Water Treatment Processes for Oilfield Steam Injection

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Steam Injection requires Water Treatment

- Thermal recovery processes, such as steamflooding, cyclic steam, and Steam Assisted Gravity Drainage ("SAGD"), require water to be boiled.
- This "feedwater" must be treated, to either prevent, or reduce, the formation of scale, corrosion, and other harmful effects.
- This presentation is an "overview" of water treatment methods that are, or have been, used for thermal injection projects around the world.
- Water treatment methods often differ between countries/regions of the world, but, with some exceptions, don't differ much within a region.
- Treatment of oilfield produced waters for purposes other than steam generation also will be *briefly* discussed.

This presentation is an update of my 2009 overview paper: World Heavy Oil Congress 2009-0411.

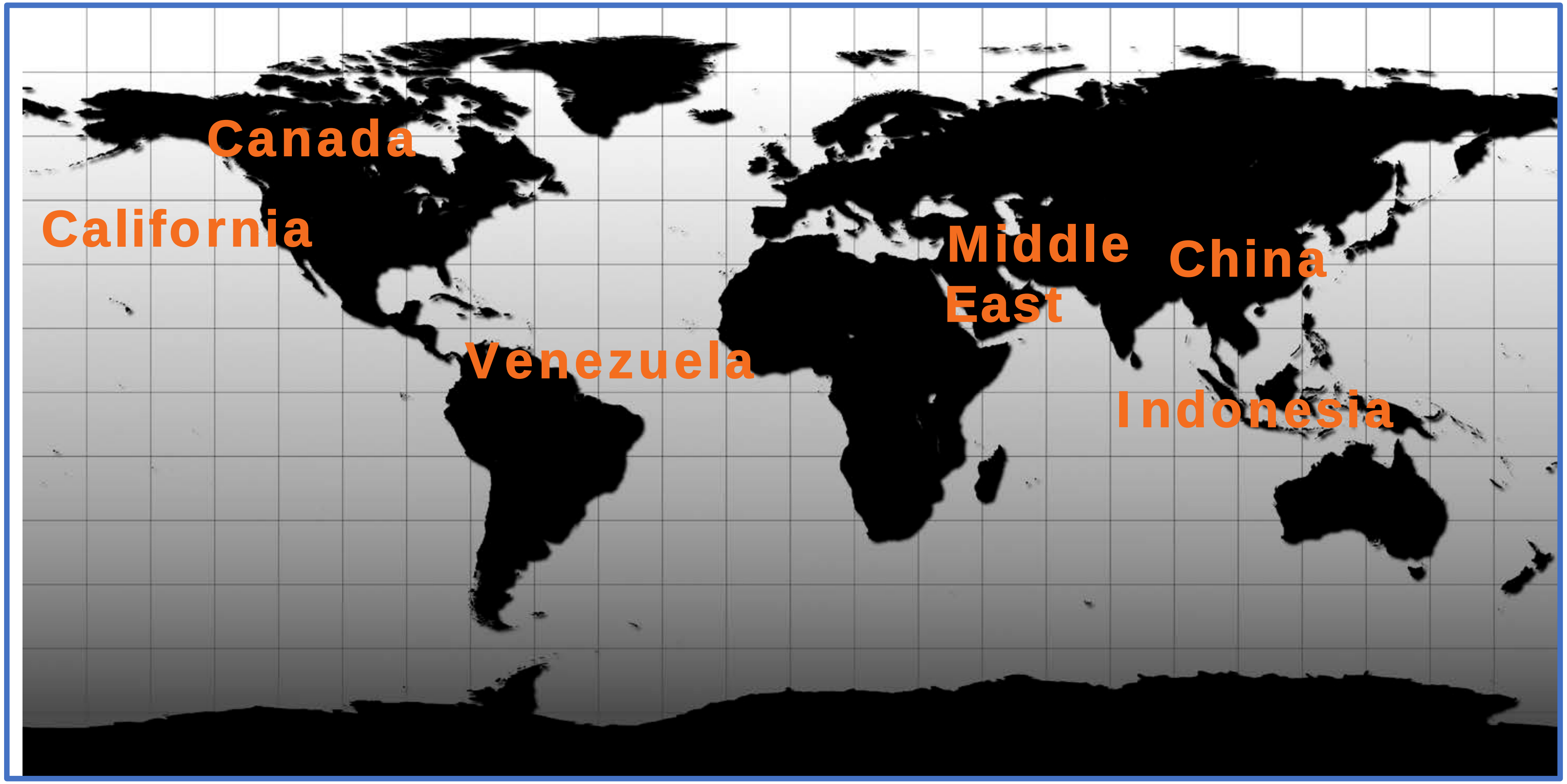
Water Treatment for Steam Generation

- Unique characteristics of each water, the requirements of the steam generation process to be utilized, the desired steam quality, and regulatory requirements should all be considered, when selecting water treatment processes for a new steam injection project.

------ IN OTHER WORDS ------

- Don’t choose the best water treatment process;
- Don’t choose the best steam generation process;
- Choose the best overall combination of water treatment and steam generation processes, to serve the requirements of the reservoir.

