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High Temperature De-Oiling of SAGD Produced Water

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ABSTRACT

Water use and greenhouse gas emissions in Alberta's oil sands are growing provincial and global concerns. For this reason, steam-assisted gravity drainage (SAGD) operators are looking for alternative technologies to increase water recycle rates while minimizing the greenhouse gas footprint of the water treatment process.

In 2013, RJ Oil Inc. (RJ), in collaboration with Alberta Innovates – Energy and Environment Solutions (AI-EES), Pengrowth Energy and Laricina Energy, undertook a five month pilot plant trial to evaluate its novel de-oiling technology configured for high temperature, high pressure operation at a SAGD facility. Recycled water is typically cooled to approximately 80°C - 90°C for treatment. The study's objective was to evaluate the effectiveness of the RJ de-oiling technology at elevated temperature (>120°C). It is expected that not cooling and re-heating the water during the course of its treatment will have significant cost and energy savings for SAGD water treatment.

The pilot was successfully completed. The technology was able to de-oil produced water at high temperatures (120°C to 135°C) and high pressures (550 kPag). Treated produced water containing an average of less than 20 ppm oil was achieved during testing after three stages of de-oiling followed by filtration regardless of the inlet feed oil content.

To realize the full energy savings of high temperature treatment, complementary polishing and hardness and silica removal technologies that operate above 120°C need to be identified.

KEY WORDS

high temperature, SAGD, de-oiling, water treatment, oil sands, produced water recycle

INTRODUCTION

In Alberta, 80% or roughly 135 billion barrels of the oil sands, are buried deep below the surface and are not accessible by open pit mining [Alberta Energy, 2013]. These deep resources are recovered using thermal in-situ production methods, such as steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS). In SAGD, steam is injected into the reservoir to mobilize the bitumen underground. The majority of the injected steam returns to the surface with the produced bitumen. The bitumen and water is separated and the water is recycled. Current water processing in SAGD facilities is effective and in general allows for recycling of up to 90% of the water [Alberta Energy, 2013]. However, this recycle comes at the cost of greenhouse gas (GHG) emissions and high operating costs.

In 2012, Alberta Innovates – Energy and Environment Solutions (AI-EES) and a consortium of industry partners commissioned the Thermal In Situ Water Conservation Study. The study considered the balance between water recycling, GHG emissions and waste generation. The study generally concluded that with existing technologies increased water recycle rates will cause increased GHG emissions due to the extra energy required to treat the water [Hill, 2012].

Recycled water is typically cooled to approximately 80°C - 90°C for treatment because the water treatment technologies operate at atmospheric pressure. The objective of the study discussed in this paper was to evaluate the effectiveness of a novel de-oiling technology configured for high temperature (>120°C), high pressure (>1 atm) operation at a SAGD facility. Recycling water at elevated temperatures should reduce the heat load on the steam generator or the evaporator (depending on the water treatment process being used), thereby reducing energy use and associated GHG emissions. This technology opportunity addresses the key gap identified in the Thermal In Situ Conservation Study, high water recycle rates with reduced GHG emissions.

RJ OIL SANDS DE-OILING TECHNOLOGY

RJ Oil Inc. (RJ) is an Alberta-based company in operation since 1998. RJ has developed a low energy separation technology that does not require heat, chemicals or rely on oil density to remove oil from liquid or slurry streams.

Process water comes into the RJ Oil/Water Separation (RJOS) system from either the free water knock out (FWKO) or skim tank. The water is fed through a patented Phase Separation device that induces dissolved and entrained gas into the water to separate oil from the water. The water is then fed into a collection cell where the water drops out and the oil/gas mixture flows over a weir into an oil collection tank. Solids in the process stream follow the water through the system. The water/oil interface is monitored and the pump speed is automatically adjusted to prevent water from flowing over the weir with the oil. This automated control allows the system to respond to variable flow rates and slugs of oil (upset conditions). Three Phase Separators and collection cells are used in sequence to maximize oil removal. Each cell removes 80 to 95% of the remaining oil. The recovered oil can be added to the inlet of the oil treating train. The water is sent to the next stage of treatment [RJ Oil, 2014]. Figure 1 shows a schematic of the RJOS process.

The RJ de-oiling technology has been under development since 2003. The technology was successfully tested at lab scale on various feeds, including drill cuttings, mature fine tailings, and produced water from multiple types of oil and gas facilities. In 2008, RJ developed a portable 5 m^3/hr unit that was used for multiple field tests ranging from one week to two months in length. Today RJ has installed two commercial scale units in operation at a conventional oil facility and a SAGD facility.

