use of evaporation for heavy oil produced water treatment

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abstract

Heavy oil recovery processes have traditionally used "once through" steam generators (OTSG) to produce high pressure steam for injection into geological formations containing heavy oil. The heat given up by the condensing steam fluidizes the heavy oil and allows the oil/water mixture to be brought to the surface. The oil is recovered as product and the water, referred to as produced water, is de-oiled and treated for feedwater to the OTSG. The typical treatment method for produced water is warm or hot lime softening (WLS or HLS), filtration, and weak acid cation exchange (WAC).

An alternative method of produced water treatment is vertical tube, falling film, vapor compression evaporation. This method:

1. Eliminates physical-chemical produced water treatment.
2. Results in lower lifecycle costs.
3. Does not produce any softener sludge for disposal.
4. Minimizes the number and volume of waste streams requiring disposal.
5. Requires fewer maintenance materials and less maintenance labor
6. Reduces the required amount of produced water de-oiling equipment.
7. Dramatically increases OTSG feed water quality, improving OTSG reliability.
8. Provides increased system availability and reliability.

For steam assisted gravity drainage (SAGD) processes, which require 100% quality steam, it has the added advantage of producing water of sufficient quality for use in standard packaged boilers in lieu of OTSG. Packaged boilers are less expensive than OTSG, produce a much smaller liquid blowdown stream, and results in a boiler feed system which is 20% smaller than that of an OTSG.

introduction

The uncertainties of world politics have promoted the need for diverse sources of world oil supply. The oil reserves located in Canada, specifically Northern Alberta, are vast and production of these reserves is increasing at a fast pace. Current recovery of this oil resource requires utilization of another valued resource, water.

Heavy oil recovery requires large volumes of water commensurate in volume to the production of oil that it yields. Water is used in the form of steam to heat the geological formations that hold the oil. The oil is fluidized by the condensing steam and the oil/water mixture is pumped to the surface. The oil and water are separated. The oil is recovered as product and the water, referred to as produced water, is de-oiled and treated for reuse in the steam generator.

Traditionally, once-through steam generators (OTSG) have been used to produce 80% quality steam (80% vapor, 20% liquid) for injection into the well. A relatively new heavy oil recovery process, referred to as Steam Assisted Gravity Drainage (SAGD), requires 100% quality steam to be injected into the well (i.e., no liquid water). To produce 100% quality steam using once-through steam generators, a series of vapor-liquid separators are required to separate the liquid water from the steam. The 100% quality steam is then injected into the well.

For both SAGD and non-SAGD applications, the produced water can generally be characterized as predominantly sodium chloride brine with high silica and minimal calcium and magnesium. High alkalinity, or carbonates, is present as well. The produced water generally contains about 4000 mg/l total dissolved solids but can be much higher depending on the geological contribution. Dissolved and emulsified organics (oil) are present at a variety of levels depending on the oil separation processes used.

This paper compares and contrasts the traditional physical-chemical produced water treatment methods with an alternate approach which is currently being utilized in Alberta; falling film, vertical tube, vapor compression evaporation. The technical and economic advantages of the evaporative approach will be discussed and compared to traditional methods.

Use of conventional or packaged boilers, in conjunction with the evaporative approach, will also be addressed in lieu of OTSG. Treatment of the concentrated evaporator blowdown stream to "zero liquid discharge" will also be discussed for circumstances where deep well injection is not an option.

traditional produced water treatment

Produced water has been processed in a variety of different ways during the development of heavy oil recovery. Several methods have been utilized to manage and recover this water. Some concern has arisen from past practices and it is clearly recognized that produced water is a resource to generate steam, but it has to be treated and the boiler design must compliment the degree of water treatment.

Currently, in the majority of SAGD and non-SAGD heavy oil recovery applications, produced water is treated in multiple steps requiring silica, calcium, and magnesium reduction. The oil is removed to as low a level as is feasible by a polishing step prior to these inorganic reductions. The treated water can then go to an OTSG that can produce high pressure steam (typically 1000 to 1600 psig) from water that has high TDS (typically 2000 to 8000 ppm [mg/l]) of dissolved inorganic and organic content.

traditional produced water treatment system

Figure 1 shows a traditional produced water treatment system after a variety of oil separation processes have been utilized to recover oil and remove oil from the water. This method of produced water treatment has been applied to both SAGD and non-SAGD applications. The process that reduces silica to low enough levels to be utilized in an OTSG is either a warm or hot lime softener (WLS or HLS) followed by a filtration system. Calcium and magnesium are also reduced in the lime softener, which lightens the load for the weak acid cation (WAC) ion exchange system. The major chemicals added in the softener are lime and magnesium oxide. These chemical systems require chemical silos and solids transport equipment. Other chemical additions are also required in the form of a coagulant and a polymer. The chemical additions reduce silica content to manageable levels for the OTSG.

