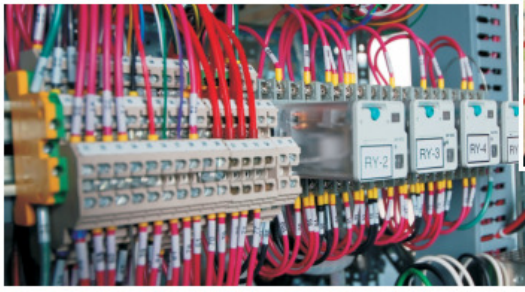

GLOBAL ANALYZER SYSTEMS

Total Reduced Sulphur Continuous Emission Monitoring System

CONFIDENTIAL FINAL REPORT

May 2018

Prepared for
Emissions Reduction Alberta

Non-Confidential Final Report

ERA Project #	E110166
Company:	Global Analyzer Systems Ltd.
Project Title:	Sulphur Recovery Plant Stack Top Temperature Reductions Based on Continuous Measurement of Total Reduced Sulphur (TRS) Compounds
Company Contact:	Brian Rosentreter, President, Global Analyzer Systems
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Executive Summary

Global Analyzer Systems (Global) provides turnkey solutions, equipment and services to industrial facilities requiring Continuous Emission Monitoring Systems (CEMS) across multiple industry sectors in Western Canada. Annually, Global works with more than 90% of the petroleum processing and sour gas facilities in Alberta requiring CEMS.

In Alberta, Total Reduced Sulphur (TRS) emissions (namely H_2S, COS, and CS_2) from sour gas plant sulphur recovery unit (SRU) incinerator stacks are typically measured by manual testing methods on either an annual or bi-annual basis. TRS emissions from SRU's are required to be maintained below 300 ppm to reduce impacts on both human health and the environment. As the stack top temperature of an incinerator stack increases, the TRS level in the stack decreases due to increased thermal conversion (oxidation) of TRS compounds into sulphur dioxide (SO_2). Sour gas plants operating SRU's are regulated to maintain minimum stack top temperatures to ensure the adequate oxidation of TRS compounds and sufficient dispersion of stack effluent into the atmosphere. Maintaining elevated stack top temperatures directly translates to high fuel consumption in the incinerator which results in high emission rates of carbon dioxide (CO_2) from the combustion process, a known greenhouse gas (GHG).

Global has developed an innovative CEM System that has the ability to both accurately and precisely measure TRS emissions from high temperature sources in real-time. Global, partnered with SemCAMS, Emissions Reduction Alberta (ERA), and the Canadian Environmental Technology Advancement Corporation (CETAC-WEST) to evaluate this system for implementation into a sour gas processing facility in Alberta. The goals for the project were to:

1. Measure accurately and continuously the total reduced sulphur compounds being emitted from a high temperature SRU incinerator stack.
2. Facilitate the AER permitting process for a stack top temperature reduction on an SRU incinerator stack.
3. Achieve a minimum greenhouse gas reduction of approximately 4,850 tonnes of CO_2e per year by lowering the incineration (and stack top) temperature.

Global installed the TRS CEMS at the SemCAMS Kaybob Beaverhill Lake Gas Unit No. 3 Sour Gas Processing Plant (SemCAMS K3) near Fox Creek, Alberta, which was successfully verified by a third party in August of 2016.

This project has enabled the SemCAMS K3 facility to achieve a stack top temperature reduction. The stack top temperature limit of the SRU at the onset of the project was approximately 420 ^oC, and by October 2014 SemCAMS K3 was approved to operate with the stack top temperature as low as 330^oC (dependant upon the facility's sulphur inlet rate). Field testing completed by Global Analyzer Systems,

Sulphur Experts and AGAT Laboratories shows that if the facility operates with an average stack top temperature of 360^{o}C it would result in an approximate GHG emission reduction of between 14,000 and 27,750 tonnes CO_2e per annum.

Global has also constructed a mobile TRS CEMS unit. This unit was designed to be deployed at a variety of sites throughout the province and can be tied directly into a facility's SRU incinerator stack for the continuous monitoring of TRS concentrations. This new platform will be used as a tool to quantify emissions, validate incinerator performance, and optimize SRU performance.

Table of Contents

Background

Technology Description

Global Analyzer Systems (Global) has developed a Continuous Emission Monitoring System (CEMS) to measure Total Reduced Sulphur (TRS) namely H_2S, COS and CS_2 in high temperature incinerator stacks. This innovative advancement builds upon Global's proven CEMS sampling technology, and it can be used as a tool to quantify and validate emissions and performance criteria at sour gas processing facilities. Sulphur Recovery Unit (SRU) incinerator stacks at natural gas processing facilities must maintain a minimum stack top temperature to ensure sufficient dispersion and destruction of TRS into the atmosphere. By being able to quantify TRS levels in real-time and demonstrate that they exist at safe levels, the stack top temperature can safely be lowered. Lowering the stack top temperature has a direct correlation to a reduction in fuel gas consumed in the incinerator and subsequently a reduction in CO_2 emissions (a combustion by-product).

