

Steam Generation Using Produced Water: Lessons Learned

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PAPER NUMBER: IWC-09-36

KEYWORDS: Produced Water, OTSG, Evaporator, Steam Generation, SAGD

ABSTRACT: Produced water presents challenges for high-pressure steam production. Silica causes mineral scale formation on heat transfer surfaces. Volatile components not present in conventional boiler water distribute throughout the system. Field data on silicate scale formation and the distribution of volatile components in various Steam Assisted Gravity Drainage systems are presented.

INTRODUCTION

The steam assisted gravity drainage technique (SAGD) uses steam to stimulate the production of bitumen from the oil sands deposits of Alberta Canada. The technique uses a pair of horizontal wells bored into the oil containing formation. The upper bore is used to inject steam. The lower well bore, positioned directly below the steam injection line, continuously produces the heavy hydrocarbon called bitumen. The bitumen is extracted as a complex emulsion with water. The emulsion is broken and the produced water is treated for reuse in the steam generators. This produced water has a much lower purity than water commonly used to feed conventional boiler systems. High concentrations of silica and soluble organic species are present. Ammonia and sulfide ion are also regularly present. Special once-through steam generators (OTSGs) that can tolerate water of this purity are often used. Evaporators can also be employed to distill the produced water prior to the steam generators and produce boiler feedwater of a dramatically higher purity.

Extensive field work has been performed to characterize the produced water generated at SAGD facilities and study many of the unique problems that are encountered when the produced water is used for steam generation. Deposition of particulate matter and the formation of silicate scales in OTSGs are discussed here. Data on the distribution of several volatile species through evaporator systems used to purify produced water is also presented.

DEPOSIT FORMATION IN ONCE-THROUGH STEAM GENERATORS

Once-through steam generators for oil field use are designed to tolerate deposit formation as much as possible and to be relatively easy to clean by mechanical means. Even with these special design features deposit formation often limits the reliability of steam generation and the overall capacity of a facility to produce steam and oil. When deposits from OTSGs are analyzed two main components are commonly found. Coke (carbon) which is produced by the deposition of hydrocarbon or soluble organic species in the water is one component. Silica and silicate minerals are another major component of OTSG deposits. The silica in OTSG deposits may be found in an amorphous form, it may be present as quartz, or it may be found in the form of a wide variety of silicate minerals that also contain calcium, magnesium or iron. Regardless of their composition all deposits have a negative impact on steam generation. They insulate the heat transfer surface and can cause metallurgical failure due to overheating. A variety of corrosion mechanisms can be fostered at metal surfaces residing under deposits. Particulate matter in the boiler circuit or the release of deposit particles from tube surfaces may also have an impact on erosion of the boiler tube bends in the higher velocity sections of OTSGs. Limiting deposit formation is a prime concern of OTSG operators.

Studies were undertaken to gain a better understanding of the formation of silicate containing deposits in OTSGs. The studies were performed at a facility producing bitumen in Alberta. At this particular facility the produced water first passes through a train of de-oiling process units. The deoiled water is then treated with warm lime softening (WLS). The design purpose of the softener is to lower silica and hardness concentrations. The hardness is reduced mainly by the introduction of lime that increases pH and drives the precipitation of calcium carbonate. Magnesium oxide addition drives the silica reduction process through the precipitation of magnesium hydroxide/silicate. The precipitated solids settle with the aid of a flocculant chemical and are collected as sludge at the bottom of the vessel. Anthracite filters follow the lime softener to reduce suspended solids and weak acid cation exchange reduces hardness in the final boiler feedwater. The combination of the lime softener and cation exchange reduces silica concentration from about 200 ppm to around 20 ppm and total hardness drops from around 8 ppm to less than 0.3 ppm.

Once-through steam generators that produce steam at 10.2 MPa (1475 psig) are operated with a feedwater flow rate of about 150 m³/hr. Each steam generator has six passes nested together in groups of three. Each pass is a continuous mild steel tube that first travels through an economizer pre-heater section and then through a radial furnace. Water is forced through the pass with pumps and enters as a liquid. As the water flows through the pass boiling begins and the liquid is converted to steam. As water travels through the pass the percentage of steam in the fluid and the velocity of the fluid increase. At the steam pass exit the fluid might contain roughly 70% steam by weight, known as 70% steam quality. Manufacturer of the steam generator equips each steam pass exit with a sampling device that uses a combination of cyclonic action and baffles to reliably separate a small flow of liquid water from the vapor/liquid mixture. When operated continuously at the recommended flow rate these sample points are useful for measuring the chemistry of the liquid phase and controlling steam quality. In addition to collecting samples of the liquid at the steam pass exit, boiler feedwater was sampled just prior to the high-pressure pumps. Mass balance across a given steam pass may be calculated by measuring water impurities both prior to the steam pass and in the liquid water sample at the exit of the steam pass. This mass balance is expressed in terms of percentage transport for a specific water impurity. Percent transport for a given impurity is

defined as follows:

$$\text{Percent Transport} = \frac{100 (\text{concentration in liquid at pass exit} / \text{concentration in boiler feedwater})}{\text{sodium cycles of concentration}}$$

Where:

$$\text{Sodium cycles of concentration} = \frac{\text{sodium concentration in liquid at the steam pass exit}}{\text{concentration of sodium in the boiler feedwater.}}$$

Sodium is the most soluble, and thusly most inert, ion present in the water matrix. Normalizing impurity transport to sodium cycles of concentration corrects the transport for the evaporative concentration that occurs in the system.

