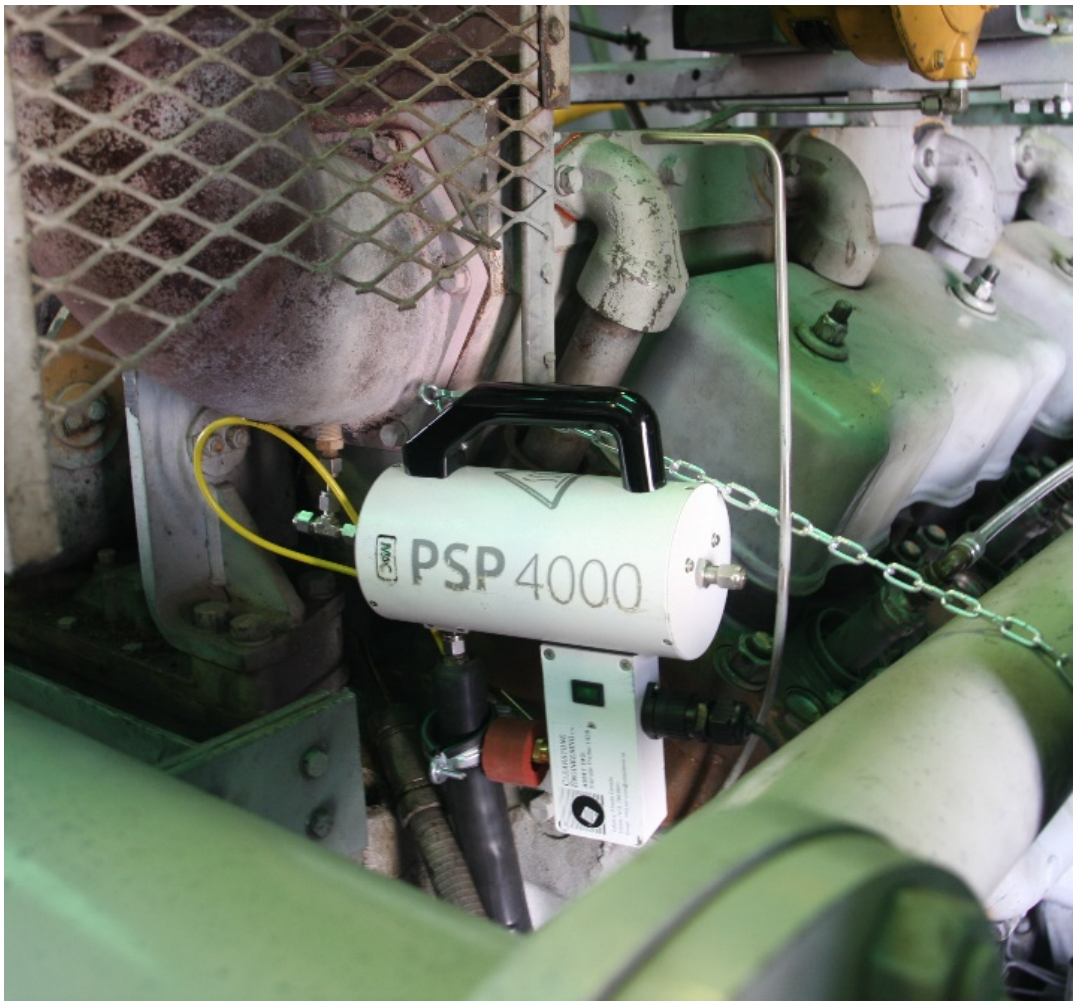
TECHNICAL REPORT



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Development of N_2O Emission Factors for Upstream Oil and Gas Fired Equipment

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EXECUTIVE SUMMARY

Limited data is currently available on N_2O emissions from natural gas-fired equipment in the upstream oil and gas (UOG) industry and the N_2O emission factors presently in use have high uncertainties. The primary objective of this study was to determine N_2O emission factors for selected types of natural gas-fired equipment commonly used in the UOG industry, namely, process heaters, reciprocating engines, and stationary gas turbines. In addition, emission factors were determined for CH_4, CO, CO_2, and NO_x.

Measurement campaigns were conducted in May 2014, December 2014, and April 2015 at five sweet gas processing plants in southern Alberta. A total of twenty-one sources were surveyed including ten process heaters, eight reciprocating engines, and three stationary gas turbines.

A mobile combustion laboratory featuring an array of continuous analysers and temperature sensors was used to monitor the fuel and flue gas compositions and exhaust gas temperature for each source. Three cavity ringdown spectrometers were used to measure N_2O, CO, CO_2, CH_4, O_2, and H_2O concentrations in the flue gas and a chemiluminescence analyser was used to measure NO and NO_2 concentrations. The fuel gas was analyzed for CO_2 and C_1 to C_{5+} compounds using an optical gas chromatograph. A heated filter, heated sample line, and chiller were used to condition the sample gas in accordance with US Environmental Protection Agency (EPA) Recommended Operating Procedure (ROP) No. 56. The setup described above is the final version; modifications were made after the first two campaigns to enhance the system capabilities. Measurements at each source were conducted for an average of 25 minutes.