Figure 1. Global TRS CEMS instrumentation rack

Global's TRS CEMS is unique from existing technologies because it uses Global's innovative sampling system. The sampling system minimizes losses which are common during extraction and transport from the flue gas stream to the analytical equipment. This establishes an environment where the accurate measurement of TRS compounds is possible. Historically TRS has been measured by designing sampling programs where a sequence of manual grab samples are taken at several different plant operating conditions and then run through a gas chromatograph for analysis. This technique has shown issues with accuracy due to sample loss and degradation over time, in addition to issues with precision due to varying gas compositions over the integrated sample time. Stack top temperature limits are typically established by using the analytical results from these manual sampling techniques in engineering dispersion and process models.

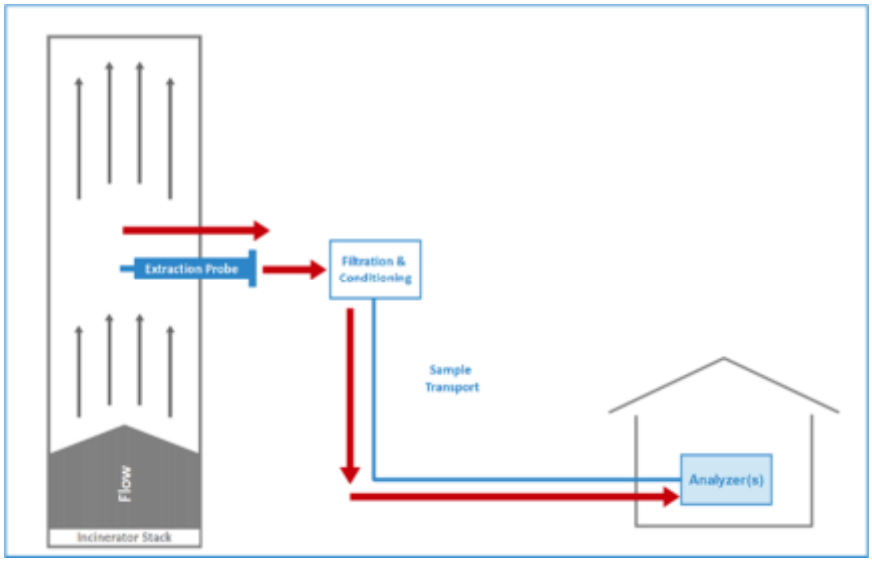

Figure 2 - Extractive CEMS Block Diagram

Increased accuracy and precision of the TRS measurement can be achieved through continuous measurement and improved sample extraction techniques. With continuous (real-time) measurement of the oxidation efficiency, the minimum stack top temperature can be

determined dynamically, maximizing fuel gas savings and minimizing CO_2 emissions.

A block diagram of the technology can be found in Figure 2. As shown in the diagram, an extraction probe is inserted into the exhaust stack. A sample is drawn through this probe into a Sample Conditioning Unit (SCU) where it is filtered and diluted with instrument air at a known and controlled rate. This diluted sample is then driven through a pneumatic bundle from the extraction point to the instrumentation (as shown in Figure 1) located in a shelter at ground level. At this point the sample is passed through an analytical assembly and the concentration of TRS is measured. The measured value is recorded and validated on the Data Acquisition System (DAS) and communicated with the plant Distributed Control System (DCS).

Alberta Sour Gas Plant Regulatory Environment

According to "*Fuel Gas Best Management Practice – Tail Gas Incineration"*, in Canada 20% of the fuel gas is consumed by sour gas plants, with the tail gas incinerator specifically using approximately 25% of the total fuel consumed at the plant. Running the incinerator at optimum conditions is critical as a 1% increase in excess oxygen can result in a 10% increase in fuel gas required, as well as a 25 degree Celsius increase in stack top temperature can result in a 10% increase in fuel gas used.

In Alberta, the criteria for the minimum incinerator stack top temperature is specified by the Environmental Protection and Enhancement Act (EPEA) and the specific facility operating approval issued by Alberta Environment. A provincial guideline on TRS emissions from sour gas plants is defined by the Alberta Energy Regulator (Formerly ERCB) Informational Letter IL-OG-76-24. The letter states that in order to be approved for a stack top temperature reduction the plant must achieve a satisfactory oxidation of all sulphur compounds (H_2S, COS, and CS_2, which are collectively called TRS compounds) to a combined maximum concentration of 300 ppm. Additionally, they must also demonstrate that the maximum ground level concentration of sulphur dioxide (SO_2) is equal to or less than 0.2 ppm.

The Alberta Energy Regulator (AER) requires most of the sour gas processing facilities in the province to continuously monitor SO_2 (concentration and mass emission rate), and effluent temperature, and flow rate. Completion of bi-annual SO_2 and TRS manual stack surveys are typically also completed on sulphur recovery unit (SRU) incinerator stacks. In these manual stack surveys, TRS concentrations are determined by manually extracting "grab" samples, which are small volume, short duration samples that represent the unit operational conditions at a single point in time. The Informational letter also states that in an effort to ensure maximum TRS levels are not exceeded, most sour gas plant operators keep their stack top temperature 25-150 degrees Fahrenheit above their approved limit.[1]

Global's TRS CEMS technology enables sulphur recovery units in the province of Alberta to accurately monitor their TRS emissions while undergoing or maintaining a reduced stack top temperature operating limit. Reducing the operating temperature of an SRU incinerator stack directly translates to a reduction in fuel gas usage by the incinerator, which in turn provides a reduction in GHG emissions.