Table 1 shows data from a silica transport study run while the OTSG was not treated with any antiscalant chemical. One set of samples was taken each day for 10 days and the analysis was performed using inductively coupled plasma atomic spectroscopy (ICP). The ICP analysis was performed on the sample as received and again after a portion of the sample was filtered through a 0.45 micron filter pad to remove any particulate matter. FW denotes concentrations in the boiler feedwater while Exit denotes concentrations in the liquid phase at one particular steam pass exit.

Table 1. Silica mass balance across a steam pass without antiscalant treatment.

Day	Na FW ppm	Na Exit ppm	Cycles	Steam Quality %	Total SiO ₂ FW ppm	Total SiO ₂ Exit ppm	Total SiO ₂ Transport %	Filtered SiO ₂ FW ppm	Filtered SiO ₂ Exit ppm	Filtered SiO ₂ Transport %
1	960	3500	3.6	73	19	62	90	20	64	88
2	770	2900	3.8	73	19	67	94	20	67	89
3	810	3000	3.7	73	20	70	95	20	69	93
4	840	2900	3.5	71	22	68	90	21	69	95
5	960	3400	3.5	72	30	99	93	30	99	93
6	940	3600	3.8	74	75	95	33	27	95	92
7	940	3600	3.8	74	26	94	94	27	95	92
8	750	2500	3.3	70	18	51	85	16	52	98
9	1000	4100	4.1	76	39	150	94	39	140	88
10	1200	4100	3.4	71	33	110	98	33	110	98
Average	917	3,360	3.7	73	30	87	86	25	86	92
Std. Dev.	133	530	0.2	1.7	17	29	19	7.2	27	3.6
						Avg without Day 6	92			
						Std. Dev.	3.7			

Silica concentration varies from day to day in the boiler feedwater due to changes in plant operation and the efficiency of the warm lime softening process. The results on day 6 stand out in the data set and are marked in red on Table 1. The day 6 data show that total silica concentration was 75 ppm in the boiler feedwater, but only 27 ppm was present after the sample was filtered, indicating that 48 ppm of silica was present in the form of particulate matter. On that day there was an upset in the operation of the warm lime softener that caused some of the floc that normally settles and is removed as sludge in the vessel to travel out of the softener with the overflow water. This sort of upset is fairly common in the operation of all lime softeners and can be caused by relatively rapid changes in flow rate, temperature or water chemistry. This problem is referred to as lime softener carryover. Anthracite filters are installed after lime softeners to ameliorate this problem but, as is often the case, they prove

less than 100% effective especially for magnesium silicate floc formed when magnesium oxide is added to reduce silica concentration in the lime softener effluent. The magnesium silicate floc can be present as very small particles that anthracite media filters cannot completely remove.

The wide ranging influence of lime softener carryover is further illustrated in Figure 1. Figure 1 shows data that was obtained from another lime softener carryover event at the same facility. This data was obtained by gravimetric analysis of 0.45 micron filter pads before and after passing 1 liter of sample water through the filter at the sample point of interest. This analysis yields a value for total filterable solids in the sample. Data from three days for three different sample locations are shown for comparison. It is clear that high concentrations of particulate matter were present in the system on day 2. The particulates originated in the warm lime softener and ICP analysis of water samples taken at the same time showed high concentrations of magnesium and silica present as particulates, a result consistent with lime softener carryover. The particulates carried over from the lime softener were somewhat reduced by the anthracite after filters but elevated filterable solids were present at every sample point downstream of the lime softener, even the medium pressure steam separator downstream of the OTSGs. Although elevated particulate concentration was detected at the medium pressure steam separator sample point there was clearly some loss of mass. The water present in the medium pressure steam separator has been concentrated by about 4 fold over the water at the outlet of the anthracite filters but the particulate matter is much lower indicating that a large portion of the particulate matter was lost somewhere between those two sample locations.