Regions where Thermal Oil Recovery (steamfloods, cyclic steam, or SAGD) takes place



I will discuss 4 Regional Approaches to Water Treatment for Steam Generation Purposes

- Treatment of Fresh Waters
  - Common methods for thermal projects in Venezuela

- Treatment of Low-TDS Produced Waters
  - Common methods for thermal projects in California
- Treatment of High-Hardness Waters
  - Common methods in the Middle East
- Treatment of Produced Waters for Silica Removal
  - As utilized in thermal projects in Canada
  - This region has seen the greatest recent evolution in methods.

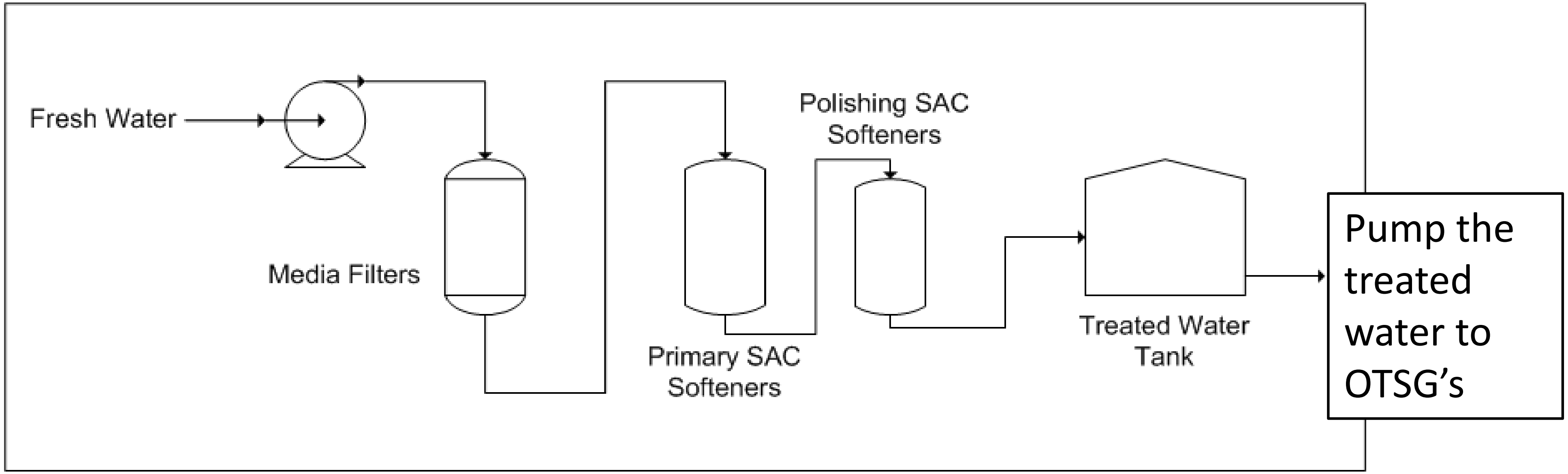
➢As a wrap-up, I will list potential emerging water treatment technologies, for oilfield produced waters.

Treatment of Fresh Waters

- Commonly used for thermal projects in Venezuela, but has been used elsewhere.
- Can be used wherever fresh water, from surface sources, or near-surface aquifers, is readily available, and regulations allow its use.
- These methods could also apply to “brackish” water.
- Must use fresh or brackish water, or some other available water stream, when the amount of water produced with the oil is relatively small.
- Feedwater is fed to Once-through Steam Generators (“OTSG’s”).
- Treatment focus: Suspended solids removal, hardness removal, oxygen scavenging.

References for fresh water treatment include SPE 10710, SPE 17388, Morales et al 5th UNITAR, SPE 13720., SPE 89411.

