Produced Water Treatment for Heavy Oil in SAGD Application

By Tim Johnson and Ken Severing, US Filter

Introduction

The Tar Sands of Alberta hold more than 900 billion barrels of oil reserves. As much as twenty percent of this oil is recoverable directly through mining the Tar Sands. Steam Assist Gravity Drainage (SAGD) is an alternate method to recover oil found in tar sands too deep to mine, beneath cap rock or unrecoverable due to environmental concerns. SAGD projects require a large amount of water for high-pressure steam generators to assist in producing the low API crude found in Alberta Canada. Recycling Produced Water can be an economical advantage for SAGD projects.

Recycling the produced water provides a cost-effective source of the water to supply the medium to high pressure steam generators. Recycling also provides an alternate to expensive surface discharge or deep well injection of the produced water. Because of environmental issues, Alberta is showing great interest in zero discharge and this promotes recycling of the produced water. The recycle produced water treatment process is specialized to fit the feed requirements of the stream generators while treating the lower API crude in the produced water. Many process options are available to treat the produced water to meet both sets of design parameters. Careful selection of the process equipment can result in lower operational cost while maintaining a conservative design with a long operational life. Correct individual process selection also provides overlapping produced water treatment within the total process stream and helps protect against oil and suspended solids overloads during upset conditions.

This paper briefly describes both the SAGD oil recovery process and the produced water recycle treatment system providing water for one SAGD type project. This process is for a project currently in the engineering, procurement and fabrication phase located in Alberta Canada. Other fields will have different produced water parameters and generator requirements and therefore will require slightly different process equipment selection.

The SAGD Process

The SAGD process is used to produce heavier than normal API crude often in the range of 6° to 12° API. Because the crude, or bitumen, will not flow within the reservoir, high temperature steam is injected in situ into the oil bearing sands. The heated steam is injected into horizontal perforated pipelines located above paralleling horizontal producing pipelines. The steam injection lines are located approximately 15 to 20 feet above the producers and are spaced longitudinally 600 feet apart. The injection wells and producing pipelines are strategically drilled over a given area to extract the oil from the sands. The steam injection lines heat a zone of the tar sands above each injection well. As the steam comes in contact with the bitumen, the steam condenses and drains with the bitumen to the producing wells or pipelines. The heated crude then flows back through the pipeline to the surface production facility. The steam injection, heating and drainage can take from two to twelve months to start the recovery process.

The oil recovered is approximately thirty percent oil and seventy percent water, but the water cut will vary from field to field. From the producing pipeline the crude goes to the production facility. It's at this stage diluent is added to change the API from 8° to between 17° -19° in order to reduce the viscosity, allow transportation and aid in the separation process. From the production equipment, the 90 °C produced water goes to the skim tanks. The skim tanks have a large residence time to provide a low oil in water content. From the skim tanks the produced water enters the Produced Water Recycle System. All the production equipment and produced water system are insulated to conserve heat and to protect field personnel.

Produced Water Recycle Process

The function of the produced water recycle system is to remove the oil to an acceptable limit, and also protects the downstream ion exchange resin, remove the solids and to treat the water for the once through steam generator. The steam generators, in this case, are high pressure (2000 psi) generators and require silica removal to 50 mg/l of SiO_2 to prevent scale formation. Further, the hardness level is required to be less than or equal to 0.2 mg/l as $CaCO_3$. The hardness and silica content will vary depending on the requirements of the steam generators. The produced water recycle system therefore is split into two parts: the upstream oil and solids removal equipment and the downstream silica removal and water softening equipment. The design criteria for the project and the inlet and outlet water parameters are shown in figure 1. The overall produced water recycle process is shown in figure 2 and consists of an Induced Gas Flotation, Walnut Shell Filter, Warm Lime Softening, Multimedia Filters and Primary and Polishing Ion Exchangers. A centrifuge is used to de-water the sludge.

The addition of the diluent upstream raises the API to between 17° to 19°. Though still slightly heavy, this provides for conventional oil removal treatment. The Skim Tanks also act as a equalization basin and improves the consistency of the produced water and will act as a buffer from any oil slugs from the production equipment. With inlet oil concentration in the range of 50 to 100 ppm induced gas flotation was selected for the primary oil removal step. The client wanted a closed system to prevent heat loss and emissions so a pressurized unit was chosen. As the crude is still viscous the float is removed by gravity instead of a paddle skimming system. This also eliminates the vessel seals and provides a cost-effective alternate. The IGF will remove between 90 to 95% of the free oil and 80% of the solids.