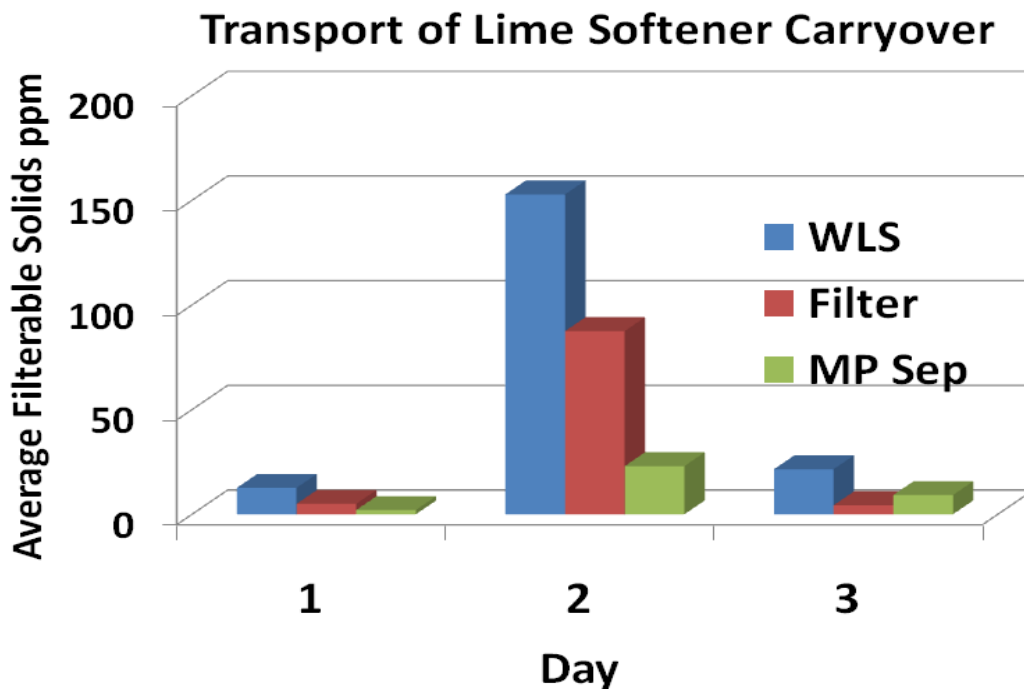


Figure1. Distribution of Lime Softener Carryover at a SAGD Facility.

Referring back to the data in Table 1 we can discover that particulates from lime softener

carryover are deposited in the OTSGs. Total silica transport during the lime softener carryover event on day 6 was only 33%. However, the transport of soluble silica was identical to the average for the entire study, 92%. Comparison of these two numbers indicates that the 48 ppm of particulate silica in the boiler feedwater deposited almost quantitatively in the OTSG. Particulate matter is known to have a high propensity to deposit in conventional drum boilers as well. Previous studies have shown that corrosion product particles are far more likely to form deposits on boiling surfaces in comparison to soluble iron species.¹ The extremely high scale formation rates for particulate matter indicates that a very strong focus should be placed on careful operation of the lime softening process to prevent carryover events. A disproportionate amount of the mineral scale that accumulates in an OTSG can deposit during relatively short carryover events as is discussed in greater detail below.

The transport of soluble silica is also not complete in the OTSG system in the absence of antiscalant treatment. Table 1 indicates that the average transport of soluble silica is 92%. This result is comforting in some sense since only 8% of the soluble silica in the feedwater is forming mineral scale in the OTSG. However, even this deposition rate can account for a very high mass of deposit over time as is discussed below.

A second study was undertaken while a polymeric antiscalant was in use at the same facility and that data is shown in Table 2. Experimental protocols were identical to the study that is summarized in Table 1 with percentage transport being calculated over a single pass in an OTSG. The soluble silica transport in this study was nearly complete averaging 99%, a good indication that the antiscalant was having a positive effect in the system. There were no significant lime softener carryover events during this study so no definitive comments can be made about the effect of the antiscalant on reducing the rate of particulate matter deposition in the OTSG. However, experience with particulate matter deposition in conventional drum boilers would suggest that even though dispersants can reduce particulate deposition rates we should not expect any dispersant to be 100% effective. Although dispersant treatments may prove to be useful in combating particulate deposition in OTSGs, maintaining low particulate concentration by vigilant lime softener operation will certainly remain the most effective way to prevent particulate deposition.

Table 2. Silica mass balance across a steam pass with antiscalant treatment.

Day	Na FW ppm	Na Exit ppm	Cycles	Steam Quality %	Total SiO ₂ FW ppm	SiO ₂ Exit Total	Total SiO ₂ Transport %	Filtered SiO ₂ FW ppm	Filtered SiO ₂ Exit ppm	Filtered SiO ₂ Transport %
1	1200	4000	3.33	70	12	35	88	11	34	93
2	1400	4200	3.00	67	15	48	107	15	47	104
3	1600	5200	3.25	69	22	72	101	21	72	105
4	2000	6800	3.40	71	35	120	101	34	120	104
5	2000	6700	3.35	70	29	95	98	28	91	97
6	1800	6200	3.44	71	23	77	97	22	76	100
7	1300	3800	2.92	66	14	42	103	14	42	103
8	1200	3600	3.00	67	15	40	89	13	39	100
9	1200	3500	2.92	66	14	41	100	14	39	96
10	1200	3600	3.00	67	16	43	90	16	43	90
Average	1490	4760	3.2	68	20	61	97	19	60	99
Std. Dev.	335	1345	0.2	2.1	7.6	29	6.5	7.4	28	5.3

Further illustration of the effect of the antiscalant treatment is evident in Figure 2. This plot presents the data in a way that provides further insight into the scale formation process. The y

axis of Figure 2 plots the soluble silica concentration at the steam pass exit divided by the cycles of concentration caused by evaporation of water in the OTSG. The x axis of Figure 2 plots the soluble silica concentration in the boiler feedwater. If there was no loss of mass over the OTSG pass we would expect the data presented in this format to fall on a line with slope = 1.0. In effect, that is what we observe for the system when antiscalant treatment is present. A regression fit has an R^2 statistical parameter equal to 0.988 indicating very good linearity ($R^2 = 1.0$ is a perfect line). The slope is actually slightly greater than 1 at 1.05, statistically identical to complete transport of soluble silica. Regression fit for the data set with no antiscalant treatment also shows good linearity ($R^2 = 0.978$) but the slope is less than 1 at 0.89 which would indicate 89% soluble silica transport in good agreement with the arithmetic average soluble silica transport for the data set of 92%.