Treatment of Fresh Waters



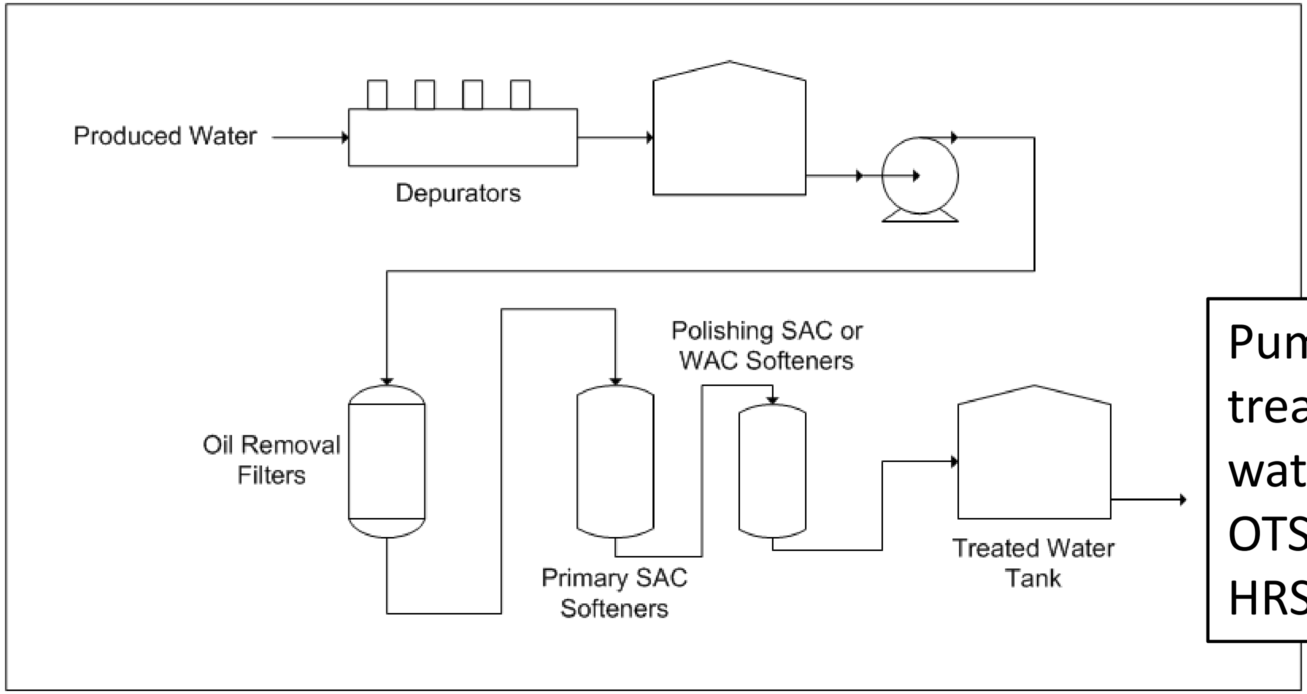
- Concept: Surface water is abundant. Total Dissolved Solids ("TDS"), and hardness, are low. No need to remove oil.
- Just collect fresh water, filter it, soften it, and add chemicals (typically, oxygen scavenger; possibly, a corrosion inhibiter).
- "SAC" softeners stands for Strong Acid Cation; regenerate them with salt.
- Key message: Avoid the problem of having to separate produced oil from the water, if you don't need to.

Treatment of Low-TDS Produced Waters

- Commonly used for steamflood projects in California's San Joaquin Valley, but has also been used in Indonesia, Venezuela, and China.
- Can be used wherever oilfield produced water volumes are high, and/or water disposal options are limited. Treating and re-using produced water helps to lessen water disposal costs.
- Treated water can be fed either to OTSG's, or to cogeneration-plant Heat Recovery Steam Generators ("HRSG's").
- Treatment focus: Oil separation and filtration, hardness removal, oxygen scavenging.
- NO ATTEMPT to remove silica from the produced water.
- This is an imperfect strategy. The feedwater contains hardness leakage, and high silica. So, some silicate scale will form . . . . Just pig it occasionally.

References for produced water treatment include SPE 1265, SPE 27870, Camacho et al 5th UNITAR, Dong O&GJ v97 #38 pp.76-78.