Development of the technology prior to 2012 and commercial deployment has focused on operation at standard water treatment temperatures and pressures (80°C and 1 atm). The objective of the project discussed in this paper was to test the RJ de-oiling technology at elevated temperature and pressure.

FIELD DEMONSTRATION METHODOLOGY

In the fall of 2013, RJ, in collaboration with AI-EES, Pengrowth Energy and Laricina Energy, undertook a five month pilot plant trial to evaluate its novel de-oiling technology configured for high temperature (120°C to 135°C) and high pressure (550 kPag) operation at a SAGD facility.

The field demonstration took place at the Pengrowth Energy Lindbergh Thermal SAGD Pilot Plant. The objective was to evaluate RJ technology's capability to:

- Process oily produced water at high temperature (>120°C) and high pressure (>1 atm)

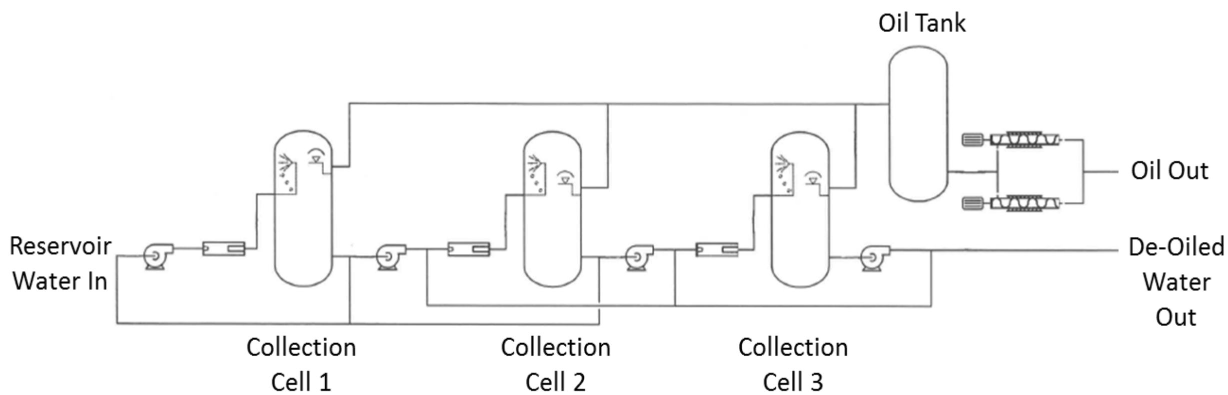

Figure 1: Schematic of the RJOS process [Lightbown, 2014]

- Produce a water stream with 10 ppm or less oil concentration
- Simplify the overall water treatment process train by the elimination of heat exchangers.

Testing commenced on December 16, 2013 and continued through to May 15, 2014. The pilot unit was operated under three test scenarios as shown in Table 1.

Table 1: Test scenarios

Scenario	*1*	*2*	*3*
Time Period	December 16, 2013 – February 3, 2014	February 3, 2014 – May 9, 2014	May 9, 2014 – May 15, 2014
Feed Source	FWKO discharge	FWKO discharge and emulsion	FWKO discharge and emulsion
Average Flow Rate (m^3/hr)	5.36	5.18	3.77
Average Differential Pressure across Phase Separator (kPag)	372	372	413
Average Temperature (°C)	126.27	125.01	128.7
Notes			Phase Separator retrofit with smaller nozzles

In test scenarios 1 and 2 it was noticed that the pumps were unable to reach the desired pressure differential. For test scenario 3 the 5 m^3/hr phase separators were replaced with 3.8 m^3/hr phase separators. These were downsized to allow the process pumps to produce a higher differential pressure across the device. The differential pressure across the phase separator was increased by an additional 41 kPag. The purpose of the retrofit was to enable operation of the pilot plant closer to its original design set-point and to assess any potential improvements in performance as a result of this retrofit.

The pilot unit was equipped with five sampling stations listed in Table 2. Water and oil samples were collected three to four times daily for on-site analysis. The water samples were analyzed for pH, turbidity, and oil and grease concentration (filtered and unfiltered). The oil samples were analyzed for base sediment and water (BS&W). Weekly samples from the inlet feed and final water discharge (stage 3 separation cell) were collected and sent for third-party analysis of one or more of alkalinity, calcium, chlorides, silica, electrical conductivity, magnesium, total dissolved solids (TDS), total suspended solids (TSS), and total organic carbon (TOC).