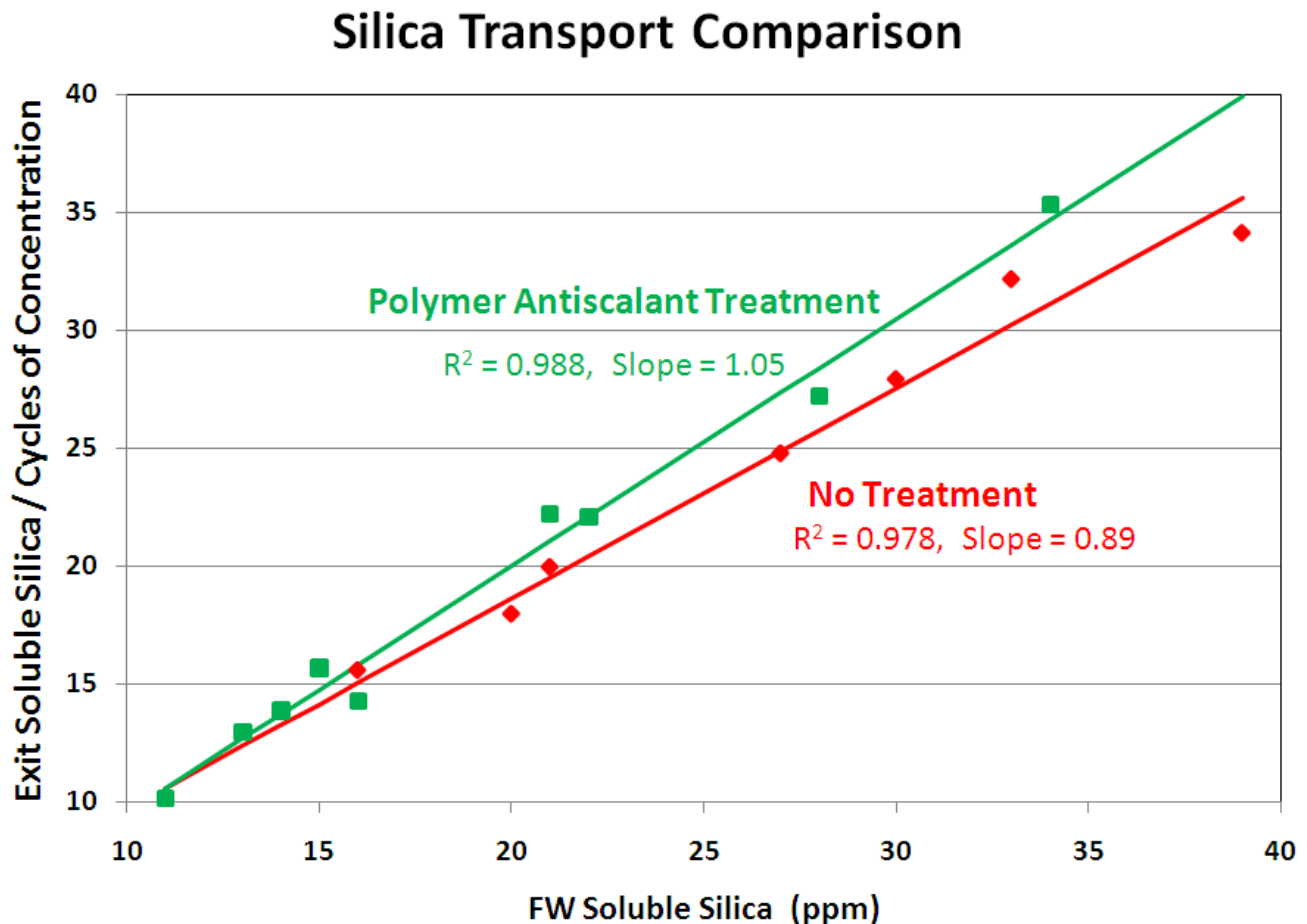


Figure 2. Comparison of Soluble Silica Transport With and Without Antiscalant

A basic feature of the data presentation in Figure 2 may have some bearing on the scale formation mechanism in OTSGs. The data presented in this format is, in fact, linear. There is no curvature that would indicate that soluble silica transport is worse at higher silica concentration. A constant percentage of soluble silica is deposited regardless of concentration over a wide range of boiler feedwater quality. There is no evidence that silica reaches some sort of solubility limit in this concentration range. The scale formation process may be governed more by kinetic considerations than by thermodynamic solubility equilibria. This

contrasts with most observations from conventional boiler systems that indicate scale formation and inhibition are governed by competitive chemical equilibria. The short residence time at temperature in OTSGs compared to the extremely long holding time in conventional drum boilers may account for this difference. If the rate of scale formation in OTSGs is governed by kinetic rather than thermodynamic considerations different scale inhibition mechanisms may function OTSGs in comparison to drum boilers.