Treatment of Low-TDS Produced Waters

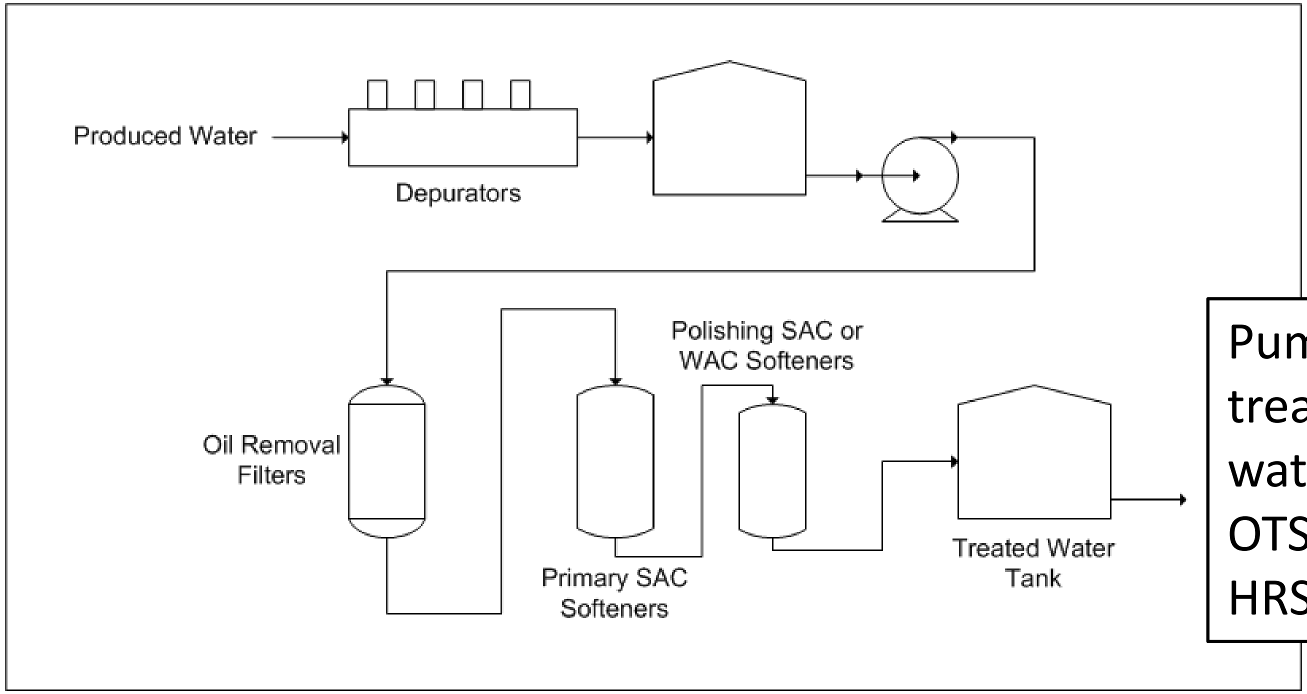


Pump the treated water to OTSG's or HRSG's

- Concept: Water is abundant, there is much more water available than the volume of steam needed.
- Soften only your feedwater; dispose of the excess.

- Because water is abundant, achieving a high "Recovery Factor" (the % of water re-usage) isn't a concern.
- Modern plants use walnut-shell filters, which remove oil better than media ("sand") filters.

Treatment of Low-TDS Produced Waters



Pump the treated water to OTSG's or HRSG's

- SAC softening is the lowest-cost, but, if TDS is high, use SAC/WAC softening (WAC = Weak Acid Cation, regenerated by acid). Both styles are utilized in California.

- I have seen waters as high as 7,000 TDS be softened at SAC/SAC plants, despite specs that suggest a max of 3 – 5,000 ppm.
- Specs may require <1ppm hardness, but this is difficult to measure with accuracy, and water is often used that doesn't achieve this spec.
- Key message: All processes proven over decades, and relatively efficient.

Depurator, or Inert Gas Flotation unit

Walnut Shell Filter

SAC primary
SAC polisher
Softener train

Example Produced Water characteristics from 3 thermal oilfield regions –

Hardness and TDS of a typical Middle East water is extremely high.

	California 1	California 2	California 3	Middle East	Canada 1	Canada 2	Canada 3
Ca	30	40	55	2,000	40	2	4
Mg	5	15	7	500	7	0.5	0.3
Hardness (as $CaCO_3$)	96	162	166	7,053	129	7	11
Na	100	2,400	2,500	6,000	1,900	330	700
Cl	100	3,200	3,600	15,000	2,750	250	930
HCO_3	250	1,300	325	1,000	350	400	330
Si (as SiO_2)	50	350	175	15	275	314	260
TDS	600	7,600	6,800	40,000	5,700	860	2,400

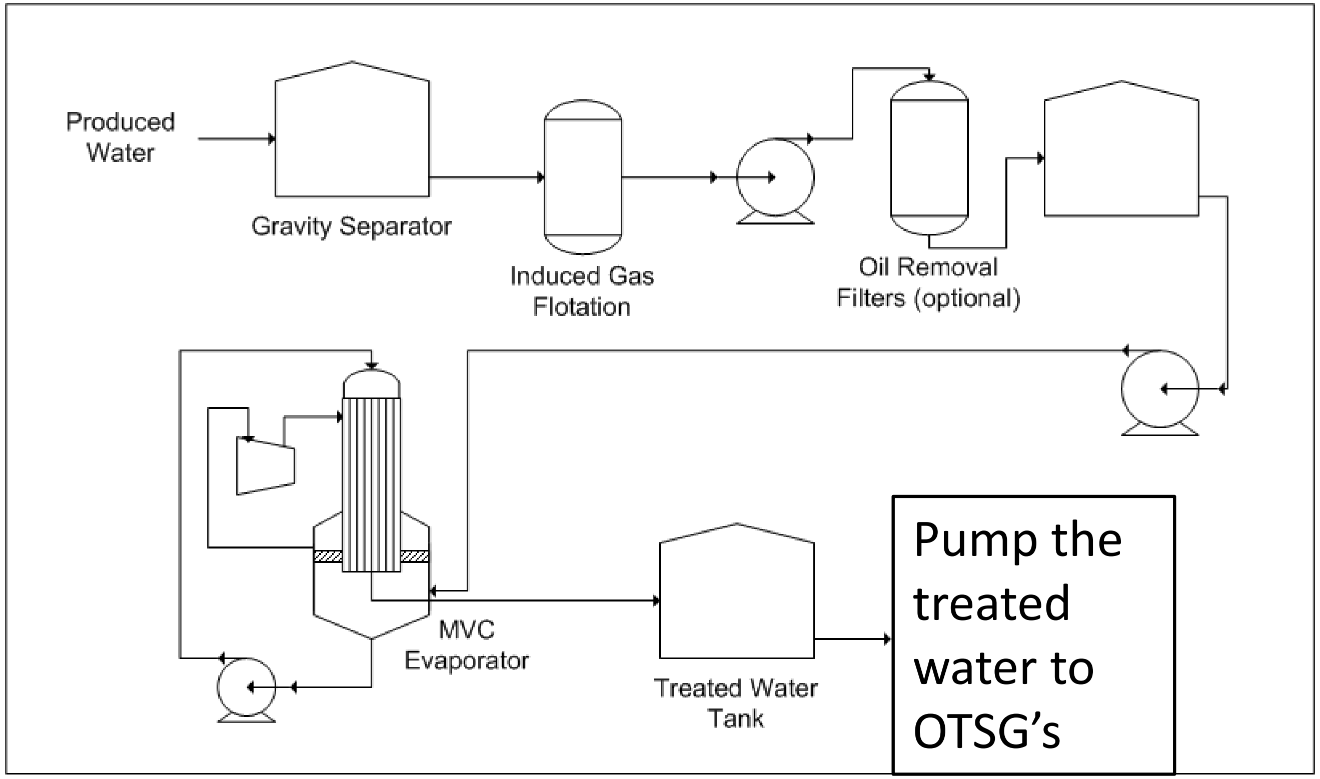
Silica of the Canadian waters is considered high, but can be just as high in California.

