Enhancements to an Online Steam Analyser for Thermally Enhanced Heavy Oil Recovery

Final Report

Project ecoEII External UOSE045 2015-16

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Disclaimer

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1 Executive Summary

This project is concerned with improving energy efficiency and reducing greenhouse gas (GHG) emissions and water consumption in thermal in situ oil sands operations. Specifically, the project is a progression along the technology development curve for the online steam quality analyser under development by Luxmux Technology Corporation and Agar Canada Corporation. The steam quality analyser will allow oil sands companies to operate at a higher level of steam quality thereby requiring less fuel to generate the same amount of steam, which results in lower GHG emissions and water consumption.

The project builds on prior proof of concept and bench scale development work by Luxmux and Agar. The scope of the project was to design, construct, commission and operate a Dual Boiler System which enabled the steam quality analyser to be tested under conditions representative of oil sands steam operations. The project also included initial testing of the steam quality analyser by the Dual Boiler System.

Phase 1 of the project encompassed the complete design of the dual boiler system. This included detailed engineering, Process Flow Diagrams (PFD), Process and Instrumentation Diagrams (PID), flow parameters, operating parameters and any additional metrics required by the system to validate steam quality.

The second phase delivered a built, commissioned and operational dual boiler system. This included purchasing of the materials, construction, commissioning and validating the control of the loop per the design while meeting all the safety criteria for operating the loop. Hazardous and operability study (HAZOP) was included before construction.

The third phase was the performance of preliminary testing using the dual boiler system to demonstrate that the steam quality analyser would perform under conditions representative of the oil sands steam operations

The project successfully achieved its objectives, namely the design, construction, commissioning and initial operations of the Dual Boiler System, and preliminary performance testing of the steam quality analyser under conditions representative of the oil sands team operations. Testing is continuing to further improve the efficiency of the Dual Boiler System and the performance of the steam quality analyser.

After completion of the Project, a robust data set will be developed demonstrating the performance of the steam quality analyser at conditions representative of the oil sands team operations in order to convince oil sands operators to provide field demonstration sites.

Demonstration of the steam quality analyser at operational oil sands sites will follow, in order to prove the reliability and accuracy of the steam quality analyser under real operating conditions.

2 Introduction

This report provides a final account of the project *Enhancements to an Online Steam Analyser for Thermally Enhanced Heavy Oil Recovery* undertaken by PTAC Petroleum Technology Alliance Canada (PTAC) in collaboration with Luxmux Technology Corporation, Agar Canada Corporation, and a senior oil sands producer. The project took place from November 4, 2014 to June 30, 2016.

The project builds on prior proof of concept and bench scale development work by Luxmux and Agar. The prototype unit consisted of an explosion proof housing and an insertable / retractable probe coupled with the Luxmux photonics laser sensor to measure water droplet size in a vapor stream. Bench scale tests used steam evaporated from a flask and air cooled, and steam generated by a pressure cooker. The output of the spectrum interpreted by the Luxmux priority algorithm converted spectral data and accurately measured droplet size in the vapor stream using near infrared light. These bench scale tests proved that optical measurement of steam quality using photonics was possible.

The purpose of this project was to test and demonstrate the performance of the steam quality analyser in conditions representative of oil sands operations, in other words in flowing live steam at high temperatures and pressures.

The 3 phases of the project were:

1. <u>Phase 1. Steam Loop Design</u>: Design and engineering review of the proposed closed system steam loop.
2. <u>Phase 2. Steam Loop Construction</u>: Construction and commissioning of the closed system steam loop.
3. <u>Phase 3. Steam Analyser Testing and Validation</u>: Full analyser development which includes the insertion probe, testing of the system quality analyzer on the steam loop and demonstrating the technology capability to readout steam quality which is validated against actual steam quality in the steam loop.

This report describes the methodology and results of the project as performed.

3 Background

Canada has 174 billion barrels of oil, 169 billion of which are located in the oil sands. This gives "Canada the third largest oil reserves in the world". For in-situ operations commonly referred to as thermally enhanced heavy oil recovery, steam is produced and injected into the ground to reduce the viscosity of oil so that it can be extracted. In 2015, thermal oil production in Canada was 1.2 million barrels per day (bpd) requiring approximating 2 billion kg/year of steam from ~191 steam generators leading to ~11% of Canada's total GHG emissions generated by burning natural gas to generate the steam. Oil production, steam generation and the number of operating steam generators are expected to increase due to projects already under construction. SAGD is the dominant technology for in situ oil sands production.

