2021 In Situ Water Research Report

PUBLISHED NOVEMBER 2022 (v3)

cosia

INTRODUCTION

This report summarizes progress for projects related to improving the use and management of water by the in-situ Group of Canada's Oil Sands Innovation Alliance (COSIA) Water Environmental Priority Area (EPA). Projects included cover the period from 2019 to 2021.

Please contact the Industry Champion identified for each research project if any additional information is needed. The COSIA Water EPA In Situ Group participants during the period of this report were: Canadian Natural Resources Limited, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Imperial Oil Resources Limited, Suncor Energy Inc.

This report is funded by:

- Canadian Natural Resources Limited
- Cenovus Energy Inc.
- ConocoPhillips Canada Resources Corp.
- Imperial Oil Resources Limited
- Suncor Energy Inc.
- Syncrude Canada Ltd.
- Teck Resources Limited

October 2022

The cover photo is from WE0033 - NAIT High Temperature Produced Water Testing Facility.

CONTENTS

PROCESS MONITORING

WJ0019 - SAGD Well Testing and Multiphase Flow Meter Application

COSIA Project Number: WJ0019

Research Provider: Canadian Natural Resources Limited

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: N/A

Status: Completed

PROJECT SUMMARY

Scope

This project tested Multiphase Flow Meters (MPFM) from multiple vendors with the potential to replace a test separator system, which is currently used to measure production well multiphase flow.

Background

In situ production facilities often face challenges with accurate measurement of oil, water and gas flow rates from production wells. This is mainly because of harsher conditions with high temperature and pressure, varying compositions of emulsion, varying compositions/chemistry of individual phases (oil, water, gas), and presence of solids as silt or clays. In the current typical configuration, the emulsion from the SAGD, CSS or steam flood wells is fed to a test separator to separate the gas from liquid.

The gas from the test separator is measured with an orifice meter and the liquid flow rate is measured with a coriolis meter. The water cut is typically measured with water cut (WC) analyzers which operate on the principle of permittivity (which is based on dielectric constant). To reduce the land footprint and cost, typically only one test separator system is installed per SAGD pad with multiple wells, and the oil, water and gas production rates for each well is periodically tested using the switching valves. Testing for each well is conducted for the duration to meet AER Directive 17 regulatory requirements. Since the oil, water and gas produced by individual wells are not continuously measured, the rates determined during well tests are used to estimate the well's production for the period beginning with the well test and continuing until another test is conducted. Per Directive 17, the ratio of monthly actual volumes measured at the central processing facility to the volumes estimated from well tests for all the wells should be within a proration factor of 0.85-1.15. This proration factor applies to oil and water volumes independently.

Test separator systems require plot space, are costly, and sufficient time must be allowed between tests to purge the test separator of the emulsion from the previous test. Moreover, depending on the oil, water and gas rates, the test separator can experience flow surges causing gas underflow, which results in low water cut readings from permittivity-based water cut analyzers. The proper test separator liquid level controller tuning and smooth operation of the test separator level control valve are also important to ensure good readings from downstream coriolis and WC meters. The coriolis meter measures lower density with the presence of gas but the results may be significantly affected depending on the gas void fraction (GVF) in the fluid. For low gas content (up to 5% GVF), the AGAR WC reading can be corrected by comparing the coriolis density with the estimated mixture density from individual phase densities at operating conditions. Since the gas content in the emulsion varies, the test separator is typically connected to make-up natural gas to maintain the desired pressure. Depending on the variability of the gas flow rate, the gas flow measurement accuracy may also be compromised if outside the orifice meter calibration range.

A multiphase flow meter which can provide an accurate measurement of oil, water and gas flow rates for wide flow ranges would be ideal to replace test separators. MPFM will not only reduce the cost associated with pad test separator systems but will also provide more well test data since purging would be quick due to the low system volume compared to a test separator system. Moreover, if the meter is cost effective, it would be worth installing the meter on individual wells, which would provide continuous real time data for better control. This may be required especially during start-up and ramp-up and/or for those wells where injection steam conformance and chamber pressure maintenance is critical for optimal production especially due to bottom water and/or top gas chambers.

Some of the multiphase flow meter technologies that could be applicable for SAGD operation include AGAR MPFM-50, Medeng SAGD MPFM MD-04, Schlumberger VX Spectra MPFM, Roxar MPFM 2600 MVG, Weatherford Red Eye MPFM, etc. An accurate well gas flow measurement is not critical and is not part of the reporting requirement for SAGD operations. The test separator system can potentially be avoided if an accurate liquid mass flow rate is measured in the presence of gas. There are some technologies available to achieve this task, which include Krohne Optimass 6400 coriolis with Entrained Gas Management (EGM) and Micro Motion coriolis meter with Advanced Phase Measurement (APM). For high GVF conditions, the density measurement accuracy from a coriolis meter is improved by recording the drive gain and maintaining the desired resonance frequency. Note that these improved coriolis meters require an accurate water cut meter to measure the WC at high GVF, which is currently a challenge.

A PERM Nuclear Magnetic Resonance (NMR) WC analyzer is an alternate WC measurement technology which uses low field nuclear magnetic resonance to measure oil and water cuts. As such, it is unaffected by salinity, density, or gas content, and recalibrations are typically not required.

Tests

Canadian Natural conducted tests with MEDENG SAGD MPFM MD-04 and AGAR MPFM-50 for the MC1 SAGD pad at Wolf Lake from 2012 to 2014. Tests with Micro Motion coriolis with APM were conducted for a CSS Pad 40 at Primrose South in 2016. Tests with Krohne Optimass 6400 coriolis with EGM, Emerson Micro Motion coriolis with APM, and PERM NMR for water cut meter were conducted for SAGD Pad “A” at Kirby South in 2017. The MPFM and coriolis meters were installed upstream of the test separator to enable testing with the gas phase.

For AGAR and MEDENG MPFM trials, the liquid flow rates were compared with the test separator corolis meter liquid flows and the water cut values from MPFM were compared with the Dean Stark analysis of the pressurized samples taken at the outlet of MPFM. The pressurized samples were taken using a constant pressure cylinder to avoid flashing of the fluid during the sample collection. The pressurized samples were also sent to PERM laboratory for WC measurements using PERM NMR to compare with the Dean Stark WC measurements.

The objective for testing Emerson Micro Motion and Khrone Optimass coriolis meters was to evaluate the accuracy of liquid flow measurement in the presence of high GVF. The tests were conducted for both circulation (start-up) and SAGD phases. For coriolis meters, the liquid flow rates were compared with the test separator coriolis meter liquid flow. The PERM NMR WC was also tested against AGAR WC meter during this trial which could receive the sample with gas and without gas for WC analysis.

In all these trials, the gas flow measurement was evaluated only qualitatively and was not considered as a performance metric. For the liquid flow rates a relative error was used whereas for the water cuts an absolute error was used. Some of the key MPFM performance metrics (KPIs) include:

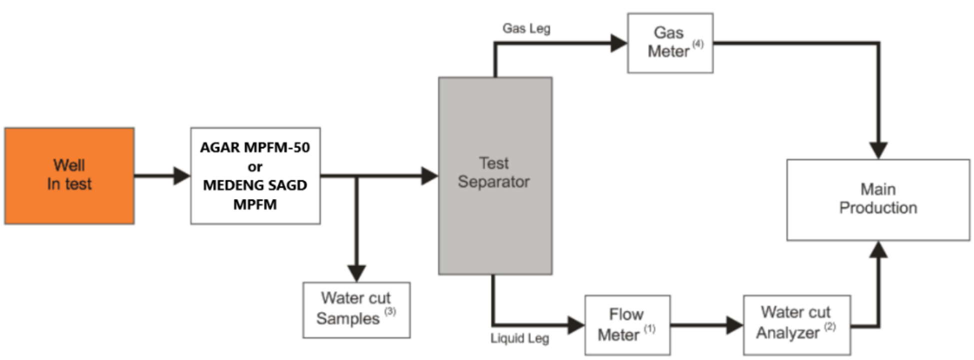
1. MPFM liquid flow rate to be within acceptable range of test separator liquid flow measured using coriolis meter i.e. 90% of the data points (confidence level) within ±5% difference. For a better comparison, the MPFM flow rates are totalized for the well testing period.

2. MPFM water cuts to be within acceptable range of Dean Stark water cut analysis of pressurized samples i.e. 90% of the data points within ±5% difference. For a better comparison, the average MPFM WC value was used during the pressurized sample collection.

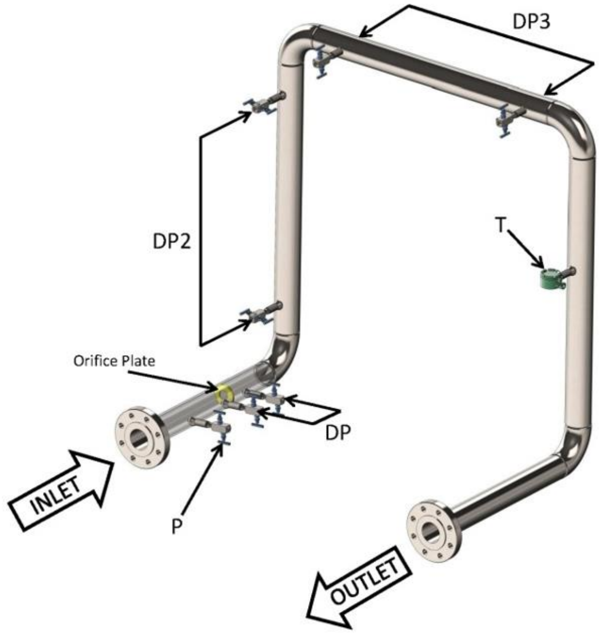
PROGRESS AND ACHIEVEMENTS

Six separate Multiphase Flow Meters were tested, and the high level learning’s are summarized below.

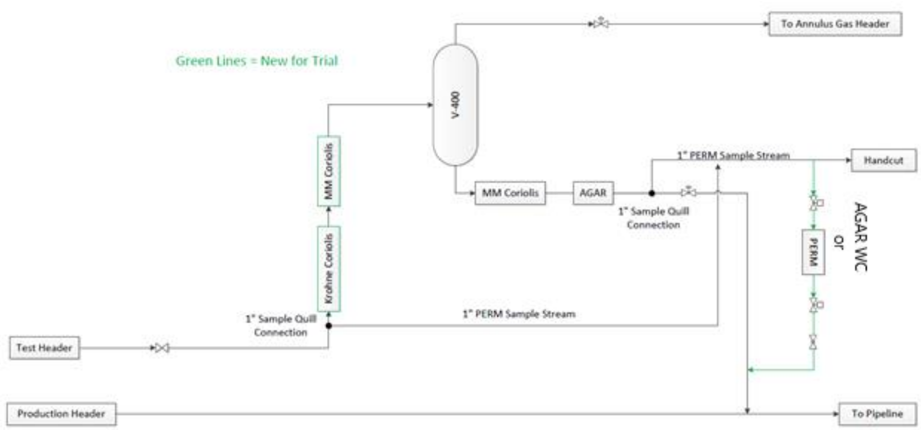
The AGAR and MEDENG MPFMs were tested separately for the MC1 SAGD pad at the Wolf Lake facility. The AGAR MPFM-50 skid consisted of a straight tube coriolis meter and a dual venturi meter to help with calculating liquid and gas mass flows, AGAR OW-200 for water cut measurement, and a AGAR ID-201 interface detector for water or oil continuous phase detection, which helps to choose the right calibration curve for water cut calculations from AGAR WC analyzer. The coriolis meter helps to measure the net mass flow and density to determine the GVF, and the venturi meter measures the momentum of multiphase flow in a non-homogeneous flow system to account for any slip at high GVF conditions. The venturi measurement combined with the coriolis measurement will give net liquid and net gas flows corrected for the slip ratio. The AGAR OW-200 water cut measures the fluid permittivity to calculate the water cut. Since the permittivity is measured in multiphase conditions, the GVF is used to correct the reading and calculate the liquid-only permittivity.



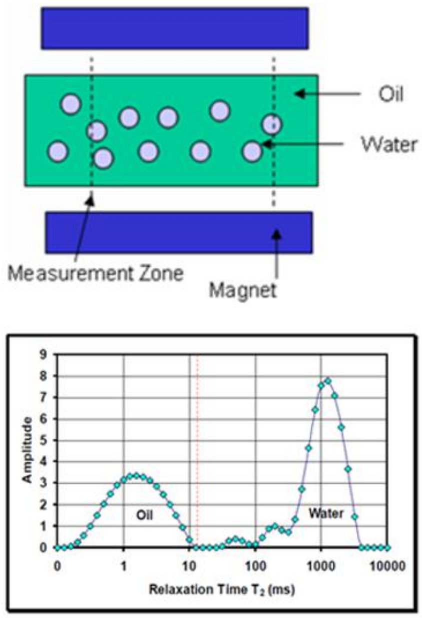
The MEDENG SAGD MPFM MD-04 skid consisted of an orifice meter at the inlet, pressure drop measurement across the vertical leg and pressure drop measurement across the horizontal leg. The law of mass conservation and momentum transfer partial differential equations are solved simultaneously to calculate 3 unknowns including water flow, oil flow and gas flow. The water cut (WC) and GVF values are calculated using the individual phase flows.



Both the Emerson Micro Motion and Khrone Optimass coriolis meters were installed upstream of the test separator at Kirby South SAGD Pad “A”. The intention was to eliminate the test separator for future commercial implementation. The liquid flow rates from these coriolis meters were verified with the test separator liquid coriolis meter. Arrangements were made to receive the samples through a 1” sample stream from both upstream and downstream of the test separator for AGAR WC or PERM WC measurements. The sensitivity of the existing AGAR WC meter downstream of the test separator GVF was also evaluated in a separate trial. In this case, a pad with a steady WC was selected and a measured quantity of fuel gas was introduced just upstream of the AGAR WC. Tests were run at various GVF to evaluate the impact of GVF on the AGAR WC measurements.



The PERM NMR WC analyzer utilizes relaxation time of the hydrogen bearing protons for WC measurements. The magnetic field causes the hydrogen bearing protons to line up. An oscillating magnetic field is then pulsed, causing the protons to spin. The spinning protons release a signal that is collected. It takes oil and water different lengths of time to relax and go back to their original position due to differing viscosities. The result is a relaxation time spectrum which can be analysed to determine water and oil cuts. The PERM NMR WC analyzer was installed which could get samples from both upstream and downstream of the test separator. The PERM NMR WC analyzer was arranged with switching valves to obtain batch samples with a measuring period of 4-5 minutes per sample. The PERM NMR WC results were compared with the existing AGAR WC meter available downstream from the test separator.



LESSONS LEARNED

Listed below are the key lessons learned from the trials:

1. The MPFMs typically meet the liquid flow rate KPI more easily than the water cut KPI. This means MPFMs still require WC improvement for accurate water and oil flow measurements when compared to pressurized sample Dean Stark WC measurements.

2. Dean Stark analysis of pressurized samples, which provides more accurate water cut results compared to centrifuge phase separation method, is currently used as an industry standard for evaluating MPFMs and WC meters.

3. Having an accurate reference water cut is important for evaluating MPFMs WC results. The current industry method of collecting a cooled sample at atmospheric conditions and mixing with Varsol, and spinning it in the centrifuge for water and oil phase separation (referred as hand-cuts) is not accurate enough to use as a reference. The hand-cut approach may be prone to errors because of insufficient cooling, flashing of water due to gas/steam, and human errors with sampling and measurement.

4. It is highly recommended to collect the pressurized samples close to the MPFM and in sufficient volumes (500 ml) to obtain representative samples. There are alternative sampling systems available for collecting the representative samples including inline or slip stream batch sampling, isokinetic sampling, composite sampling, etc. However, these options could be costly and have thepotential to plug the sample lines if the system is not designed or maintained properly.

5. Very accurate time-keeping is also critical since WC could vary from minute to minute and the comparison should be made with the online meter for the corresponding time frame.

6. Although it is a common practice to set the WC KPI as an absolute WC error, it should be realized that the relative error for oil will be higher for a typical emulsion containing much higher water than oil. For example, a ±2% absolute WC error for an emulsion containing 70% water and 30% oil is a relative error of ±2.9% for water and ±6.7% for oil.

7. The gas flow measurement accuracy is not well investigated so far in the industry. It is important to measure accurate liquid flow rate in the presence of variable GVF, and to ensure accurate sampling and laboratory gas measurements (GVF) methods for comparing the MPFM GVF results. Having accurate produced gas flows may provide additional clues for proper well optimization, and could help with H2S and facility fuel gas and GHG forecasting.

8. The laboratory water cut measurements using PERM's low field Nuclear Magnetic Resonance (NMR) water cut meter matched closely with the pressurized sample Dean Stark WC results. So, laboratory PERM NMR WC analyzer could be an alternative to Dean Stark WC measurements.

9. The sampling and flushing is a bit complex for an online PERM NMR WC analyzer. Since PERM NMR WC analysis is a batch process requiring the sample to stay in the system for a few minutes, the system requires automatic valve arrangements for sampling and flushing.

10. A coriolis flow meter with advanced control algorithms and synthesized drive control, can give liquid flows with reasonable accuracy depending on the GVF. The current AGAR WC seems to perform well for GVF up to 5%. If the well GVFis low, a combination of coriolis and AGR WC can eliminate the test separator requirement.

11. Rather than exploring opportunities with one technology vendor, there may be an opportunity to develop a configuration using technologies from different vendors to measure phase flow rates and water cut accurately.

12. To implement MPFMs for every well the meters have to be very cost effective. If MPFMs are compact and easy to install and remove, rather than installing for every well, it may be worth installing them for start-up wells or for challenging wells to help with steam injection optimization until they reach a steady state.