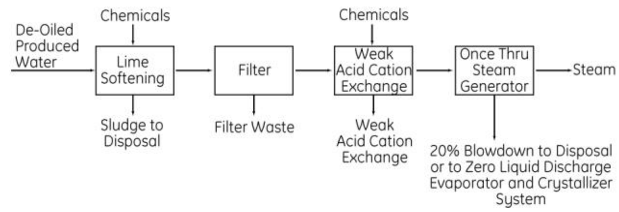

Figure 1: Traditional Produced Water Treatment System

The clarate is filtered prior to being treated with the WAC ion exchange system, which reduces magnesium and calcium. Sludge produced from this softening process has high water content and is separated with a centrifuge. The sludge must be disposed of in some manner. Centrate is recycled back to the process.

The WAC ion exchange system is regenerated with hydrochloric acid and caustic. Reduction of metals such as calcium, magnesium, and iron to low levels occurs in the exchange process. WAC does not reduce silica any further than the lime softening process. The strong regeneration waste is neutralized and possibly recycled to the softening system or disposed in some other manner. The resin bed rinses are recycled back to the softening system.

Conventional treatment of produced water being processed in a OTSG produces a blowdown which is about 20% of the boiler feedwater volume and results in a brine stream which is about fivefold the concentration of the boiler feed. This stream must be disposed of by deep well injection or, if there is limited or no deep well capacity, by further concentrating the blowdown with a zero liquid discharge Brine Concentrator and Crystallizer system, producing a dry solid for disposal. Some of the OTSG blowdown can be recycled to the softener system but as the solids are cycled up in the system, more maintenance issues are evident in the OTSG.

alternate evaporative method of treating produced water

The traditional de-oiling, softening, filtration, and ion exchange produced water treatment scheme depicted in Figure 1 is complex, costly, produces several waste streams requiring disposal, is labor intensive, requires the use of OTSG, and requires vapor/liquid separation systems (to produce the desired steam quality for SAGD processes). Therefore, an alternate approach to produced water treatment which is simpler, more cost effective, more reliable, and which reduces the size and complexity of the steam generation system is desirable. Falling film, vertical tube, vapor compression evaporation is an approach which is currently being implemented in Alberta to obtain these objectives. This simplified method of produced water treatment is shown in Figure 2.

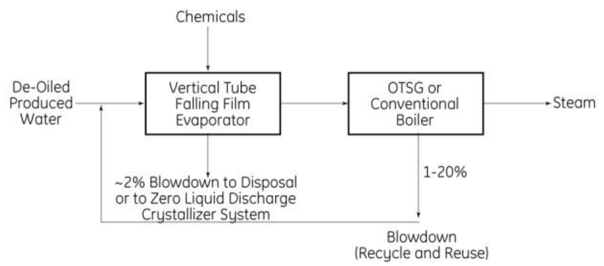

Figure 2: Vertical Tube Falling Film Vapor Compressor Evaporator System

This approach to produced water treatment involves direct treatment of the produced water in an evaporation system. The lime softener (WLS or HLS), filtration, WAC exchange systems, and certain de-oiling steps are eliminated.

Evaporation can be applied to SAGD and non-SAGD heavy oil production to recover up to 98% of the produced water as high quality distillate (<10 ppm [mg/L] non-volatile inorganic TDS) for use in OTSG or conventional boilers. Using evaporation as the treatment process instead of lime softening and WAC has several advantages:

- Overall life cycle costs are less for an evaporative produced water treatment system than for a traditional lime softening/WAC approach.
- Physical separation processes using solid chemical additions are eliminated.
- High water solids content sludges are eliminated.
- Waste streams requiring further disposal treatment are eliminated.
- Oil removal equipment can be reduced.
- Boiler blowdown and heat recovery equipment can be reduced in size.
- Overall operational and maintenance requirements are reduced.
- Overall water treatment system reliability and availability are increased.
- OTSG reliability is dramatically improved.
- Overall oil recovery process availability is increased.
- The use of conventional steam boilers is possible due to dramatically increased boiler feedwater quality.
- Use of conventional boilers reduces capital costs by eliminating vapor/liquid separators, and reducing the size of the boiler feed system by 20%.
- If zero liquid discharge (ZLD) is required due to a lack of disposal well capability, the evaporative approach to produced water treatment results in a ZLD system that is about 80% smaller than that required if the physical-chemical produced water treatment approach is utilized.

