

**Discussion for IWC-09-36:
Prepared Discussion For:
Steam Generation Using Produced Water: Lessons Learned
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Thank you Mr. Godfrey for presenting the field data collected from studies of OTSG and Evaporator boiler systems utilizing produced water for boiler feedwater in SAGD operations. The produced waters that are recovered with the thermal insitu (SAGD, steam assisted gravity drainage, or CSS, cyclic steam stimulation) oil processes definitely provide water treating challenges leading to scaling and volatilization of contaminants within boiler tubes. Being better able to understand the potential for boiler feedwater contaminants to scale, volatilize, and/or transport through a boiler is critical knowledge for operators to gain, so one can ensure that proper treatment processes and designs are implemented to protect the Boiler Equipment and Reservoir long term.

The questions posed in this discussion will focus on enhancing the information presented in the paper through comparison to my knowledge and experience gained from the thermal insitu operations at the CNRL Wolf Lake Facility in Alberta, Canada.

Boiler Water Contaminants

Produced waters cycle up with many contaminants and treated boiler feedwaters can have up to 10,000 ppm TDS (total dissolved solids). Contaminants referred to by the author are “high concentrations of silica and organic species” in the resultant boiler feedwaters. One other main contaminant worth mentioning is the high concentrations of chlorides. The authors comment that “ammonia and sulfides are also regularly present” requires further clarification and investigation as I do not know of many produced water streams that have ammonia present. How has this regularity of ammonia been determined? How many sites have ammonia in produced water that you know of? What test method was used to determine the ammonia presence?

Deposit Formation (Scale)

Scaling due to contaminant precipitation on the boiler tubes occurs due to the fact that “each contaminant has an established solubility in water and will precipitate when it is exceeded”¹. As the water travels through the once through steam generator, the water percentage decreases as the steam percentage increases to 75% - 80% which cycles up the amount of contaminants in the 20 to 25% water phase at which point many contaminants precipitate out on the boiler tubes in the higher heat flux zones.

In the authors study, “when deposits from OTSGs are analyzed two main components are commonly found”. The first main component being “coke (carbon) which is produced by the deposition of hydrocarbon or soluble organic species in the water”. Although the carbon in the scale deposit could be from an inorganic source (injected with chemicals

added to the water and not from the oil separated from the water). How can you definitively determine that the carbon in the scale deposited was from an organic source and not from an inorganic source?

Whereas the second main component found by the author was the “silica and silicate minerals”. How have you been able to derive that the silica and silicate minerals are the second major component of OTSG deposits?

In contrast, in my experience silica and silicate minerals make up to 90% of our scale deposits in our OTSG boilers and carbon is only a fraction which may make up to 20% of the deposit or not be present at all. As well, we also have experienced another main component in scale deposits which are forms of iron oxide precipitates: iron oxides, magnetite, and corrosion products – amount varies % wise.

BFW Transport Study in OTSG

In regards to the authors comments about “limiting deposit formation” being a prime concern of OTSG operators this is a debatable topic. As there are two sides that must be considered, one side being the boiler tube and heat transfer reduction while the other side being the affects of transporting the water contaminants to the reservoir. As the scale deposits on the tubes it acts as an insulator not allowing heat from the boiler gases to transfer to the water, thus “this heat resistance results in a rapid rise in metal temperature to the point at which failure can occur”¹. As an operator, one must be cognizant of the boiler tube scaling rates and ensure the boiler is taken down for cleaning as required to not allow boiler tube failures from the scale during operation. This downtime costs the operations in steam which is undesirable.

In contrast, one can use boiler feedwater transport chemicals to try to transport all of the water contaminants through the boiler out to the reservoir in the steam condensate. Thus, minimizing the scale deposition and heat transfer loss in the boiler. But, one must then be cognizant of the silica forms in the water phase as the author states “the silica...may be found in 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.” As found by research done by Bowman et al., “amorphous silicates are porous” but “the problem is the metal silicate scales (iron silicate) which can form impermeable barriers” and “often the silicate scales are within a few feet of the production wellbore (due to steam flashing) and can plug off the producton interval, thus requiring redrilling of the well”². Operationally the cost to redrill a well far outweighs the cost to clean a boiler periodically due to scale deposition if metal silicates are commonly deposited in the boiler tubes.

So as an operator, one will need to determine if transporting any or all of the water contaminants will be beneficial or detrimental to their operation.