Flue gas concentrations of N_2O were <1 ppm for all but one source (i.e., a 4-stroke lean-burn reciprocating engine). N_2O flue gas concentrations are expected to be <5 ppm from all combustion sources except for fluidized beds due to the fast destruction reactions of N_2O during combustion at high temperatures (Hayhurst and Lawrence 1992).

N_2O emission factors determined from the measurements were less than 1.5 ng/J for all sources expect for one 4-stroke lean-burn reciprocating engine. N_2O emission factors for gas turbines agree with those published by the US EPA, while measured N_2O emission factors for process heaters and reciprocating engines are about five times less than reference values published by the US EPA and Environment Canada (EC), but within the assessed uncertainty bounds of those values. The reference US EPA and EC values are based on studies of limited sources conducted during the 1990s. A sampling bias is known to be present in N_2O measurements conducted in this era using grab samples (Ryan and Karns 1993; Hayhurst and Lawrence 1992). This may explain the discrepancy between the reference emission factors and those determined in the present study.

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LIST OF ACRONYMS

CAC	Criteria air contaminant
CDIAC	Carbon Dioxide Information and Analysis Center
EC	Environment Canada
EPA	Environmental Protection Agency
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
THC	Total hydrocarbon
UOG	Upstream oil and gas
WCI	Western Climate Initiative

1 INTRODUCTION

There is very little measurement data available on N_2O emissions from combustion sources, and the reliability of the emission factors currently used by the upstream oil and gas (UOG) industry to estimate these greenhouse gas (GHG) emissions is unclear.

The primary objective of this study was to determine N_2O emission factors for natural gas-fired combustion equipment commonly used in the UOG, namely: process heaters, reciprocating engines, and stationary gas turbine engines. In addition, emission factors were also determined for CO_2, CH_4, NO_x and CO.

Section 2 presents details of the surveyed sources. Section 3 discusses the mobile combustion laboratory used to conduct the testing and the test procedures that were followed.

The developed emission factors, along with the specifications of the equipment tested, are presented in Section 4. The emission factors are expressed on an energy-input basis as nanograms (ng) of pollutant emitted per joule (J) of fuel consumed (based on the higher heating value of the fuel).

The conclusions and recommendations of this study are presented in Section 5, while the raw data, detailed results and methodology are provided in the appendices. Appendix A presents the exhaust gas concentrations and fuel compositions measured at each source. Appendix B delineates the methodology used to determine the emission factors from the measurement data. The required calculations were performed using Clearstone's web-based CSimOnline engineering analysis software application. Appendix C provides the combustion analysis reports created by CSimOnline.

2 SCOPE OF WORK

Developing the emission factors requires analyzing the fuel or waste gas input for each combustion source and the flue gas emitted by the source. Three measurements campaigns were conducted, the first in May 2014, the second in December 2014, and the third in April 2015. A total of five sweet gas processing plants were surveyed in southern Alberta using a mobile combustion laboratory designed to provide continuous real-time analysis of the fuel and flue gas compositions. In most cases, the stack temperatures were also continuously monitored. Twenty one sources were tested, including ten process heaters, eight reciprocating engines, and three stationary gas turbines. The sources surveyed are listed in Table 1.

Table 1: List of surveyed fired equipment included in Measurement Campaign 1 (May 2014), 2 (December 2014) and 3 (April 2015).				
Type of Combustion Source		**Unit ID**	**Facility ID**	**Measurement Campaign**
Primary Category	**Sub-Category**			
Process Heater	> 29 MW	PTAC.1.19	PTAC.1	2
	< 29 MW, Low NOx Burner	PTAC.1.4	PTAC.1	2
	≤ 29 MW	PTAC.1.1	PTAC.1	2
		PTAC.1.3	PTAC.1	2
		PTAC.1.5	PTAC.1	2
		PTAC.1.6	PTAC.1	2
		PTAC.1.18	PTAC.1	2
		PTAC.2.9	PTAC.2	3
		PTAC.2.10	PTAC.2	3
		PTAC.3.11	PTAC.3	3
Reciprocating Engine	2-stroke lean burn	PTAC.2.12	PTAC.2	3
	4-stroke lean burn	PTAC.3.13	PTAC.3	3
		PTAC.3.15	PTAC.3	3
		PTAC.4.16	PTAC.4	3
		PTAC.4.18	PTAC.4	3
		PTAC.5.20	PTAC.5	1
	4-stroke rich burn	PTAC.4.17	PTAC.4	3
		PTAC.3.14	PTAC.3	3
Turbine Engine	All	PTAC.1.2	PTAC.1	3
		PTAC.1.7	PTAC.1	3
		PTAC.1.8	PTAC.1	3

3 METHODOLOGY

The equipment setup and instrumentation used to conduct the measurements are described in Section 3.1, while Section 3.2 outlines the procedures followed during testing.