Treatment of High-Hardness Waters

- Commonly used for steamflood projects in the Middle East, where hardness levels of available waters can be extremely high (>7,000 ppm), but silica content can be very low.
- Can be used for either reclaimed oilfield produced water, or aquifer waters. In this region, both will have very high levels of hardness.
- Treatment focus: Oil separation, solids removal, oxygen removal, hardness removal by evaporation, corrosion inhibition.
- Evaporation is a high-energy-cost hardness removal method, but, for waters with very high hardness, it is cheaper to evaporate the water, than to soften it (with either ion exchange, or precipitation).

References for high-hardness water treatment using evaporators include SPE 120205 & SPE 191695 (produced H2O), and SPE 30300 (aquifer H20).

Treatment of High-Hardness Waters



- Concept: Evaporation removes almost all dissolved solids from produced water.
- Thermal projects in Oman have used aquifer water (oil removal not needed), but this is the same concept otherwise.

- Since silica is low, silica removal isn't the reason to use an evaporator.
- Corrosion inhibition is critical, since evaporated water is corrosive.
- Key message: Evaporation is a proven method for waters that would be expensive to soften by ion exchange, or precipitation, methods.

Corrosion inhibition can be accomplished by deaeration, pH increase, oxygen scavengers and/or corrosion inhibitors.

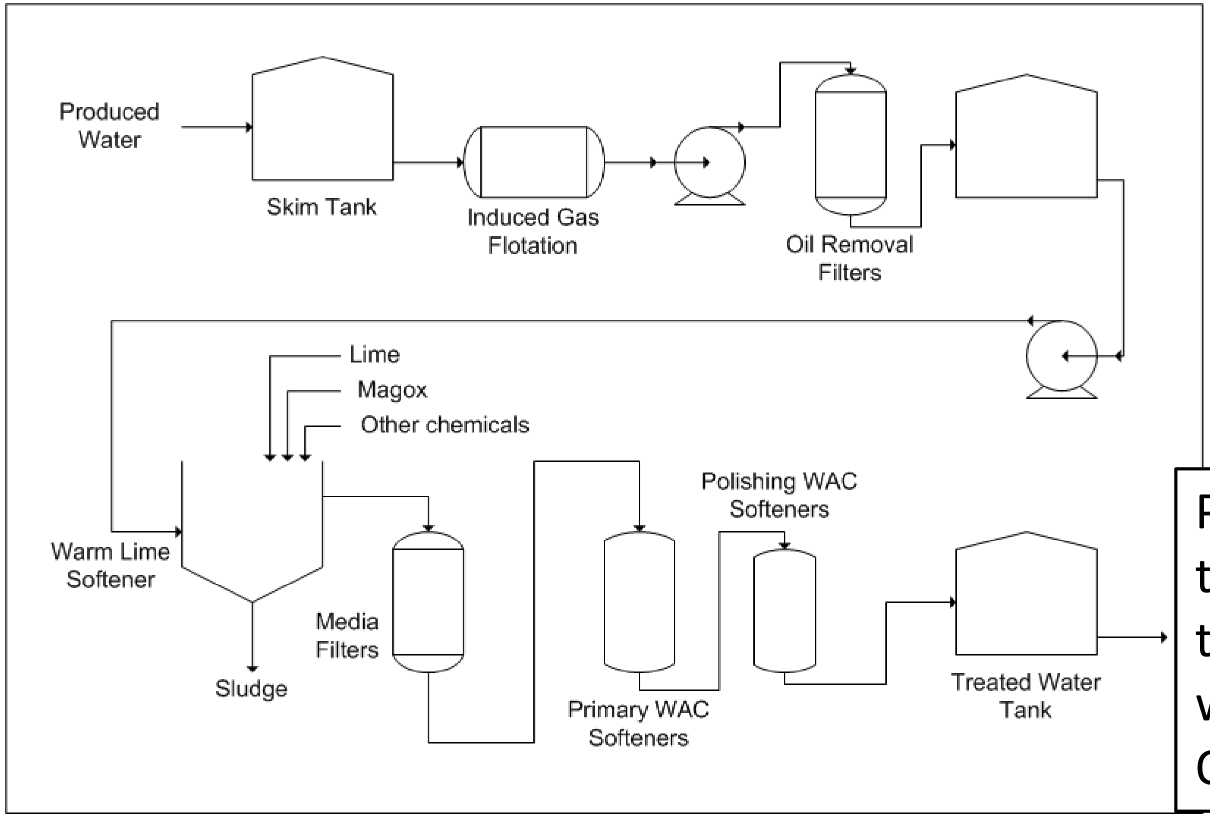
Evaporator to treat OTSG feedwater, in the Middle East