Steam quality is a measure of vapor to liquid portion in the steam. The actual “heat” or energy that is desired for production resides in the vapor portion and therefore, the maximum steam quality is desired to most efficiently produce heavy oil with the least amount of GHG emitted and water usage. In heavy oil operations, the maximum steam quality allowed to avoid boiler tube failure is approximately 80% for Once Through Steam Generators (OTSGs), which is the most common steam generator technology in use in the oil sands. The reason for this limitation is that the Alberta Energy Regulator (AER) limits the amount of fresh, typically brackish water that producers are allowed to use and dispose, requiring producers to typically recycle over 85% of the produced water. The water thus needs to be treated and contaminants such as oil, silica and hardness must be removed in order for the water to be sufficiently clean to be fed into the OTSG. This treated recycled water may however still contain some contaminants that would endanger the OTSG. Thus, the 80% steam quality guideline limit is applied to allow the OTSG to safely handle some level of residual contamination.

Presently, steam quality is measured manually which means periodicity and delays between measurements and potential corrective actions. An online steam quality analyser would allow producers to operate OTSGs more efficiently and increase steam quality, and therefore reduce GHG emissions and water needs.

The environmental benefits can be estimated by calculating the enthalpy of the feed water and the enthalpy of the steam output in order to derive the amount of heat applied to the system. If the calculation is performed for a system producing a steam flow rate of 124,800 kg/h, it can be calculated that a system operating at 76% will need 79.82 MW while a system operating at 80% steam quality will only need 78.31 MW to produce the same amount of steam. In other words, for a given amount of oil, 8,211 kg/h of more water is needed in the 76% operations comparing to the 80%. Typically 15% make up water is required in operations which will allow for savings of 9,517 m^3/year when using the online analyser to operate at 80% steam quality. The air emissions reductions can be calculated for a 1.51 MW reduction in heat requirements for a system operating at 80% vs. 76%: based on the emission factors for burning natural gas to generate steam, the following air emissions reductions are expected per boiler: 2,521,947 kg/year of CO_2, 2,664 kg/year of NOx, 135 kg/year of particulate matter and 11 kg/year SOx.

To address the industry gap, Luxmux has applied in this project its ultra-wide photonic solutions. Current photonic solutions require the user to compromise resolution, power and/or bandwidth for a specific application. Luxmux’s BeST-SLED® (Broad Spectrum Tunable Superluminescent Diode) light source possesses the power of a laser with 1,000 times the bandwidth. Luxmux offers the technology solution that simultaneously maximizes resolution, power and bandwidth. Luxmux is utilizing the developed Bands version for measurement of steam quality for the thermal heavy oil market (See Figure 1).

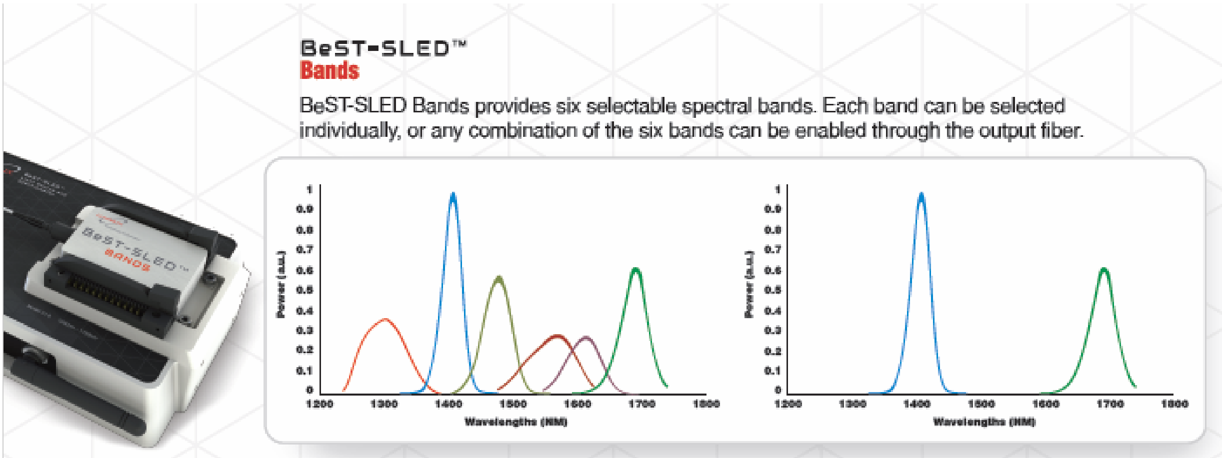

Figure 1. BeST-SLED Bands

In this project, Luxmux has partnered with Agar Canada Corporation to utilize their experience in the industry providing specialized instrumentation solutions for the heavy oil industry.