3.1 MOBILE COMBUSTION LABORATORY SETUP

The setup of the mobile combustion laboratory used to conduct the source testing is shown in Figure 1. At each source continuous measurement of the exhaust gas composition, fuel gas composition, and exhaust gas temperature was conducted.

A heated filter and heated sample line (set to 120 °C) were used to ensure that water did not condense in the lines before reaching the chiller. The chiller removes moisture from the exhaust gas, decreasing the gas dew point to 4 °C. The exhaust gas is then pumped to the analyzer bank. Three cavity ring-down spectrometers were used to measure the N_2O, CO, CO_2, O_2, CH_4, and H_2O content of the exhaust gas. NO and NO_2 concentrations in the exhaust gas were measured using a chemiluminescence analyzer. The fuel gas was analyzed for CO_2 and C_1 to C_{5+} compounds using an optical gas chromatograph. The chiller was sized to have a pump with a flow rate greater than the combined flow rate drawn by the analyzers. To avoid problems due to the presence of pumps in both the chiller and the analyzers, a bypass with a check valve was installed in parallel with the analyzers. A rotameter was installed in the bypass line to allow visual confirmation that the pump flow rate exceeded the draw of all of the analyzers.

The setup shown in Figure 1 was upgraded between each set of measurement campaigns to enhance system performance and address some challenges that were encountered during initial attempts to measure N_2O emissions from engines. During the first two measurement campaigns, the heated filter, heated sample line, and chiller were not present. No condensation was observed in the sample lines during the first campaign but some condensation did occur during the second campaign and was trapped using a small inline Teflon impinger. Additionally, during the first measurement campaign, O_2, NO, and NO_2 measurements were conducted using a TESTO 350 XL combustion analyzer. During the second campaign, three cavity ring-down spectrometers were used to measure O_2, NO, and NO_2. The spectrometers were sufficient for the second campaign due to the low NO and NO_2 concentrations of the process heaters that were tested. In the third measurement campaign, the NO and NO_2 spectrometers were replaced with a chemiluminescence analyzer capable of measuring high concentrations of NO and NO_2 (i.e., as observed in engine exhaust). All but one engine were tested during Measurement Campaign 3.

All analyzers were calibrated using appropriate span gases. The linearity of the analyzers in the range of measured values was checked by diluting the span gases with a high purity nitrogen mixture. The spectrometer used to measure N_2O cannot measure N_2O in the presence of high

concentrations of CO. During the first two measurement campaigns, the analyzer was not able to measure N_2O if the CO concentrations were above 10 ppm due to interference in the absorption curve; however, this was only an issue for some engines. Only data for one engine from the first campaign was useable. No engines were surveyed during Measurement Campaign 2 because of this limitation. Prior to Measurement Campaign 2, the N_2O analyzer was sent to the manufacturer for an adjustment to the configuration, allowing measurement of N_2O in the presence of CO up to 1000 ppm.