[1] IL-OG 76-24: Stack Exit Temperatures for Acid Gas Incinerators Associated with Gas Processing Plants, December 15, 1976.

Global's vision is to provide a better measurement platform for TRS determination, and thereby a mechanism to achieve GHG reductions and fuel gas savings by lowering the incineration temperature while ensuring safe destruction of reduced sulphur compounds. Data generated by TRS CEMS will provide all stakeholders with better quantitative data and help facilities to achieve increased economic and environmental operational efficiency. This system could also provide regulators with monthly quality assured TRS CEMS data which could help elicit significant changes to future policy and facility operations across the province.

Technology Development Stages

Global Analyzer Systems started the development of the TRS CEMS in 2011 with support from the National Research Council Industrial Research Assistance Program (NRC-IRAP). An early prototype was installed at a facility near Calgary, Alberta, and compared favorably with manual stack testing methods performing within the limits defined by the 1998 Alberta CEMS Code.

From here Global began developing a second generation prototype incorporating the learnings from the first prototype. In 2012, Global applied to the ERA (formerly CCEMC) for funding to perform a field demonstration of this technology, and to design and build a mobile (trailer mounted) version of the TRS CEM System.

Project Details

Project Description

The project identified three primary goals:

1. Measure accurately and continuously the total reduced sulphur compounds being emitted from a high temperature SRU incinerator stack.
2. Facilitate the AER permitting process for a stack top temperature reduction on an SRU incinerator stack.
3. Achieve a minimum greenhouse gas reduction of approximately 4,850 tonnes of CO_2e per year by lowering the incineration (and stack top) temperature.

In order to meet the project goals a suitable test facility was needed which could accommodate Global's TRS CEMS technology and be able to undertake the optimization and temperature reduction study required. The SemCAMS Kaybob South Beaverhill Lake Gas Unit No. 3 Sour Gas Processing Plant (Kaybob South 3), located near Fox Creek, Alberta, was selected and agreed to participate as sponsor on the project.

Figure 4. SemCAMS Kaybob South #3 Gas Plant, located near Fox Creek, Alberta

According to the 2012 AER report titled *"Sulphur Recovery and Sulphur Emissions at Alberta Sour Gas Plants"* the Kaybob 3 facility is approved for a production rate of 1,999 t/d of sulphur, making it the second largest sour gas plant in Alberta.

SemCAMS Kaybob South 3 facility has a 462 ft. tall incinerator exhaust stack, which tapers at the top to a diameter of approximately 14 ft., and is approximately 16 ft. in inside diameter at the TRS CEMS sample extraction point (first platform). There are three separate platforms located on the stack, with the first platform at approximately 150 ft. above grade where there is a small instrumentation shelter. The second platform is at approximately at elevation of 300 ft., and is used to access four different sample nozzles where stack samples can be extracted when using manual testing techniques. The third platform is primarily used to access and maintain an aircraft warning lighting system located near the top of the stack.

The TRS CEMS was installed on the first platform in order to take advantage of pre-existing equipment and in order to utilize an existing nozzle/port which would not interfere with periodic routine stack testing needed to be performed by the facility. Some parts from a pre-existing CEMS unit were used in order to reduce overall project costs.

The advantages for a sulphur recover plant having a Total Reduced Sulphur Continuous Emissions Monitoring System are:

- Reduction in stack top temperature which directly relates to a reduction in fuel gas usage in the tail gas incinerator.
- Global's Data Acquisition System (DAS) which is included in the CEMS TRS package, can acquire real time data for facility operators on various process parameters including TRS and SO_2 concentrations, volumetric flow and flue gas temperature. With an increased demand for GHG reductions and monitoring, reliable and precise measurement will be of the utmost importance.
- Fluctuations in TRS levels in the stack can be an indicator of other underlying problems in the sulphur recovery unit or other unit operations. Therefore, operators will have access to an additional tool which they can use to safely and efficiently operate their facility.
- TRS CEMS may also be used as a predictor for catalyst bed replacement, therefore minimizing potential maintenance costs.

Project Participants and Roles

Project Management and Prime Contractor

Global Analyzer Systems Inc.

Global was the technology developer and prime contractor on this project. Global provided the equipment/technology, performed the installation and commissioning of the TRS CEMS, and have been intimately involved throughout the technology verification process.

Project Sponsors

SemCAMS Kaybob South Beaverhill Lake Gas Unit #3 Sour Gas Processing Plant

SemCAMS was the main project champion. They own the gas plant where the TRS CEMS is installed and provided 50% of the project funding through cash contributions, in-kind equipment and labour.

Emissions Reduction Canada (formerly CCEMC)

ERA provided 50% of the project funding through cash contributions.

Project Support

Sulphur Experts

Sulphur Experts was contracted by Global to provide engineering support via sulphur plant and incinerator modelling and simulations before and after the TRS CEMS installation.

AGAT Laboratories

AGAT Laboratories was contracted by Global to provide a third party verification of various performance specifications of the technology using approved manual methods for TRS measurement.

CETAC-West

CETAC-West was an original project partner and provided project management support throughout the planning stages of the project along with support for the third party verification.