4 Objectives

The objectives of the project were to design and build the dual boiler system and conduct initial testing of the steam quality analyser under conditions representative of oil sands steam operations.

4.1 Objective 1 – Design and engineer the dual boiler system

This first objective was to deliver a complete design of the dual boiler system. This included detailed engineering, Process Flow Diagrams (PFD), Process and Instrumentation Diagrams (PID), flow parameters, operating parameters and any additional metrics required by the system to validate steam quality.

4.2 Objective 2 – Construct and commission the dual boiler system

The second objective was to deliver a built, commissioned and operational dual boiler system. This included purchasing of the materials, construction, commissioning and validating the control of the loop per the design while meeting all the safety criteria for operating the loop. Hazardous and operability study (HAZOP) was included before construction.

4.3 Objective 3 – Perform testing of the steam quality analyser under conditions representative of oil sands steam operations

The third objective was the performance of preliminary testing using the dual boiler system to demonstrate that the steam quality analyser would perform under conditions representative of the oil sands steam operations.

5 Results of Project

5.1 Project Achievements

5.1.1 Achievement 1 - Design, construction, commissioning and operation of the dual boiler system

Objectives 1 and 2 were fully achieved and the dual boiler system was designed, engineered and reviewed for safe operations. Materials were ordered and the unit was constructed in Calgary. It was then shipped to the Agar shop facility in Houston and successfully commissioned.

5.1.2 Achievement 2 - Demonstration of the performance of the steam quality analyser under conditions representative of the oil sands steam operations

Objective 3 was achieved. The steam quality analyser was tested under conditions of static steam and in the dual boiler system. The integrity of the steam analyser unit was demonstrated. In addition, tests were conducted to determine the impact of steam contaminants on the performance of steam analyser measurements. As of the writing of this report, tests of the steam quality analyser are continuing using the dual steam boiler system to further optimize the performance both the dual steam boiler system and the steam quality analyser.

5.2 Benefits

5.2.1 Benefit 1 – Availability of the dual boiler system and an innovation infrastructure

The design, construction and operations of the dual boiler system will benefit the development steam instrumentation by Canadian technology developers. In particular, Luxmux and Agar are now equipped with a critical testing apparatus which will enable continued development of advanced instrumentation in steam systems whether in oil sands application or in other applications such as industrial steam turbines. The existing steam quality analyser is showing promising performance but will certainly require refinements and continued development in future years. The availability of the dual boiler system will ensure that this development takes place in a timely and cost-effective fashion.

5.2.2 Benefit 2 – GHG reductions in Canada

The availability of the dual boiler system paves the way for a robust data set to be generated about the performance of the steam quality analyser under conditions representative of oil sands team operations. This is a necessary step in order to justify the field testing steam quality analyser by oil sands companies. Graduated adoption and deployment of the steam quality analyser by oil sands companies will result in the GHG reductions, air pollution improvements and water consumption reductions shown in Table 1 and Table 2.

Table 1. Forecasted GHG Emissions Reductions and Air Quality Improvements

GHG & Clean Air Tables Water Analyser Package

	Canada					NOx		PM		SOx	
Year	No. of New Installations	Capacity (annualized)* Per Boiler	Cumulative Total Annual Capacity	GHG Reduction of New Installations (CO2 Equivalents kilotonnes/year)	Cumulative GHG Reduction (CO2 Equivalents kilotonnes/year)	Pollutant 1 Reduction by New Installations (tonnes/year)	Cumulative Pollutant 1 Reduction (tonnes/year)	Pollutant 2 Reduction by New Installations (tonnes/year)	Cumulative Pollutant 2 Reduction (tonnes/year)	Pollutant 3 Reduction by New Installations (tonnes/year)	Cumulative Pollutant 3 Reduction (tonnes/year)
2015	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2016	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2017	1	5	5	13	13	13.54	13.54	0.69	0.69	0.06	0.06
2018	1	11	16	28	41	29.80	43.34	1.51	2.20	0.12	0.18
2019	2	18	35	47	88	49.17	92.51	2.49	4.69	0.20	0.38
2020	2	34	69	85	173	90.14	182.65	4.57	9.26	0.37	0.75
2021	4	56	124	141	314	148.73	331.39	7.54	16.79	0.61	1.37
2022	4	41	165	103	417	109.07	440.46	5.53	22.32	0.45	1.82
2023	4	36	201	91	508	95.98	536.44	4.86	27.18	0.40	2.22
2024	6	30	231	75	583	79.19	615.62	4.01	31.20	0.33	2.54
2025	6	33	264	82	665	87.10	702.73	4.41	35.61	0.36	2.90
2026	7	30	294	76	741	79.85	782.57	4.05	39.66	0.33	3.23
2027	7	33	327	83	824	87.83	870.40	4.45	44.11	0.36	3.59
2028	9	36	363	91	915	96.61	967.02	4.90	49.00	0.40	3.99
2029	9	40	403	101	1016	106.27	1073.29	5.39	54.39	0.44	4.43