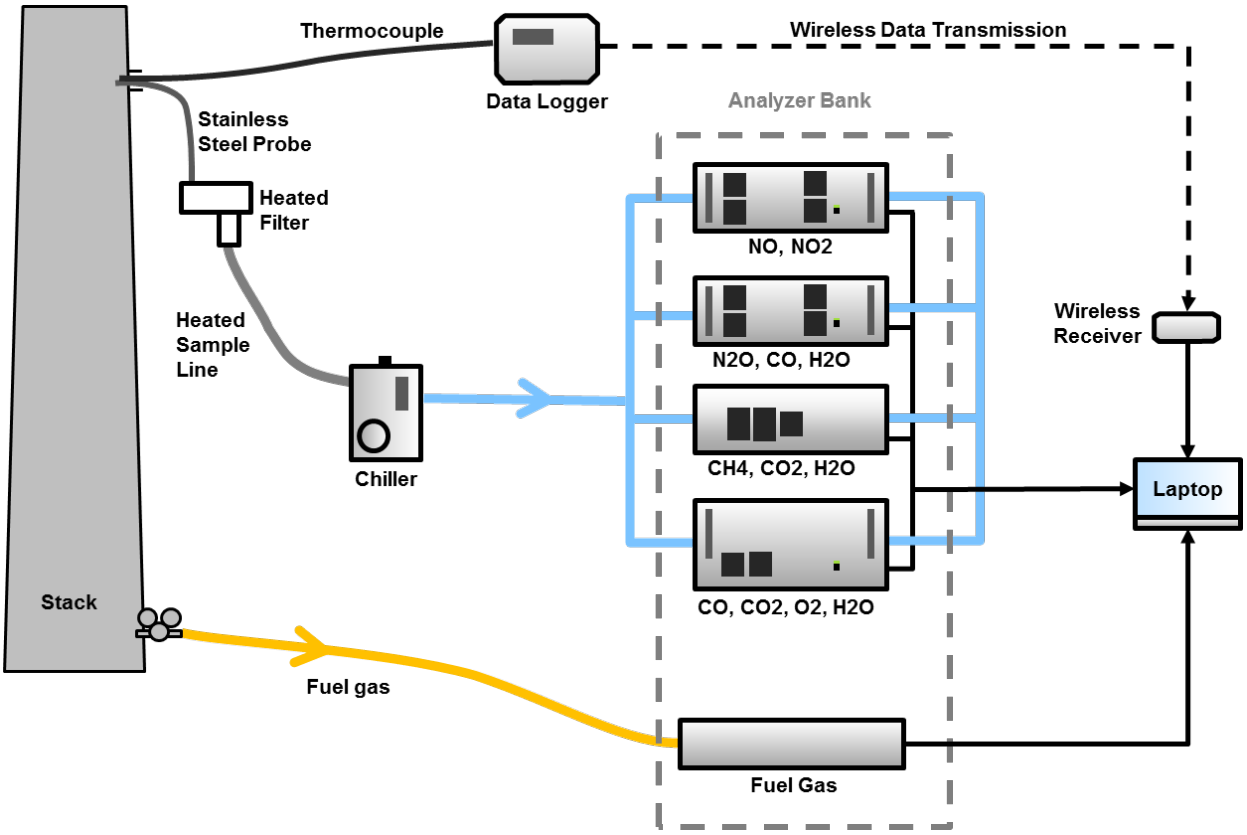

Figure 1: Mobile combustion laboratory setup used to analyze fuel and exhaust gas compositions.

3.2 TEST PROCEDURES

Prior to the start of each measurement the equipment was allowed to reach stable conditions. In particular, the fuel gas analyzer required approximately 30 to 45 minutes at the start of the day to reach the required operating temperature of the monitoring cell; the heated sample lines required approximately 20 minutes to heat up; and the chiller required approximately 20 minutes to reach the set dew point temperature. The rotameter was monitored to ensure that the flow rate supplied by the pump inside the chiller was greater than the flow rate drawn by the analyzers. During the first two measurement campaigns, the sample line was monitored for excessive water condensation. If an excessive amount of water collected in the sample line it was replaced and a

comparison of the old and new readings was done to ensure that the water did not affect the measured concentrations. Measurements were conducted for 10 to 45 minutes, depending on the variability of the source characteristics, with an average duration of 25 minutes. Between test points, ambient air was sampled as a convenient check that the analyzers were performing as expected. Measurements of N_2O concentrations in the ambient air are shown in Table 9 in Appendix A. Ambient N_2O levels are typically very stable and provided a good reference to ensure that the N_2O analyzer was functioning properly.

4 RESULTS

The developed emission factors for N_2O, CH_4, CO, CO_2, and NO_x are presented in Table 2, Table 3 and Table 4 for process heaters, reciprocating engines, and stationary gas turbines, respectively. Emission factors were determined using the methodology outlined in Section A.2. All emission factors are stated on an energy-input basis in ng/J, using the higher heating value of the fuel. These factors are based on measured concentrations in the exhaust gas, except for CO_2 emission factors which are calculated knowing the fuel composition and assuming complete combustion of all carbon in the fuel gas. Average emission factors for each source category along with their respective 95% confidence intervals are presented in Table 5. The manufacturer, model, and maximum rated power output of each source are presented in Table 6. The measured exhaust gas concentrations, fuel compositions, and time-series concentration trends of N_2O for each source are presented in Appendix A.

A gross emission factor relates the total emissions of a given substance of interest to the amount of fuel consumed. A net emission factor relates the total emissions of a given substance of interest, minus any input contributions associated with the combustion air, to the amount of fuel consumed. Thus, a net emission factor of zero means that the combustion device is not generating any emissions of the specified substance, and a negative net emission factor means the combustion process is actually removing some of the specified substance of interest from the combustion air.

The US Environmental Protection Agency (EPA) values are referenced from the AP-42 compendium of emission factors and are shown for comparison purposes (US EPA 1998a; US EPA 2000a; US EPA 2000c). The US EPA assumes a fuel composition of 100 percent methane whereas the measured fuel compositions contain C_2^+ fractions. Confidence intervals for US EPA emission factors were calculated using statistical data (number of tests and standard deviation) for the published emission factors (US EPA 1998b; US EPA 2000b; US EPA 2000c) except for N_2O. N_2O confidence intervals are based on default uncertainties published in the IPCC Good Practice Guidelines (IPCC 2006). The N_2O emission factor for reciprocating engines is referenced from an Environment Canada report (Environment Canada [EC] 2014).

4.1 N_2O EMISSION FACTORS

Figure 2 presents a comparison of the average determined gross N_2O emission factors to corresponding reference values from the EPA for heaters and turbines (EPA 1998a; EPA 2000a) and from Environment Canada (EC 2014) for reciprocating engines. The error bars indicate the 95% confidence interval for the presented emission factors.

The average gross N_2O emission factor determined for process heaters is 0.17 ng/J, based on measurements from eight small process heaters and boilers (<5 kW maximum rated power). This value is five times less than the EPA value of 0.9 ng/J. However, this is still within the uncertainty bounds of the EPA value. The EPA emission factor for large wall-fired boilers without controls is based on data from five sources.