Treatment of Produced Waters for Silica Removal

- I will present 3 treatment methods that have been used for thermal projects (mostly SAGD) in Canada (although precipitation softening has been done elsewhere).
- The Canadian industry has evolved over the past two decades.
- Treatment focus for each process includes: oil separation, solids removal, hardness and silica removal, oxygen removal, corrosion inhibition.
- The Canadian thermal water treatment industry is challenged by a commonly accepted specification of <50 ppm of silica. (In California, produced waters w/silica >200 ppm are commonly used).
- Evolution in methods has occurred because of regulations to increase the recovery factor of oilfield produced waters, to reduce surface water usage.
- Water treatment research continues to be conducted here, so expect future evolutionary developments.

Does the Canadian industry need to remove silica? Consider: Zalewski et al JCPT Vol. 37 #4; and SPE/PS-CIM/CHOA 97686.

Treatment of Produced Waters for Silica Removal – Traditional Canadian Concept



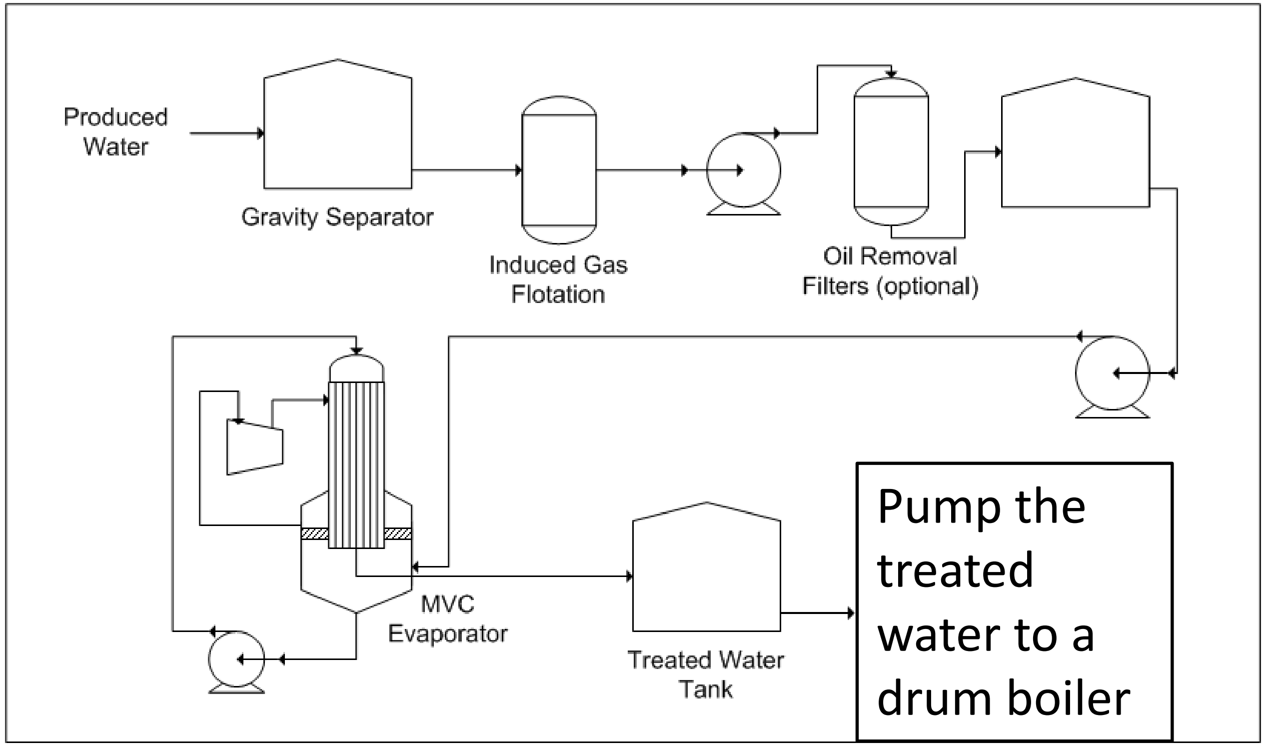
Pump the treated water to OTSG's

- Concept: Lime softening (Warm, or Hot) removes most hardness, and silica.
- Precipitation softening: sludge is collected; filters needed downstream.
- MagOx promotes silica precipitation.
- Recovery Factor is limited to 65%-80%. To increase, add an evaporator for the blowdown.