PRESENTATIONS AND PUBLICATIONS

Key Resources and Web Links:

https://www.agarcorp.com/multiphase-flow-meters-mpfm-50/

http://www.medeng.com/mpfm#SAGD

https://krohne.com/en/products/flow-measurement/flowmeters/coriolis-mass-flowmeters/optimass-6400/

https://www.emerson.com/en-ca/automation/measurement-instrumentation/micro-motion/advanced-phase-measurement

https://perminc.com/resources/publications/low-field-nmr-water-cut-metering/

RESEARCH TEAM AND COLLABORATORS

Company/Institution: Canadian Natural Resources Limited

Principal Investigators:

1. Subodh Peramanu, P.Eng., PhD, Process & Technology Advisor, Canadian Natural Resources Limited
2. Gwen Sturdy, P.Eng., Facilities Manager, Canadian Natural Resources Limited

Research Collaborators: None

WJ0128 - Online Dissolved Oxygen Analyzer Trial

COSIA Project Number: WJ0128

Research Provider: Imperial Oil Resources Limited

Industry Champion: Imperial Oil Resources Limited

Industry Collaborators: N/A

Status: Completed

PROJECT SUMMARY

Within steam generation systems, the presence of dissolved oxygen within Boiler Feed Water (BFW) can result in corrosion of steam generation equipment. Water treatment in cyclic steam stimulation (CSS) and steam assisted gravity drainage (SAGD) facilities utilize deaeration and/or chemical programs to minimize dissolved oxygen within the BFW to protect integrity of Once Through Steam Generators (OTSG) and Heat Recovery Steam Generators (HRSG).

Failure analysis from steam generation equipment indicated that in some instances, failures were indicative of dissolved oxygen induced corrosion. Ad-hoc measurements of dissolved oxygen within BFW showed levels higher than recommended values.

A HACH K-1100 analyzer was tested for continuous monitoring of BFW dissolved oxygen to optimize equipment performance and chemical programs at Imperial's Cold Lake operations.

PROGRESS AND ACHIEVEMENTS

The HACH K-1100 analyzer was installed at the Nabiye Plant in April 2019 and has been in operation since. The unit has been able to measure and report dissolved oxygen within the BFW allowing for ongoing surveillance and optimization.

With regular maintenance, the analyzer was capable of providing reasonable dissolved oxygen results.

LESSONS LEARNED

During the trial, upwards drift of the reported dissolved oxygen was reported by the analyzer, eventually culminating with erratic results (Figure 1). Periodic cleaning of the sensor was implemented and was determined to maintain the online analyzer performance (Figure 2). Vendor recommendations for preventative maintenance include zero-point calibration and soft sensor replacement once a year.

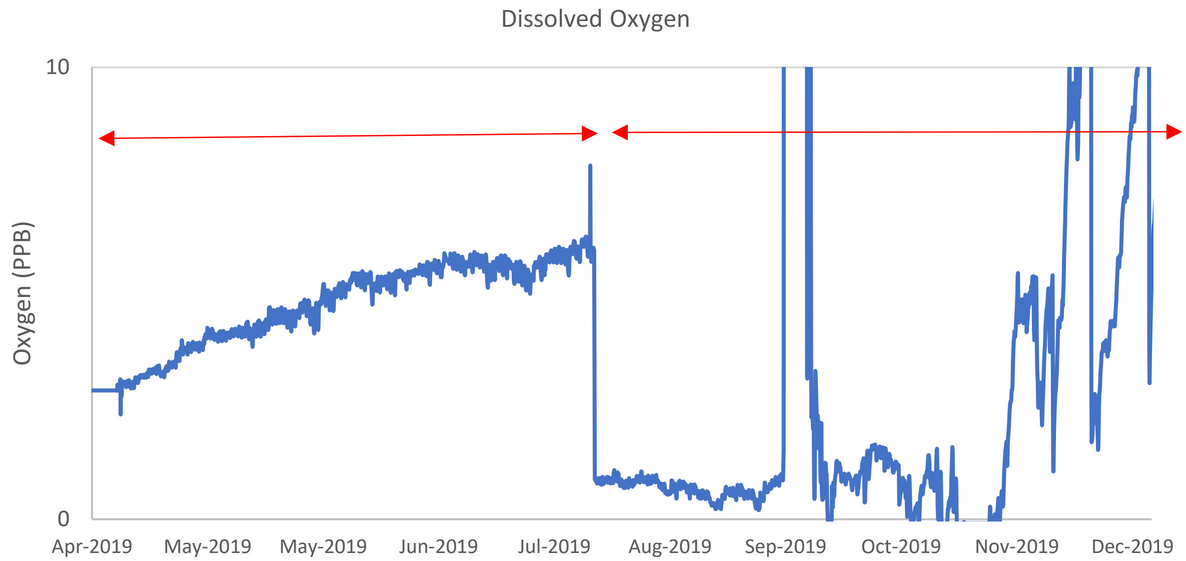


Figure 1. DO analyzer trend after commissioning in April 2019.

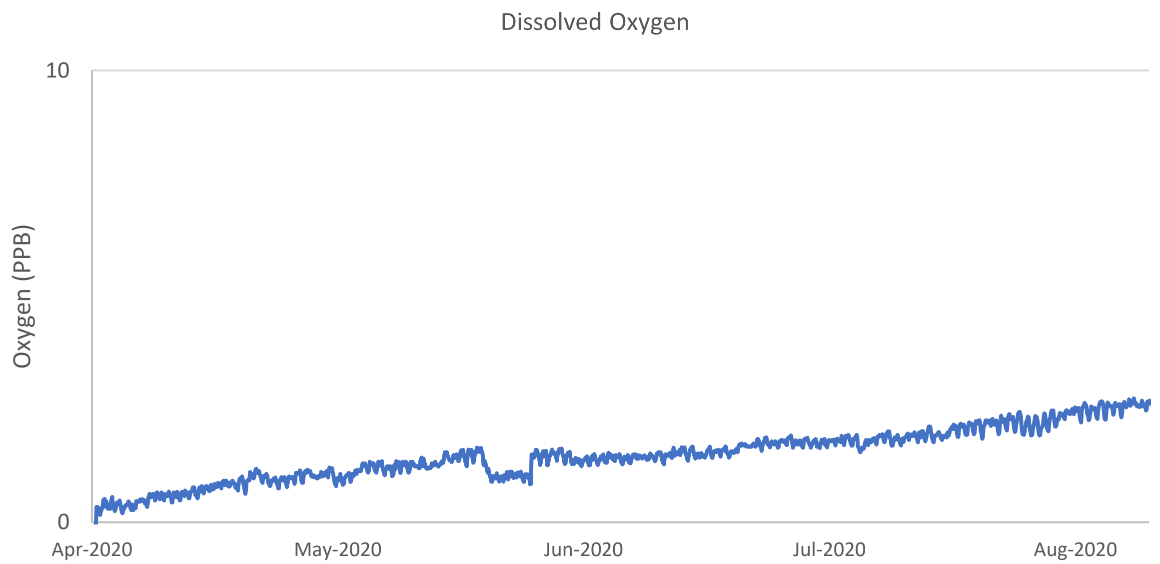


Figure 2. DO analyzer performance with regular cleaning / preventative maintenance after April 2020.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications.

RESEARCH TEAM AND COLLABORATORS

This research was conducted by Imperial and no external research bodies were enlisted.

WJ0169 – In Situ Steam Generator Thermal Camera

COSIA Project Number: WJ0169

Research Provider: Cenovus Energy Inc.

Industry Champion: Cenovus Energy Inc.

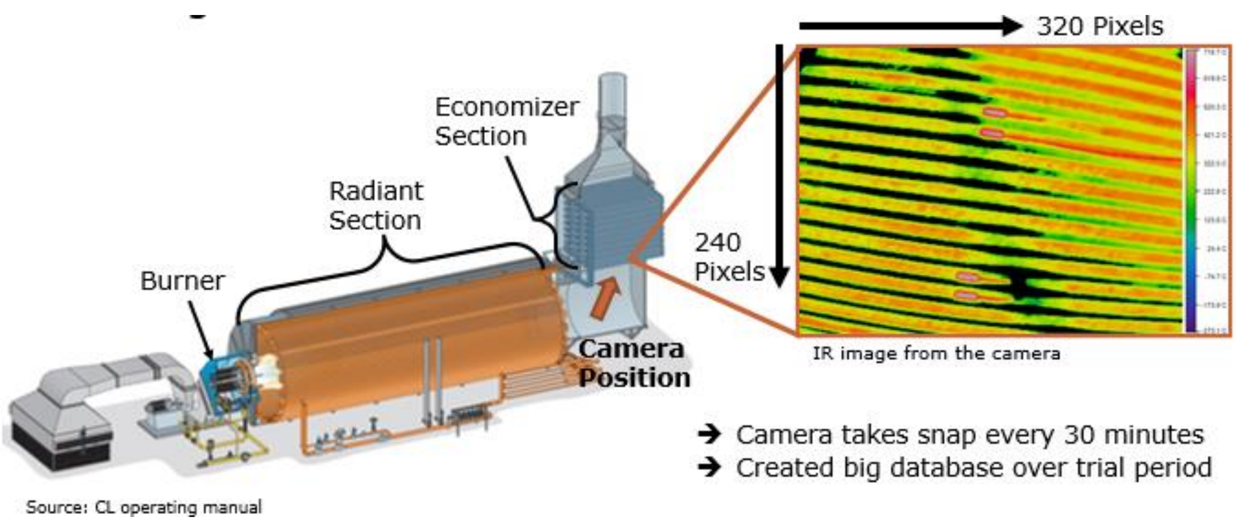
Industry Collaborators: N/A

Status: Complete

PROJECT SUMMARY

In an industry first, a thermal camera was installed on a Once Through Steam Generator (OTSG) at Cenovus Energy Foster Creek on FC3-B-0205 in 2017 to provide continuous monitoring of the shock tubes of an OTSG.

1. The primary goal of the project was to produce a reliable means of measuring the shock tube (see image) temperature to support a novel boiler technology project. It is understood that doing two trials at once is not ideal. This trial would allow for accurate and continuous monitoring of a novel boiler design in operation.



2. The secondary goal of the project was to replace the skin temperature thermocouples that are prone to failure and have a high cost of replacement.

PROGRESS AND ACHIEVEMENTS

The results of the trial indicate:

- The camera operated successfully with minimal operator interaction providing continuous data.
- The thermal camera can locate hot spots, provide trending, and demonstrates reliable measurement.
- The thermal camera has a higher reliability than skin thermocouples on this single test case.

- The thermal camera provides better monitoring of the shock row tubes as it observes all the tubes rather than a single point.
- The thermal camera can identify variability from the operating conditions.

LESSONS LEARNED

- Accurate measurement of the boiler tubes in the OTSG is critical to protect the boiler and determine then optimize the time between piggings. Failure to properly detect hot spots can result in tube failures and downtime.
- Accurate temperature measurement is also required for blowdown boiler operation, process upset identification, and high steam quality operation of the OTSG in existing operations.

PRESENTATIONS AND PUBLICATIONS

None.

RESEARCH TEAM AND COLLABORATORS

Institution(s): Cenovus Energy Inc.

Principal Investigator(s): N/A

STEAM GENERATION

WE0026, WE0081 - Lab Scale OTSG at SAIT (Phase 1 and 2)

COSIA Project Number: WE0026, WE0081

Research Provider: Southern Alberta Institute of Technology (SAIT)

Industry Champion: ConocoPhillips Canada Resources Corp.

Industry Collaborators: Cenovus Energy Inc., Canadian Natural Resources Limited, ConocoPhillips Canada Resources Corp., Imperial Oil Resources Limited, Suncor Energy Inc.

Status: Completed

PROJECT SUMMARY

The "steam" in the Steam Assisted Gravity Drainage (SAGD) process is typically produced in Once Through Steam Generators (OTSG), and is then injected into bitumen-rich reservoirs to heat the heavy oil, thereby enabling it to flow. Produced water and oil then return to the surface where the oil is separated from the water. Most of the produced water is cleaned and sent to the OTSGs to be recycled into steam again. Although the produced water is treated, residual salts and oils remain in the water and can form scale – like what appears in an electric tea kettle – inside the OTSG tubes, leading to ineffective operation, equipment failure and prolonged outages.

Conducting experiments in a laboratory setting is desirable due to the ability to control the parameters being tested, and the speed at which results can be generated, whereas full-scale field trials on commercially operating OTSGs take a lot of time and money, and the quality of results can be difficult to interpret. The lab-scale OTSG attempts to duplicate the inner workings of a commercial OTSG in a fraction of the time.

PROGRESS AND ACHIEVEMENTS

In situ produced water from multiple COSIA member sites was shipped to the Southern Alberta Institute of Technology (SAIT) facility to be used in various trials. The initial testing has focused on evaluating chemical additives that could be added to the water to reduce the likelihood of scale build-up on the tube walls, thereby reducing the heat transfer efficiency and increasing the time the equipment can be online before requiring cleaning.

Approximately 12 different chemical additives have been tested on produced water from three facilities. Once the additive testing has concluded, the information is intended to be made public, to further aid research. This data would have taken decades to collect had it not been for the collaboration made possible through COSIA.

LESSONS LEARNED

Although the logistics of establishing a complex research program offered multiple challenges (e.g., designing fit-for-purpose equipment, securing suitable space, training personnel), there is promising evidence that some chemical additives are effective at reducing scale formation within OTSGs. The conclusions from this work will need to be validated in field trials.

PRESENTATIONS AND PUBLICATIONS

N/A

RESEARCH TEAM AND COLLABORATORS

Institution: Southern Alberta Institute of Technology (SAIT) Centre for Energy Research and Clean Unconventional Technology Solutions (CERCUTS), Department of ARIS

Principal Investigator: Vita Martez

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Expected Degree Completion Date or Year Completed (Students Only)
Dr. Evgeny Anisimov	University of Calgary (Research Scientist at SAIT 2016 to 2020)	MSc., Mechanical Engineering	2016	2019
Michael Fairhurst	Southern Alberta Institute of Technology	Chemical Laboratory Technology	2016	2019
Alessandro Stoppa	Finished BSc. Medical Science, University of Novara, Italy Southern Alberta Institute of Technology	B.Sc. Medical Science and Environmental Technology	2016	2019
Vincent Morga	Southern Alberta Institute of Technology	Chemical Engineering Technology	2019	2021
Xavier Dumas	Southern Alberta Institute of Technology	Chemical Engineering Technology	2019	2021
Nicolas Layton	Southern Alberta Institute of Technology	Chemical Engineering Technology	2019	2021

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Expected Degree Completion Date or Year Completed (Students Only)
Joshua Weatherall	Southern Alberta Institute of Technology	Chemical Engineering Technology	2019	2021
Justin Mah	Southern Alberta Institute of Technology	Chemical Engineering Technology	2019	2021
Matthew Henry	Southern Alberta Institute of Technology	Environmental Technology	2019	2021
Jens Martens	International Exchange Student UCLL Leuven-Limburg, Flemish Region, Belgium	BSc., Chemistry	2019	2022
Mike Crozier	Southern Alberta Institute of Technology	Chemical Laboratory Technology	2020	2020
Kim Tran	Southern Alberta Institute of Technology	Chemical Laboratory Technology	2020	2020
Diego Rivera Vazquez	Southern Alberta Institute of Technology	Chemical Engineering Technology	2020	2022
Rajni Sharma	Finished her B.Sc. at Ly. Khalsa College Jalandhar, India Southern Alberta Institute of Technology	BSc. Chemistry and Chemical Engineering Technology	2020	2022
Gabriel Cusanelli	Southern Alberta Institute of Technology	Chemical Engineering Technology	2020	2022
Matthieu Trudell	University of Western Ontario	B.Sc. Biochemistry	2018	2022
Eric Low	Royal Roads University	MSc., Environmental Management	2021	2023
Mark Donner	Alberta Innovates	Director, NSERC-SAIT Chair Board Member		
Vicki Lightbown	Alberta Innovates	Director, Former NSERC-SAIT Chair Board Member		
Ross Chow	InnoTech Alberta	Managing Director, Former NSERC-SAIT Chair Board Member		
John Van Ham	InnoTech Alberta	Executive Director, NSERC-SAIT Chair Board Member		
Vita Martez	SAIT	NSERC- Industrial Research Chair and SAIT Chair Board Member		
Lifeng Zhao	SAIT	Research Chemist and Water Research Laboratory Coordinator		
Joseph Apawan	SAIT	Research Engineer and OTSG Laboratory Coordinator		

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Expected Degree Completion Date or Year Completed (Students Only)
Rogelio Lozano	SAIT	Research Engineer and Clean Tech Innovation Laboratory Coordinator		
Marlon Norona	SAIT	Researcher/CICAN Recipient		
Charlie Atkins	SAIT	Researcher/CICAN Recipient		
Arnel Angeles	SAIT	Research Chemist/CICAN Recipient		
Aprami Jaggi	SAIT	Research Scientist/CICAN Recipient		
Evgeny Anisimov	SAIT	Former New Graduate and Researcher		
Alessandro Stoppa	SAIT	Former New Graduate and Researcher		
Michael Fairhurst	SAIT	Former New Graduate and Researcher		
Nelia Julca	SAIT	Research Chemist		
Sarah Tripp	SAIT	Researcher/CICAN Recipient		
Eric Low	SAIT	Environmental Chemist/New Graduate/CICAN Recipient		
Maryam Izadifard	SAIT	Research Scientist and Engineering Consultant		

WE0043 - Advancing Scientific Knowledge on Fouling, Erosion and Corrosion in Once Through Steam Generators (OTSGs)

COSIA Project Number: WE0043

Research Provider: University of Calgary

Industry Champion: Suncor Energy Inc. and ConocoPhillips Canada Resources Corp.

Industry Collaborators: Cenovus Energy Inc., Canadian Natural Resources Limited., and Imperial Oil Resources Limited

Status: Completed

PROJECT SUMMARY

Canada is well positioned to deliver safe, secure and reliable energy to markets, especially via steam-assisted in situ production of oil sands deposits. This requires highly economic approaches to produce steam in Once Through Steam Generators (OTSGs), while produced fluids are recycled to minimize the environmental footprint of in situ oil sands operations. The boiler feed water (BFW) constituents are prone to cause mineral and organic precipitates upon heating in steam generators, and erosion and corrosion often result in premature OTSG failure.

This research project aims to reduce inorganic and organic fouling, erosion and corrosion in OTSGs to enhance water and energy efficiency and achieve greenhouse gas emission reductions. The fiveyear project is being conducted by a research team comprised of members from the University of Calgary, the University of Alberta and SAIT. All aspects of this research program are designed to obtain a science-based technical operating envelope (TOE) for OTSGs.