The average measured net N_2O emission factor for process heaters is -0.07 ng/J, which reflects the fact some units tested emitted less N_2O that was present in the input combustion air. Ambient concentrations of N_2O measured during the three test campaigns were in the range of 320 to 340 ppb. This is consistent with measurements done by the Carbon Dioxide Information and Analysis Center (CDIAC) in 2014 which show ambient N_2O concentrations of 327 ppb (CDIAC 2014).

For reciprocating engines, the average determined gross N_2O emission factor of 0.86 ng/J is based on measurements from five 4-stroke lean-burn engines and one 2-stroke lean-burn engine. Two 4-stroke rich-burn engines were tested; however, N_2O concentrations were not successfully measured due to performance limitations of the analyzer at the time. It should be noted that five out of six engines tested had N_2O emission factors below 0.6 ng/J, while one from the first measurement campaign had a factor of 3.6 ng/J. The average determined gross emission factor is 5 times less than the reference Environment Canada value of 5.72 ng/J. Information on the basis of the reference Environment Canada N_2O factor and its confidence limits was not available. The average net emission factor determined for reciprocating engines is 0.6 ng/J, which is slightly less than the gross value.

For stationary gas turbine engines the average gross N_2O emission factor of 1.0 ng/J was determined based on measurements from three stationary gas turbines, which is in good agreement with the corresponding US EPA value of 1.3 ng/J. The EPA N_2O emission factor is based on measurements from a single gas turbine with steam injection. The average determined net N_2O emission factor is 0.45 ng/J, which is approximately half of the gross value.

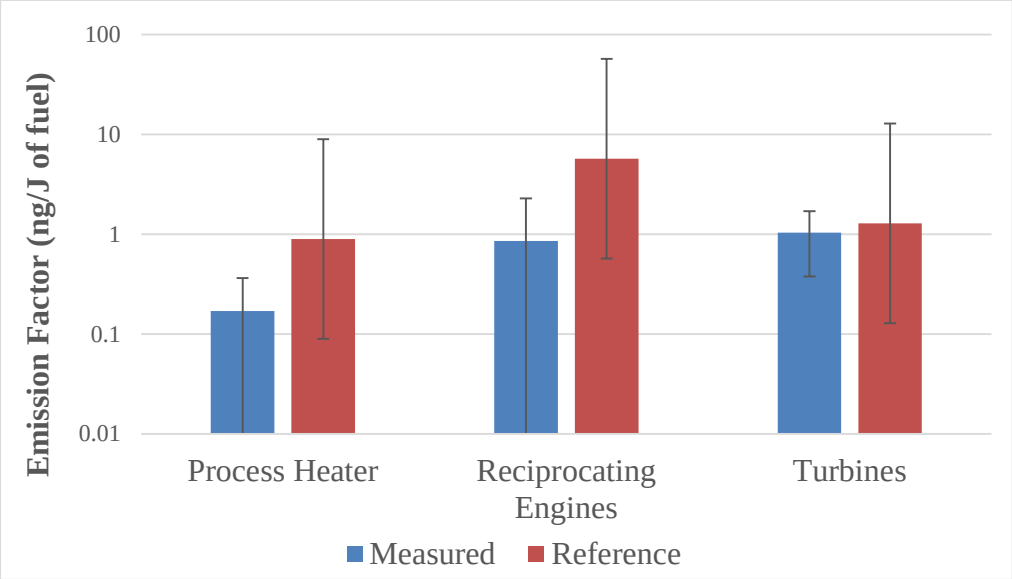

Figure 2: Comparison of the average gross N_2O emission factors determined for natural gas fueled process heaters, reciprocating engines turbines to corresponding reference values.

Overall, the gross N_2O emission factors determined during this study for all sources were less than 1.5 ng/J, and are less than the reference values but within their uncertainty bounds. US EPA and EC emission factors are based on measurements conducted in the early to mid-1990s. Details about the sampling methods used in determining the N_2O emission factors published by the EPA and EC studies could not be found; however, the most common technique at the time was to collect grab samples and analyze them using gas chromatography (Ryan and Karns 1993). This technique was found to be susceptible to a sampling artifact where N_2O is generated in the sampling container in the presence of NO_x, sulphur dioxide (SO_2) and moisture (Ryan and Karns 1993; Hayhurst and Lawrence 1992). It is possible that the reference emission factors published by the US EPA and EC were affected by this bias, causing an overstatement of the values.

N_2O emissions from industrial combustion sources are generally expected to be less than 5 ppm, except for fluidized beds (Hayhurst and Lawrence 1992). This is consistent with measurements obtained during this study, where N_2O emissions were below 1 ppm for all but one source (PATC 5.20). Low N_2O emissions are the result of the destruction of N_2O during high temperature combustion (Hayhurst and Lawrence 1992). This effect can be seen in Figure 3, which shows the concentrations of O_2 and N_2O in the exhaust gas of utility heater PTAC.3.11 during the firing cycling. When the burner is off, the oxygen levels are high and N_2O levels are close to ambient. When the burner is turned on, the oxygen is consumed and the N_2O is destroyed during combustion, causing the concentrations of both to decrease. The negative net N_2O emission factor for process heaters indicates there is a net destruction of N_2O.