- Key message: Lime softeners are expensive, "messy", and inefficient. Must add one mole of hardness ions (Ca, Mg) in order to precipitate out two moles of hardness.

References for this traditional approach include Zalewski et al JCPT Vol. 37 #4, Ighani et al 1st Heavy Oil Conference (Beijing), Nelson et al AOSTRA-Can. Heavy Oil Assoc. 1992. Outside of Canada: SPE 19759, SPE38799.

Treatment of Produced Waters for Silica Removal – Emerging concept in the late 00's



- Concept: Evaporators can soften, and remove silica from, produced water.
- Capable of Recovery Factors that are 10%-20% greater than the traditional concept.
- Drum boilers produce 100% quality steam, matching the SAGD requirement of 100% quality steam.
- Oil Removal Filters (typically walnut-shell) optional, as evaporators tolerate oil.
- Key message: Drum boilers have tight specifications for water quality, and can't be pigged, if scale does begin to form.

References for this approach include Heins JCPT vol 47, #9, Heins JCPT vol. 49, #1.

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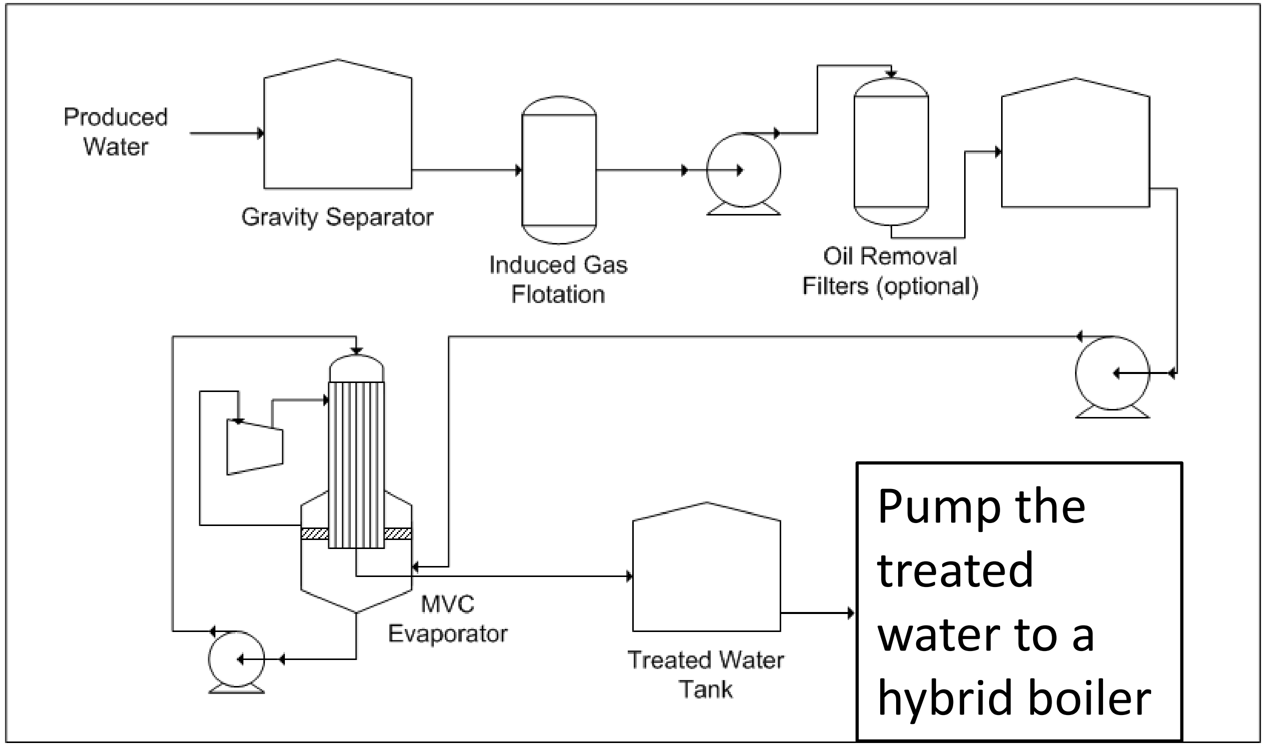
Treatment of Produced Waters for Silica Removal – Emerging concept today



- Concept: Evaporation necessary to achieve the high Recovery Factors being required for new projects.
- Hybrid boilers tolerate more hardness & silica than drum boilers, handle upsets better, and (like OTSG's) are piggable.
- By using forced circulation, they produce 100% quality steam.

- Key message: The Canadian industry, unlike other thermal recovery regions, produces scarce water. Minimizing startup/makeup water is an important regulatory, and industry perception, issue. This system achieves 100% quality steam, AND a high Recovery Factor, more reliably than a drum boiler.