Table 2: Sample collection points

Station Number	*Sample Location*
1	Inlet feed
2	Water effluent from stage 1 oil-water separation cell
3	Water effluent from stage 2 oil-water separation cell
4	Water effluent from stage 3 oil-water separation cell
5	Emulsion from inlet to emulsion collection tank

Operating parameters, including flow rate, pressure and temperature, were measured online and recorded on the daily data sheet. All data obtained from the on-site lab or within the pilot unit, was recorded on the daily data sheet with notes made to indicate any changes or irregularities in collection or performance.

RESULTS

Water Quality

The pilot unit operated reliably throughout the full testing period. There were a few operational issues identified during commissioning of the unit (e.g., fluctuating blanket fuel gas pressure); however, these issues were addressed prior to the start of continuous operation.

Results of the on-site analysis are summarized in Table 3. The oil content in the feed varied widely (2.4 ppm to 250,000 ppm) depending on the scenario. For scenario 2 and 3 where a mix of FWKO effluent and emulsion was used, a globe valve was installed on the emulsion inlet line to permit flow control and blending of the emulsion into the feed stream. Adjustment and control of this globe valve to maintain consistent feed into the pilot plant was

Table 3: On-site analysis results

		Inlet Feed				Final Effluent (Stage 3)			
Scenario	*Parameter*	*Unfiltered Oil & Grease (ppm)*	*pH*	*Turbidity (NTU)*	*Temp (°C)*	*Unfiltered Oil & Grease (ppm)*	*Filtered Oil & Grease (ppm)*	*pH*	*Turbidity (NTU)*
1	Average	59.2	7.37	124.4	126.3	17.3	-	7.12	35.7
	High	302.4	7.56	316	134.9	60.2	-	7.38	113
	Low	2.4	7.27	65.2	112.1	0.7	-	6.39	14
2	Average	5769	7.39	757	127.4	123.4	33	6.88	184
	High	30000	7.61	1000	131.4	365.8	161.4	7.89	456
	Low	62.5	7.03	111	15.8	6.3	0.5	6.12	11.7
3	Average	19369	7.5	932	128.7	185.3	18.8	7.25	174
	High	250000	7.63	1000	130.1	1180	56.3	7.49	347
	Low	704	7.4	616	126.8	39	4.1	6.49	76

found to be extremely difficult. Minor adjustments in the globe valve setting produced drastic swings in the inlet feed oil and grease content, with the swing concentrations ranging from 500 ppm to as high as 10,000 ppm. Despite the large variation, the pilot unit was able to consistently remove approximately 96% of the oil from the feed.

Scenario 3 results are consistently lower than scenario 2. Scenario 2 was not operating at the original designed differential pressure and should be regarded as suboptimal performance. Scenario 3 results will be considered indicative of operating performance with high oil content in the inlet feed. In Scenario 3 the Phase Separator was modified to achieve the targeted differential pressure.

Usually when the oil content in the treated water increased, there was a visible increase in particulate, or a cloudy appearance at the water/solvent interface. This was possibly from excess chemical in the produced water. It was noted that the oil and grease in the final treated water was influenced by the level of turbidity. Higher levels of turbidity, which is a measure of colloidal and particulate material in the water, resulted in higher levels of oil and grease in the samples.

The appearance of visible particulate in the collected samples of de-oiled water prompted additional testing. The samples were split into two. One was left unfiltered and one was filtered to remove suspended particulate. Oil and grease testing was then completed on both the filtered and unfiltered de-oiled water. Results of this testing showed the oil and grease content was consistently lower in filtered treated water samples.

The pH of the water was largely unaffected by the RJOS treatment process; however, pH was generally lower in the de-oiled water than in the feed water. The slight drop in pH could be attributed to carbon dioxide in the fuel gas blanket (used to maintain pressure in the vessels) dissolving in the water.

The third-party water analysis did not show any significant changes in general water chemistry parameters. The anion and cation concentrations, irrespective of the test condition scenario, were similar between the inlet feed and final treated water. The difference in TOC concentrations between the inlet feed and the final treated water varied from a 33% decrease to a 10% increase which likely reflects the large variation in the oil content of the inlet feed and the relative timing of when the samples were taken (i.e. inlet feed and effluent samples were not taken at the same time).