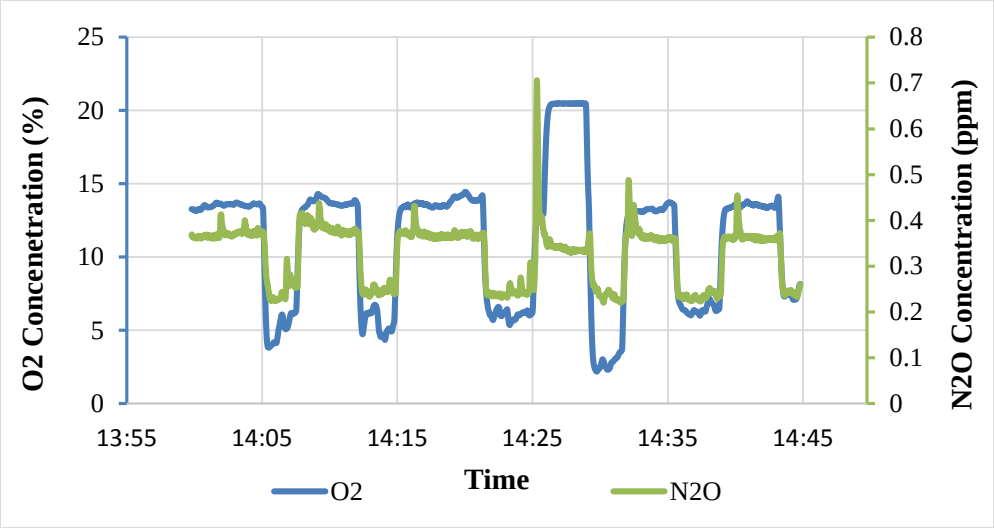

Figure 3: Measured concentrations of O_2 and N_2O in the exhaust gas of utility heater PTAC.3.11.

4.2 SUPPLEMENTARY EMISSION FACTORS

For the one large heater tested (>29 MW), the determined CH_4 and CO emission factors are 2000 and 35 times greater than the US EPA values, respectively, due to the fact the unit was poorly tuned (it was used infrequently in a backup role). The average determined CH_4, CO, CO_2, and NO_x emission factors are comparable to (i.e., within in the confidence limits of) the US EPA values.

The CH_4 emission factor determined for the sole 2-stroke lean-burn engine is eight times greater than the US EPA value, while the NO_x emission factor determined is 50 times less than the US EPA value, indicating the unit is somewhat out of tune. This engine was only used in backup service. The CO emission factors determined for the two 4-stroke rich-burn engines tested are both ten times greater than the US EPA value. The NO_x emission factors determined for these two engines are 24 times less than the US EPA value. All other average measured CH_4, CO, CO_2, and NO_x emission factors for the reciprocating engines are comparable to US EPA values.

For stationary gas turbine engines the determined CH_4, CO_2, CO, and NOx emission factors are all comparable to the corresponding US EPA emission factors.

Table 2: Gross, net and reference GHG and CAC emission factors for process heaters on an energy-input basis.														
Equipment Category	**Unit ID**	**Emission Factors (ng/J of Fuel[1])**												
		N_2O[2]			**CH_4**		**CO_2**		**CO**		**NO_x**		**NO**	**NO_2**
		Gross	**Net**	**EPA**	**Gross**	**EPA**	**Net**	**EPA**	**Gross**	**EPA**	**Gross**	**EPA**	**Gross**	**Gross**
> 29 MW	PTAC.1.19[2]	NA	NA	0.9	2301.3	1	49697	50579	1203.2	35	9.8	118	9.7	0.1
≤ 29 MW, Low NOx Burner	PTAC.1.4	0.07	-0.12	0.26	6.8	1	49697	50579	0.0	35	14.6	21	13.9	0.7
≤ 29 MW	PTAC.1.1	0.04	-0.14	0.9	0.4	1	49697	50579	0.1	35	25.2	42	23.3	1.9
	PTAC.1.3	0.05	-0.16	0.9	0.1	1	49697	50579	0.1	35	25.4	42	24.9	0.5
	PTAC.1.5	0.03	-0.18	0.9	0.3	1	49697	50579	0.6	35	34.4	42	31.6	2.8
	PTAC.1.6	0.03	-0.19	0.9	7.5	1	49697	50579	0.1	35	43.6	42	40.8	2.8
	PTAC.1.18[2]	NA	NA	0.9	22.2	1	49697	50579	90.1	35	10.9	42	5.6	5.3
	PTAC.2.9	0.70	0.02	0.9	2.8	1	50741	50579	12.9	35	30.5	42	28.1	2.4
	PTAC.2.10	0.15	0.15	0.9	0.5	1	50741	50579	3.8	35	13.5	42	10.0	3.5
	PTAC.3.11	0.29	-0.01	0.9	2.1	1	50870	50579	19.8	35	24.0	42	16.9	7.1
	Average	**0.19**	**-0.07**	**0.9**	**4.5**	**1**	**50105**	**50579**	**15.9**	**35**	**25.4**	**42**	**22.7**	**2.7**

NA Not available

1. Referenced based on the gross (or higher) heating value of the fuel.
2. N_2O was not successfully measured from two heaters due to analyzer performance limitations.