Preliminary findings revealed that inorganic fouling results predominantly in Mg-, Na-, Fe- and Ca silicates that co-precipitate with considerable amounts (17-74%) of organic carbon. Geochemical model results supported by pilot rig experiments suggest that minimizing the concentration of Mg in boiler feed water to very low levels may have considerable promise for minimizing inorganic scale formation in OTSGs. Investigations assessing to what extent organic solid formation is dependent on hydrothermal pH variations, dissolved organic matter (DOM) composition and reaction systems are ongoing. Erosion and corrosion investigations revealed there are multiple damage mechanisms at play, e.g. pitting followed by flow-accelerated broadening of the pits, which can lead to localized areas of high turbulence where damage is exacerbated. Models have been developed capable of simulating multi-phase multi-regime flow with evolution of water to steam for an entire OTSG pass. The impacts of a foulant layer on the inside of the OTSG tube were modelled, and it was demonstrated that the tube wall temperature does increase significantly when the foulant layer is present due to its relatively low thermal conductivity.

Progress in the first three years of this fiveyear project has been highly encouraging, suggesting that all original project milestones and goals will likely be reached by December 2023.

PROGRESS AND ACHIEVEMENTS

The objective of this research project is to reduce inorganic and organic fouling, and erosion and corrosion in OTSGs to enhance water and energy efficiency and achieve greenhouse gas emission reductions. The research team members from the University of Calgary, the University of Alberta and SAIT pursue this goal in collaboration with industry partners in four inter-related research themes a) inorganic fouling, b) organic fouling, c) erosion and corrosion, and d) modelling, and integration of the respective findings from these themes. A unique aspect of this project is the ability to test the applicability of key findings from laboratory and modelling investigations in large-scale pilot OTSG rigs.This is because it is infeasible to test new BFW limits, operating conditions, and advanced materials in the field due to the significant production scale of boilers, safety risks and unreliability issues.

Inorganic Fouling: Characterization of several scale samples from OTSGs using a wide range of analytical techniques revealed that mineral phases in scales are dominated by Mg-, Na-, Fe- and Ca-silicates that have comparable mineralogy, regardless of the exact operating conditions and location of fouling in the OTSG [3]. Geochemical models were developed capable of replicating the composition of the condensate phase while reproducing the detected minerals allowing better constrained thermodynamic and chemical operating parameters. Preliminary modelling results indicate that minimizing the concentration of Mg in BFW to very low levels appears to show great promise for minimizing inorganic scale formation in OTSGs [5]. Steam quality was found to have little impact on the mass of inorganic scale formed in OTSGs since most of the minerals precipitate from the BFW at temperatures between 150 to 200 °C prior to steam generation [5]. Therefore, pushing the operating envelopes of current OTSGs to steam qualities of >80% should be achievable without risking significantly increased amounts of inorganic scale formation.

Organic Fouling: Analysis of several scale samples from OTSG operators revealed organic carbon contents varying from 16 to 74% in the deposits, confirming that organic fouling is a major contributor to scale formation in OTSGs. It was also observed that a vast amount of organic carbon from scale is baked to coke. In addition, several BFW samples from different regions were investigated to study their organic molecular compositions and associated hydrothermal processes and reaction products. The results revealed that dissolved organic matter (DOM) composition, pH change and solid formation through heat exposure are different depending on the geographic source of the BFW. This suggests that the organic solid formation may depend on pH variations, which in turn seems related to the DOM composition and reaction systems (e.g., hydrolysis of esters, abundance and type of organic sulfur species involved in the formation of precipitates).

Fig. 1: Damage in a OTSG tube removed from one of the industrial sponsor's operations. Flow is into the page, with a straight tube section upstream of a bend.

Erosion and Corrosion: Analysis of damaged specimens obtained from a number of COSIA members has shown that there are multiple damage mechanisms at play, e.g. pitting followed by flow-accelerated broadening of the pits, which can lead to localized areas of high turbulence where damage is exacerbated. The relative importance of the damage mechanisms is highly temporal, i.e. the key mechanism shifts from one to another over time. Moreover, the damage mechanisms that drive the damage are different at different locations (both axially and circumferentially). Figure 1 shows an example in a straight tube section leading to a bend. The grey areas indicate some protection by a magnetite passivation layer; at the three and nine o'clock positions, highly localized damage is visible. Further magnification of these damaged areas (not shown) suggests that the damage is initiated by corrosion pitting. Then, due to high velocity steam flow (with dispersed liquid droplets), the surrounding passivation layer is removed, and pits expand and merge. The fact that the damage begins with pitting indicates that changes in water chemistry and/or tube metallurgy should attenuate the damage.

Modelling: Within the OTSG, the tubes through which the boiler feed water flows are exposed to conductive, convective and radiative heat transfer. Under this heating, the water in the tubes changes from liquids to vapour, leading to evolving multiphase flow regimes. Dissolved solids in the water can scale the tubes with a consequent heat transfer resistance forming on the inside wall of the tube. Furthermore, the solids can peel from the tube and potentially erode the tubes. An analytic model has been developed and converted to a working research code for full-scale OTSGs, and the code has been validated. In addition, computational fluid dynamics (CFD) models have been successfully extended to simulate flow in different sections of an actual OTSG system.

Pilot Rigs: Since it is not feasible to conduct focused research and test new boiler feed water limits in commercial OTSGs, the SAIT-led research team developed, tested and utilized skid-mounted OTSG pilot rigs to conduct pilot scale studies. Two OTSG pilot scale test rigs (#1 and #2) were commissioned, operated and tested with synthetic and actual BFW from COSIA member facilities to improve the understanding of the operational and chemical conditions that contribute to scaling in the pre-heat and steam tube bundle sections. A third OTSG (#3) pilot skid designed for erosion and corrosion studies was installed and commissioned. Several experimental test runs were conducted but the third unit experienced a failure of the steam generator (60 kW heater/boiler). Currently, efforts are underway to redevelop a more robust heater alternative and rebuild OTSG pilot test rig #3. Meanwhile, the SAIT team has successfully pursued a hybridization of OTSG #1 to accommodate a corrosion test article downstream of the steam section to meet the deliverables of the erosion and corrosion research program.

So far, the results of this research project have been published in three peer-reviewed journal articles with three further manuscripts in review. More than five conference abstracts were also published. Furthermore, three postdoctoral fellows, two Ph.D. students, three MSc students, and several undergraduate students and research associates are currently working on this project or have contributed in the past.

LESSONS LEARNED

A key finding of the geochemical analyses and modelling is that concentrations of dissolved Si, Mg, Fe and dissolved organic carbon (DOC) in boiler feed water are the main factors controlling the mass and mineralogy of scale in OTSGs. In contrast, the concentrations of total dissolved solids (TDS) and Ca in BFW appear to have only a minor influence on the scale mass in OTSGs. This is consistent with findings from OTSG pilot test rig experiments with both synthetic and real boiler feed waters that have demonstrated that Mg is almost entirely removed from the water during experimental runs, whereas Ca is only partially removed, while in some cases Fe concentrations increased, suggesting an internal iron source. It has also been shown that the chemical compositions of different BFW from various companies react differently to the same chemical additive. Another key finding of the preliminary investigations is that steam quality has little impact on the mass of inorganic scale formed in OTSGs since most of the minerals precipitate from the BFW at temperatures between 150 to 200°C prior to reaching steam temperatures. Therefore, pushing the operating envelopes of current OTSGs to steam qualities of >80% should be achievable without risking significantly increased amounts of inorganic scale formation.

Based on the analysis of specimens cut from OTSGs and based on CFD simulations, it seems unlikely that particle-impact erosion plays a significant role in OTSG tube damage. Operation at elevated pH values appears to degrade the quality of the passivation layer, making it heterogeneous and porous, rather than a thin and dense passivation layer that is desired in OTSG operations. The role of a degrading magnetite passivation layer as a source of iron for frequently observed Na-Fe silicate scale deposits such as aegirine [5] is currently under investigation.

Modelling results have shown that the research team can simulate multi-phase multi-regime flow with evolution of water to steam for an entire OTSG pass. The impacts of a foulant layer on the inside of the OTSG tube were simulated and revealed that the tube wall temperature does increase significantly when the foulant layer is present due to its relatively low thermal conductivity. Modelling of the impact of the placement of thermocouples on the tubes demonstrates that the V-pad thermocouple with shield is preferred over the case without the shield and that the difference between the measured temperature with the thermocouple versus the bare tube is between 2 and 40°C. On the analytic model, a fouling model is being added to the system of governing equations. However, it is unlikely that a dynamic (transient) fouling model can be added to the CFD model. For fouling studies using the large-scale single pass OTSG CFD model, the research team will add a fouling layer to determine the impact on wall temperature versus foulant thickness at various locations.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

1) Arizaleta, M.L., M. Nightingale, B.M. Tutolo (2020) A rate law for sepiolite growth at ambient temperatures and its implications for early lacustrine diagenesis. Geochimica et Cosmochimica Acta 288: 301-315.
2) Che, Z., M. Nightingale, B.M. Tutolo (2021) Probing the application of kinetic theory to Mg-phyllosilicate growth with Si isotope doping. Geochimica et Cosmochimica Acta 310, 205-220.
3) Klyukin, Y. I., Nightingale, M., Perdicakis, B., Mayer, B. & Tutolo, B. (2022) Mineralogical characterization and thermodynamic modelling of scales formed in once through steam generators. Fuel 308, 121990.
4) Adedeji, O.E, Kumar, A., Perdicakis, B., Sanders R.S., Investigation of erosion-related failure in SAGD OTSG boiler tubes and the limitations of API RP 14E, J. Eng. Failure Analysis (submitted).
5) Klyukin, Y. I., B., Mayer, B. & Tutolo, B., Effects of boiler feed water composition on inorganic scaling in Once Through Steam Generators estimated using a Monte Carlo modelling approach. Currently in internal review with industry partners; for submission to Applied Geochemistry.
6) M. Sivagnanam, I.D. Gates, A. Mehrotra, et al., Thermal and Structural Analysis of V-Pad Thermocouples used on Once-Through Steam Generation Tubes. To be submitted by end of April to Journal of Heat Transfer.

RESEARCH TEAM AND COLLABORATORS

Institution(s): University of Calgary

Principal Investigator: Dr. Bernhard Mayer, Ph.D. (Professor, Department of Geoscience).

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Expected Degree Completion Date or Year Completed (Students Only)
Dr. Benjamin Tutolo	University of Calgary	Associate Professor		
Dr. Thomas Oldenburg	University of Calgary	Adjunct Professor		
Dr. Steve Larter	University of Calgary	Professor		
Dr. Sean Sanders	University of Alberta	Professor		
Dr. John Nychka	University of Alberta	Professor		
Dr. Ian Gates	University of Calgary	Professor		
Dr. Anil Mehrotra	University of Calgary	Professor		
Dr. Vita Martez	SAIT	Professor		
Maria Arizaleta	University of Calgary	BSc Student	Dec 2018	Aug 2020
Simone Shelley	University of Calgary	BSc Student	June 2019	July 2020
Jasmine Chase	University of Calgary	BSc Student	May 2020	Aug 2021
Ian Fleming	University of Calgary	BSc Student	Sept 2021	Present
Zhengqiang Che	University of Calgary	MSc Student	May 2019	May 2021
Dr. Yury Klyukin	University of Calgary	Postdoctoral Fellow		
Michael Nightingale	University of Calgary	Research Associate		
Ali Naderi	University of Calgary	PhD Student	July 2020	Present
Melisa Brown	University of Calgary	Research Associate		
Ryan Snowdon	University of Calgary	Research Associate		
Hossein Hosseini	University of Calgary	Research Associate		
Kim Nightingale	University of Calgary	Research Associate		
Omnath Ekambaram	University of Alberta	MSc Student	Jan 2019	On leave
Saeid Dehghani	University of Alberta	MSc Student	Jan 2020	June 2022
Dr. Farzad Ahmadi	University of Alberta	Postdoctoral Fellow		
Marcio Machado	University of Alberta	Research Associate		
Kevin Hodder	University of Alberta	Research Associate		
Dr. Samira Haf-Shafiei	University of Calgary	Postdoctoral Fellow		
Mohan Sivagnanam	University of Calgary	PhD Student	Sept 2020	Present
Dr. Aprami Jaggi	SAIT	Research Scientist		
Marlon Norona	SAIT	Lead Researcher		
Charlie Atkins	SAIT	Researcher		
Arnel Angeles	SAIT	Researcher		
Joseph Apawan	SAIT	Lab Coordinator		
Sarah Tipp	SAIT	Lead Researcher		
Matt LaPrairie	SAIT	Lab Coordinator		
Lifeng Zhao	SAIT	Chief Chemist		
Nelia Julca	SAIT	Researcher		
Eric Low	SAIT	Researcher		

WASTE MANAGEMENT

WE0045 - Development of Technologies for Treatment and Management of Evaporator Blowdown Wastes from Oil Sands Operations

COSIA Project Number: WE0045

Research Provider: University of Calgary

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Cenovus Energy Inc., Canadian Natural Resources Limited, Imperial Oil Resources Limited, Suncor Energy Inc.

Status: Ongoing

PROJECT SUMMARY

Steam Assisted Gravity Drainage (SAGD) is the most prominent method for in situ recovery of unconventional oil reserves in Alberta. In the SAGD technology, steam is injected into oil reservoirs to decrease the viscosity of bitumen before pumping it to the surface. One of the main challenges the oil sands operators face is treating and managing blowdown liquids from steam generators and evaporators during the SAGD process. After heavy oil recovery, the produced water contains production chemicals, traces of bitumen, and dissolved solids and minerals, including a high concentration of silica. Conventional wastewater treatment of produced water primarily involves two major steps, including deoiling and softening before it is sent back for steam generation. The industry adopts once-through steam generators (OTSGs) for steam generation. Typically, OTSGs convert about 80% of the water into steam. The remaining 20% of the water is termed blowdown water, which is a concentrate of inorganic and organic impurities. However, conventional treatment does not remove all impurities and continuous recycling of blowdown water results in higher concentrations of silica and organics. The accumulation of silica and organic impurities in the boiler feed water (BFW) promotes numerous operational problems, such as foaming, decomposition, corrosion, scale and contaminant deposition in steam generators.

The industry has adopted evaporators as an alternative approach for BFW treatment to reduce the feed water intake. Evaporators using falling film, vertical tube, vapour compression evaporation technology produce very high-quality distillate water used as BFW. Using evaporators eliminates the need for lime softening, filtration and ion exchange systems. The evaporators also have superior tolerance to withstand poor quality water without encountering traditional operational problems. Moreover, the evaporators function with very high efficiency by recovering 90 to 95% of the water through distillation. The remaining water fraction exiting the evaporators is termed evaporator blowdown (EBD) wastewater. The EBD waste stream varies in TDS from 50,000 mg/L to 300,000 mg/L solids with very high volatile and non-volatile organics fractions. About 2% of the EBD is disposed of, and the rest is recycled to the start of the produced water treatment train. At present, the EBD wastes are trucked out or are disposed of by deep well injection into salt caverns. EBD wastewater presents a cocktail of organics and inorganics, mainly silica, at very high concentrations, which are not removed via conventional treatment. Another challenge faced is the gelation of silica in the blowdown liquids, which prevents efficient dewatering leading to the generation of large quantities of waste slurry, which needs disposal, often at high costs. Thus, there is a need to develop newer technologies to treat and manage EBD wastewater to reduce freshwater intake. Improved boiler feed water quality will mitigate scaling problems in evaporators improving fuel efficiency resulting in considerable GHG reductions.

PROGRESS AND ACHIEVEMENTS

The long-term objective of this research is to develop economically viable methods for removing silica and organics from the evaporator blowdown wastes in order to achieve higher blowdown water recycle rates and meet the EPA standards for disposal of EBD wastes without facing issues such as plugging and clogging of the wellbores. This proposed research project mainly aims to understand the characteristics of EBD and then develop novel techniques and processes to treat and manage EBD wastes. Specifically, the project intends to achieve a higher quality of treatment for blowdown treatment targeting enhanced removal of silica and organics, thereby improving the reliability of the dewatering (DWT) process and improving the overall performance of the disposal wastewater system (e.g., reduced fouling of downstream filters and reduced plugging of disposal waters).

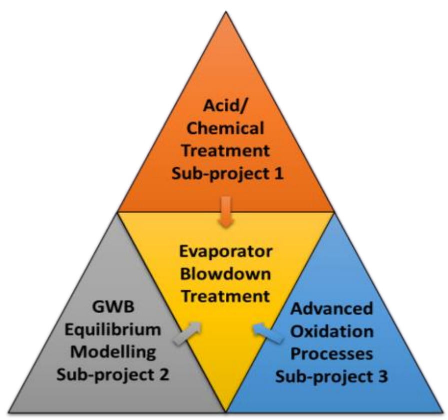


Figure 1: The aim of this research project is to remove silica and organics from the EBD waste streams.

To accomplish our objectives, we defined milestones over three years. The necessary activities to achieve milestones are categorized into three main subprojects. Figure 1 describes the linkage between these sub-projects. Sub-project 1 focuses on laboratory experiments for treating EBD water using acid and softening chemicals to precipitate silica and organics. Sub-project 2 focuses on the equilibrium modelling aspect of the EBD wastes and formation water using the Geochemist's Workbench (GWB) software. Sub-project 3 focuses on employing various Advanced Oxidative Processes (AOPs) on the EBD wastes to degrade organics and remove silica.

So far, studies have been conducted on highly concentrated synthetic silica samples. High concentration silica on pH neutralization generally results in gel formation. This study employed single-step and two-step methods for silica gel prevention. As outlined in a patent, the two-step process prevents gel often formed via the single-step process. The experiments were conducted on the synthetic solution with high concentration silica (~ 15,000 ppm) found in the EBD wastes. The single-step process involved reducing the pH from an initial alkaline pH to final neutral pH of 7 or 8. In contrast, the two-step process involved reducing the pH from an initial alkaline pH to a pH of 7 or 8 with an intermediate pH. The single-step and two-step experiments were first performed with no salt present. In both cases, the gel was formed, and the final concentrations for silica were found to be similar with comparable filtration rates. The preliminary studies indicated no significant difference between the two processes, leading to silica gelation. Experiments were then conducted for single-step and two-step processes while maintaining a minimum of 10% salt concentration for both processes. Both processes resulted in easily filterable precipitates instead of gel-like substances. These preliminary findings indicated no significant impact on silica gel suppression via single-step and two-step (with an intermediate pH) processes. The gel suppression was mainly influenced by the presence and absence of salt (NaCl), which was the determining factor in silica precipitation as a solid filterable species or gel. Further experimental design studies were undertaken to delineate the effect of salt on precipitation behaviour in high concentration silica solutions. The study further confirmed that the sodium chloride to silicon concentration ratio played an essential role in the type of precipitate being formed (either gel or filterable solids), thus affecting the filtration performance.