Notes:

1. Capacity is the number of individual boilers on which the steam quality analyser is installed in the given year.
2. The calculations are based on improving steam quality by 4%, i.e. from 76% to 80%.

Table 2. Forecasted Reduction in Water Consumption

	Canada				
Year	No. of New Installations	Additional Capacity (annualized)* Boilers	Cumulative Total Annual Capacity	Water Reduction by New Installations (l/yr)	Cumulative water Reduction (l/yr)
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	1	4	4.237016667	40,323,688	40,323,688
2018	2	9	13.55845333	88,712,113	129,035,800
2019	3	15	28.93882383	146,374,986	275,410,786
2020	6	28	57.13616975	268,354,141	543,764,928
2021	9	47	103.6617905	442,784,333	986,549,260
2022	7	34	137.7805791	324,708,511	1,311,257,771
2023	6	30	167.805113	285,743,489	1,597,001,260
2024	5	25	192.5753535	235,738,379	1,832,739,639
2025	5	27	219.822618	259,312,217	2,092,051,856
2026	5	25	244.7992772	237,702,865	2,329,754,721
2027	5	27	272.2736023	261,473,152	2,591,227,873
2028	6	30	302.4953599	287,620,467	2,878,848,340
2029	7	33	335.7392932	316,382,514	3,195,230,854

Notes:

1. Capacity is the number of individual boilers on which the steam quality analyser is installed in the given year.
2. The calculations are based on improving steam quality by 4%, i.e. from 76% to 80%.

5.3 Technology/Knowledge Development Objectives

5.3.1 Design and Engineering of the Dual Boiler System

The design is based on two boiler chambers 8" in diameter and connected at the top with 2" pipe, a globe valve and orifice nozzle. The left chamber is titled the "receiver chamber" and the right chamber is called the "boiler chamber" as it is the main source of steam. The boiler's function is to generate saturated steam (100% steam quality) at the temperature of 343 deg. C (650 deg. F) and pressure of 14,824 kPa (g) (2,150 psig). The receiver's function is to receive the steam coming from the boiler via the top pipe and cause condensation since it is at the lower temperature of 300 deg. C (572 deg. F) and 8,584 kPa(g) (1245 psig).

The idea is that during this natural condensation, caused by pressure and temperature drop, a fine cloud of wet steam will be developed in the top chamber of the receiver. The steam cloud is an ideal condition to test and calibrate the steam quality sensor located on the receiver chamber.

Both the boiler and receiver chambers are equipped with 6 kW heaters and are insulated and heat traced. The boiler is additionally equipped with a heater with a capacity of 6 kW at the top to guaranty 100% quality steam leaving the boiler.

The purpose of the main heater is to keep the fluid at saturation condition at fixed pressure / temperature set point, while the heat tracing purpose is to keep the boiler walls at the temperature of the saturated steam and compensate for heat loss through the insulation and therefore maintain the adiabatic boiling and condensation process.

5.3.2 Construction and Commissioning of the Dual Boiler System

The HAZOP (Hazard and Operability Analysis) review for the Dual Boiler System was conducted by ACM Facility Safety in Calgary Alberta and completed in January 2015. In addition, two HAZOP sessions where conducted at the offices of a senior oil sands producer in Calgary with a team of engineers from Luxmux, Agar Houston and of the oil sands company. The safety review was based on the initial Dual Boiler P&D. The review identified safety conditions ranging from Unacceptable to Workable with recommended actions, as well as 16 suggested improvements. The HAZOP was completed successfully and modifications where made to the dual boiler design.