Table 3: Gross, net and reference GHG and CAC emission factors for reciprocating engines on an energy-input basis.														
Equipment Category	**Unit ID**	**Emission Factors (ng/J of Fuel[1])**												
		N_2O			**CH_4**		**CO_2**		**CO**		**NO_x**		**NO**	**NO_2**
		Gross	**Net**	**EC[2]**	**Gross**	**EPA**	**Net**	**EPA**	**Gross**	**EPA**	**Gross**	**EPA**	**Gross**	**Gross**
2-Stroke Lean Burn	PTAC.2.12	0.24	-0.10	5.72	5,236.3	624	50741	47291	53.2	152	18.5	834	3.1	15.4
4-Stroke Lean Burn	PTAC.4.16	0.26	0.05	5.72	187.5	537	50871	47291	196.7	239	371.8	364	289.9	81.9
	PTAC.4.18	0.54	0.33	5.72	229.1	537	50871	47291	253.8	239	552.3	364	461.7	90.6
	PTAC.3.13	0.27	0.02	5.72	518.8	537	50870	47291	141.7	239	94.8	364	81.2	13.6
	PTAC.3.15	0.23	0.01	5.72	193.6	537	50870	47291	200.9	239	190.0	364	127.2	62.9
	PTAC.5.20	3.62	3.31	5.72	241.1	537	49628	47291	1.3	239	274.7	364	269.7	4.9
	Average	**0.99**	**0.74**	**5.72**	**274.0**	**537**	**50622**	**47291**	**158.9**	**239**	**296.7**	**364**	**245.9**	**50.8**
4-Stroke Rich Burn	PTAC.3.14[3]	NA	NA	5.72	208.9	99	50870	47291	15613.5	1509	45.7	976	45.5	0.2
	PTAC.4.17[3]	NA	NA	5.72	388.6	99	50871	47291	16498.1	1509	36.3	976	32.9	3.4
	Average	**NA**	**NA**	**5.72**	**298.7**	**99**	**50870**	**47291**	**16055.8**	**1509**	**41.0**	**976**	**39.2**	**1.8**

1. Referenced based on the gross (or higher) heating value of the fuel.
2. There are no EPA AP-42 N_2O emission factors for reciprocating engines. The N_2O emission factor for reciprocating engines is from an Environment Canada repot (EC 2014)
3. N_2O was not successfully measured from the four stroke rich burn engines due to analyzer performance limitations.

Table 4: Gross, net and reference GHG and CAC emission factors for stationary gas turbine engines on an energy-input basis.														
Equipment Category	**Unit ID**	**Emission Factors (ng/J of Fuel[1])**												
		N_2O			**CH_4**		**CO_2**		**CO**		**NO_x**		**NO**	**NO_2**
		Gross	**Net**	**EPA**	**Gross**	**EPA**	**Net**	**EPA**	**Gross**	**EPA**	**Gross**	**EPA**	**Gross**	**Gross**
All	PTAC.1.7	1.09	0.37	1.29	14.8	3.7	50036	47291	63.5	35	64.6	138	39.1	25.6
	PTAC.1.8	0.75	0.23	1.29	2.7	3.7	50119	47291	5.2	35	71.4	138	60.9	10.5
	PTAC.1.2	1.28	0.76	1.29	0.2	3.7	50119	47291	35.5	35	237.0	138	196.4	40.6
	Average	**1.04**	**0.45**	**1.29**	**5.9**	**3.7**	**50091**	**47291**	**34.7**	**35**	**124.3**	**138**	**98.8**	**25.6**

1. Referenced based on the gross (or higher) heating value of the fuel.

Table 5: Average gross, net and reference GHG and CAC emission factors and confidence intervals (CI)[1].																		
Equipment Category	**N_2O**						**CH_4**				**CO**				**NO_x**			
	Gross		**Net**		**EPA**		**Gross**		**EPA**		**Gross**		**EPA**		**Gross**		**EPA**	
	Mean[2]	**CI[3]**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**
> 29 MW	NA	NA	NA	NA	0.9	900	2301.3	NA	1.0	37	1203.2	NA	35.0	36	9.8	NA	78.0	23
≤ 29 MW, Low NOx Burner	0.17	114	-0.07	136	0.3	900	6.8	NA			0.0	NA			14.6	NA	21.0	67
≤ 29 MW					0.9	900	4.5	400			15.9	162			25.9	34	42.0	25
2-Stroke Lean Burn	0.86	165	0.60	232	5.7	NA	5236.3	NA	624.0	13	53.2	NA	152.0	23	18.5	NA	834.0	36
4-Stroke Lean Burn							274.0	63	537.0	12	158.9	75	239.0	22	296.7	74	364.0	125
4 -Stroke Rich Burn	NA	NA	NA	NA			298.7	382	99.0	NA	16055.8	35	1509.0	185	41.0	145	976.0	18
Turbines	1.04	64	0.45	152	1.3	900	5.9	329	3.7	177	34.7	208	35.0	47	124.3	195	138.0	19