Project Challenges

Government Regulations

The CEMS continuously monitors the concentration of TRS through a new innovative sampling technology which is much different than the approved manual reference method required by the province. There are many factors that affect the ability to draw a Relative Accuracy (RA) comparison. Some of the main factors include:

1) Differences in the sample extraction techniques
2) Time-to-analysis
3) Skill level of the testers and quality of their equipment
4) Time of travel in the stack
5) Stratification of gas within the stack
6) Averaging induced by taking a manual sample over a long period of time vs. real time high resolution data

In order to account for these factors, some modifications to the approved reference methodology were made in an attempt to increase the accuracy of the reference method sampling. Even with modifications to the methodology, a performance evaluation of the TRS CEM System's relative accuracy proved to be challenging.

Certification Testing

Successfully passing a relative accuracy performance evaluation is one of the criteria that needs to be demonstrated in order for any CEMS to be certified for use within the province of Alberta. As identified in the project proposal, one of the primary project risks was achieving this certification, while dealing with the inherent difference in accuracy between the reference testing methodology and that of the TRS CEMS, and did prove to be problematic through the certification process. This is because Global's TRS CEMS technology has a unique way of extracting samples that is less prone to sample degradation than current accepted methods.

Technology Adoption in the Current Economic Climate

In the current economic climate in Alberta it may be very difficult to find other champions that are willing to adopt the technology.

Throughout the project, Global has been fabricating a mobile TRS CEMS unit. This unit will support sour gas plants by providing them with a temporary TRS CEMS unit. It can be used to assist with short-term monitoring objectives and plant optimization projects, including stack top temperature reduction programs.

Global is also working with CETAC-WEST to arrange a round table discussion which will bring gas plant operators and regulators together to brainstorm on commercialization and adoption strategies.

Results

The project had three sequential modelling and testing elements, namely:

1. Incinerator Optimization Study (broken into two sub-parts)
    - Stage 1A: Incinerator TRS Oxidation Simulations
    - Stage 1B: SO_2 Plume Dispersion Modelling
2. Field Testing
3. Validation and Certification of the System

The results from the three studies are briefly discussed below.

Incinerator Optimization Study

In July of 2013 Sulphur Experts completed a simulation study of the SRU incinerator at the SemCAMS Kaybob South 3 Sour Gas Plant. The purpose of the study was to determine if the operating temperature of the incinerator could be optimized to conserve fuel gas while observing the regulatory emission limits for TRS compounds.

To complete this study Sulphur Experts looked at several process parameters such as maximum allowable inlet sulphur flow rate, maximum sulphur emission and minimum recovery efficiency, which is set and regulated by AER under the plant's EPEA Approval. Additionally, Sulphur Experts took into consideration limits on air emissions and minimum temperature requirements for the plant incinerator which is also set and regulated by AER.

Two separate operating cases were analyzed to assess the impact of the proposed stack top temperature reduction:

Case 1: Conditions under which a maximum allowable daily SO_2 emission would be reached.
Case 2: Typical conditions under which the current SO_2 emissions are reached.

The study was broken down into two different parts and the results are summarized as follows:

Stage 1A: Incinerator TRS Oxidation Simulation

The purpose of this simulation was to determine the lowest stack top temperature that could be achieved without exceeding the maximum regulated TRS concentration limits. This would ultimately determine the minimum fuel gas consumption that could be achieved by the incinerator.

The simulation was able to determine for both Case 1 and Case 2 the optimal stack top temperatures while still meeting the guidelines set out by AER. The results show what the predicted optimum gas plant conditions would be when the stack top temperature is maintained at 330^{o}C. Under normal operating conditions (Case 2) this would result in a reduction of 72% in fuel gas consumptions and a decrease in GHG emissions by about 22,500 tonnes CO_2e/year.

Stage 1B: SO_2 Plume Dispersion Study

This study was completed to determine the effect of the proposed incinerator operating conditions on the SO_2 plume dispersion. A simulation is used to predict the expected change in air quality associated with the worst-case SO_2 emissions for all cases. The overall results show that all simulated cases were in compliance with the maximum allowable ground-level SO_2 concentrations.

TRS Simulation Results

In order to produce the incinerator operating curves, Sulphur Experts performed thermodynamic simulations on a wide range of potential operating conditions. The two variables that were changed in these simulations are stack gas oxygen concentration from 1 to 5 mol% (wet), and stack top temperature from 300°C to 400°C.