On the modelling side, an equilibrium geochemical modelling study was undertaken as it was found to have many critical applications in predicting and optimizing processes that are in their initial stages of the investigation. Modelling predictions can be vital in understanding new systems and their effects in real life. This study has given some insights into the behaviour of species concentration and mineral saturation values of EBD, formation water and the mix of EBD and formation water, referred to as mixed waters. The water composition that was studied is unique and has not been studied before. This creates challenges in understanding and working on the water as there was a lot of difference observed when working on the EBD compared to waters that were studied in the literature. The major difference was the concentration of silica. Studies on waters with silica concentrations of up to 20,000 mg/L have rarely been done, so using equilibrium modelling on the waters is a great way to assess the chemistry and aid in further experimentation and analysis. The major predictions on the EBD, formation waters, and the evaporator blowdown's interaction with formation waters when mixed are described below.

The results of the equilibrium modelling study conducted on the EBD and formation waters found pH to be the most crucial variable in both species' concentrations and mineral saturation values in the waters. With the high concentration of sodium ions in the waters, the most dominant silica species formed is the $NaHSiO_3$ species. Alkaline pH results in silica being in the reactive form and will react with other species in the water to form minerals which can eventually precipitate and cause operational and plugging issues. The assumption that maintaining higher pH will help in mitigating silica precipitation is only applicable when the water has an extremely high amount of silica (to be the most dominating species that the other chemical species are irrelevant) or if the water is not being stored/ processed for a very short time that precipitation is not a concern. The addition of HCl and H_2SO_4 did not have a significant influence on the concentrations of silica species present. The saturation states of chloride and sulphate minerals increased when HCl or H_2SO_4 was added. But this did not cause any of the minerals to become supersaturated and cause precipitation. The precipitation of calcite and quartz was predicted from EBD water with a change in pH. The precipitation of quartz reduced at alkaline pH, and the precipitation of calcite increased at pH>7. The dominant species in the formation water are $CaSO_4$, Cl^-, Na^+, and SO_4^{2-}. There is also the presence of HS^- and H_2S (aq.) in the waters, with H_2S (aq.) concentration at 200 mg/L. For applications such as the disposal of EBD into deep wells, the pH conditions at which the water is present play an important role in mineral precipitation.

The results of this research project have been presented in three conference proceedings so far. Two Ph.D. students and one MSc student are currently working on this project.

LESSONS LEARNED

The results from the work to date demonstrate the lack of significant difference between the single-step and two-step processes for high concentration silica solutions in preventing gel. Preliminary studies on high concentration silica solution showed that sodium chloride had a significant impact on the treatment process and influenced the type of residue formed, either viscous gel/sol or easily filterable solids. Further studies on actual EBD samples will be conducted to study the efficacy of acid and chemical precipitation in removing silica and organics from the blowdown stream. The filtration ability will be assessed along with characterizing and analyzing the filter cake obtained from the treatment.

EBD wastes constitute a high concentration of organics with various molecular sizes and morphologies. Further investigations will be conducted to study and understand the nature of organics present in EBD wastes, which might have a significant impact on the treatment process employed. Studies will be undertaken to evaluate the possibility of complexation of unreacted organics with a high concentration of silica inherently present in the EBD wastes leading to destabilization and settling of organics and silica during the treatment process. The application of AOP methods for the treatment of EBD wastes is considered highly promising based on the literature findings of the successful breakdown of organic molecules by the AOP chemicals. This project will further test the efficacy of degrading organics via the proposed methods, namely ozonation and hydrogen peroxide. AOP treatment for EBD could be used to exploit dual benefits with the simple addition of oxidants leveraging the inherent composition of EBD for the removal of organics and silica.

The goals and outcomes of this research will aid in improved economic and environmental performance of all the oil sands operators. At present, high concentrations of silica and dissolved organics in recycled water results in numerous operational problems, such as fouling and plugging. As more water is recycled internally, more waste residues are produced and managing them becomes a challenge. Thus, increased water recycling necessitates better methods for managing EBD residues. Successful demonstration of this project will benefit the members of COSIA by improving silica and organics removal efficiencies, thereby maximizing recycling of better quality of water, which will lead to lesser operational problems. Environmental performance is also foreseen as more water will be reused in extraction processes, and ecological degradation due to the migration of contaminants will also be mitigated. The outcomes of the proposed project are expected to bring numerous positive benefits to Canadian water resources and the environment.

PRESENTATIONS AND PUBLICATIONS

Conference Paper Presentations

1) Murugan, S., Rao, S., Mehrotra, A. K., & Achari, G. (2022, April). Equilibrium Modelling of speciation and mineral saturation for high concentration silica brines in evaporator blowdown water. Paper presented at the International Conference on Advances in Chemical and Materials Sciences, ACMS 2022, India.
2) Rao, S., Murugan, S., Mehrotra, A. K., & Achari, G. (2021, December). Neutralization of high silica brines. Paper presented at the 74th Annual Session of Indian Institute of Chemical Engineers, CHEMCON 2021, India.
3) Rao, S., Dominic, J. A., Mehrotra, A. K., & Achari, G. (2020, September). Effects of various parameters on silica polymerization process. Paper presented at the 70th Canadian Chemical Engineering Conference, CCEC 2020, Ottawa, Ontario.

RESEARCH TEAM AND COLLABORATORS

Institution(s): University of Calgary

Principal Investigator: Dr. Gopal Achari, Ph.D., (Professor, Department of Civil Eng.).

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Expected Degree Completion Date or Year Completed (Students Only)
Dr. Anil K Mehrotra	University of Calgary	Professor		
Dr. Sathish Ponnurangam	University of Calgary	Associate Professor		
Sivanesh Murugan	University of Calgary	MSc Student	July 2020	Present
Saheli Rao	University of Calgary	PhD Student	May 2020	Present
Sharath Shetty	University of Calgary	PhD Student	May 2021	Present

WE0060 – SAGD Slop Oil Treatment (NSERC CRD)

COSIA Project Number: WE0060

Research Provider: Dr. Hongbo Zeng, University of Alberta

Industry Champion: Cenovus Energy Inc.

Industry Collaborators: Canadian Natural Resources Limited, ConocoPhillips Canada Resources Corp., Imperial Oil Resources Limited, Suncor Energy Inc.

Status: Year 3 of 4

PROJECT SUMMARY

Scope

- Characterization of the properties of slop oil from Steam Assisted Gravity Drainage (SAGD) central processing facilities, and developing a joint process with the oil sands industry to manage SAGD slop oil.

Key Objectives

- The overall objective of this research is to characterize the properties of slop oil generated from SAGD operations, understand the interaction mechanisms of the emulsions with and without chemical additives, and explore feasible methods for treating the slop oil.
- This work will improve the fundamental understanding of the physicochemical properties of slop oil and the stabilization/destabilization mechanisms of the slop oil emulsions with selected treating methods under the effects of various parameters. Thisis of great fundamental and practical importance and will facilitate the development of an effective approach of breaking the slop oil emulsions.

PROGRESS AND ACHIEVEMENTS

- The investigator and proponents have performed literature searches, commissioned their lab equipment, sampled multiple slop samples, and presented the results. Multiple papers have been published or are in the process of being published.
- A review paper on the techniques for treating slop oil has been published in the journal Fuel. Systematic experimental studies have been conducted on the characterization of various slop oil samples, and the different phases (oil, water and solids) separated from the slop oils. These slop oil samples have been or are being treated under the combined effects of different parameters (i.e., temperature, diluents, chemical additives and centrifugation), with several more papers in the process of being published.

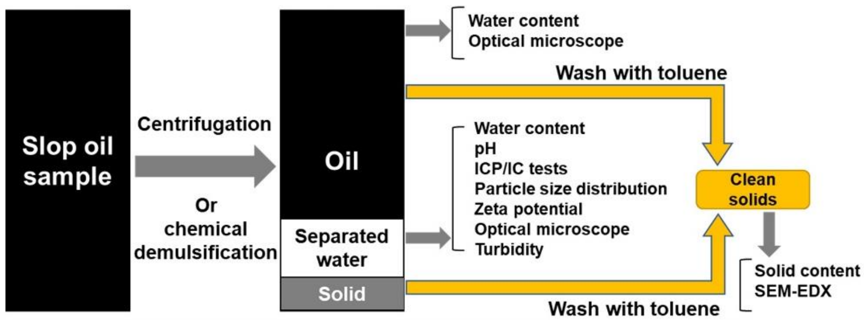


Figure 1. Schematic diagram of the characterization process of slop oil samples.

LESSONS LEARNED

- Slop oil presents a challenge in handling and an ongoing operating cost for SAGD facilities.
- Emerging lessons learned have been published in papers. Lab results have been presented to COSIA members.
- Slop oil samples can be oil-in-water (O/W), water-in-oil (W/O), and even more complex emulsions.
- For different types of slop oil (e.g., W/O, O/W), direct centrifugation or the addition of chemical reagents such as emulsion breakers (EBs) and reverse emulsion breakers (REBs) cannot efficiently treat the slop oils. It is found that combining the centrifugation method and the addition of diluent, modulating temperature, and introducing chemical additives provides a feasible approach to treating slop oils and separating them into oil/water/solid phases effectively, recovering the oil. It is also found that the optimal conditions may vary with the types of slop oil samples of different properties.
- It is found that the presence of solids trapped in the slop oils plays a negative role in the separation treatment of slop oil samples. Understanding the role of fine solids in the stabilization of various slop oils is important for developing cost-effective treatment technologies.

PRESENTATIONS AND PUBLICATIONS

- Public, Fuel, Ref: JFUE-D-20-03514, Title: Techniques for Treating Slop Oil in Oil and Gas industry: A Short Review, Fuel, 2020, 279, 118482: 1-18.

RESEARCH TEAM AND COLLABORATORS

Institution(s): University of Alberta

Principal Investigator(s): Dr. Hongbo Zeng

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students Only)	Expected Degree Completion Date or Year Completed (For Students Only)
Ziqian Zhao	UofA	PhD Student	2019	2023
Chenyu Qiao	UofA	PhD Student	2019	2023
Wenshuai Yang	UofA	PhD Student	2017	2022
Yueying Huang	UofA	PhD Student	2018	2023
Ali Habibi, PhD	UofA	Postdoctoral Fellow		2023
M. Khodakarami, PhD	UofA	Postdoctoral Fellow		2023

WJ0133 - Lenzing OptiFil Self-cleaning Filter Pilot for SAGD Wastewater

COSIA Project Number: WJ0133

Research Provider: Canadian Natural Resources Limited

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Suncor Energy Inc., Imperial Oil Resources Limited, Canadian Natural Resources Limited

Status: Completed

PROJECT SUMMARY

SAGD operators handle wastewater from sources including oil treating and deoiling units, warm lime or hot lime softeners, ion exchangers, evaporators, Once Through Steam Generators (OTSGs) and other produced water sources. Different means of disposal methods are used depending on the volume and quality of the wastewater. The typical methods for solids and water separation are centrifuge, settling in ponds, settling in salt caverns, treating with HCl/MgO to precipitate silica, etc. The water collected from these processes is further filtered before disposing of it into deep wells. The solids collected from the filtration are typically sent to a landfill. The filtration is typically conducted using cartridge or bag filters, where the filters are disposed of after use. If the solids content in the wastewater going to disposal wells is high and/or the disposal formation permeability/porosity is tight, then more filters and frequent filter change-outs are required. This is to ensure solids are removed to a much higher degree to avoid plugging the disposal wells. The filter change-outs can be costly, time consuming, generates more waste, and increases operator exposure to occupational hazards.

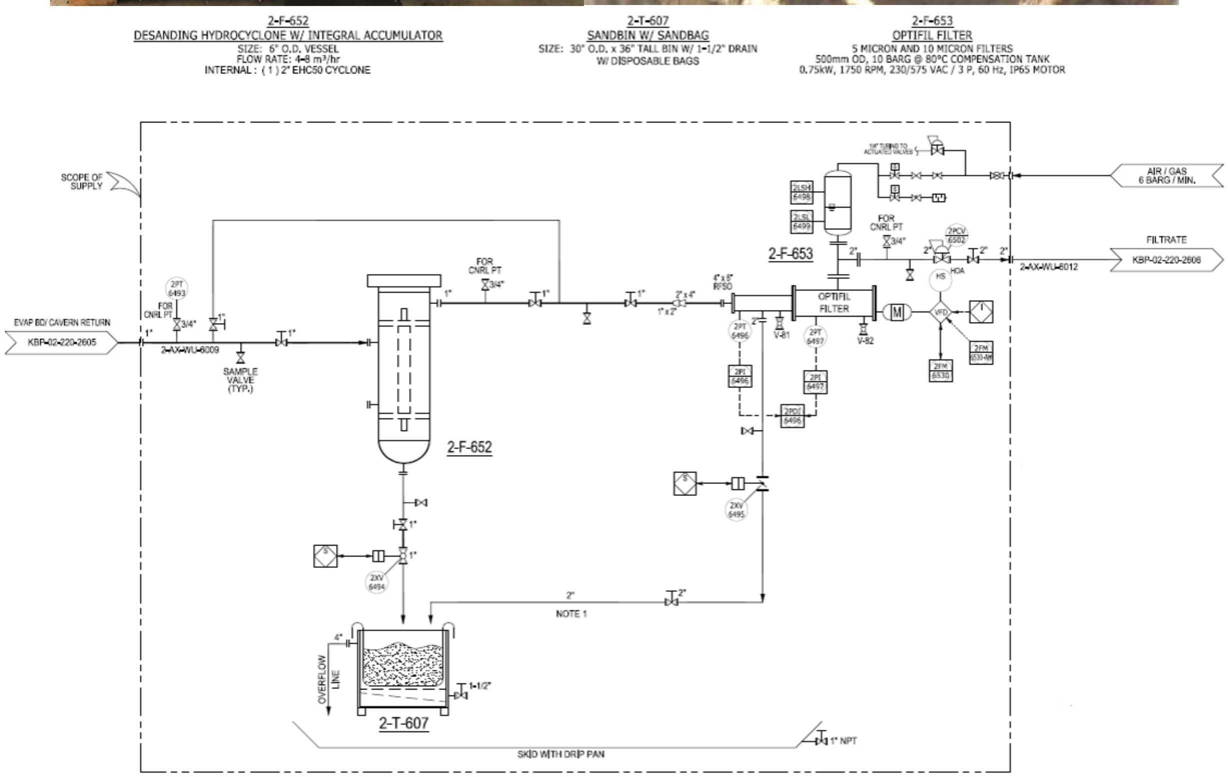
Self-cleaning filtration can be cost-effective, efficient, and have less environmental and health impact since this is a continuous operation and doesn't require frequent filter replacement. Often redundant units are not required as the filtering and backwashing (cleaning) can occur simultaneously in the same filter.

Canadian Natural tested the Lenzing OptiFil self-cleaning filter pilot unit at Kirby South SAGD facility for both evaporator blowdown and salt cavern return fluids in 2019. The objective was to test if OptiFil self-cleaning filter can remove particles similar to 10 micron size cartridge filters without causing any operational issues. Some of the key performance metrics (KPIs) include:

1. Achieve desired filtrate solids content/size removal for disposing into disposal wells
2. Achieve lower backwash frequency to increase recovery and reduce system surges
3. Ability to handle sufficient water flow rate which can be economically scaled up for commercial capacities

PROGRESS AND ACHIEVEMENTS

The pilot skid consisted of Enerscope's Hydrocyclone to remove larger, heavier particles and Lenzing's OptiFil self-cleaning filter to remove finer particles. Enerscope Systems Inc, USA, received the OptiFil filter from Lenzing Technik, Austria, and designed and built the skid. The trial was conducted for evaporator blowdown and cavern return streams using various filter screens, including 5, 10, 25 and 50-micron stainless filters and an 11-micron nylon (polyamide) filter.



For the evaporator blowdown water, even with the largest 50-micron filter, the OptiFil filter plugged rapidly due to very high solids content (1-2.5% wt). The upstream hydrocyclone didn't remove enough solids to reduce the solids content going to the downstream OptiFil self-cleaning filter.

For the salt cavern return water with 200-1000 mg/L total suspended solids (TSS) and 20-50 mg/L oil and grease (O&G) content, the OptiFil filter performed reasonably well. The flow rate was maintained at 2 m^3/h and the backwash was initiated at a pressure drop of about 240 kPa to reach the pressure drop of 120 kPa. The 10-micron stainless steel filter element removed about 70% TSS, and mean particle size was reduced from 20 microns to 10 microns, but the filter was plugged within two days. The backwash frequency was very high for the stainless steel filter (every 30 secs) since the backwash couldn't clean the filter effectively. This could be due to the nature of the solids and organics and how they bind to stainless steel material, making it hard to dislodge them completely from the filter surface during backwash. The 11-micron nylon filter required backwash every two minutes and removed the TSS and particle sizes similar to the 10-micron stainless steel filter. The 11-micron nylon filter ran for an extended period of time without plugging, and the operation resulted in about 92% water recovery with 8% reject coming from both hydrocyclone blowdown and OptiFil backwash cycles.

LESSONS LEARNED

Listed below are the key lessons learned from the trial:

- OptiFil self-cleaning filter with the 11-micron nylon filter element was efficient in removing low solids content micron size solid particles from salt cavern return water. The flow capacity reduces significantly with higher solids content in order to achieve a desired pressure drop and backwash frequency.
- The tests for the cavern return stream using a 25-micron (absolute size) stainless steel filter screen showed similar performance as a 5-micron (nominal size) cartridge filter. This means there could be an opportunity to reduce the capacity constraint to some extent, especially for high solids content streams, since bigger filter sizes can be chosen for the OptiFil to achieve a performance similar to smaller sized cartridge filters.
- Although the self-cleaning filter is backwashed at a regular frequency, the oil content and fine silt in the wastewater may foul/plug the filter screen irreversibly and may require rigorous cleaning. In this situation, the filter screen is removed and cleaned with a cleaning solution. Cleaning the nylon filter with Mr. Clean (containing ethoxylated alcohol surfactant) made it look like new and resulted in a fully recovered filtration capacity. Interestingly, washing with weak acid and/or caustic wasn't effective. For commercial installations, it is recommended to include chemical cleaning in place (CIP) in the design to avoid shutting down the unit for cleaning.
- Due to very high salinity (~24% wt) and organic content (0.4-1% wt) of salt cavern return water, measuring total suspended solids (TSS) with 0.45-micron filter paper in the laboratory was a challenge. It was found that the water washing followed by solvent washing would be the better methodology for TSS measurements, although this method gives lower TSS values compared to the method using only water washing. The water removes any salt (high NaCl from salt caverns) that is precipitated with the vacuum exerted on the filter paper during TSS measurement. Care should be taken to use the right wash water to avoid significant pH changes during washing since some TSS can dissolve with pH changes. The toluene removes any oil, and heavy organics precipitated on the filter to provide better quality solids for particle size distribution (PSD) measurements.
- For the particle size distribution (PSD), the scanning electron micron (SEM) method showed higher particle size compared to the laser diffraction method. It showed consistent particle size difference between feed and filtrate streams.