Final Process and Instrumentation Diagrams (P&IDs) were prepared. The scope of work for instruction included the following:

- Purchasing of materials
- Fabrication
- Assembly
- Non-destructive testing (NDT)
- Electric heat tracing
- Insulation
- Instrumentation
- Electrical
- Control

The Dual Boiler construction was completed in June 2016. The system was commissioned and tested in July 2016, using the following features:

- New design NIR Probe (V2)
- BeST- SLED Spectrometer
- Collimators
- Single Mode Fiber Optic Cable for the Transmitter (Tx)
- Multi Modes Fiber Optic Cable for the Receiver (Rx)

All the above mentioned activities have been completed in June 2016

Commissioning and testing commenced in July, 2016.

5.3.3 Initial Operations of the Dual Boiler system and Performance Testing of the Steam Quality Analyser

Steam quality measurements were commissioned in July 2016 and are in progress. The Dual Boiler system was commissioned and the Operating Manual was issued. Currently the dual boiler has been operating successfully. The main setback encountered during testing in August 2016 was the time it takes the dual boiler to reach the desired operating temperature and pressure, which is currently over 10 hours. Agar currently believes that the vendor recommendation of 2" insulation is not good enough and the insulation is being replaced to 4". Also, bigger heaters are being purchased to reduce the heating time.

Integration of Luxmux BeST-SLED solution with the Agar system has been started. Agar has taken the output from the BeST-SLED via Ethernet and the Modbus register map was programmed into the Agar system to read out the data. Testing will continue on the dual boiler when the 4" insulation is put on.

The impact of contaminants on the performance of the probe and its integrity at elevated pressures and temperatures were also determined.

- Sapphire Deposit Testing with produced water from an oil sands producer was conducted. It was determined that exposure of the probe to water samples taken after the skim tank and after Induced Gas Flotation caused deposits to accumulate on the surface of the probe. However, water sample after the Boiler Feed Water tank did not cause contamination.
- The probe was also stress tested for integrity under high temperature and high pressure steam conditions using a specially built static steam chamber. The high temperature, high pressure test was successful. The probes maintained their integrity at 320 deg. C and 2000 psig. The optical alignment was maintained as well. Lastly, when high pressure steam was present a good Gaussian profile of the beam was maintained throughout the steam on the receiver side.

Details for all of the above research results are provided in the technical report found in Appendix A.

5.4 Challenges and Barriers

5.4.1 Barrier/Challenge 1 – Need for Field Testing

The Project only addressed pilot testing of the steam quality analyser under conditions representative of oil sands team operations. To achieve full adoption and deployment, field testing at oil sands operating sites will be required. The current economic downturn in the oil sands industry has resulted in staff layoffs and in cutbacks to research budgets; it is therefore very challenging to find an oil sands operator willing to allocate scarce budget and a site to conduct this field test.

5.5 Gender Based Analysis

The number of full-time equivalent (FTE) positions that were involved in the construction/delivery of the project and in ongoing operations, are shown in the table below including gender information.

Table 3. Gender Analysis			
Phase	**Male**	**Female**	**Total**
Project Planning/Construction/Delivery	8	1	9
Ongoing Operations	3	1	4
Total	**11**	**2**	**13**

6 Conclusion and Follow-up

The project successfully achieved its objectives, namely the design, construction, commissioning and initial operations of the Dual Boiler System, and preliminary performance testing of the steam quality analyser under conditions representative of the oil sands team operations. Testing is continuing further improve the efficiency of the Dual Boiler System and the performance of the steam quality analyser.

The intermediate outcomes will be the steam quality analyser as a reliable device capable of measuring steam quality between 40% and 100%, with a temperature/pressure up to 350 deg. C/2381psig that will have been piloted by this project and demonstrated in future field trials.

Currently, to the best of our knowledge, no system exists in Canada which is capable of providing steam quality control in a closed system such as provided by the Luxmux and Agar online steam quality analyser.

The long term outcome from wide scale deployment of the steam quality analyser in the oil sands industry will be significant reductions in GHG emissions and water consumption arising from operating steam generators at greater efficiency. This outcome will support Canada's 2030 GHG reduction commitments undertaken in the Paris Agreement and of the Alberta Climate Leadership Plan. In addition, technology innovators such as Luxmux and Agar will be able to offer the steam quality analyser in related global market such as steam turbine used in power generation.

6.1 Next Steps

The two critical next steps following completion of this project will be:

- Development of a robust data set demonstrating the performance of the steam quality analyser at conditions representative of the oil sands team operations in order to convince oil sands operators to provide field demonstration sites.
- Demonstration of the steam quality analyser at operational oil sands sites in order to prove the reliability and accuracy of the steam quality analyser under real operating conditions.