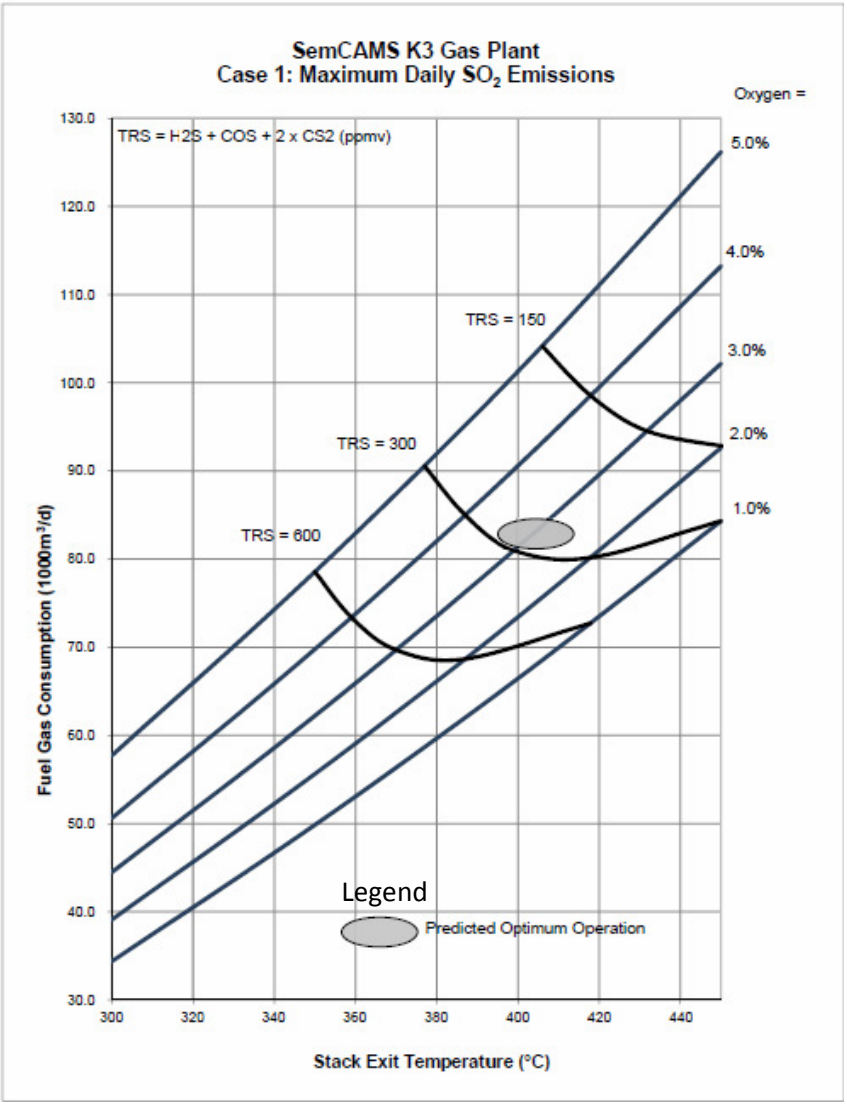

Figure 4. Incinerator Operation under Maximum SO_2 Emissions

Figure 4 shows the incinerator operating curves under maximum daily SO_2 emissions. As it can be seen in the graph, the optimum operating conditions where TRS is under 300 ppm is at approximately 410°C, with an oxygen concentration between 2 and 3 mol%.

Figure 5 shows the optimum operating condition under normal plant operation. This graph shows that in order to keep the TRS concentration below the 300 ppm limit, the minimum incinerator stack exit temperature is predicted to be approximately 330°C, with an excess oxygen concentration of 2 to 3 mol% (wet). This graph also suggests the current operation of the incinerator is far above the predicted optimum condition.