Theoretical considerations aside, the linearity of this data has one very practical implication; increasing feedwater silica concentration in an untreated system will directly increase silica deposition rate while silica deposition rate in a treated system may remain near zero over a wide range of feedwater silica concentrations. The impact of incomplete silica transport through an OTSG is easily calculated based on the data presented above. The OTSGs in this study operate at a feedwater flow rate of 150 m³/hr. Even a small percentage of silica deposition can result in a large mass of scale deposited in the OTSG. Figure 3 plots the KG of silica deposited per day of operation in the OTSG studied here as a function of feedwater silica concentration and percent silica transport. Over these studies feedwater soluble silica concentration averaged about 20 ppm. At 92% transport that would mean about 5.76 KG of silica deposited each day or about 173 KG of silica deposited in the OTSG each month. With antiscalant treatment it appears that virtually all of that deposition could be avoided. During the lime softener carryover event it appeared that about 48 ppm of particulate matter was depositing in the boiler almost quantitatively (0% transport). That would produce about 172 KG of silica deposition per day. We find that a single day of lime softener carryover can produce the same amount of silica deposition as a full month of normal operation without antiscalant treatment. This emphasizes again the importance of smooth lime softener operation. Two additional points should be considered when evaluating silica deposition based on Figure 3. First, Figure 3 only considers the mass of SiO₂ but other ions especially magnesium are often deposited with silica in OTSGs as silicate minerals so the actual mass deposited will be greater. Second, deposition in OTSGs is commonly localized so that the mass of deposits is not evenly distributed over the entire heat transfer surface. The localized nature of deposition can greatly increase deposit thickness and the chance for a localized overheating failure of the boiler tube.

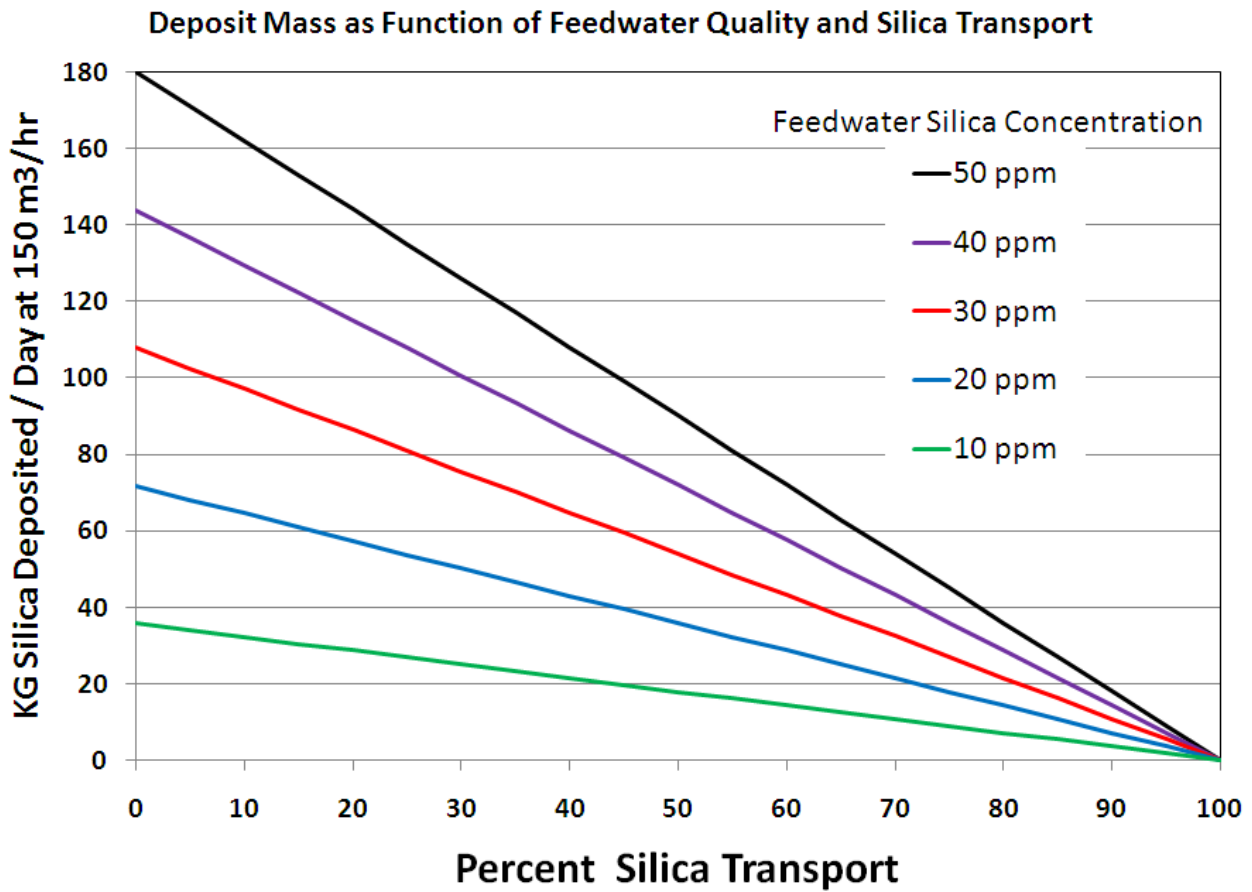


Figure 3. Calculated Silica Deposited in the OTSG as a Function of Feedwater Quality and Percent Silica Transport