PRESENTATIONS AND PUBLICATIONS

Key Resources and Web Links:

https://www.lenzing-technik.com/en/filtration-and-separation-technology/

RESEARCH TEAM AND COLLABORATORS

Company/Institution: Canadian Natural Resources Limited

Principal Investigator: Subodh Peramanu, P.Eng., PhD, Process & Technology Advisor, Canadian Natural Resources Limited

Research Collaborators: None

WATER CHEMISTRY

WE0044 - Coagulant-Flocculant Chemistry of SAGD Emulsion Breaker - Reverse Emulsion Breaker and Warm Lime Softener

COSIA Project Number: WE0044

Research Provider: University of Alberta

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Cenovus Energy Inc., Canadian Natural Resources Limited, Imperial Oil Resources Limited,

Status: Ongoing

PROJECT SUMMARY

Rationale

Steam Assisted Gravity Drainage (SAGD) is a thermally enhanced heavy oil recovery method that is broadly practiced for bitumen extraction from oil sands in Alberta, Canada. Bitumen-water separation and produced water treatment for steam generation are two critical processes in SAGD operations for oil sands extraction. Complex emulsions (such as stable water-in-oil and oil-in-water emulsion) are normally formed in bitumen extraction in SAGD operations which have to be treated to separate the bitumen and water. Therefore, chemical treatment by adding reagents such as emulsion breaker (EB), reverse emulsion breaker (REB), and diluent has normally been applied to the production fluid before it reaches the separation vessel. Warm lime softener (WLS) is also used to remove hardness and trace oil from water destined for use as boiler feed water. The characterization and an improved fundamental understanding of the emulsification, demulsification, the impact of the addition of these chemicals, as well as the interfacial properties of bitumen/water interfaces would be critical for the operators to better control the chemical treatment process and achieve more efficient oil/water separation, and better quality produced water for further treatment.

Project Objectives

The main objectives of this research are: (1) to provide new insights into the interfacial activities and interfacial properties of bitumen-water-solid interfaces close to the real SAGD operation conditions; (2) to elucidate the roles of the various factors affecting the stability and interfacial behaviors of emulsions; (3) to improve the fundamental understanding of the chemistry of coagulation-flocculation in SAGD WLS operation; and (4) to explore the mechanisms of silica, hardness and organics removal by softening-coagulation-flocculation. The results of this research will be directly relevant and of considerable value to the Canadian oil sands industry, resulting in the robustness of separation methods and further improvement of the overall quality of the discharged process water into the environment.

Methodology

To achieve the main objectives, this project has been divided into two research areas: interfacial properties of bitumen/water/solid interfaces and coagulation-floculation in WLS operation. The main goals of these research areas are presented in Figure 1.

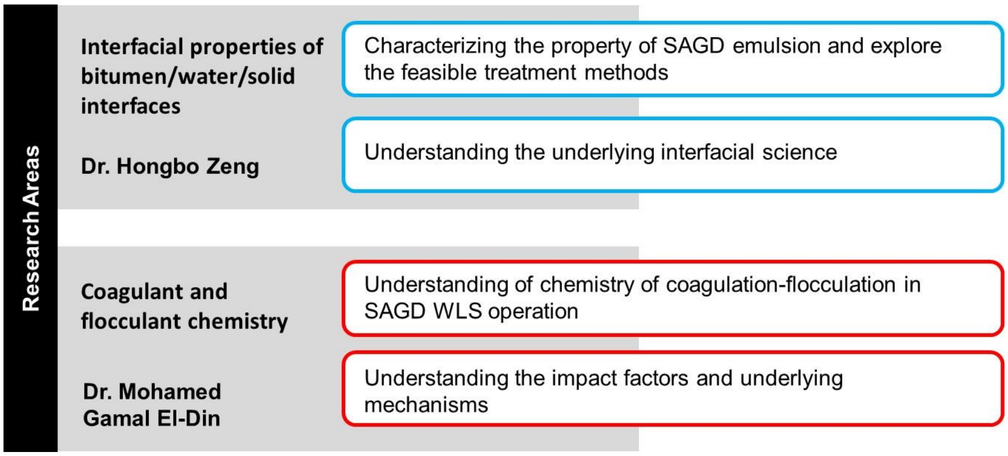


Figure 1. Main research areas of this project.

Literature Review

To meet the research objectives, a comprehensive literature review of EB, REB, WLS and coagulant-flocculant chemistry was conducted as the first step. The methods to characterize emulsions, WLS particles, as well as advanced analytical methods for interfacial characterization, were also reviewed. As a result of this task, two review papers have been published in peer-reviewed journals.

Interfacial Properties of Bitumen/Wwater/Solid Interfaces

The milestones of this research area are:

- Characterize and separate SAGD emulsions.
- Probe the interactions between asphaltenes and a poly(ethylene oxide (PEO)-poly(propylene oxide (PPO) demulsifier at oil/water interface and determine the effect of temperature.
- Probe the interactions between asphaltenes and a branched polyethylenimine at oil/water interface and determine the effect of temperature.

Coagulant and Flocculant Chemistry

The milestones of this research area are:

- Characterize real WLS feed water with and without sludge (inorganic and dissolved organics).
- Conduct screening experiments using different types and doses of coagulants, flocculants, different pH values, and different mixing conditions.
- Conduct optimization tests under different operation conditions.

- Determine the factors that impact the process performance and elucidate the removal mechanisms.

Significance of the Research to the Industry

This research will provide a fundamental and applied understanding of the stabilization mechanism of emulsions in oil production. The results of this research program will provide useful insights for industry to develop effective techniques or products to solve the challenging emulsion issues. In particular, we anticipate that the results of this research will bring about a better understanding of interfacial properties, leading to a predictable coalescence mechanism in SAGD emulsions, facilitating the design of next-generation SAGD deoiling unit operations. Moreover, the interfacial properties of the oil/water system and the ability to treat emulsions play vital roles in designing bitumen recovery techniques, which promote environmental sustainability.

PROGRESS AND ACHIEVEMENTS

This research is achieving many short term objectives, including: training of highly qualified personnel with multidisciplinary expertise; researching technical issues of strategic importance to Canada; and promoting cooperation and knowledge exchange between academia, industry and government.

- Our results on the characterization and separation of SAGD emulsion have shown that direct centrifugation with 7000 r and 30 min cannot separate the oil and water to a satisfying level. The addition of diluent and heating can slightly enhance the separation efficiency.
- PEO-PPO copolymer can break the SAGD emulsion if combined with REB and the optimal dosage is 600 ppm - 800 ppm. The EB is not able to break the SAGD emulsion by itself and REB plays a vital role in the demulsification process.
- EB possesses superior interfacial activity than the asphaltenes. It can penetrate and disrupt the interfacial asphaltenes films, repel them from the interface, and finally dominantly occupy the interface, promoting the coalescence of water droplets.
- WLS feed water contains higher amount of hydrophobic organics than hydrophilic compounds.
- Overall, cationic polyacrylamide (PAM) performed better to remove turbidity, hardness and silica than anionic PAM among most of the tested doses.
- Total hardness is the most significant factor among different water properties affecting the removal efficiency of turbidity, hardness, silica and total organic carbon (TOC), as well as mass of produced sludge.

LESSONS LEARNED

The following are the key outcomes achieved so far:

- The quality of the oil is closely related to the effect of EB. Similarly, the water quality might be closely related to the effects of REB.
- Based on the characterizations at the micro- and nano-scale and bulk bottle tests, the elevated temperature was demonstrated to play a critical role in the demulsification of water-in-oil emulsions.
- Total hardness is the most significant factor among different water properties affecting the removal efficiency of turbidity, hardness and silica.
- Increasing total hardness promotes the removal efficiencies, while increasing carbonate alkalinity inhibits the removal efficiency of turbidity, hardness and TOC.

Produced water from thermal recovery operations has long been one of the most challenging aspects of heavy oil and bitumen production in which colloidal and interfacial factors play important roles. High concentrations of dissolved inorganic species (such as silica and other dissolved solids) present as a result of the high steam temperatures, as well as considerable amounts of small oil droplets and dissolved organic matter, are some of the major concerns. Under these process conditions, the effective separation of the different components is essential and requires appropriate colloid chemical treatment strategies. Understanding the interfacial properties of bitumen-water-solid interfaces as well as the coagulant-flocculant chemistry wil be crucial for the successful operations of oil recovery processes.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Li, J., Z.T. How, H. Zeng, and M. Gamal El-Din. 2022. Treatment technologies for organics and silica removal in steam assisted gravity drainage (SAGD) produced water – A comprehensive review. Energy Fuels, 36(3), 1205-1231.

Wang, D., D. Yang, C. Huang, Y. Huang, D. Yang, H. Zhang, Q. Liu, T. Tang, M. Gamal El-Din, T. Kemppi, B. Perdicakis, and H. Zeng. 2021. Stabilization mechanism and chemical demulsification of water-in-oil and oil-in-water emulsions in petroleum industry: A review. Fuel, 286, 119390.

RESEARCH TEAM AND COLLABORATORS

Institution(s): University of Alberta

Principal Investigators: Dr. Mohamed Gamal El-Din (Professor, Department of Civil and Environemntal Engineering) and Dr. Hongbo Zeng (Professor, Department of Chemical and Materials Engineering).

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Expected Degree Completion Date or Year Completed (Students Only)
Dr. Mohamed Gamal El-Din	University of Alberta	Professor		
Dr. Hongbo Zeng	University of Alberta	Professor		
Dr. Pamela Chelme-Ayala	University of Alberta	Research Associate		
Dr. Zuo Tong How	University of Alberta	Postdoctoral Fellow		2022 (completed)
Dr. Duo Wang	University of Alberta	Postdoctoral Fellow		2022 (completed)
Jia Li	University of Alberta	PhD Student	2019	2023
Yueying Wang	University of Alberta	PhD Student	2019	2023
Ziqian Zhao	University of Alberta	PhD Student	2019	2023
Chenyu Qiao	University of Alberta	PhD Student	2019	2023

WATER TREATMENT

WJ0053, WE0023 - Steam Generation – Once Through Steam Generator Research (Phase 1 and 2)

COSIA Project Number: WJ0053, WE0023

Research Provider: University of Alberta

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Cenovus Energy Inc., Canadian Natural Resources Limited, ConocoPhillips Canada Resources Corp.,and Imperial Oil Resources Limited.

Status: Completed

PROJECT SUMMARY

In a best in situ practice, >0.2 barrels of fresh water is required to extract 1 barrel of bitumen. The cost associated with the current water treatment processes is high and presents the main economic challenge when oil prices fall. Boiler feed water (BFW) for existing SAGD processes is treated using evaporators or lime softening, with once through steam generators (OTSGs) used for steam production. Typically, produced water is >150°C when extracted from the reservoir but is cooled to <90°C for atmospheric deoiling and water treatment processes. High temperature produced water treatment processes have the potential to improve heat integration in SAGD plants, thereby producing BFW and steam with low GHG intensity.

Membrane separation processes have become one of the fastest emerging technologies for desalination and water treatment due to their distinct advantages over traditional processes such as lime softening and ion exchange resins. In particular, membrane separation processes have lower operating costs, compact design and high product quality. However, the low thermal stability of polymeric membranes and their susceptibility to fouling have limited the development of sustainable and energy-efficient membrane processes for SAGD. A membrane to perform high temperature water treatment is not yet commercial. Therefore, the main objective of this research project is to develop rational approaches to synthesize high-performance membranes that are stable at high temperatures, tolerant to harsh chemicals, and fouling resistant. The specific goals of this project are:

1. Developing polymeric composite and nanocomposite membranes with high thermal stability
2. Characterizing membranes in terms of thermal stability, surface charge, hydrophilicity, morphology, chemical composition, and membrane material integrity (compatibility with in situ fluids)
3. Bench-scale testing of membranes at 25-70°C to determine flux behavior under various flow, pH, and temperature conditions and Ca/Mg/Si, TOC, and TDS rejection
4. Optimizing membrane material development and proposing the best candidates for the construction of a high-temperature membrane module to be further de-risked at a larger testing facility

PROGRESS AND ACHIEVEMENTS

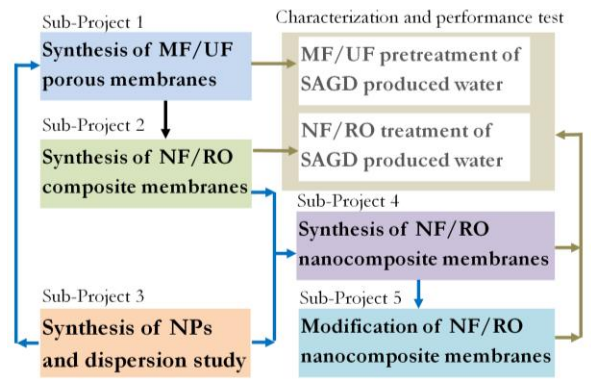


Fig. 1: Schematic of the strategy in this project to synthesize high-performance hybrid membranes

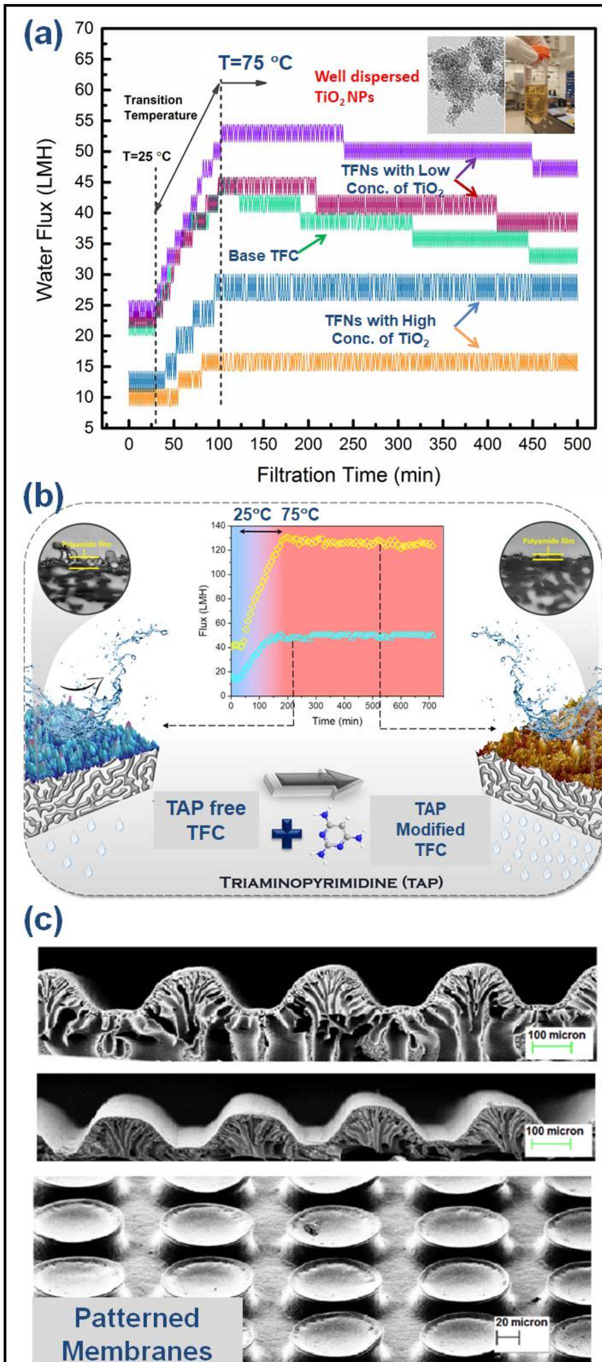


Figure 2: Developed (a) TiO2-based TFNs, (b) new generation of thermally stable TFCs, and (c) patterned membranes

Over the 3-year project period, we followed the roadmap in Figure 1 to develop advanced microfiltration/ultrafiltration (MF/UF) and nanofiltration / reverse osmosis (NF/RO) membranes. Sub-projects 1 and 2, in this roadmap, focus on preparing thermally stable baseline membranes, using high-performance polymers and tuning the chemistry of membranes. These membranes were further modified in Sub-projects 4 and 5, where hybrid membranes were developed using synthesized functional nanomaterials in Sub-project 3. Various types of composite and nanocomposite membranes were successfully fabricated and tested through microscopy characterization of membranes and filtration of BFW, warm lime softening (WLS) feed solution, and boiler blowdown (BBD) water. These membranes include (i) thermally stable thin-film composite (TFC)1–3 and TiO2-based thin film nanocomposite (TFN) NF/RO membranes4; (ii) polyethersulfone (PES)/ cellulose nanocrystals (CNC)5, PES/graphene6–8, PES/TiO2 nanotube9, PES/indium tin oxide (ITO)10,11, and PES/antimony tin oxide (ATO)12 MF/UF nanocomposite membranes; as well as, (iii) patterned PES MF/UF membranes13,14. The performance of the existing commercial NF/RO membranes was also established to provide a baseline for the synthesized membranes in this project. The commercial TFC NF/RO membranes are not thermally stable at temperatures >45˚C. The main targets achieved with all these new membrane materials include (i) thermal tolerance up to 75˚C based on various in situ process fluids; (ii) resistance to fouling when treating SAGD process fluids (<10% reduction in flux over eight hour operation); and commercially-viable contaminant rejection and flux rates (>90% TDS/TOC rejection and >50 L/m^{2}h at 225 psi).

However, the most significant contribution was the development of the state-of-the-art (i) TiO_2-based TFN membranes (Figure 2a), (ii) new generation of thermally stable TFCs (Figure 2b), and (iii) patterned membranes (Figure 2c). All synthesized membranes showed consistent permeate flux for nine hours of operation at 75°C with only a slight reduction in salt rejection.