To realize the benefit of all these advantages in treating produced water, specialized evaporation equipment is required. The use of vertical tube, falling film evaporators is essential in the evaporative approach to produced water treatment.

falling film vertical tube vapor compression evaporators

Falling film vertical tube evaporators have the highest heat transfer characteristics of all evaporator types. A high heat transfer coefficient is needed to efficiently evaporate the water and save energy. The vertical tube, falling film arrangement also allows evaporation to occur with reduced fouling effects by keeping surfaces wetted at all times. Patented distributors are used to ensure an even falling film in these evaporators.

The vapor compression cycle is the key to energy efficiency in these systems. The amount of energy put into evaporation is about 1/20th of the energy needed to evaporate water. This is because of the nature of the thermodynamic cycle, which does not have to provide the energy to vaporize the water. The compression energy is used to elevate the existing steam temperature without having to provide the initial energy to evaporate the water. The steam temperature (and pressure are elevated. It is then condensed transferring heat to the brine for evaporation, which produces steam for the compression cycle.

A simplified vertical tube, falling film, vapor compression evaporator system used to treat produced water is shown in Figure 2. This system is much simpler than the traditional physical-chemical produced water treatment system depicted in Figure 1. Additional details showing the vapor compression cycle are shown in Figure 3 and Figure 4. A photograph of a typical falling film vapor compression evaporator, similar to those being implemented in Alberta SAGD applications, is presented in Figure 5.

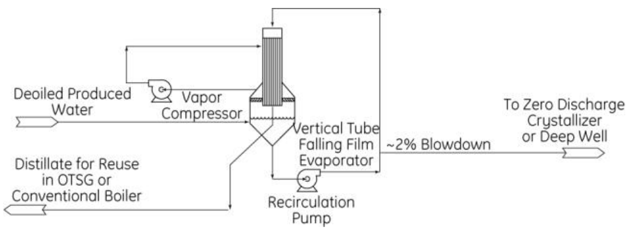

Figure 3: Simplified Vapor Compression Falling Film Evaporator System

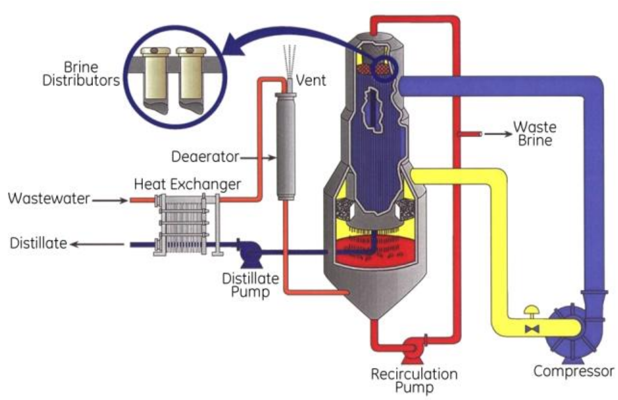

Figure 4: Vertical Tube Falling Film Vapor Compression Evaporator Schematic

Figure 5: Typical Vertical Tube Falling Film RCC* Vapor Compressor Evaporative System

De-oiled produced water enters a feed tank where the pH is adjusted. The wastewater is pumped to a heat exchanger that raises its temperature to the boiling point. It then goes to a deaerator, which removes non-condensable gases such as oxygen. Hot deaerated feed enters the evaporator sump, where it combines with the recirculating brine slurry. The slurry is pumped to the top of a bundle of two-inch heat transfer tubes, where it flows through patented liquid distributors which ensure a smooth, even flow of brine down each tube. As the brine flows down the tubes, a small portion evaporates and the rest falls into the sump to be recirculated.

The vapor travels down the tubes with the brine, and is drawn up through mist eliminators on its way to the vapor compressor. Compressed vapor flows to the outside of the heat transfer tubes, where its latent heat is given up to the cooler brine slurry falling inside. As the vapor gives up heat, it condenses as distilled water. The distillate is pumped back through the heat exchanger, where it gives up sensible heat to the incoming wastewater.

A small amount of the brine slurry is continuously released from the evaporator to control density.

The OTSG or conventional boiler blowdown can be recycled to the evaporator feed, eliminating the need to dispose of this waste stream, without affecting recovered water quality. The evaporator blowdown is disposed of via deep well injection, or treated further by a crystallizer. Utilization of a crystallizer would eliminate all liquid wastes making the entire system a zero discharge system. (The crystallizer produces a dry cake material for disposal.) A photograph of a typical zero liquid discharge crystallizer system, similar to those recently installed in Alberta, is presented in Figure 6.

the economics of the evaporator process

The economic comparison of the traditional lime treatment and WAC system with that of an evaporator requires not only the standard installed capital and operating expenses of each of these systems but also the economic impact of reduced ancillary equipment associated with the evaporator system, the increased oil production realized with the evaporation approach, and the reduced size of the zero liquid discharge system if deep well disposal is not an option.