Emulsion Quality

The high quality emulsion collected from the RJOS process was comprised principally of oil, with the oil content typically greater than 90%. It was analyzed for BS&W, rag layer, solids and water. The results are summarized in Table 4. The average BS&W value was 4.5%, ranging from 0.3% to 16.0%.

Table 4: Emulsion quality

Scenario	*Parameter*	*BS&W (%)*	*Rag Layer (%)*	*Solids (%)*	*Water (%)*
1	Average	9.7	1.3	1.0	7.4
	High	16.0	4.0	2.0	11.0
	Low	4.0	0.1	0.2	3.7
2	Average	1.7	0.02	0.1	1.6
	High	8.5	1.0	0.5	8.0
	Low	0.3	0.0	0.0	0.2
3	Average	2.2	0.05	0.4	3.2
	High	10.0	0.2	3.0	17.0
	Low	0.6	0.0	0.0	0.5
Oil Treating Inlet	Average	<10.0[a]			

a – [AkerSolutions, 2008]

GHG Emission Reduction

Currently there are two water treatment processes commonly used at SAGD facilities: warm lime softener (WLS) with a once-through steam generator (OTSG) or evaporator with a drum boiler. The potential GHG emission reductions will depend on which water treatment process is being used and the level of heat integration within an individual facility. A high level GHG emission reduction estimate is considered for the two common water treatment processes. Detailed heat integration models would be required to understand the true GHG benefits.

In the WLS with OTSG case the produced water is cooled to approximately 80°C for treatment, then heat exchangers are used to bring the temperature back up to approximately 106°C before the water is sent to the steam generator [COSIA, 2014]. For the high temperature water treatment scenario the water would be sent to the steam generator at 127°C, saving the energy required to heat the water from 106°C to 127°C.

In the evaporator with drum boiler case produced water is also cooled to approximately 80°C for oil removal, then it is pre-heated to 100°C before being fed into the evaporator for silica and salt removal. After the evaporator the water is cooled to 90°C for storage prior to being sent to the drum boiler for steam generation [Pengrowth , 2015]. In the high temperature treatment scenario the produced water will be fed into the evaporator tower at 127°C, saving the energy that is being used to heat the water from 80°C to 100°C.

Assumptions:

- 33,000 barrel per day (bpd) SAGD facility
- 340 days of production per year
- 3 barrels (bbl) of water required to produce 1 bbl of bitumen
- 90% water recycle rate
- 92% OTSG efficiency
- 97% drum boiler efficiency
- high temperature hardness and silica removal technology is commercially available

WLS with OTSG	
Parameter	*Calculations*
Produced water requiring treatment	= 3bbl x 0.9 = 2.7 bbl water per bbl bitumen
	= 0.429 m^3 water per bbl bitumen
Natural gas emission factor	= 51.75 kg CO_2/GJ
Water specific heat capacity	= 4.1868 kJ/kg °C
Water density	= 1000 kg/m^3
Current water treatment temperature	= 80°C
Current post-treatment water reheat temperature from heat integration	= 106°C
Proposed water treatment temperature	= 127°C
Reheat eliminated by operating at 127°C	= 127 – 106 = 21°C
Energy savings per barrel of bitumen	= 21°C x 4.1868 kJ/kg °C x 1000 kg/m^3 x 0.429 m^3 = 37,718.881 kJ/bbl
Account for boiler efficiency	= 37,718.881 kJ/bbl / 0.92 = 40,998.783 kJ/bbl = 0.0409988 GJ/bbl
Emission reduction per barrel of bitumen	= 0.0409988 GJ/bbl x 51.75 kg CO_2/GJ = **2.12 kg CO_2/bbl**

Emission reduction for average facility	= 2.12 kg/bbl x 33,000 bpd = 69,960 kg CO_2/d
	= 69,960 kg/d x 340d/yr = **23,786 t CO_2/yr**