The results of this research project have been published in 14 peer-reviewed journals and more than 20 conference proceedings, and three reports of invention were submitted. Five Ph.D. students, four MSc students, three postdoctoral fellows, one research associate, and seven undergraduate students have been trained and graduated as part of this project. All HQPs gained skills in advanced characterization techniques, such as high-resolution microscopy, chemical analysis spectroscopy, surface property analysis, and membrane filtration. They also enhanced their knowledge in the general field of water treatment, membrane processes, membrane fabrication techniques, and colloid and interface sciences.

LESSONS LEARNED

The results from the work to date demonstrate the challenges and limitations and the promise of polymeric membrane materials' ability to function and operate at higher temperatures. The project team has progressively developed and improved capability to develop, fabricate, characterize, operate (test), and autopsy membranes in various forms, materials and sizes. The group has designed, modified and operated various equipment donated or purchased through the program, including membrane fabrication, filtration, characterization and nanoparticle synthesis equipment.

Testing of existing commercial and novel fabricated membranes at various temperatures and operating conditions has allowed the program to focus on areas most likely to succeed. Success in this program is significant and will allow further development closer to the commercial production of high-temperature stability membranes. This will enable future field and pilot testing to progress the technology and review potential commercial applications.

PRESENTATIONS AND PUBLICATIONS

Journal Publications:

1. Karami, P.; Khorshidi, B.; Soares, J. B. P.; Sadrzadeh, M. Fabrication of Highly Permeable and Thermally-Stable Reverse Osmosis Thin Film Composite Polyamide Membranes. ACS Appl. Mater. Interfaces 2019.
2. Khorshidi, B.; Thundat, T.; Pernitsky, D.; Sadrzadeh, M. A Parametric Study on the Synergistic Impacts of Chemical Additives on Permeation Properties of Thin Film Composite Polyamide Membrane. J. Memb. Sci. 2017, 535 (December 2016), 248–257.
3. Khorshidi, B.; Soltannia, B.; Thundat, T.; Sadrzadeh, M. Synthesis of Thin Film Composite Polyamide Membranes: Effect of Monohydric and Polyhydric Alcohol Additives in Aqueous Solution. J. Memb. Sci. 2017, 523 (August 2016), 336–345.
4. Khorshidi, B.; Bi, I.; Ghosh, T.; Thundat, T. Robust Fabrication of Thin Flm Polyamide-TiO_2 Nanocomposite Membranes with Enhanced Thermal Stability and Anti-Biofouling Propensity. Sci. Rep. 2018, 8:784, 1–10.
5. Zhang, D.; Karkooti, A.; Liu, L.; Sadrzadeh, M.; Thundat, T.; Liu, Y.; Narain, R. Fabrication of Antifouling and Antibacterial Polyethersulfone (PES)/Cellulose Nanocrystals (CNC) Nanocomposite Membranes. J. Memb. Sci. 2017, 549 (December 2017), 350–356.
6. Karkooti, A.; Yazdi, A. Z.; Chen, P.; McGregor, M.; Nazemifard, N.; Sadrzadeh, M. Development of Advanced Nanocomposite Membranes Using Graphene Nanoribbons and Nanosheets for Water Treatment. J. Memb. Sci. 2018, 560, 97–107.

7. Karkooti, A.; Rastgar, M.; Nazemifard, N.; Sadrzadeh, M. Study on Antifouling Behaviors of GO Modi Fi Ed Nanocomposite Membranes through QCM-D and Surface Energetics Analysis. Colloids Surfaces A 2020, 588 (December 2019), 124332.
8. Karkooti, A.; Rastgar, M.; Nazemifard, N.; Sadrzadeh, M. Graphene-Based Electro-Conductive Anti-Fouling Membranes for the Treatment of Oil Sands Produced Water. Sci. Total Environ. 2019, 135365.
9. Mahdi, N.; Kumar, P.; Goswami, A.; Perdicakis, B.; Shankar, K. Robust Polymer Nanocomposite Membranes Incorporating Discrete TiO2 Nanotubes for Water Treatment. Nanomaterials 2019, 9 (1186), 1–18.
10. Khorshidi, B.; Hajinasiri, J.; Ma, G.; Bhattacharjee, S.; Sadrzadeh, M. Thermally Resistant and Electrically Conductive PES/ITO Nanocomposite Membrane. J. Memb. Sci. 2016, 500, 151–160.
11. Almansoori, Z.; Khorshidi, B.; Sadri, B.; Sadrzadeh, M. Parametric Study on the Stabilization of Metal Oxide Nanoparticles in Organic Solvents: A Case Study with Indium Tin Oxide (ITO) and Heptane. Ultrason. Sonochem. 2018, 40, 1003–1013.
12. Khorshidi, B.; Hosseini, S. A.; Ma, G.; McGregor, M.; Sadrzadeh, M. Novel Nanocomposite Polyethersulfone-Antimony Tin Oxide Membrane with Enhanced Thermal, Electrical and Antifouling Properties. Polymer (Guildf). 2019, 163, 48–56.
13. Koupaei, A. M.; Nazaripoor, H.; Sadrzadeh, M. Electrohydrodynamic Patterning of Polyethersulfone Membranes. Langmuir 2019, 35, 12139–12149.
14. Asad, A.; Sadrzadeh, M.; Sameoto, D. Direct Micropatterning of Phase Separation Membranes Using Hydrogel Soft Lithography. Adv. Mater. Technol. 2019, 4, 1800384.

Conference Presentations/Posters

1. M. Sadrzadeh. (2019). Fabrication of Advanced thermally stable thin Film composite membranes for reverse Osmosis of SAGD produced water, 2019 Oil Sands Innovation Summit. June 3-4, Calgary, Canada.
2. M. Sadrzadeh. (2017). Membranes for SAGD produced water treatment, COSIA-Natural Resources Canada Oil Sands Innovation Summit, March 21-22, Calgary, Canada.
3. M. Sadrzadeh. (2018). Robust fabrication of high-temperature nanocomposite membranes for oil sands produced water treatment, 2018 Oil Sands Innovation Summit. June 7-8, Calgary, Canada.

Book Chapters

1. M. Sadrzadeh, D. Pernitsky, M. McGregor. Nanofiltration for the Treatment of Oil Sands-Produced Water. in nanofiltration. ISBN: 978-1-78923-377-3. Chapter 2. pp 25-45. InTech.

RESEARCH TEAM AND COLLABORATORS

Institution(s): University of Alberta

Principal Investigator: Dr Mohtada Sadrzadeh, Ph.D., P.Eng. (Associate Professor, Department of Mechanical Eng.).

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Expected Degree Completion Date or Year Completed (Students Only)
Dr. Karthik Shankar	University of Alberta	Professor		
Dr. Ravin Narrain	University of Alberta	Professor		
Dr. Thomas Thundat	University of Alberta	Professor		
Behnam Khorshidi	University of Alberta	Postdoctoral Fellow	Oct 2017	Oct 2020
Masoud Rastgar	University of Alberta	Postdoctoral Fellow	April 2019	Present
Hadi Nazaripoor	University of Alberta	Postdoctoral Fellow	Jan 2017	Dec 2018
Amin Karkooti	University of Alberta	PhD Student	Jan 2016	Dec 2019
Pooria Karami	University of Alberta	PhD Student	Jan 2017	Present
Asad Asad	University of Alberta	PhD Student	Sep 2016	Sep 2021
Farhad Ismail	University of Alberta	PhD Student	Jan 2018	Present
Laleh Shamaei	University of Alberta	PhD Student	Sep 2017	Apr 2021
Zayed Almansoori	University of Alberta	MSc Student	Sep 2015	Nov 2017
Nusrat Helali	University of Alberta	MSc Student	Jan 2017	Jan 2020
Sadaf Noamani	University of Alberta	MSc Student	Sep 2018	Oct 2020
Farshad Mohammadtabr	University of Alberta	MSc Student	Jan 2016	Dec 2018
Ali Koupaei	University of Alberta	Research Associate	Jan 2018	Dec 2018

WE0033 - NAIT High Temperature Produced Water Testing Facility

COSIA Project Number: WE0033

Research Provider: Northern Alberta Institute of Technology (NAIT) – Centre for Oil Sands Sustainability (COSS)

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Canadian Natural Resources Limited

Status: Complete

PROJECT SUMMARY

Background & Opportunity

Bitumen is generally recovered from oil sands ore using surface mining or in situ extraction. Steam Assisted Gravity Drainage (SAGD) is currently the most commonly used in situ recovery method. Both mining and SAGD process large amounts of water and utilize advanced water-recycling technologies. Insitu bitumen recovery operates at temperatures over 180°C, with produced water containing impurities, including dissolved salts, metals, silica and organic compounds, requiring treatment before being fed to steam generation processes. Currently, at in-situ oil sands facilities, the pressure and temperature of the produced water are decreased to utilize atmospheric conventional water treatment technologies (e.g., evaporation and warm lime softening). The water is re-heated, with the same glycol system that cooled the produced water to preserve energy, prior to steam generators.

SAGD operators are exploring new technologies to improve produced water quality efficiently and cost effectively to enable higher quality steam generation with less blowdown production (which is recycled back to the process). Higher quality boiler feed water in SAGD operation can improve the environmental performance of the in situ process through lower greenhouse gas emission intensity. There are opportunities to improve environmental and economic produced water recycling performance using emerging membrane technologies, particularly in replacing thermal evaporation technologies. Membranes are considered promising technology in produced water treatment applications because of their high separation and energy efficiency, simple operation and low maintenance cost.

Description

COSIA supported NAIT COSS in developing a Membrane Technology Assessment Program (MTAP) with aims to:

1. Design, fabricate and commission a skid-based high pressure and temperature membrane testing unit for high-tolerance polymeric membranes.
2. Provide the ability to simulate conditions typical to in situ bitumen extraction operations.
3. Validate novel produced water treatment technologies developed by industry and small and medium-sized enterprises (SMEs) in Western Canada.

The project comprised of three major scope items:

1. Conceptual and detailed design, including HAZOP.
2. Component selection and fabrication.

3. Commissioning in partnership with external partners.

PROGRESS AND ACHIEVEMENTS

NAIT successfully designed a unique membrane skid able to operate at significantly higher temperatures than conventional membrane systems. Challenges included problem solving for component and device selection, existing building modifications to allow for safe operation, and installation of the MTAP testing unit within the newly developed area. The MTAP testing unit fabrication was completed, hydro-tested and delivered on May 16, 2022.

NAIT, working closely with COSIA, was able to leverage the COSIA funding for further external investments of $2.5 million towards building infrastructure needs for the MTAP project and increasing lab capabilities in supporting de-risking industrial water treatment applied research. This collaboration resulted in a broad base of support and funding for the project, including COSIA, NAIT, federal funding from Prairies Economic Development Canada (formerly Western Economic Diversification Canada), and provincial funding from Alberta Innovates and the Ministry of Jobs, Economy and Innovation (formerly Economic Development and Trade).

Hurdles included overcoming design challenges, COVID-19 related delays (supply chain) and third-party funding challenges, which were all resolved prior to commissioning in Q3 2022.

LESSONS LEARNED

Building one-of-a-kind test facilities, like the High Temperature Produced Water Testing Facility, is challenging. It always requires more time and effort than planned for due to the unique challenges of building a downscaled version of commercial equipment.

Challenges relevant to any downscaled test facility included identifying small versions of mechanical and control equipment and analyzers, which apply to any downscale test facility.

Challenges unique to a high temperature test membrane facility for oil and gas service include design to create sufficient flux (flow velocity), and areas classification due to the nature of samples handled.

Working closely with COSIA through bi-weekly steering committee meetings was effective in resolving fabrication contract negotiations, fabrication progression, and brainstorming logistic delay solutions, but there were delays nonetheless. This helped NAIT learn about current technologies and gain technical knowledge on anticipated challenges of developing technologies in this space, and prepared them to better operate the facility.

PRESENTATIONS AND PUBLICATIONS

1. Sedgwick A., Laszlo J., and H. Hu., Membrane Technology Assessment Program (MTAP) at NAIT's Centre for Oil Sands Sustainability, 2019 Membrane Technology Conference, New Orleans, Louisiana, USA.
2. Messele S.A., Bahgat O., Sedgwick A., Membrane Technology Assessment Program (MTAP) at NAIT's Centre for Oil Sands Sustainability, Dec 6, 2021, Alberta Innovates WIP webinar - Run of Show.

RESEARCH TEAM AND COLLABORATORS

Institution: Northern Alberta Institute of Technology (NAIT) – Centre for Oil Sands Sustainability (COSS).

Principal Investigator: Andrea Sedgwick, M.Eng., P.Eng.

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students Only)	Expected Degree Completion Date or Year Completed (For Students Only)
Andrea Sedgwick	NAIT	Ledcor Applied Research Chair in Oil Sands Sustainability		
Omar Bahgat	NAIT	Operations Manager		
Selamawit Messele	NAIT	Research Associate		

WE0069 - Development of Advanced Polymeric Membranes for SAGD Produced Water Treatment

COSIA Project Number: WE0069

Research Provider: University of Alberta

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Canadian Natural Resources Limited, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., and Imperial Oil Resources Limited,

Status: Ongoing

PROJECT SUMMARY

In the conventional SAGD process, the bitumen and the produced water are first separated to isolate residual oil from the produced water. The deoiled produced water is then treated before recycling in the SAGD process. High levels of organic matter and silica in recycled water cause numerous operational problems, e.g., fouling of pipelines and equipment, and clogging of injection wells. Also, the fouling of heat exchangers reduces the heat transfer efficiency and increases energy consumption to produce steam, leading to more energy- and GHG-intensive oil production. Therefore, water and energy management is essential to the oil sands industry, and they are continuously seeking alternative technologies to current methods for water treatment that reduce environmental footprint (water use, GHG intensity, waste generation), while decreasing capital and operating costs. The proposed research project will develop and manufacture high-performance membranes to treat SAGD-produced water. Based on previous investigations in WJ0053 & WE0023, the major obstacles for the sustainable application of membrane separation processes for SAGD-produced water treatment are high temperature of SAGD process streams, and the high concentration of contaminants in these streams that lead to a substantial decline in water flux and separation performance through the fouling and degradation of the membranes.

The commercial thin-film composite (TFC) RO membranes are not thermally stable at temperatures higher than 45°C and their flux must be recovered by frequent chemical cleaning. The main targets for new membrane materials include (i) high thermal tolerance (at 90-130°C based on various in situ process fluids); (ii) resistance to fouling when treating SAGD process fluids (<10% reduction in flux over six months); and commercially-viable contaminant rejection and flux rates (>90% salt and organic matter rejection and >50 L/m^2h at 10 atm).

The project outcomes will be (1) new generation of thermally stable reverse osmosis (RO) composite and nanocomposite membranes; (2) fouling-resistant micro/nano-patterned membranes; (3) Canadian-made large-scale membrane elements (18x12"); (4) an outstanding training program through scientific discovery and the application of state-of-the-art knowledge; and (5) transfer the research results to Canadian industries.

PROGRESS AND ACHIEVEMENTS

The long-term objective of this research is to commercialize high temperature and fouling-resistant RO membrane modules that are process-tolerant of SAGD-produced water conditions. In particular, robust and efficient filtration of highly contaminated SAGD process streams at temperatures >90°C) is critical to proving this technology in the

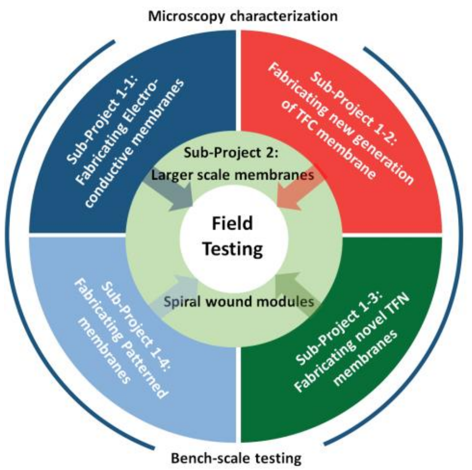


Figure 1: The strategy in this research project to synthesize nano-enabled membranes.

field. To accomplish our objectives, we defined milestones over a 3-year period. The necessary activities to achieve milestones are categorized into two main sub-projects. Figure 1 describes the linkage between these sub-projects. Sub-project 1 focuses on developing high-performance membranes for larger production in Sub-project 2.

So far, various types of nano-enabled membranes have been successfully fabricated and tested through microscopy characterization of membranes and filtration of SAGD-produced water. These membranes include (i) thin-film composite (TFC) and thin-film nanocomposite (TFN) NF/RO membranes using lignin and nanodiamond1–3; (ii) self-assembled MF/UF nanocomposite membranes4–6; as well as, (iii) patterned PES MF/UF and nanofiltration membranes7,8. The main targets achieved with all these new membrane materials include (i) thermal tolerance up to 75 C based on various in situ process fluids; (ii) resistance to fouling when treating SAGD process fluids; commercially-viable contaminant rejection and flux rates (>90% TDS/TOC rejection and >50 L/m^{2}h at 225 psi for NF/RO membranes). In addition, the roll-to-roll casting system (Gen 2) is also developed, and the first 1812" spiral wound MF/UF membranes were fabricated. The performance of the existing commercial NF/RO membranes was also established to provide a baseline for the synthesized membranes in this project (Figure 2).

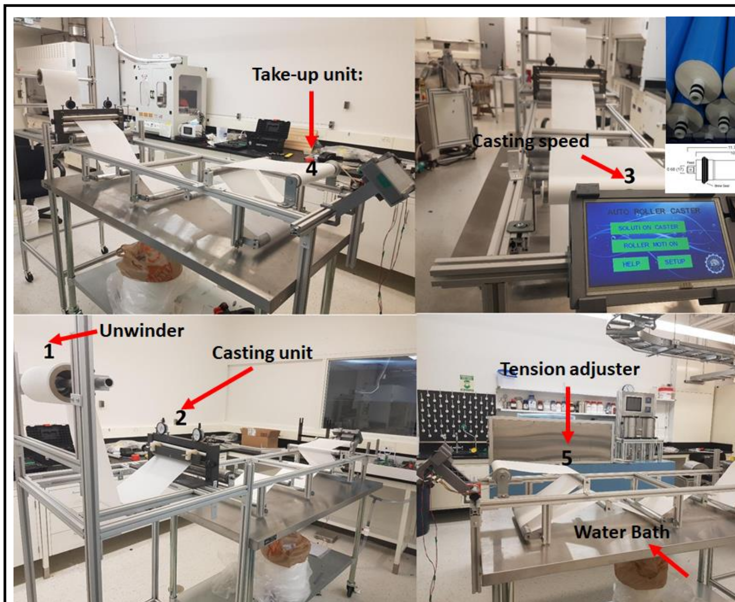


Figure 2: The roll-to-roll membrane manufacturing system developed in AWRL.