Walnut Shell Filters were selected for the second oil removal step for further reduction of both the free oil and the solids. These units will reduce the oil to less than 2 mg/l and total suspended solids to less than 5 ppm. These filters are working well within their normal inlet parameters and will serve as protection for downstream equipment if higher inlet conditions are encountered during upset conditions. Walnut Shell Filters were selected primarily due to their ability to remove oil to low levels without the need of surfactant chemicals. Another benefit is their inherent low backwash water requirements. Make-up water is required to replace ground water loses, and backwash and regeneration waste that are not recoverable. Make-up is added just after these units to take advantage of the downstream silica removal and softening.

Because Silica removal was an important design criteria, Warm Lime Softening (WLS) was selected to reduce the silica to the 50 mg/l requirement. There are several other methods to reduce silica, including anion base exchangers and R.O., but both would require cooling the produced water and the complete removal of hydrocarbons. Cooling then heating would be an additional expense so the WLS actually helps reduce the operational expense through BTU savings. Hot Lime Softening was also considered but the client felt the additional requirement for steam and a large pressure vessel, with its additional capital and operational cost, was not worth the benefit of lower sludge production and the nominal increase in speed of the ion exchange reaction. The higher operating temperature of the Warm Lime Softening process is more efficient and reduces the chemical requirements when compared to cold lime softening.

The Warm Lime Softening solution consists of a solids contact clarifier with internal and external re-circulation. The unit will operate at 90 °C in an atmospheric condition, although the unit is covered for climatic conditions and H_2S containment. The principle purpose is the reduction of silica but warm lime units also remove trace amounts of oil. The unit is sized using a very conservative rise rate in order to minimize precipitation carryover and hence the loading on the downstream Media Filters. Lime and magnesium oxide are added to precipitate magnesium hydroxide. The silica is absorbed to the metal hydroxide and is precipitated out. The removal of silica by magnesium hydroxide has been described as an adsorption phenomenon, but probably it is a chemical reaction with the production being magnesium silicate. This floc is very light and is another reason a conservative flux rate was selected. In this system the WLS actually adds hardness due to the low level of hardness in the produced water. The sludge from the clarifier is discharged to a sludge tank and/or recycled to maintain the proper amount of solids in the clarification zone. Excess sludge is dewatered to 60% moisture content in a centrifuge to minimize waste solids.

The effluent from the Warm Lime Softeners contains calcium and magnesium floc, which have not settled out in the clarification zone. This precipitate is removed in Media Filters with Anthracite media. Anthracite media was used to prevent the addition of silica and has higher solids holding capacity. Anthracite also requires lower backwash water rates, and with elevated operating temperature that require higher backwash rates, there is a savings in the water recovery system. The Media Filters protect the downstream softeners from fouling with solids and reducing the resin efficiency. The total suspended solids are reduced to less than 1 ppm.

The Softeners selected use a macroporous weakly acidic cation (WAC) exchange resin. This type was selected due to expected higher TDS and the need to reduce overall hardness to 0.2 mg/l. The original design criteria provided a TDS level of 2,270 mg/l but after months of operation it is expected the inlet TDS will be as high 8,000 mg/l due to concentration through recycle process. The WAC would operate in the sodium cycle and be regenerated with 4% hydrochloric acid followed with 4% caustic to return the resin to the sodium form. A two step softening process was selected with the primary softeners acting as gross softening and the polishers for final polishing and to pick up any leakage. The primaries are conservatively designed and will generally achieve the overall hardness limitation. The polishing units will have a much longer run cycle and will further reduce the hardness to meet the 0.2 mg/l hardness requirement. These units are regenerated co-currently with HCl and counter-current with NaOH to minimize the resin attrition due to swelling to the sodium form. The effluent from the WAC softeners goes to storage tanks to be pumped into the steam generators.