Evaporator with Drum Boiler	
Parameter	*Calculations*
Produced water requiring treatment	= 3bbl x 0.9 = 2.7 bbl water per bbl bitumen
	= 0.429 m^3 water per bbl bitumen
Natural gas emission factor	= 51.75 kg CO_2/GJ
Water specific heat capacity	= 4.1868 kJ/kg °C
Water density	= 1000 kg/m^3
Current water treatment temperature	= 80°C
Current pre-evaporator water reheat temperature	= 100°C
Proposed water treatment temperature	= 127°C
Reheat eliminated by operating at 127°C	= 100 – 80 = 20°C
Energy savings per barrel of bitumen	= 20°C x 4.1868 kJ/kg °C x 1000 kg/m^3 x 0.429 m^3 = 35,922.744 kJ/bbl
Account for boiler efficiency	= 35,922.744 kJ/bbl / 0.97 = 37,033.757 kJ/bbl = 0.0370338 GJ/bbl
Emission reduction per barrel of bitumen	= 0.0370338 GJ/bbl x 51.75 kg CO_2/GJ = **1.92 kg CO_2/bbl**
Emission reduction for average facility	= 1.92 kg/bbl x 33,000 bpd = 63,360 kg CO_2/d
	= 63,360 kg/d x 340d/yr = **21,542 t CO_2/yr**

The calculations show the potential for a reduction of 1.92 - 2.12 kg CO_2/bbl of bitumen produced or 21,542 - 23,786 t CO_2/yr for an average SAGD facility, varying with the type of water treatment process used. The estimated reduction is significant but may be overestimated depending on the level of heat integration at the facility.

DISCUSSION

The pilot unit operated from December 2013 to May 2014 under a variety of operating conditions and consistently achieved less than 20 ppm oil and grease content after filtration of the treated water. Filtration is needed because the RJ technology is not capable of removing oil wet particles as they do not attach well to micro bubbles. This challenge is not a function of temperature.

The RJ technology performance varies slightly depending on the site and reservoir characteristics. The produced water used in this demonstration had a high level of particulates. The RJ technology operating at 1 atm and 80°C consistently achieves 10 ppm oil and grease content when treating SAGD produced water. Operation and performance did not appear to change with the high temperature, high pressure pilot unit so it is expected that it would be able to produce lower oil and grease contents under different site conditions than were seen in this trial. Testing at additional SAGD sites is needed to prove robustness.

Increasing the inlet feed oil and grease concentrations by three orders of magnitude still resulted in an average final treated water oil and grease content of less than 20 ppm (filtered) after three stages of treatment. Existing de-oiling technologies often need to be taken off line after upsets for cleaning and/or allow oil slugs through to the water softening stage.

Third-party lab analysis showed that the RJ technology does not impact general chemistry parameters, with the exception of a slight decrease in pH. The decrease is minor and may be a result of the gas blanket used in the separation vessels.

In all cases, the oil emulsion separated from the produced water was high quality (<10% BS&W) and could be sent to the inlet of the oil treating train. This will bring in extra revenue that could help cover some of the cost of treatment.

Test scenario 2 and test scenario 3 had similar input feeds; however, the phase separator in scenario 2 was replaced with a smaller unit for scenario 3, allowing the pilot unit to run at a higher pressure differential (372 kPag vs 413 kPag). Results from the two scenarios showed that scenario 3 was able to meet the average 20 ppm (filtered) oil and grease content, while scenario 2 had an average oil and grease content of 33 ppm (filtered). For future designs it will be important to size the pumps and phase separators for a larger pressure differential to get optimal performance of the technology.

Preliminary GHG calculations show a strong potential for significant reductions; however, the reductions will depend on the water treatment/steam generation method, the level of heat integration at the SAGD facility, as well as the availability of a commercial high temperature silica and hardness removal technology. Further engineering and technology development is required.

CONCLUSION

The field demonstration of the RJ de-oiling technology configured for high temperature, high pressure operation was able to satisfy, or mostly satisfy the objectives set at the beginning of the pilot.

- Processed oily produced water at temperatures up to 135°C and pressures above atmospheric conditions (550 kPag).
- When the oily produced water had <1000 ppm oil and grease content, the pilot unit produced a final filtered treated water quality with an oil and grease content of less than 10 ppm. On average the final filtered treated water oil and grease content was less than 20 ppm. The oil content in the final treated process water was impacted by the amount of particulate and colloidal matter remaining in the treated effluent.
- Unit handled feed water with 250,000 ppm oil and grease
- The pilot unit plus filtration to remove oil wet particulate proved itself capable as a replacement technology for the skim tank and Induced Gas Flotation cell (IGF). The RJ technology could also eliminate the requirement for heat exchangers to cool the produced water.

If SAGD produced water can be treated and recycled at high temperature the potential GHG emission reduction is approximately 1.92 - 2.12 kg CO_2/bbl of bitumen production. However, to fully realize the estimated GHG emission reduction complementary polishing, and hardness and silica removal technologies that operate above 120°C need to be identified. Additional testing at SAGD facilities will be required to prove the robustness of the technology.

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