DISTRIBUTION OF VOLATILE COMPOUNDS IN SAGD SYSTEMS

Produced water is quite different from the surface waters or shallow well waters that are used as the raw water source for most conventional steam generation. Produced water commonly contains high concentrations of salt and dissolved minerals. Water produced from the SAGD process contains particularly high concentrations of soluble organic compounds. The oil bearing formations in Alberta have been seen to contribute three classes of volatile impurities that may require some special attention, ammonia, sulfide and organics. Ammonia is added to many electric utility steam generators at low concentration as a pH buffer so its properties in steam systems are well characterized but this compound is present at high concentration in most SAGD circuits. The source of ammonia is uncertain at this time. Many deep aquifer formations in Alberta contain ammonia naturally. Oil treating chemistries or the diluent used in the emulsion breaking process could contain nitrogen that might decompose at high temperature to form ammonia. Sulfide is virtually never encountered in conventional steam generation operations but reduced sulfur species are plentiful in produced waters. Naturally occurring organics such as tannins, carbohydrates and protein are encountered in many surface water sources at concentrations of a few ppm due to biological activity. There is a good level of experience concerning the interaction of these naturally occurring organic materials with water pretreatment devices and their decomposition products in boilers are relatively well known. However, the produced water at SAGD facilities commonly contains soluble organic species at concentrations of several hundred ppm. The general chemical classifications of these organics are known to some degree but their fate in boiler systems is more uncertain.

The distribution of volatile species was measured at a second SAGD site. This system uses a two stage evaporation process to prepare water for conventional drum boilers and the distribution of volatile components in this system provides an excellent example of what can be expected when vapor/liquid partition occurs with produced water. The temperatures present in evaporators are much lower than those present in steam generators. The temperature differences influence not only the vapor/liquid partition of volatile components but their overall thermal stability. Samples were obtained for the evaporator feedwater, the distillate from both stages of evaporation and the sumps of both evaporators plus several points in the boiler circuit. Samples for ammonia tests were fixed for later analysis by adding ultrapure nitric acid to the sample container. Sulfide was determined by adding zinc chloride to the sample container. The zinc precipitates sulfide ion as ZnS which is stable in the solid state for long periods of time. Total sulfur was then determined for the samples before and after filtration by ICP analysis. The difference between the unfiltered and filtered sulfur concentrations is assumed to be sulfur that was initially present as sulfide ion and precipitated by the zinc. Total organic carbon testing was used as a measure of soluble organic material. Sodium analysis was performed by ICP as a reference for evaporative concentration. This data is presented in Figure 4.

Distribution of Volatiles In 2 Stage Evaporation

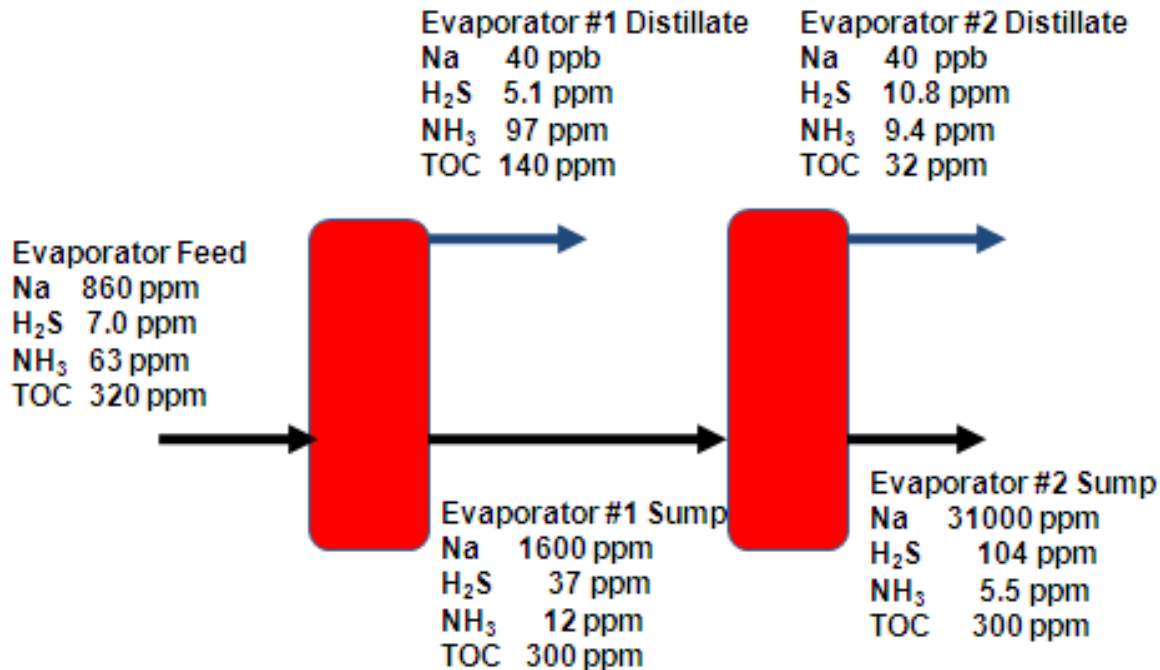


Figure 4. Distribution of Volatile Species and Sodium in an Evaporator System.