One of the most significant economic advantages of using a falling film, vertical tube, evaporator system is the on-line reliability and redundancy associated with these systems. The evaporative produced water treatment approach results in an increase of about 2% to 3% in overall heavy oil recovery plant availability as compared to a conventional lime treatment process. This increase in on-line availability relates directly to increased oil production and a large economic advantage over the life of the plant.

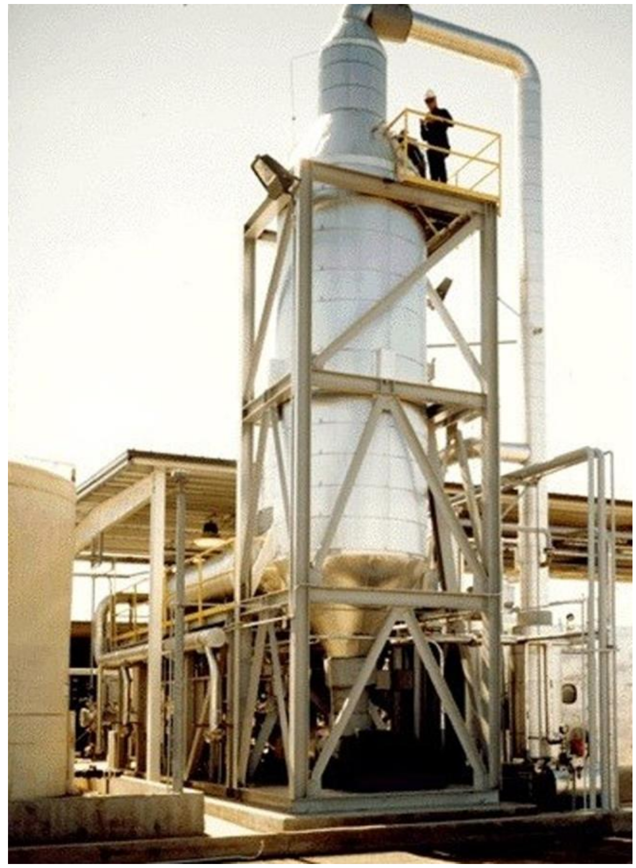

Figure 6: Typical ZLD RCC Crystallizer System

The use of a falling film, vertical tube, evaporator system eliminates certain oil separation pretreatment steps, lime softening equipment, and ion-exchange equipment, thus improving the system economics. A smaller boiler blowdown facility also results from having a much higher quality feedwater to the OTSG. With evaporator distillate, an overall blowdown rate of 5% can be achieved from the OTSG.

Another possibility to further save capital and operating expense is to use conventional boilers in place of OTSG. This is possible since the distillate produced by the evaporator is of sufficient quality to be used as feed to a conventional boiler, possibly following a final polishing step. Use of conventional boilers reduces the boiler feed system and evaporative produced water treatment system size by 20%, eliminates the vapor/liquid separation equipment, and reduces the boiler blowdown flowrate by about 90%.

conclusions

1. Falling film, vertical tube, evaporation is a technically and economically viable process to recover more than 98% of the produced water as high quality distillate for use as boiler feed water in SAGD and non-SAGD heavy oil recovery operations.
2. The overall life cycle costs are less for an evaporative produced water treatment system than for a traditional lime softening/WAC approach.
3. The evaporative produced water treatment approach results in an increase of about 2% to 3% in heavy oil recovery plant availability, directly resulting in increased oil production.
4. Installed capital and operating costs are less for the evaporative approach when credits are taken for reduced oil separation equipment, reduced boiler blowdown equipment, reduced zero liquid discharge system size (if required), and elimination of the lime softening, filtration, and WAC equipment.
5. Further economic savings can be realized when conventional boiler systems are utilized in lieu of OTSG systems, reducing capital costs of the boiler system, eliminating the need for costly vapor/liquid separation equipment, reducing the size of the boiler feed system by as much as 15%, and reducing the boiler blowdown by as much as 90%.
6. Zero liquid discharge, if required, is more easily attainable with the evaporative produced water treatment approach. A relatively small crystallizer is all that is required. If zero liquid discharge is required using the traditional lime softening/WAC produced water treatment system, a large Brine Concentrator and a crystallizer would be required.