Typical Feedwater Specifications

based on the type of steam generation process

All values are maximum allowable, except for pH.

	• OTSG's and HRSG's based on a range of published values	• Drum Boilers ABMA specs for 1,000 – 1,500 psi	• Hybrid Boilers Forced circulation – conceptual specs
Hardness (as $CaCO_3$)	0.5 – 1.0	0.05	0.3
Silica (as SiO_2)	50 - 100	2	2
TDS	8,000 – 12,000	10	10
Fe	0.05 – 0.25	0.01	0.01
Dissolved O_2	0.01 – 0.05	0.007	0.007
pH	7 - 11	8.8 - 9.6	8.8 - 9.6

- By adding forced circulation to a boiler, the system can be made piggable, and also will tolerate a significant level of hardness leakage, approaching what can be sent to an OTSG. However, tolerances for silica and TDS are still very low, which is why evaporation is still required.

OTSG specification references include: SPE/PS-CIM/CHOA 97750, Zaidi et al 4th UNITAR, Sarathi and Olsen USDOE 1992, SPE 13720, Nelson et al AOSTRA-Can. Heavy Oil Assoc. 1992.

What technologies may emerge in the future?

- Membrane treatment of produced waters is the leading research concept.
- Membranes could be particularly useful in the Middle East, where:
  a. produced water is abundant; therefore,
  b. high recovery factor isn't a compelling issue; therefore,
  c. evaporators can be viewed as a high-cost alternative; and,
  d. The resource base could support many new major projects.
- However, hardness is a technical challenge for membrane treatment.
- From a feedwater treatment perspective, membrane treatment is not an economically favorable choice, yet.
- Ultrafiltration ("UF") and Reverse Osmosis ("RO") membranes have been used in two California oilfields, *to meet regulatory disposal requirements*.
  - Therefore, produced water membrane treatment can be considered "proven".
- Chemical constituents in each field are unique; such differences must be considered, in designing efficient membrane treatments.

References for produced water treatment for surface/near-surface discharge in California include SPE 26003, SPE 121520 and IPTC 17394 .

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What technologies may emerge in the future?

- In California, research and field testing of produced water treatment has been focused on regulatory disposal specifications, not steam feedwater.
- The ability to get rid of excess produced water using "disposal wells" is being limited by regulations. This situation won't get better in the future.
- A long list of concepts is being developed by large, medium, and small-sized companies.
- Many such concepts are designed with shale/frac flowback and produced waters in mind. Some of those concepts could emerge, as also being efficient to treat thermal oilfield produced waters.
- A few years ago, I participated in a study of novel water treatments, that identified over 60 water treatment technologies, in various stages of development, which could be considered for use with thermal oilfield produced waters.

A partial list of Emerging Water Treatment concepts

OIL SEPARATION/REMOVAL TECHNOLOGIES

- Compact flotation devices
- Other compact separation devices

} *Goal: smaller footprints*

- Improved flotation systems (Inert Gas Flotation, Dissolved Gas Flotation)
- Membrane Bioreactors
- Modified silica beads
- High-efficiency filter media

A partial list of Emerging Water Treatment concepts

WATER TREATMENT TECHNOLOGIES

- Polymeric membranes (MF, UF, NF, RO): standard temperature limit is generally 43C: cooling would be required for thermal produced waters.
- High-temperature polymeric membranes
- Ceramic membranes
- Hollow fiber membranes
- pH management for membrane treatment
- Custom-design membrane packaging systems
- Forward osmosis
- Improved distillation systems
- High-efficiency and high-purity softening systems
- Electrodialysis
- Electrocoagulation

If you need to select a Water Treatment concept for your project, where do you start?

- Are surface waters available, in what quantity, and for how many years?
- The unique characteristics of each potential feedwater source, including mineral content and oil/water separation difficulty, should be investigated.
- If this is a "greenfield" project, with little or no samples to judge produced water characteristics by, start by considering what is proven in your region of the world.
- Reservoir steam requirements must be understood. Specifically, can the reservoir tolerate injection of a liquid phase, along with the steam vapor?
- Consider whether produced water will be "limited", driving the need for a higher recovery factor, or "abundant".
- Develop a clear understanding of process requirements, and regulatory requirements
  - Specifications should add value, by helping to avoid real problems.
- Consider your tolerance for unproven technology risk.

If you need to select a Water Treatment concept for your project, where do you start?

- Don’t consider just the water treatment technologies;
- Don’t consider just the steam generation technologies;
- Water treatment, steam generation, and water disposal technologies have to work together, to support steam injection for thermal recovery.
- Choose the combination of technologies that project to meet the steam injection requirements:
  - Lowest overall life-cycle costs when considering water treatment, steam generation, and water disposal;
  - Whether or not the reservoir can tolerate some liquid phase injection;
  - Regulatory requirements;
  - Technology maturity and risk;
  - System reliability;
  - Any other metrics pertinent to your project.
- This is a holistic choice, not just a “water treatment” choice.

Acknowledgments

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Thanks!
Any Questions for me . . . . ?

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