Questions regarding the boiler feedwater transport study performed in the OTSG as presented in this paper:

1) In regards to the authors comment, “the exit of each steam pass is equipped with a sampling device that separates the liquid water from the vapor/liquid mixture”

In my experience, the sampling of a saturated steam sample is very subjective and can at times be very inaccurate if the sampling flow rate is not held around 1 L/min flow rate.

What type of sampling device is utilized at this facility?

Are you able to provide a sketch of the sampling device setup?

Was the sampling flow rate held constant when samples were taken?

If so what sampling flow rate was used?

2) In regards to the authors comment “sodium is the most soluble, and thusly most inert, ion present in the water matrix”

In my experience, sodium can be found at times in our OTSG scale deposits and that chloride cycles of concentration should be the more stable ion to utilize for determining percent transport through the OTSG.

Did you compare the results obtained for percent transport to other ion cycles of concentrations like chlorides, silica, iron, to see what the variance was when using other ions instead of sodium?

It would be beneficial to provide more than the sodium for comparison – can you provide this or could you provide the detailed water analyses of the boiler feedwater and the steam condensate water so that one could compare the differences in the transport percentages in this trial?

Other ions like silica or iron could be utilized to calculate percent transport but, our experience has found that silica and iron are not reliable to utilize:

Silica:

one must remember that the silica ion vaporizes partially into the steam phase – so you must calculate the portion of silica vaporized

and that sometimes scale flakes off so you get spikes of higher silica transporting out (since scale is mostly made of silica)

Iron:

iron testing methods do not work very well in produced waters. And iron will be higher coming out if corrosion is occurring in the boiler tubes.

3) In regards to the data presented on the trials presented in Table 1 no chemical and Table 2 with transport chemical

Which BFW transport chemical was trialed?

Was this data captured from the same boiler?

Was the boiler(s) cleaned prior to each of the trials?

If not, what state was the OTSG at in terms of cleanliness (how many months till boiler was to be cleaned)? And how much scale was already deposited thickness wise on the tubes? Is there tubewall thermocouples in place that you could provide temperatures so that one could backcalculate and determine the scale thickness already in place on the tubes?

If was not cleaned prior to the trials, then how can you definitely prove that the increase in silica transport with the addition of BFW transport was not due to the transport chemicals ability to remove silica from the scale already built up in the OTSG tubes?

4) Trial length

In my experience, a 10 day trial is not a long enough trial period to prove/disprove the effectiveness of the transport chemical – one needs to run the trial over a boilers cleaning frequency timeframe (which can be from less than a year to over 3 years depending on the OTSG operation and target steam quality) and then compare results.

We have also experienced a change in scale deposition depending on the steam quality targeted – less scale develops at 65 % steam quality (can extend cleaning intervals out to 2 to 3 years timeframe) as we increase closer to 75-80% range (cleaning intervals have reduced to 10 months timeframe)

Are you thinking of retrialing the test trials at the same average quality – as is a 5% difference (73% versus 68%) in the average qualities during the no chemical and chemical trial runs?

5) Silica Volatility and Distribution Ratio

One needs to correct for the amount of silica that vaporizes into the steam phase as are operating over 900 psig pressure. “Distribution Ratio of Silica – at just below 1500 psia the distribution ratio of silica in steam to silica in boiler water is around 0.0055”³.


If the silica distribution ratio is applied to the trial data supplied increases the transport % slightly as per modified Tables 1 and 2 columns below:

Table 1. Variance in % transported (modified for silica to steam ppm amount included)

Day	Cycles	Total SiO2	Total SiO2	Total SiO2	Total SiO2	Total SiO2	% Variance
		FW ppm	Water ppm	Steam ppm	Transported	Transported (no steam portion)	
1	3.6	19	62	0.341	91.14	90	1.14
2	3.8	19	67	0.3685	93.31	94	-0.69
3	3.7	20	70	0.385	95.11	95	0.11
4	3.5	22	68	0.374	88.80	90	-1.20
5	3.5	30	99	0.5445	94.80	93	1.80
6	3.8	75	95	0.5225	33.52	33	0.52
7	3.8	26	94	0.517	95.66	94	1.66
8	3.3	18	51	0.2805	86.33	85	1.33
9	4.1	39	150	0.825	94.32	94	0.32
10	3.4	33	110	0.605	98.58	98	0.58

