate to flow to the bottom of the pipe, allowing more effective operation of the drop pots.

### 5.5 Fluid Chemistry Changes

Steam purity can be improved by making changes to the chemistry of the geothermal fluid. Changes to the geothermal fluid to improve steam may not be practicable in many cases due to a variety of issues including alternative fluid supply and a reduction in enthalpy of the fluid. However, having sufficient flexibility in the steamfield as well as a comprehensive monitoring program to identify fuel supply variations and their relationship to reservoir performance may present opportunities to tailor production well mixes and optimize the resultant steam purity.

A geothermal power plant in New Zealand commenced injection of steam condensate into the two phase geothermal fluid upstream of steam separation. One impact of the condensate injection is the dilution of dissolved species in the geothermal fluid prior to steam separation. This dilution results in lower salinity brine (in the case of brine carry-over), while also reducing the volatile transport of semi-volatile contaminants in the steam (also due to the lower concentration of species in the brine).

## 6. CONCLUSIONS

Steam purity is an important consideration in the design and operation of geothermal power plants. Poor steam purity can result in significant plant damage, expensive repairs and lost generation. Steam purity can be managed through appropriate power plant design, especially of steam separators, steam pipelines and washing systems and moisture removal systems. Frequent monitoring of steam purity is recommended to identify changes in steam purity and to identify the cause of these changes such that corrective actions can be commenced as required.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge Mighty River Power for their support in the preparation of this paper. The authors would also like to thank Jeff Winick and Farrell Siega for their assistance in reviewing this paper.

## REFERENCES

Hirtz, P., Miller, J., Prabhu E.: Operational results of a dry-steam resource chloride corrosion mitigation system. *Geothermal Resources Council Transactions Vol. 14, Part 2. (1990).*

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.*

Jung, D.: An overview of geothermal separators. *Geothermal Resources Council Transactions Vol. 13, October (1989).*

Jung, D.: *Boundary layer condensate drain pot.* Patent US 5740917 A, USA (1996).

McCloskey, T., Dooley, R., McNaughton, W.: *Turbine steam path damage: theory and practice*. Electric Power Research Institute (EPRI), Palo Alto, USA (1999)

Morris, C., Bacon, L.: Turbine washing to remove nozzle deposition at Wairakei. *Proc. 23rd NZ Geothermal Workshop 2001.*

Palmer, D., Fernandez-Prini, R., Harvey, A.: *Aqueous systems at elevated temperatures and pressures.* Elsevier (2004)

Saunders, W.P.: *Turbine Steam Path, Maintenance & Repair*. Vol. 1 (2001) by PennWell Corporation.

Styrikovich, N., Martynova, O.: Contamination of the steam in boiling reactors from solution of water impurities. *Translated from Atomnaya Energiya, Vol.15, No 3, pp214-218 (1963)*

Takaku, H., Niu, L., Kawanishi, H., Takamura, N., Moma, K., Sakai, Y., Yamashita, M., Shiokawa, K.: Corrosion behaviour of steam turbine materials for geothermal power plants. *14th International Conference on the Properties of Water and Steam, Kyoto, Japan 2004.*

Takayama, K., Komiyama, N., Takahashi, Y., Shakunaga, N.: Silica scale abatement system on the Uenotai geothermal steam turbine. *Proc. World Geothermal Congress 2000, Kyushu – Tohoku, Japan. (2000).*

Van Der Mast, V., Goldman, E., Soo-Hoo, R.: Steam purity for geothermal power plants. *Geothermal Resources Council Transactions Vol. 10, (1986).*

*Cycling, Startup, Shutdown, and Layup Fossil Plant Cycle Chemistry Guidelines for Operators and Chemists.* EPRI, Palo Alto, CA: 2009. 1015657. (2009)

*The Volatility of Impurities in Water/Steam Cycles* EPRI, Palo Alto, CA: 2001 1001042 (2001)