One striking feature of this data set is the exceptional performance of the evaporators for removing non-volatile ionic species. Sodium in the evaporator feed is 860 ppm but only 43 ppb in the combined distillate representing a carryover of only 0.005%. From the standpoint of non-volatile salts this water is certainly fit for the purpose of producing high-pressure steam. The exceptionally high purity of the water in terms of common salts means that the conductivity of the water in the boiler circuit is largely determined by the volatile components.

The ammonia concentration entering the evaporators is about 63 ppm. This volatile species partitions into the gas phase strongly at every opportunity so that the concentration is diminished only slightly to 53 ppm when the distillate from both evaporator stages is blended to produce the boiler feedwater. Most of the ammonia entering evaporator#1 is stripped into the gas phase and is found in the distillate. The vapor/liquid partition coefficient for evaporator #1 is about 8.1 and consistent with that expected for ammonia under those conditions. The stream entering evaporator#2 is highly depleted in ammonia, but what remains still partitions into the distillate with a vapor/liquid ratio of about 1.7. This value seems rather low given the high pH and the relatively low temperature in the unit. The extremely high concentration of salts and organic material in the sump of evaporator #2 may influence the partition of ammonia. The ammonia in the boiler feedwater also strongly partitions into the steam. The vapor/liquid partition ratio is about 3.75 in close agreement to what is expected for boilers at this operating pressure (6.2 MPa, 900 psig). The ammonia vapor/liquid partition coefficient decreases as temperature increases. The high-pressure steam contains 60 ppm NH₃ virtually the same concentration of ammonia as the evaporator feedwater.

When ammonia gas dissolves in water it creates ionic species in the following reaction.



In the absence of non-volatile salts high concentrations of ammonia will dominate the overall electrical conductivity of the water. Most of the ammonia travels with the gas phase during steam generation and causes the conductivity of fully condensed steam samples to be higher than the conductivity of the boiler blowdown. This can be a very confusing observation for boiler operators who are accustomed to waters where the conductivity is solely due to the presence of non-volatile ionic salts such as NaCl. Figure 5 illustrates this phenomenon.

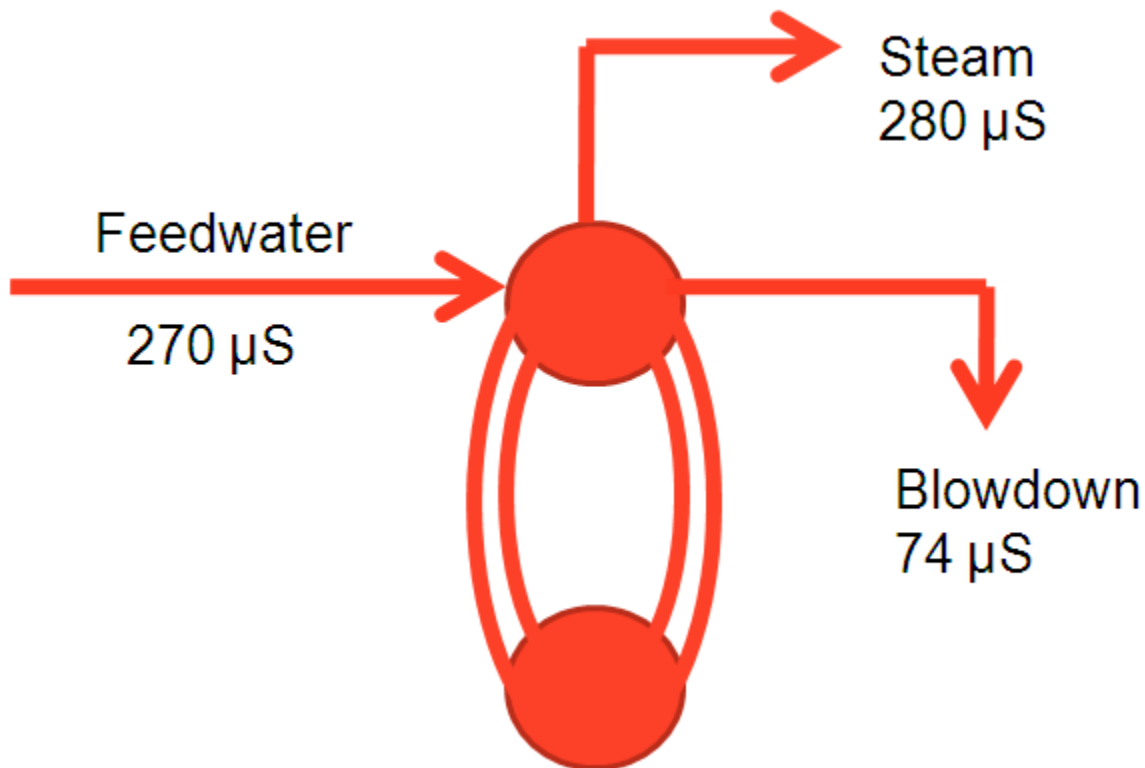
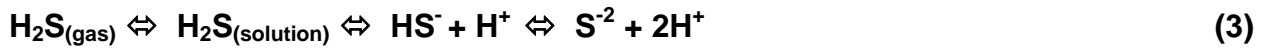


Figure 5. Conductivity in the Steam Generation Circuit (Conventional Drum Boilers).