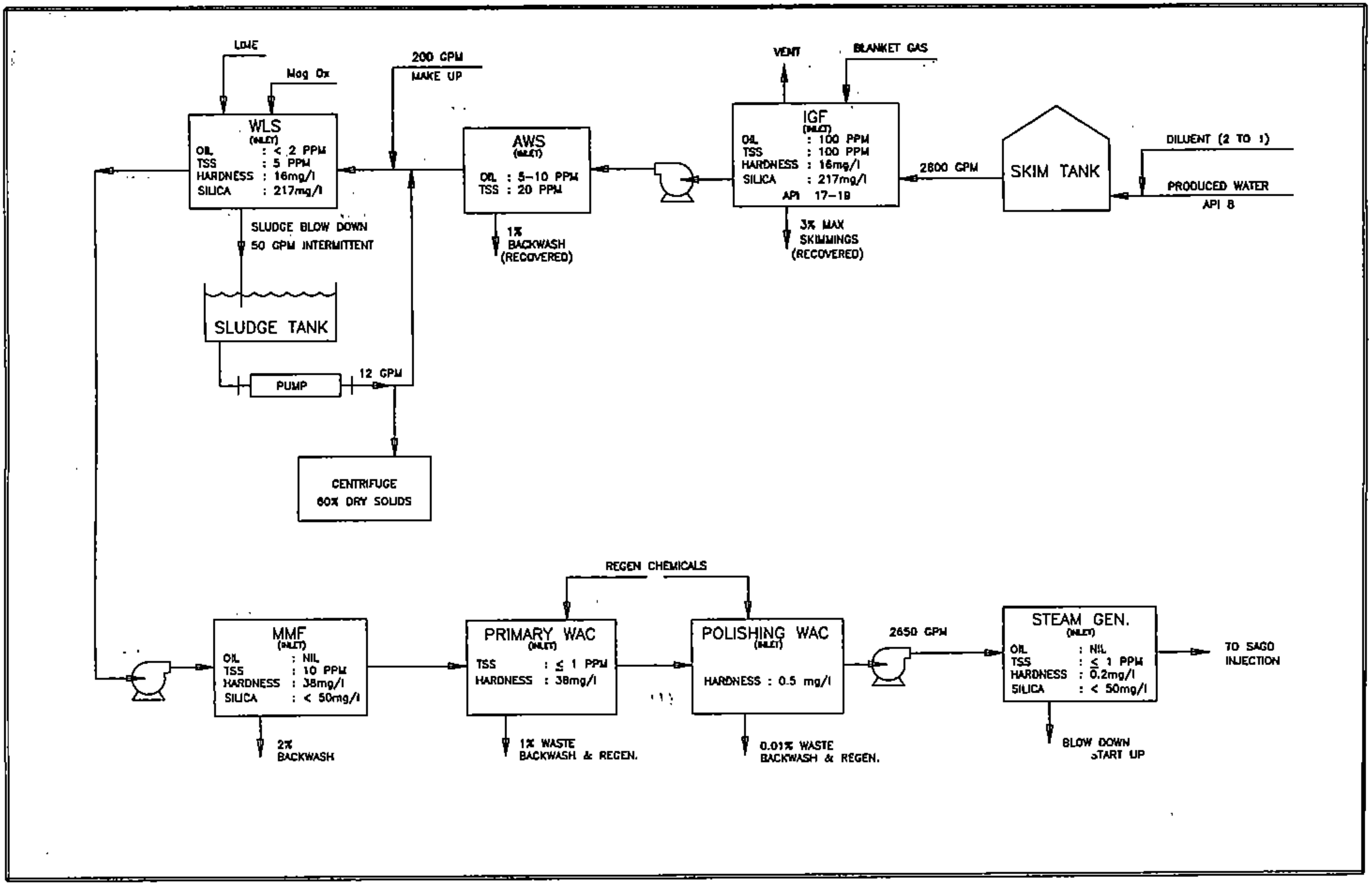
Summary

The overall process provides a conservative design required for environmental conditions and to compensate for upset conditions prevalent in this type of operation. This process design is a balance between operational efficiency and capital cost. During the process and equipment design major consideration was given to the harsh operating conditions, to minimizing the heat and water loses and to operator safety. The produced water recycle system selected should provide years of continuos and reliable operations at reduced Opex and a competitive installed cost.

SAGD Water Analysis

Parameter	Units	Influent	Effluent
Temperature	Celsius	90	85
Water Density	S.G.	1.003	1.003
Oil Density	S.G.	0.94	0.94
Liquid pH	pH	7	7
TDS	mg/l	2270	2270
TSS	mg/l	100	1
Hardness	mg/l as $CaCO_3$	16	0.2
Oil Content	mg/l	50-100	<1
Silica	mg/l as SiO_2	217	50

Figure 1



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