The results of this research project have been published in eight peer-reviewed journals and more than 10 conference proceedings, and one report of invention was submitted so far. Six Ph.D. students, three MSc students, one postdoctoral fellow, and one research associate are currently working on this project.

LESSONS LEARNED

The results from the work to date demonstrate the challenges and limitations and the promise of polymeric membranes at larger scales (1812" spiral wound) to function and operate at higher temperatures. The project team has screened the highest performance materials in terms of thermal stability and antifouling properties in the first phase of the project to be produced and tested at a larger scale in this project. The group has designed, modified, and operated a roll-to-roll membrane manufacturing system. The thermal stability of membrane modules is found not to be only dependent on the membrane material but also on the other parts of a module (such as glue, permeate collector, etc.).

Preliminary testing of our recently developed modules at various temperatures and operating conditions has allowed the program to focus on areas most likely to succeed. Success in this program is significant and will allow further development closer to the commercial production of high-temperature stability membranes. This will enable future field and pilot testing to progress the technology and review potential commercial applications.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

1. Shamaei, L.; Karami, P.; Khorshidi, B.; Farnood, R.; Sadrzadeh, M. Novel Lignin-Modified Forward Osmosis Membranes: Waste Materials for Wastewater Treatment. ACS Sustainable Chemistry and Engineering 2021, 9 (47), 15768–15779. https://doi.org/10.1021/acssuschemeng.1c03861.
2. Karami, P.; Khorshidi, B.; Shamaei, L.; Beaulieu, E.; Soares, J. B. P.; Sadrzadeh, M. Nanodiamond-Enabled Thin-Film Nanocomposite Polyamide Membranes for High-Temperature Water Treatment. ACS Applied Materials & Interfaces 2020, 12 (47), 53274–53285. https://doi.org/10.1021/acsami.0c15194.
3. Karami, P.; Aktij, S. A.; Khorshidi, B.; Firouzjaei, M. D.; Asad, A.; Elliott, M.; Rahimpour, A.; Soares, J. B. P.; Sadrzadeh, M. Nanodiamond-Decorated Thin Film Composite Membranes with Antifouling and Antibacterial Properties. Desalination 2022, 522. https://doi.org/10.1016/j.desal.2021.115436.
4. Helali, N.; Shamaei, L.; Rastgar, M.; Sadrzadeh, M. Development of Layer-by-Layer Assembled Polyamide-Imide Membranes for Oil Sands Produced Water Treatment. Scientific Reports 2021, 11 (1). https://doi.org/10.1038/s41598-021-87601-4.
5. Shamaei, L.; Khorshidi, B.; Islam, M. A.; Sadrzadeh, M. Industrial Waste Lignin as an Antifouling Coating for the Treatment of Oily Wastewater: Creating Wealth from Waste. Journal of Cleaner Production 2020, 256. https://doi.org/10.1016/j.jclepro.2020.120304.
6. Shamaei, L.; Khorshidi, B.; Islam, M. A.; Sadrzadeh, M. Development of Antifouling Membranes Using Agro-Industrial Waste Lignin for the Treatment of Canada's Oil Sands Produced Water. Journal of Membrane Science 2020, 611, 118326. https://doi.org/https://doi.org/10.1016/j.memsci.2020.118326.
7. Asad, A.; Aktij, S. A.; Karami, P.; Sameoto, D.; Sadrzadeh, M. Micropatterned Thin-Film Composite Poly(Piperazine-Amide) Nanofiltration Membranes for Wastewater Treatment. ACS Applied Polymer Materials 2021, 3 (12), 6653–6665. https://doi.org/10.1021/acsapm.1c01096.
8. Asad, A.; Rastgar, M.; Sameoto, D.; Sadrzadeh, M. Gravity Assisted Super High Flux Microfiltration Polyamide-Imide Membranes for Oil/Water Emulsion Separation. Journal of Membrane Science 2021, 621. https://doi.org/10.1016/j.memsci.2020.119019.

RESEARCH TEAM AND COLLABORATORS

Institution(s): University of Alberta

Principal Investigator: Dr Mohtada Sadrzadeh, Ph.D., P.Eng. (Associate Professor, Department of Mechanical Eng.).

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Expected Degree Completion Date or Year Completed (Students Only)
Dr. Joao Soares	University of Alberta	Professor		
Dr. Mike Serpe	University of Alberta	Professor		
Masoud Rastgar	University of Alberta	Postdoctoral Fellow	April 2019	Present
Fatima Seyedpour	University of Alberta	PhD Student	Sep 2021	Present
Pooria Karami	University of Alberta	PhD Student	Jan 2017	Present
Sadegh Aghapour	University of Alberta	PhD Student	Sep 2018	Present
Amirhossein Taghipour	University of Alberta	PhD Student	Sep 2021	Present
Mizan Mizan	University of Alberta	PhD Student	Sep 2020	Present
Farah Rahman Omi	University of Alberta	PhD Student	Sep 2020	Present
Asad Asad	University of Alberta	PhD Student	Sep 2016	Sep 2021
Laleh Shamaei	University of Alberta	PhD Student	Sep 2017	Apr 2021
Amin Soleimanzade	University of Alberta	MSc Student	Sep 2019	Dec 2021
Zahra Zandi	University of Alberta	MSc Student	Sep 2021	Present
Taposh Saha	University of Alberta	MSc Student	Sep 2021	Present
Kazem Moradi	University of Alberta	MSc Student	Sep 2021	Present
Ahmad Rahimpour	University of Alberta	Research Associate	July 2021	Present

WJ0001 - Water Technology Development Centre (WTDC)

COSIA Project Number: WJ0001

Research Provider: N/A

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Canadian Natural Resources Limited, , CNOOC Petroleum North America ULC, Cenovus Energy Inc.

Status: Active

PROJECT SUMMARY

The Water Technology Development Centre (WTDC, or the Centre) is a $143 million live-fluid test facility constructed at Suncor Energy Inc.'s (Suncor) Firebag Steam Assisted Gravity Drainage (SAGD) oil sands facility (Figure 1). The WTDC's main objective is to accelerate the safe development of water technologies that reduce environmental impact, reduce capital and operating costs, and increase facility reliability, which will improve the performance and sustainability of thermal in situ oil sands operations so that they can be competitive in a low oil price and low greenhouse gas (GHG) intensity environment. Piloted technologies may include but are not limited to emulsion separation, oil removal, water treatment, steam generation, water waste management, produced water coolers, chemical optimization, instrument and analyzer, and advanced process control. The WTDC is specifically designed to meet the substantial industry challenges to develop technologies beyond the lab or bench scale and into the field or near-commercial piloting scale. The WTDC provides a location to test water technologies with live fluids drawn directly from an operating plant (i.e., Firebag) at a pilot-scale to establish commercial viability. Construction was completed in 2019 and is now operational with nine Year 1 and 2 pilots currently in their testing phases. The Centre will run for a minimum of five years with an option for additional testing.

Cenovus Energy Inc. (Cenovus), Canadian Natural Resources Limited , and CNOOC Petroleum North America ULC (CNOOC) are participants at the WTDC, with Suncor as the Centre's owner and operator. The WTDC will test pilots within five test plan years. The Year 1 and 2 Test Plan objectives are to:

- reduce chemical costs (both emulsion water treatment chemicals) through the (i) Emulsion Breaking Chemistry Optimization Pilot;
- obtain real-time data from online instrumentation to enable proactive process control, facilitate optimization, and enable advanced process control, machine learning, artificial intelligence, and digitally disruptive technologies through the (iii) Online Instrumentation Pilots (i.e., oil-in-water, level interface, steam quality);
- achieve consistent high-quality BFW through the (iv) PW Filtration Optimization Pilot (i.e., Oil Removal Filters and After Filters), and (ii) WLS Pilot;
- maximize steam quality through the (v) OTSG Steam Quality Optimization Pilot;
- reduce PWC cleaning frequency through the (vii) PWC Optimization Pilot; and
- increase reliability through many of the pilots listed above.

Figure 1: Left:3-D model shot of WTDC looking from the NW (~75 m by 75 m). Right: photograph of the WTDC taken at Suncor's Firebag SAGD Facility from the NW in March 2019.

PROGRESS AND ACHIEVEMENTS

The primary achievement to date has been the collaborative effort among the WTDC participants to sanction and construct the $143 million facility, which is one of the largest technology projects in the history of the oil sands industry. This facility will move the burden and risk of testing new technologies away from an operating plant to a specially designed facility, significantly reducing piloting costs for operators and vendors. In turn, this will enable the more rapid development of new technologies to reduce water, land, waste, and GHG impacts and increase the industry's international competitiveness. The risks and costs associated with piloting will be shared among operators, allowing each to test more technologies than they could on their own. Although costs are shared, the benefits will be additive, meaning the environmental and economic benefits of applying technologies across the industry (e.g., via COSIA) will be significant.

With the facility's construction complete, technology piloting is now underway. To date, the WTDC's operations team has successfully overcome typical commissioning and start-up challenges, and eight Year 1 pilots and one Year 2 pilot are currently operational and performing well. Three of the Year 1 pilots are nearing completion and will be suspended by mid-2022. Two additional Year 2 pilots will be brought online soon, as established by the WTDC's Five Year Test Plan, and work is underway on engineering, procurement, and construction of both Years 3 and 4 pilots. Currently, only up to Year 4 of the Five Year Test Plan is sanctioned (Table 1). The fifth and final year is currently tentative but will seek to pursue at least one transformational steam generation technology and some important emulsion-related technologies. As piloting and engineering continue over the course of the WTDC's initial five-year test period, the WTDC will be well-positioned to test a wide range of incremental and breakthrough technologies.

Table 1 – WTDC Sanctioned Pilots (Years 1 through 4)

Pilot #	Name	TP Yr	Lead Company	Status
3	Emulsion Breaking / Reverse Emulsion Breaking Chemistry	1	Suncor	Operating
4	Oil In Water Analyzers	1	Canadian Natural	Operating
5	Produced Water Cooler Fouling - Phase 1	1	Suncor	Operating
7	Once Through Steam Generators - Phase 1 (High Steam Quality	1	Suncor	Operating
8	High Pressure Steam Separation	1	Suncor	Operating
9	Steam Quality Analyzer	1	Canadian Natural	Commissioning
11	Level Interface Measurement	1	Canadian Natural	Operating
1	Warm Lime Softening Optimization	2	Suncor	Operating
2	After Filter /Oil Removal Filter Media	2	Suncor	Commissioning
12	Water Cut Analyzers - Phase 1	2	Canadian Natural	Not Operating
14	Emulsion Breaking / Reverse Emulsion Breaking Chemistry - Phase 2	3	Suncor	Not Operating
15	Produced Water Cooler Fouling - Phase 2	3	Suncor	Not Operating
16	Once Through Steam Generators - Phase 2 (Scale Inhibitors)	3	Suncor	Not Operating
13	High Temperature Reverse Osmosis	4	Suncor	Not Operating
18	Water Cut Analyzers - Phase 2	4	Canadian Natural	Not Operating
17	Hardness Analyzers	4	Canadian Natural	Not Operating
19	Once Through Steam Generators - Phase 3 (Magnetite Stability / Passivation)	4	Canadian Natural	Not Operating

LESSONS LEARNED

The project is now well into the 'run and maintain' mode. Technology piloting is well underway, and new pilots are being developed and started up frequently.

The WTDC has learned numerous valuable lessons during the planning, construction and operation of the Year 1 Test Plan pilots. These learnings are summarised briefly below:

- Simultaneously managing the development, administration, review, and selection of bid packages and proposals for more than eight pilots simultaneously is unrealistic. Vendors, EPC contractors, and the WTDC member companies were challenged by resource constraints while attempting to progress all of the original Year 1 pilots in unison.
- To optimize the pilot start up process, start dates for most pilots should be staggered. Operators were forced to overcome several challenges when starting up the WTDC's first pilot. Although these challenges were manageable and reasonable, it may be difficult to handle similar challenges from several pilots simultaneously.

- Close collaboration between partners is critical. The development of technology projects benefited from having technology champions from within the WTDC member companies closely engaging with the EPC contractor and vendors.
- Operating small-scale equipment is challenging (e.g., OTSG has struggled since its start-up). There were also numerous challenges related to small-diameter piping, in particular:
  - Freezing in cold environments;
  - Temperature changes causing inaccurate chemical feeding due to expansion/contraction; and,
  - Plugging of small-diameter chemical feed/slurry lines.
- Night shift operations are required to ensure pilots are running reliably. Early on, and before there was a night shift operator, issues would have to be resolved by day shift. With numerous pilots operating simultaneously, there simply wasn't enough manpower to ensure sampling and maintenance activities were being executed in a timely fashion, particularly given the manual nature of these systems.
- Pilot plans often change, and pilot leads need to adapt accordingly. In the case of Pilot 3, adapting to the various chemical supplier availability was necessary.
- Simultaneous pilot operation needs to be carefully coordinated. Similarly, close attention must be paid to the headers to ensure there are no conflicts that could result in the inability to conduct the pilot testing.
- Having vendors participate in the pilot testing lends value to the pilot. Having the vendors engaged throughout the testing avoids wasting time and allows the pilot leads to be agile and adjust to real-time results accordingly.
- Instrumentation pilots seem to struggle with reliability. In almost all of the instrumentation pilots conducted to date, there have been significant challenges with the integrity of the prototypes used. This is not necessarily a reflection of the inadequacy of the technology, but rather, further engineering evolution is often required to develop a successful analyzer pilot.

PRESENTATIONS AND PUBLICATIONS

As the WTDC pilot potentially undertakes up to 23 pilots, it is estimated that numerous patents, prototypes, best practices, standard laboratory procedure, and technical operating envelope (TOE) recommendations may be developed. Already three prototypes are in development (i.e., WLS pilot, filtration pilots, membrane pilot), standard laboratory methods are being developed, compared and optimized (e.g., hardness, bitumen in water, etc.), and TOE specifications are being refined (e.g., 90% steam quality). The learnings from WTDC piloting will be shared with COSIA via equitable contributions of final reports.

Conference Presentations/Posters

Myszczyszyn, M. and Sobey, B. 2018. COSIA Water Technology Development Centre, WTDC – A Live Fluids Test Center to Solve Current Produced Water Technology Challenges in the areas of Water Deoiling, Softening, Filtration, Steam Generation, and Heat Integration. Presentation given at Canada's Oil Sands Innovation Alliance (COSIA) Innovation Summit, June 7-8, Calgary, AB, Canada

Sobey, B., Perdicakis, B., and Bernar, R. 2018. Canadian Thermal Oil Industry Water Technology Development Center – Purpose, Design and Vision. Paper and presentation submitted to the International Water Conference, November 4-8, Scottsdale, AZ, USA

Perdicakis, B. 2019. The Water Technology Development Centre (WTDC) – Year 1 Test Plan. Presented at Alberta Innovates' Water Innovation Program Forum. Edmonton, AB, Canada

Squires, M. 2019. The Water Technology Development Centre (WTDC) Overview. Presented at the Canadian Heavy Oil Association (CHOA) Fall Conference, November 6-7, 2019. Calgary, AB, Canada

Reports & Other Publications

Ashcroft, K. 2018. Innovation Profile: Basil Perdicakis and the Water Development Centre. Published in the Canadian Association of Petroleum Producers (CAPP) Context: Energy Examined magazine. Calgary, AB, Canada

JWN staff. 2019. Meet the 2019 Daily Oil Bulletin Energy Excellence Award champions. Published online by JWN May 3, 2019. Calgary, AB, Canada

Perdicakis, B. 2018. Full Project Proposal (FPP) Form: Clean Technology Facilities Support Program. Funding application submitted to Alberta Innovates (on behalf of the WTDC), November 15, 2018. Edmonton, AB, Canada

Perdicakis, B. 2018. Full Project Proposal (FPP) Form (Technology Development). Funding application submitted to Alberta Innovates' Clean Energy Division (on behalf of the WTDC), November 2018. Calgary, AB, Canada

Perdicakis, B., McGregor, M., Gerbino, AJ., and Petersen, M. 2019. High Temperature Reverse Osmosis Membrane SAGD Process Design Assessment. Published at the 2019 International Water Conference (Paper # IWC 19-61). Orlando, Florida, United States of America

RESEARCH TEAM AND COLLABORATORS

Work in preparation for and during all testing years at the WTDC has been highly collaborative, engaging technology providers and chemical suppliers, as well as organizations such as COSIA, the Universities of Calgary (U of C) and Alberta (U of A), InnoTech, and the Southern and Northern Alberta Institutes of Technology (SAIT and NAIT). For example, as part of the Year 1 Test Plan, the WTDC is directly interfacing with ~18 technology and chemical suppliers and ~8 engineering firms. It is expected that hundreds of technical personnel from operators, engineering companies, technology suppliers and academic institutions will gain direct relevant industry experience from collaborating on the WTDC.

In addition, COSIA is in the process of sponsoring a program at the U of C focused on evaporator waste management and programs at the U of A focused on chemical optimization, with goals to pilot test developed technologies at the WTDC. Suncor is also a lead COSIA company in establishing an "OTSG Centre of Excellence" that will create bench-scale testing facilities at the U of C and pilot-scale testing facilities at SAIT to support pilot testing on the WTDC OTSG. U of A is also involved in this project, providing expertise on erosion-corrosion phenomena. Ecodyne, InnoTech, Jacobs, Exergy Solutions, and U of A were involved in the design of a one-of-a-kind WLS test Pilot that builds on best practices global chemical suppliers have established for thickening operations.

The water treated in Alberta's oil sands industry is some of the most challenging in the world. Investing in research and development in this sector should create a knowledge base on water treatment and steam generation within Alberta that can be translated to other industries, both in Canada and globally. For example, one of the closest parallels to the silicate scales that foul in situ oil sands steam generators is from the geothermal industry. Essentially, if Albertans can further expand their skill sets on treating highly challenging oil sands waters and reliably generating steam, the opportunity exists to transfer and export those skills to other industries across the globe, especially as water and energy constraints become more severe as both the global population and energy demand continue to grow.

WJ0074 - Hydrocyclone Pilot for De-oiling

COSIA Project Number: WJ0074

Research Provider: ConocoPhillips Canada Resources Corp.