Table 2. Variance in % transported (modified for silica to steam ppm amount included)

Day	Cycles	Total SiO2	Total SiO2	Total SiO2	Total SiO2	Total SiO2	% Variance
		FW ppm	Water ppm	Steam ppm	Transported	Transported (no steam portion)	
1	3.33	12	35	0.1925	88.07	88	0.07
2	3	15	48	0.264	107.25	107	0.25
3	3.25	22	72	0.396	101.25	101	0.25
4	3.4	35	120	0.66	101.39	101	0.39
5	3.35	29	95	0.5225	98.32	98	0.32
6	3.44	23	77	0.4235	97.86	97	0.86
7	2.92	14	42	0.231	103.30	103	0.30
8	3	15	40	0.22	89.38	89	0.38
9	2.92	14	41	0.2255	100.85	100	0.85
10	3	16	43	0.2365	90.08	90	0.08

Day 2 and Day 4
 seem to not be calc'd right
in original table?

6) In regards to the authors comments “we find that a single day of lime softener carryover can produce the same amount of silica deposition as a full month of normal operations without antiscalant treatment”

It seems key that the insoluble species from a lime softener carryover creates the largest amount of scale in the boiler tubes in a short period of time. Yet this trial of the transport chemical did not see such an upset condition to truly be able to compare the transport chemical’s ability to the no chemical trial case.

Have you determined/tested to figure out what the insoluble species was and whether or not the transport chemical can in fact transport this form of silica or insoluble particulate?

Would one be able to add enough transport chemical to mitigate the insoluble species deposition when it occurs?

Are you going to be repeating the BFW transport test trial so that you can prove/disprove the effectiveness of the transport chemical during a lime softener carryover upset condition as was experienced in the no chemical trial?

Evaporation

Volatility of contaminants (ammonia, sulfide, and organics) found in boiler feedwaters resulting from produced water treatment are becoming more apparent as the evaporator is being used to purify the produced waters at new thermal insitu SAGD sites. These volatile components affects need to be studied further and accounted for in new system designs as new scales (ammonium carbonates) and corrosion issues (sulfide corrosion) are arising that need to be dealt with.

Questions regarding the volatility of the produced water contaminants (ammonia, sulfide, and organics) in the Evaporation system as presented in this paper:

- 1) In regards to the authors comments "...but produced water at SAGD facilities contains soluble organic species at vastly higher concentrations"

What level of soluble organic species are you referring to concentration wise being vastly higher to what reference level?

- 2) Where is the ammonia originating from – is this truly from the reservoir formation or a byproduct from decomposition/breakdown of upstream injected chemicals?
- 3) In regards to the authors comments "iron sulfide materials have been found in the boiler circuit at this site"
Iron sulfide is a safety concern when handling equipment during shutdowns – what extra precautions does this site undertake during shutdowns of the system?
- 4) In regards to the authors comments "H₂S can also be removed from the system in the gas phase and handled with vapor treatment system"
What vapor treatment system would you recommend?
- 5) In regards to the authors comments "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."

The lack of common decomposition products would this suggest that the carbon species are not from the formation (oil separation process) but from another source - which could be being injected with impure chemicals in the treatment process perhaps? Or why do you think this is?

Conclusion

This paper is an excellent presentation of trial work done to determine the effectiveness of transport chemistry in OTSG's and the volatile species in evaporation for boiler feed waters from produced water source. It would be beneficial to repeat the OTSG transport study for a longer timeframe (up to a year) to see the additional effects of lime softener upsets on the BFW transport chemical in the system. Ideally if the transport trial could be done at varying steam quality ranges to see what effect a change of 5% steam quality has on the scale deposition rates in the OTSG. Determination of the silicate scales formed, amorphous, quartz, or metal silicates, would allow an operator to determine if complete transport of silica species to the reservoir would be beneficial to the boiler heat transfer wise or detrimental to the wellbores. As well, further clarification of the source of the carbon (organic or inorganic) and volatile (ammonia, sulfide, organic) species would allow operators the needed information to be able to figure out ways to remove or mitigate the scaling or corrosive tendency of the species prior to OTSG boiler or evaporator.

References

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- 3 Nooter Eriksen, 2002 HRSG Conference, Silica Volatility Distribution Ratio Graph, Water Chemistry Section.