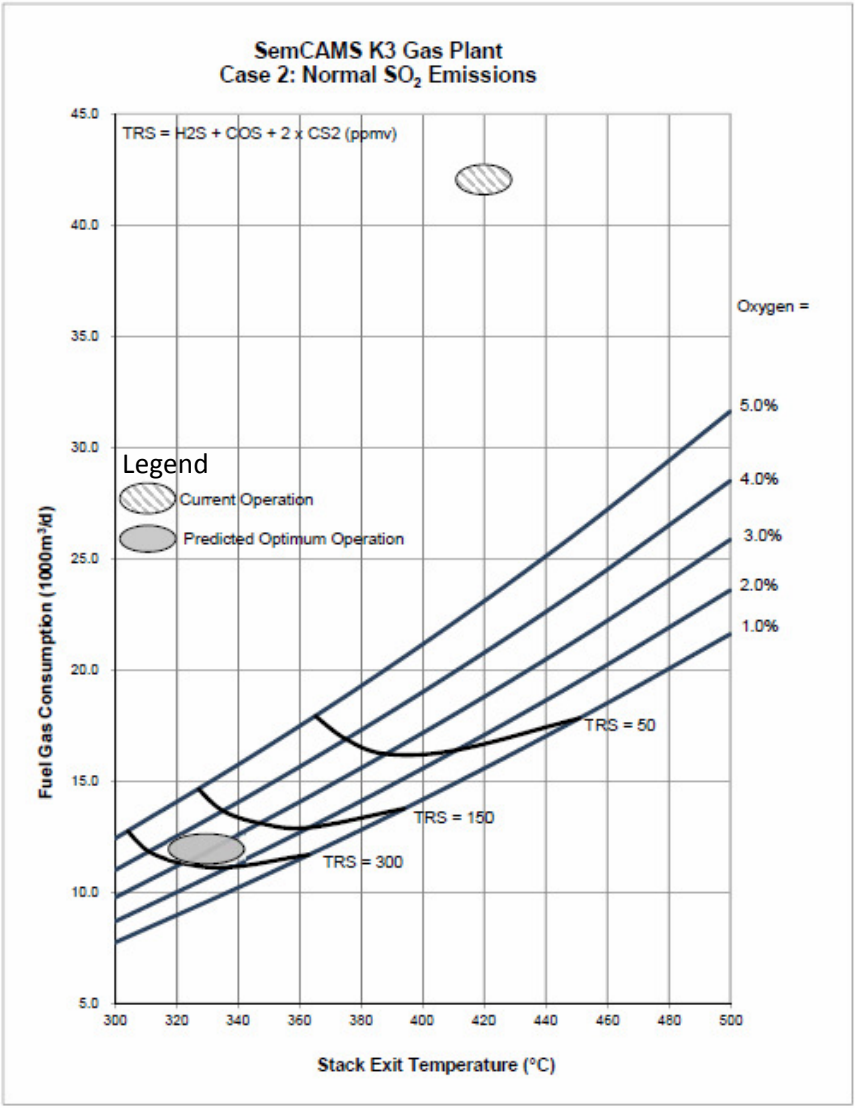

Figure 5. Fuel Gas Consumption at Normal SO_2 Emissions

The main takeaway from both of these graphs is the potential reduction in fuel gas consumption. If the plant throughput is such that daily maximum SO_2 emissions are achieved, then the plant would need to maintain their stack exit temperature above 410°C. However, under normal operations and normal SO_2 emissions, the simulations show the plant can maintain a stack exit temperature of 330°C without exceeding the TRS limit.

Fuel Gas Savings and CO_2 Emission Reductions

The simulations performed by Sulphur Experts show how stack top temperature could be decreased from 410°C to approximately 330°C. Under the current conditions (410°C; 2-3% O_2) the plants fuel consumption is approximately 42,700 m^3/day which results in an emissions of 86 tonnes of CO_2e/day from the fuel combustion. If the plant was to decrease their stack top temperature to 330°C and maintain a 3% O_2 level, the plant would be able to operate with a fuel gas consumption of about 11,900 m^3/day which would decrease GHG emissions by 62 tonnes of CO_2e/day, or 21,700 tonnes of CO_2e per year (assuming 350 operating days/year).

Sulphur Experts also noted that operating the stack at 400°C and maintaining a stack O_2 level of between 2-3% would also result in significant savings for the plant.

Field Testing

On January 27th and 28th, 2014, Sulphur Experts conducted a field test on the SemCAMS Kaybob South 3 sulphur gas plant incinerator. The purpose of the field test was to determine the potential for fuel gas savings by operating the incinerator at significantly lower stack top temperature while ensuring compliance with all of the plant air quality objectives. This field test refined and confirmed the incinerator operating curves that were developed by Sulphur Experts during the simulation performed for the plant.

The incinerator had been operating at 420°C. During this test the stack exit temperature was reduced in steps from 420°C to 330°C. Throughout the process of reducing the temperature, Sulphur Experts also controlled the air flow to the incinerator in order to control the oxygen content during the combustion process.

The results of this field test are shown in the table below which is taken from the Sulphur Experts *"Incinerator Optimization Study".*

Table 1. Optimization Test Results

Pre-test (time)	Incinerator Temperature (°C)	Stack Exit Temperature (°C)	Excess O_2 [1] (%)	TRS [1, 2] (ppmv)
12:10 on Dec. 17	505	426	9.3	37
15:45 on Dec 17	410	366	9.1	34
16:57 on Dec 17	368	341	8.8	22
11:40 on Dec 18	385	342	9.8	38
13:10 on Dec 18	379	341	8.9	37
14:30 on Dec 19	408	343	4.2	50

[1] Wet basis - the stream water content was determined by material balance.
[2] The sum of $H_2S+COS+2xCS_2$.

Table 1 (previous page) demonstrates that as the temperature in the incinerator decreases, the stack exit temperature decreases at which point the TRS concentration rises to 50 ppm which is well below

the compliance target of 300 ppm. This test shows that stack exit temperature can be safely decreased without exceeding the provincial guidelines for TRS emissions.

During the field test the fuel use in the incinerator was also measured to determine the fuel gas savings. Using the fuel gas savings figures the CO_2 emissions were calculated assuming 100% combustion. The following results were achieved:

Table 2. Incinerator Fuel Gas Consumption

Current Fuel Use (420°C) [1] ($1000m^3/d$)	Optimised Fuel Use (330°C) [1] ($1000m^3/d$)	Metered Reduction in Fuel Use ($1000m^3/d$)	Annual Reduction in Fuel Use [2] ($1000m^3/a$)	Annual Reduction in CO_2 Emission [2,3] (tonne/a)
60.1	20	35	12250	24256

[1] Calculated fuel use from heat and material balance
[2] Based on operation of 350 days per annum
[3] Based on the fuel gas analysis where 1000 m^3 of fuel releases 1.98 tonne of CO_2 at 100% combustion

The incinerator uses a mixed fuel stream composed of wet fuel gas and sales gas. The sales gas feeding the incinerator is metered, and the wet fuel gas is flash gas from the glycol and amine flash drums. At the current operating conditions the plant uses approximately 60,000 m^3/d of fuel gas from which 35,000 m^3/d is sales gas.

The tests run by Sulphur Experts show that if the stack exit temperature is reduced to 330°C it would result in a reduction of fuel gas use by 35,000 m^3/day which translates to 12,250,000 $m^3/year$ resulting in a reduction of 24,256 tonnes $CO_2e/year$. At today's natural gas prices this equates to a savings of approximately $630,000/year in fuel savings and $740,000/year in GHG taxes for a total annual savings of approximately $1,375,000 /year (CAD).