NA Not available

1. CO_2 emission factors are based on the fuel composition and not on the measured exhaust gas concentration of CO_2. As a result, they are in good agreement with EPA values and were not included in this table.
2. Mean emission factors expressed on an energy-input basis in ng/J.
3. 95% confidence interval expressed as a percent of the mean.

Table 6: Surveyed equipment specifications							
Type of Combustion Source			Unit ID	Facility ID	Manufacturer	Model	Rated Power (kW)
Primary Category	Sub-Category	Description					
Process Heater	> 29 MW	Heat Medium Oil Heater	PTAC.1.19	PTAC.1	Born Inc.	NA	38650
	≤ 29 MW, Low NOx Burner	Regeneration Gas Heater	PTAC.1.4	PTAC.1	Wheco	NA	4276
	≤ 29 MW	Regeneration Gas Heater	PTAC.1.1	PTAC.1	Maloney Steel	NA	1347
		Regeneration Gas Heater	PTAC.1.3	PTAC.1	Maloney Steel	NA	1347
		Utility Heater	PTAC.1.5	PTAC.1	Napanee	554 100 HW	1010
		Utility Heater	PTAC.1.6	PTAC.1	JR Stephenson	4A-150K-M8	1245
		Reboiler	PTAC.1.18	PTAC.1	Broach	NA	3462
		Free Water Knockout	PTAC.2.10	PTAC.2	Natco	NA	1261
		Utility Heater	PTAC.3.11	PTAC.3	Propak Systems	NA	NA
		Heat Medium Oil Heater	PTAC.2.9	PTAC.2	Parker	NA	1337
Reciprocating Engine	2-Stroke Lean Burn	NA	PTAC.2.12	PTAC.2	Ajax	K06581	186
	4-Stroke Lean Burn	NA	PTAC.4.16	PTAC.4	Caterpillar	3516	858
		NA	PTAC.4.18	PTAC.4	Caterpillar	3512	NA
		NA	PTAC.3.13	PTAC.3	White	8GT-825	783
		NA	PTAC.3.15	PTAC.3	Caterpillar	3516	1044
		NA	PTAC.5.20	PTAC.5	Waukesha/ Worthington	L5790GS1/0F6H4	984
	4-Stroke Rich Burn	NA	PTAC.3.14	PTAC.3	Waukesha	L7042GSIU	895
		NA	PTAC.4.17	PTAC.4	Caterpillar	D398	298
Turbine Engine	All	NA	PTAC.1.2	PTAC.1	Rolls Royce	RB211	28000
		NA	PTAC.1.7	PTAC.1	General Electric	M5261	16260
		NA	PTAC.1.8	PTAC.1	General Electric	M5372B	26850

NA Not available

5 CONCLUSIONS AND RECOMMENDATIONS

A measurement program was undertaken to quantify N_2O emission factors from natural gas-fueled equipment in the upstream oil and gas sector. Twenty one total sources were tested at five facilities, including ten process heaters, eight reciprocating engines, and three stationary gas turbines. While the primary compound targeted by this study was N_2O, emission factors were also determined for CH_4, CO, CO_2, and NO_x.

It was confirmed that natural gas-fueled combustion equipment have relatively low N_2O emission factors. N_2O concentrations in the exhaust gas were expected to be below 5 ppm (Hayhurst and Lawrence 1992), and the measured concentrations were below 1 ppm for all but one source (a 4-stroke lean-burn reciprocating engine). The determined N_2O emission factors are presented on both a gross and net basis. The gross values assume that all emitted N_2O is generated by the combustion process, and the net values correct for the background concentrations of N_2O present in the input combustion air. Gross N_2O emission factors determined for process heaters, reciprocating engines, and stationary gas turbines were all below 1.5 ng/J and less than reference values from the US EPA and EC. For process heaters, the net N_2O emission factor was negative, indicating a net destruction of N_2O. The large uncertainties associated with the reference emission factors precludes any statistically meaningful comparison between the determined emission factors and the reference values. However, the fact the reference N_2O emission factors are appreciably greater than the determined values may reflect a positive bias in the reference values due to sampling issues known to occur before the mid-1990s, which is when the studies upon which the reference values are based were performed (Ryan and Karns 1993; Hayhurst and Lawrence 1992).

Except for several outliers caused by the units being out of tune, the determined CH_4, CO, CO_2, and NO_x emission factors were comparable to US EPA reference values.

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