Ammonia can cause corrosion of copper alloys but SAGD systems generally employ all ferrous metallurgies in the steam generation circuit. Evaporators provide great reductions in carbonate/bicarbonate alkalinity but in SAGD systems with warm lime softening ammonia has caused a special problem in combination with carbon dioxide in the steam system. In dry deadlegs of steam lines where some cooling occurs ammonia can combine with water vapor and carbon dioxide to form solid ammonium bicarbonate. This material has clogged pressure transducer lines in some SAGD systems



Sulfide testing confirms that a large portion of the sulfur present in the system is in the form of sulfide. Hydrogen sulfide has two acid dissociation equilibria.



In the pH range found in this produced water evaporation system almost all of the sulfide in solution will be present in the form of the HS^- anion. The HS^- anion is not volatile and would not partition into the gas phase but even at high pH there will still be a small concentration of H_2S in solution. The neutral H_2S molecule can easily migrate into the gas phase and leave the liquid. In flowing systems that separate gas and liquid phases, such as evaporators and boilers, any H_2S that partitions into the gas phase is quickly drawn away from the liquid. This situation is quite different from the static chemical equilibrium that would be found in a closed vessel with no flow. When H_2S is drawn away in the gas phase the chemical equilibrium in solution shifts to replace it (Le Chatelier's principle) and the process continues. The combination of the different chemical equilibria and flow establish a steady state that can allow a surprisingly large portion of H_2S to be transferred into the distillate or steam even at a relatively high pH.

Roughly half of the sulfur entering the evaporators appears to be in the form of sulfide. Interestingly, the balance seems to shift substantially in evaporator#1 with about 62% of the sulfur in the sump being precipitated by zinc and presumably in the form of sulfide. There is actually about 5.3 times as much sulfide in the evaporator #1 sump compared to the concentration in the evaporator feedwater. However, the inert sodium ion only concentrates by a factor of 1.9 times in evaporator#1. These results appear to indicate that sulfide is actually formed in evaporator #1 perhaps from decomposition of sulfur containing organic species. The vapor/liquid partition ratio in evaporator #1 for sulfide is about 0.2 but due to the high flow rate of the distillate much of the mass of sulfide will still be transferred to the distillate. The higher pH of evaporator #2 suppresses the volatility of H_2S even more and the vapor/liquid partition ratio in that vessel is about 0.1. By contrast the H_2S present in the boiler feedwater is much more volatile due to the lower pH and higher temperature in the boiler drums. A vapor/liquid partition ratio of about 7.5 is noted for H_2S in the boilers.

Iron sulfide minerals have been found in the boiler circuit at this site. This is evidence that sulfides carried over from the evaporator may be causing corrosion. Sulfide corrosion is not a new phenomenon. It is well known in oil refining and transport systems but it is essentially unheard-of in the context of boiler water chemistry. The presence of sulfides may need to be addressed in some SAGD systems. Sulfide can be destroyed by scavenging or oxidation. It can be precipitated as a solid and separated from the liquid or sulfide corrosion can be addressed with chemical inhibitors. H_2S can also be removed from the system in the gas phase and handled with a vapor treatment system. The best approach is governed by the design of the specific plant.

Produced water at SAGD facilities contains very high concentrations of dissolved organic species. The majority of these compounds appear to be carboxylic acids. They may precipitate from solution if the pH is lowered or if the temperature of the water is reduced. In evaporators these carboxylic acid compounds tend to be non-volatile and they accumulate in the evaporator sumps. However, total organic carbon is also high in the distillate samples and seems to preferentially partition into the steam when it enters the boilers. These organic compounds have been analyzed by purge and trap gas chromatography/mass spectroscopy

testing. Preliminary results indicate certain light aromatic compounds are present along with ketones and phenols. It would appear that none of the compounds identified at this time would present a serious risk for corrosion of the steam system piping. No small organic acids such as formic, acetic, propionic or glycolic acid, the common decomposition products of naturally occurring organics found in surface waters, were detected in the steam or distillate samples.

CONCLUSIONS

Extensive work has been performed to characterize the water chemistry in SAGD systems. Studies on silicate scale formation in OTSGs have shown that particulate matter is much more likely to form deposits than is soluble silica. Preventing lime softener carryover events thus gains a heightened importance. Mineral formation from soluble silica can be prevented with the use of proper antiscalant chemistries. Even small percentage losses of soluble silica over steam generator passes can account for large weights of silicate deposits. The distribution of volatile components in a SAGD system using evaporators for the production of boiler feedwater was studied. The evaporators produced an excellent quality of distillate in terms of non-volatile salts but the boiler water still contains significant concentrations of ammonia, sulfide and organic compounds. The ammonia and organic compounds appear to be largely benign in evaporator systems but sulfide may require removal or chemical treatment to prevent sulfide corrosion in the boiler circuit.

REFERENCES

1. M. R. Godfrey and T. -Y. Chen, "Monitoring corrosion in boiler systems with colorimetric tests for ferrous and total iron", **Corrosion**, 51(10), pp 797-804, 1995.