Overall, the field data indicated the Kaybob South 3 sulphur plant incinerator would be able to operate at a temperature below the current permitted value while maintaining TRS residuals in the stack at less than 300 ppm.

Certification of the TRS CEMS System

In accordance with the Alberta 1998 Continuous Emission Monitoring System (CEMS) Code of Practice for new installations, a TRS CEMS must show it meets the design and performance specifications as appropriate to the application. The TRS CEMS unit was commissioned on August 19, 2014. Certification testing was conducted between April 26 and May 2, 2016. During this time period it was proven that the TRS CEMS can continuously monitor gas concentrations of total reduced sulphur compounds (namely COS, CS_2 and H_2S).

The activities performed on the unit during the certification process are shown below in Table 3.

Table 3. Completion Record of Certification Requirements

Requirement	Completion Date
CEMS Installation	August 19, 2014
CEMS Commissioning	August 19, 2014
Conditioning Test Period (CTP)	April 14 at 00:00 through April 20 at 23:59, 2016
Operational Test Period (OTP)	April 26 at 00:00 through May 2 at 23:59, 2016
Written Notification to AER of intent to conduct the Relative Accuracy Test Audit (RATA)	April 8, 2016
RATA and Bias Tests	April 26-27, 2016
Linearity (Cylinder Gas Audit [CGA]) High and Low Range	April 27, 2016
TRS Analyzer Zero and Span Drift (24 hr)	April 26 through May 2, 2016

The main test that provides third party verification of the system is the relative accuracy test audit (RATA) combined with a bias test. Nine comparison tests were completed in accordance with the United States Environmental Protection Agency *Method 15 Determination of Hydrogen Sulfide, Carbonyl Sulfide, and Carbon Disulfide Emissions from Stationary Sources* and the *1998 Alberta Continuous Emission Monitoring Systems Code*.[2]

AGAT Laboratories was retained by SemCAMS to perform a source emissions survey on the SemCAMS incinerator stack. During these tests results were obtained by AGAT and were compared to the TRS CEMS unit on site. According to the 1998 Alberta CEMS Code, the relative accuracy of the Global TRS CEMS systems must be within 20%; therefore, the data shown in Figure 6 below proves the Global TRS CEMS will fall within this limit and passes this test.

[2] Alberta Environmental Protection Service 1998, United States Environmental Protection Agency (US EPA), 2016.

Waste Gas Incinerator				
Test Number	Test Time	Reference Method (ppm)	C.E.M.S (ppm)	Difference (ppm)
16/04/26-27				
1	1600 - 1630	51.1	46.9	4.22
2	1645 - 1715	53.7	46.9	6.81
3	0829 - 0859	55.2	54.1	1.06
4	0909 - 0939	54.9	51.7	3.24
5	0951 - 1021	55.6	50.3	5.34
6	1030 - 1100	54.0	48.3	5.72
7	1118 - 1148	51.6	45.8	5.84
8	1155 - 1225	50.1	43.2	6.88
9	1230 - 1300	52.5	43.7	8.82
Average		53.2	47.9	5.33
Bias Calculation: 0.0896%		Relative Accuracy: 13.3%		

Figure 6. Source Emissions Survey results compared to the TRS CEMS unit

Greenhouse Gas Emissions Reductions

Measurements were taken by Sulphur Experts during the Stage 2 Field Testing that show what the fuel gas usage was under the then current operating conditions (stack exit temperature of 420°C). The fuel gas use was 60,100 m^3/day which resulted in GHG emissions of approximately 119 tonnes CO_2e/day or 41,649 tonnes CO_2e/yr[3]. The 60,100 m^3 of gas per day includes all of the "wet gas" produced by the plant which generally goes to the flare and an additional 35,000 m^3/day of sales gas.

During the project the facility successfully reduced the incinerator stack top temperature to 360°C under typical operating conditions. Based on a fuel gas analysis where 1000 m^3 of fuel gas used releases 1.98 tonnes of CO_2e at 100% combustion, the approximate yearly greenhouse gas reduction that results from a reduction of 60°C in stack top temperature is between 14,000 tonnes CO_2e/year and 27,750 tonnes CO_2e/year.

Overall Conclusions

Under this project, Global Analyzer Systems successfully installed and operated the first Total Reduced Sulphur Continuous Emissions Monitoring System on a high temperature incinerator stack at one of the largest sour gas plants in Alberta. The system passed all of the specified performance tests which are required by the provincial regulators.

[3] Calculations are based on the fuel gas analysis performed by Sulphur Experts during the "Incinerator Optimization Study" where 1000 m^3 of fuel translates to 1.98 tonnes of CO_2 at 100% combustion. Additionally, it was assumed a total of 350 operational days per year.

All three projects goals were met or surpassed. The TRS CEMS was successfully installed, certified and validated showing that it could continuously monitor TRS concentrations at the SemCAMS Kaybob South #3 facility. Global successfully demonstrated that TRS levels in a high temperature SRU incinerator stack could be measured accurately and reliably in real-time. The project also demonstrated that the TRS CEMS could be used as a valuable tool for the successful reduction, and subsequent operation of a sulphur recovery incinerator stack at a reduced stack top temperature. The new stack top temperature limit achieved by the facility also provided greater than the minimum GHG reduction target of approximately 4,850 tonnes of CO_2e/year. At the beginning of the project, the plant was operating with a minimum stack top temperature of 420^oC, and currently is operating with an average stack top temperature of 360^oC. This translates to an approximate GHG reduction of between 14,000 tonnes CO_2e/year and 27,750 tonnes CO_2e/year for the plant, depending on operational parameters.