Industry Champion: ConocoPhillips Canada Resources Corp.

Industry Collaborators: N/A

Status: Completed

PROJECT SUMMARY

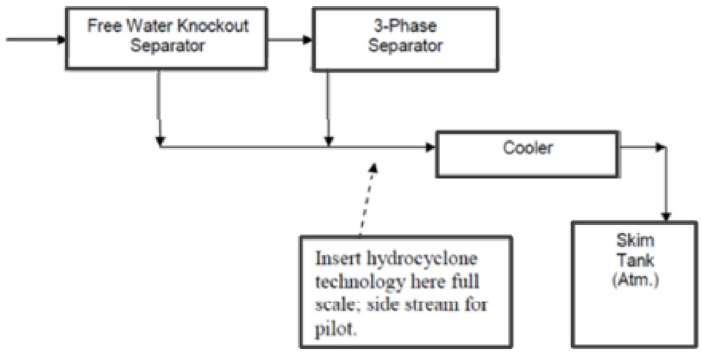
Steam Assisted Gravity Drainage (SAGD) Central Processing Facilities (CPF) treat the oil and water produced from SAGD wells, removing the oil, and further treat the water to a quality suitable for steam generation. The steam is then reinjected to produce more oil. The first step taken in a CPF is the separation of oil from the produced water. This project piloted using a hydrocycle for separation.

Hydrocyclones separate products based on differences in gravity. To remove oil from produced water, the centrifugal forces within the hydrocyclone move the heavier water to the outer wall while the less dense oil is displaced towards the inner core.

Smaller skim tanks equipped with hydrocyclone separators have the potential to replace the need for larger skim tanks for oil/water separation, delivering these benefits:

- Operational flexibility through modularization
- Lower capital expenditure and offers opportunities to improve efficiency at existing facilities
- Lower facility footprint
- Lower volume of flow that needs further treatment (reject rate) (~2% of inlet flow, compared with ~5-10% for Skim Tanks)
- Enables increased water reuse rate

Hydrocyclones are frequently used on offshore oil and gas platforms where physical space is limited and efficiency is critical. In 2013, ConocoPhillips piloted a de-oiling hydrocyclone at its Surmont oil sands joint venture – a steam assisted gravity drainage (SAGD) operation – to remove oil from produced water above 100°C installed upstream of the skim tank.



The pilot's objective was to determine the:

- Reject ratio (target <3%)
- Pressure differential ratio for efficient oil removal
- Turndown ratio (the minimum amount of flow through the hydrocyclone that achieves good separation)
- Backwash frequency (the system requires periodic flushing of solids out of the equipment)
- Maintenance requirements
- Feasibility to replace large skim tanks in future facilities or offer improved efficiency at existing facilities

PROGRESS AND ACHIEVEMENTS

The pilot hydrocyclone was put into service for two separate two-week trials at Surmont. Since the pilot hydrocyclone treated water from an operating facility, it experienced a wide range of oil-in-water concentrations (from 100ppm to >5000ppm). The goal of the hydrocyclone was to remove similar or better amounts of oil from the produced water as compared with a skim tank.

The pilot hydrocyclone experienced some challenges, including:

- Consistent clean water
- Seal damage on the equipment due to the flashing of fluid inside the hydrocyclone
- Increased differential pressure across the equipment requiring frequent backwashing

LESSONS LEARNED

- Increasing the inlet pressure to the hydrocyclone is necessary to increase the driving force for separation of the oil and water to reduce the amount of fluid that flashes within the equipment. Alternatively, the hydrocyclone could be installed at a location downstream of the skim tanks and coolers where the water temperature is ~90°C so that the water will not turn into steam.
- More work is needed to confirm the commercial applicability of hydrocyclones in SAGD to improve deoiling of the produced water.

PRESENTATIONS AND PUBLICATIONS

None

RESEARCH TEAM AND COLLABORATORS

None

WJ0165 - Christina Lake Commercial Demonstration Compact Floatation Unit

COSIA Project Number: WJ0165

Research Provider: Cenovus Energy Inc.

Industry Champion: Cenovus Energy Inc.

Industry Collaborators: Suncor Energy Inc.

Status: Completed 2020

PROJECT SUMMARY

The Cameron Compact Flotation Unit (TST-CFU) is a vertical unit that uses dissolved and induced gas flotation with centrifugal force to separate and remove hydrocarbons.

This project piloted a small version of the technology to de-risk a commercial plant design incorporating a CFU. The pilot was completed between November 2017 and April 2019 at Cenovus's Christina Lake Steam Assisted Gravity Drainage (SAGD) facility. The goal of the project was to demonstrate the reject rate and outlet oil and grease content of the produced water. Additionally, the pilot tested various gas flow rates, chemical injection rates and operational conditions.

PROGRESS AND ACHIEVEMENTS

- The pilot was operated between 2017 and 2019 at Cenovus Energy's Christina Lake, AB Plant.
- The pilot demonstrated low reject rates and exceptional oil and grease removal.
- The gas flow rates during the trial were within vendor specifications.

LESSONS LEARNED

- The CFU has the potential to drastically reduce greenfield or brownfield deoiling capacity capital costs with a fraction of the plot space requirements.

PRESENTATIONS AND PUBLICATIONS

- https://www.oilsandsmagazine.com/news/2020/10/2/cenovus-files-application-for-optimization-work-at-christina-lake

RESEARCH TEAM AND COLLABORATORS

Institution: Cenovus Energy

Principal Investigator: N/A

OTHER

WE0021, WE0035 - Water & Energy Recovery from Flue Gas Stage I (Scoping Study) and Stage II

COSIA Project Number: WE0021, WE0035

Research Provider: University of Calgary, Stantec Consulting Ltd.

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Cenovus Energy Inc., CNOOC Petroleum North America LLC, ConocoPhillips Canada, Imperial Oil Resources Limited, Suncor Energy Inc., Syncrude Canada Limited, Teck Resources Limited

Status: Completed

PROJECT SUMMARY

Focusing on developing environmentally responsible energy and sustainable management of water resources, COSIA member companies evaluated technologies that have the potential to recover usable water and energy from the flue gas of boilers deployed at in situ and mining oil sands facilities. While considerable research on capturing waste heat is being conducted globally, the level of research on technologies that recover both water vapour and a portion of its associated heat from flue gas is less clear. If some of the waste heat and water could be recovered, then a considerable amount of primary fuel, emitted greenhouse gases (GHGs), and makeup water could be saved. A typical 33,000 BPSD SAGD facility requires 2,000 GJ/h (HHV) of natural gas, and the combustion flue gas contains 260 GJ/h (HHV Basis) of waste heat and the equivalent of 1,800 m^3/d of water.

The objective of this project was to identify and evaluate technologies that can capture water and recover energy from natural gas combustion flue gas from oil sands steam generators. Stage I of the evaluation, which was completed by the University of Calgary included the assessment of various water and heat recovery technologies and four technologies were selected to proceed to Stage II of the evaluation. These four technologies were:

- Gas Absorption Heat Pump - a device that is thermally driven by external heat such as high-pressure steam or waste heat to transfer heat from a low temperature heat source to a high temperature heat sink.
- Transport Membrane Condenser - utilizes a robust nanoporous ceramic separation membrane capillary condensation separation mechanism to recover a portion of the water and energy content in the flue gas.
- Condensing Economizer - cools hot flue gas below dew point by indirectly exchanging heat with a cooling medium.
- Multistage Heat Exchanger - has six individual sections of heat exchangers that preferentially condenses sulfuric acid in first sections, resulting in less acidic condensed water in the latter sections.

Stage II, conducted by Stantec, was the techno economic and emissions assessment of the technologies. The assessments of the mining applications are excluded from this summary report. Stantec found that some of the technologies are unable to be integrated into the applications due to their commercial status and process integration complexity, resulting in the following in situ scenarios and their associated work scope:

- Technical Assessment and High Level Economic Assessment for Gas Absorption Heat Pump in SAGD (Steam-Assisted Gravity Drainage) application

- Technical Assessment and High Level Economic Assessment for Transport Membrane Condenser in SAGD application
- Techno economic Assessment for Condensing Economizer in SAGD application

The SAGD reference facility has a production capacity of 33,000 BSPD with a steam oil ratio (SOR) of 3.0, a produced gas to oil ratio (GOR) of 5.0, and a 10% water loss to the reservoir. The makeup water demand is 3,600 m^3/d.

PROGRESS AND ACHIEVEMENTS

Technical Assessment and High Level Economic Assessment for Gas Absorption Heat Pump in SAGD Application

- In order to integrate the gas absorption heat pump system with SAGD process, the following equipment is also required to recover water from flue gas;
- A new three-stage condensing economizer to drop the flue gas temperature.
- A glycol air cooler to dissipate the heat in the medium temperature stream to the environment.
- The technical evaluation results show that it is possible to recover up to 72% of the water content in the flue gas, which is about 35% of the total makeup water requirement. The recovered water quality is relatively clean but may be acidic due to dissolved SO3 and CO2, which requires a caustic dosing station to balance the pH prior to reusing in the process as BFW.
- Since the temperature (175°C) of recovered water from the reservoir in the SAGD process is much higher than a typical heat grade (35°C - 57°C) available from the heat pump, recovery of heat energy is not possible in this scenario. The available low-grade heat is dissipated to the atmosphere via the glycol air cooler system. As a result, there is no saving on fuel consumption and no change in the CO2 emissions from the SAGD facility.
- Due to a large flue gas volume, the integration requires eight of the largest commercially available single-stage heat pumps, which significantly increases the complexity of the integration, which is also not recommended by the heat pump vendor. The total integration footprint, including heat pumps, condensing economizers and glycol air coolers, is approximately 950 m^2.
- From preliminary economic evaluation, the CAPEX is approximately $45 million CAD, with the OPEX of about $3 million CAD. The recovered water cost is roughly $1,172 CAD/bbl, which is significantly higher than the current makeup water cost.

Technical Assessment and High Level Economic Assessment for Transport Membrane Condenser in SAGD Application

- To integrate the membrane condenser, the flue gas temperature needs to be cooled down to about 66°C prior to entering the transport membrane condenser. Therefore, the integration also requires an economizer and glycol air cooling system.
- The technical evaluation results show that it is possible to recover up to 72% of the water content in the flue gas, which is about 35% of the total makeup water requirement.
- Since no heat sink is available in the SAGD process, low-grade heat available from the membrane condenser system will also be dissipated to atmosphere through a glycol air cooler. As a result, there is no saving on fuel consumption and no change in the CO2 emissions from the SAGD facility.
- Since the only size of the transport membrane condenser that been commercialized is based on 300 boiler horsepower (BHP), it would require about 140 units to recover water and energy from the flue gas of the

selected SAGD process. The total integration footprint, including 140 units and the glycol air coolers, is approximately 230 m^2.

- From preliminary economic evaluation, the CAPEX is approximately $156 million CAD, with the OPEX of about $10 million CAD annually. Due to high CAPEX, the recovered water cost is $4,049 CAD/bbl, which is significantly higher than the current makeup water cost.

Techno economic Assessment for Condensing Economizer in SAGD Application

- The integration of a condensing economizer will result in the recovery of 42% of the total flue gas water content, which is approximately 21% of the total makeup water requirement. The recovered water quality is relatively clean but may be acidic due to dissolved SO3 and CO2, which requires a caustic dosing station to balance the pH prior to reusing in the process as BFW.
- Since no heat sink is available in the SAGD process, energy recovered by the condensing economizer cannot be utilized and will be dissipated to the atmosphere via the glycol air cooler system. As a result, there is no saving on fuel consumption and no change in the CO2 emissions from the SAGD facility.
- Only one condensing economizer as a stand-alone unit is required to recover the flue gas water. The condensing economizer will have its new, separate stack to safely disperse cooled flue gas back to the atmosphere. The total integration footprint, including one condensing economizer and the glycol air cooler, is approximately 197 m^2.
- The CAPEX is estimated to be approximately $53 million CAD with an OPEX of $3.4 million CAD annually. The recovered water cost is $2,257 CAD/bbl, which is significantly higher than the current makeup water cost.

LESSONS LEARNED

Despite their commercial availability, the gas absorption heat pump and the transport membrane condenser have a limitation on their capacity to process large flue gas volumes, leading to a complex integration as multiple units are required. In addition, the impact of the sulfur in the fuel on the technology performance is not fully understood. These gaps prevented the full techno economic analysis of these technologies.

The condensing economizer technology is technically simple and a technically viable option for the SAGD process to recover water. However, it is not economically viable unless a heat sink near the SAGD process is available to utilize the recovered heat from the flue gas.

Although this work concluded that flue gas water recovery for SAGD applications is not economically viable with existing commercial technology, there is value in the economic evaluation results. As mentioned, if a heat sink was identified, that would improve the business case. But also, in areas of water scarcity or where the make-up water sources are of low quality, recovery of flue gas water could be potentially economically viable when you consider the alternatives. Additionally, the evaluation provides a benchmark for any new technology development in the area of flue gas water recovery. This work identifies the economic hurdle for any new technology in order to outperform the existing commercial technology.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications

RESEARCH TEAM AND COLLABORATORS

Institution(s): University of Calgary (WE0021), Stantec Consulting Ltd. (WE0035)

Principal Investigator(s):

Name	Institution or Company	Degree or Job Title
Dr. Nader Mahinpey	University of Calgary	Professor
Robert (Bob) Drever	Stantec	Project Manager
Shikhar Singh	Stantec	Project Approver/Tech Lead
Bhurisa Thitakamol	Stantec	Process Engineer

APPENDIX – INDEX BY TOPIC AND ALPHABETICALLY

INDEX (BY TOPIC)

INDEX (BY TOPIC)

INDEX (ALPHABETICALLY)

Summary Report Title	Project Number	Topic	SOURCE REPORT 2021	SOURCE REPORT 2019
90% Steam Quality Using Rifled Tubes - Phase 1	WJ0036	Steam Generation		2019
90% Steam Quality Using Rifled Tubes - Phase 2	WJ0075	Steam Generation		2019
Advancing scientific knowledge on fouling, erosion, and corrosion in Once Through Steam Generators (OTSGs)	WE0043	Steam Generation	2021	
An Innovative Solution to Steam Assisted Gravity Drainage (SAGD) Blowdown Water - Blowdown Boiler Technology - Phase 1	WJ0079	Waste Management		2019
An Innovative Solution to Steam Assisted Gravity Drainage (SAGD) Blowdown Water - Blowdown Boiler Technology - Phase 2	WJ0080	Waste Management		2019
Best Practices	WE0002	Best Practices		2019
Blowdown Handling Working Group	WJ0065	Waste Management		2019
Boiler Blowdown Reduction Technology	WJ0015	Waste Management		2019
Christina Lake Commercial Demonstration Compact Floatation Unit	WJ0165	Water Treatment	2021	
Coagulant-Flocculant Chemistry of SAGD Emulsion Breaker - Reverse Emulsion Breaker and Warm Lime Softener	WE0044	Water Chemistry	2021	
Development of advanced polymeric membranes for SAGD produced water treatment	WE0069	Water Treatment	2021	
Development of Technologies for Treatment and Management of Evaporator Blowdown Wastes from Oil Sands Operations	WE0045	Waste Management	2021	
Flash Steam Generation - Steam Generation Without Water Treatment - Cost Estimation	WJ0111	Steam Generation		2019
Flash Steam Generation - Steam Generation Without Water Treatment - Pilot Study	WJ0110	Steam Generation		2019
Horizontal Evaporator Mini-Pilot	WJ0108	Water Treatment		2019
Hydrocyclone Pilot for De-oiling	WJ0074	Water Treatment	2021	
Insitu Steam Generator Thermal Camera	WJ0169	Process Monitoring	2021	

INDEX (ALPHABETICALLY)

Summary Report Title	Project Number	Topic	SOURCE REPORT 2021	2019
InsituSIM - Water Module Development	WE0056	Process Chemistry and Simulation		2019
Lab Scale OTSG at SAIT	WE0026	Steam Generation	2021	2019
Lenzing OptiFil Self-cleaning Filter Pilot for SAGD Wastewater	WJ0133	Waste Management	2021	
NAIT High Temperature Produced Water Testing Facility	WE0033	Water Treatment	2021	
NSERC IRCC Lab Scale OTSG at SAIT (Phase 2)	WE0081	Steam Generation	2021	
OLI Model for Lime Softener Operation	WE0020	Water Treatment		2019
OLI Model for Lime Softener Operation	WE0058	Water Treatment		2019
Online Dissolved Oxygen Analyzer Trial	WJ0128	Process Monitoring	2021	
Online Oil-In-Water (OIW) Analyzer Trial	WJ0138	Process Monitoring		2019
Online Silica Analyzer Pilot	WJ0071	Process Monitoring		2019
Online Total Inorganic Carbon (TIC) Analyzer Trial	WJ0089	Process Monitoring		2019
Organics Characterization and Fouling - Phase 1	WJ0011	Process Chemistry and Simulation		2019
Organics Characterization and Fouling - Phase 2	WJ0098	Process Chemistry and Simulation		2019
OTSG Steam Quality Measurement Control	WJ0093	Steam Generation		2019
Regional Groundwater Solutions Groundwater Monitoring Study	WE0007	Regional Water Projects		2019
Review of Emerging Desalination Technologies in SAGD	WE0048	Water Treatment		2019
SADG Slop Oil Treatment (NSERC CRD)	WE0060	Waste Management	2021	
SAGD Well Testing and Multiphase Flow Meter Application	WJ0019	Process Monitoring	2021	2019
Seeded Slurry Evaporator Improvements	WJ0059	Water Treatment		2019

INDEX (ALPHABETICALLY)

Summary Report Title	Project Number	Topic	SOURCE REPORT 2021	SOURCE REPORT 2019
Southern Athabasca Oil Sands Regional Geochemical Isotope Study	WE0022	Regional Water Projects		2019
Steam Generation – Once through Steam Generator Research	WJ0053	Water Treatment	2021	
Tannin Boiler Feedwater Additive	WJ0090	Steam Generation		2019
U of A High Temperature Membrane Materials for SAGD (Phase 2)	WE0023	Water Treatment	2021	
Water & Energy Recovery from Flue Gas (Phase II)	WE0035	Other	2021	
Water & Energy Recovery from Flue Gas (Scoping Study)	WE0021	Other	2021	
Water Technology Development Centre (WTDC)	WJ0001	Water Treatment	2021	