One of the challenges identified by Global prior to commencement of the project was the difficulty encountered by industry obtaining a stack top temperature reduction from the provincial regulator. One main driver for the development of the TRS CEMS was to minimize the risk for regulators (and the public) when approving stack top temperature reductions by continuously monitoring H_2S, COS and CS_2 ensuring they remain at safe levels. With the successful demonstration of this technology Regulators will now be able to ensure sufficient oxidation (continuously) of Total Reduced Sulphur compounds when a stack top temperature reduction is assessed.

The reduction of greenhouse gas emissions is an important part of the climate change agenda today and most likely into the future. Reducing stack temperatures in order to conserve fuel and lower greenhouse gas emissions is a viable way to reduce emissions within Alberta. However, if we are to lower incinerator stack top temperatures at sour gas processing facilities in the province, we will need an accurate method to ensure the total reduced sulphur compounds do not exceed the compliance limits which were set to safeguard human health and the environment. The TRS CEMS, through continuous monitoring, helps mitigate this potential hazard.

Communications Plan and the Next Steps

It is the intent of Global to continue to develop and market the technology. Non-confidential results from this and future related projects will be shared with industry, the academic community and various governmental agencies. Future communication and collaboration are planned to include:

I. *White Papers* – it is intended that the results of this project be published in one or more media publications.
II. *Corporate Website and News Release* - results from this study will be posted on Global's corporate website and used publicly as a corporate news release through the ERA.
III. *Student Thesis Project* – a portion of this project was completed in tandem with a Royal Roads University Master's of Science Thesis project being completed by Charles Grimm. The results of this currently unpublished manuscript will be published (upon approval by the University) in the Royal Roads University's digital archive, Library and Archives Canada, and ProQuest.

IV. *Conferences and Technical Seminars* – Several conferences and technical seminars are currently being perused throughout North America and the Middle East.

Final Financial Summary

The Project, Sulphur Recovery Plant Stack Top Temperature Reductions Based on Continuous Measurement of Total Reduced Sulphur (TRS) Compounds, was started in May 2013 and completed in February 2018. Estimated cost for the project was $690,089, with agreed funding support coming from CCEMC of $300,000, or 43.47%. The total project costs, upon completion, were $711,574, a difference from the budget of $21,485, or 3.11%.

Glossary of Terms

AEP - Alberta Environment and Parks; AEP protects the province's air, land, water and biodiversity. AEP works in areas including conservation, climate change, wildfire, endangered species, pollution, recreation, wildlife and natural resources. Source: aep.alberta.ca/

AER – the Alberta Energy Regulator; ensures the safe, efficient, orderly, and environmentally responsible development of hydrocarbon resources over their entire life cycle. This includes allocating and conserving water resources, managing public lands, and protecting the environment while providing economic benefits for all Albertans.

Energy regulation in Alberta spans more than 75 years and has evolved over time. This evolution continued in 2013 when the AER became a new organization and began taking on regulatory functions related to energy development that were previously held by Alberta Environment and Sustainable Resource Development (ESRD). This transition is now complete, and the AER is now the single regulator of energy development in Alberta—from application and exploration, to construction and development, to abandonment, reclamation, and remediation. Source: https://www.aer.ca/about-aer/who-we-are

The (Alberta) Regulator – this generic term may reference any or all of the following, AER, AEP or the ERCB

CEMS – Continuous Emission Monitoring System; A CEMS monitors the effluent stream from a duct prior to being exhausted to the atmosphere. The CEMS can measure multiple gaseous concentrations as well as flow, pressure and temperature of the effluent gases. Required measurements are typically dictated by regulatory agencies and may vary from facility to facility.

CEMS Code – the 1998 Alberta CEMS Code. It is a regulation prescribing how to install, monitor, test, report and ensure the quality of emissions data continuously collected from large industrial sources.

DAS - Data Acquisition System; this is a device used by a CEMS to collect signals from transmitters, validate CEMS readings, calculate and provide outputs to a plant PLC / DCS.

EPEA – The Environmental Protection and Enhancement Act

ERCB – the Energy Resources Conservation Board, which has now been amalgamated into the AER

GHG – Greenhouse Gas. These are gases that absorb and re-emit thermal energy.

PLC / DCS – Programmable Logic Controller / Distributed Control System; these terms are generically used to describe a facility's central control system.

SCU – Sample Conditioning Unit; the SCU is a component of a CEMS where filtration and conditioning of a CEMS sample happens. It generally consists of a filter assembly, and heaters in a temperature controlled enclosure. It may also include a dilution

SRU – Sulphur Recovery Unit; this is a system of a processing plant where sulphur is removed from the hydrocarbon stream. Sulphur that cannot be recovered as elemental sulphur is commonly incinerated and vented into the atmosphere.

TRS – Total Reduced Sulphur; with respect to SRUs TRS generally refers to COS, CS_2 and H_2S. The incinerator at the tail end of an SRU is intended to oxidize these components into SO_2.