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Catalytic Heaters at Oil and Gas Sites May be a Significant yet Overlooked Seasonal Source of Methane Emissions

Simon A. Festa-Bianchet, Milad Mohammadikharkeshi, David R. Tyner, and Matthew R. Johnson*

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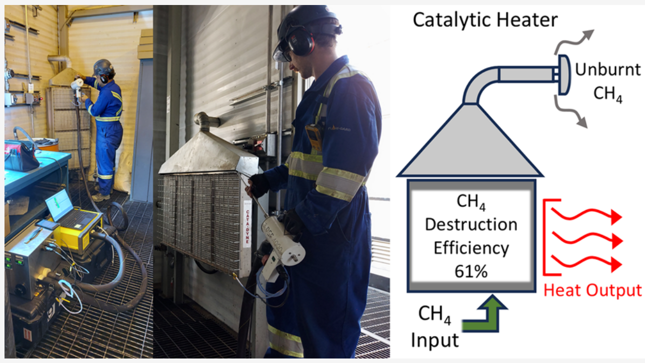
ABSTRACT: Successful reduction of oil and gas sector methane emissions to meet near-zero intensity targets requires the identification and mitigation of all possible sources. One potentially important source is catalytic heaters, which have largely escaped attention in regulatory and mitigation efforts despite being ubiquitous at upstream production sites in cold climate regions. This study reports direct in situ measurements of the exhaust streams of 38 natural gas-fired catalytic heaters at upstream production sites in British Columbia, Canada. All heaters in the sample showed consistently poor methane conversion with mean destruction efficiencies of 61 ± 5% while releasing 235 [+31/−28] g of methane per cubic meter of fuel. Although individual units are generally small methane sources (mean of 0.28 ± 0.04 kg/h), their prevalence means they could represent 6% of the total provincial upstream methane inventory and as an aggregate methane source could be 5× more significant than abandoned wells. Notably, these heaters are seasonal sources whose emissions would be missed in measurement campaigns occurring solely in summer months. However, additional measurements from a small number of heat medium burners demonstrate that, where feasible, methane emissions can be reduced by approximately 425× by replacing catalytic heaters with centralized heat systems.



KEYWORDS: *methane slip, upstream oil and gas, incomplete combustion, destruction efficiency, catalytic heater, emissions, field measurements*

INTRODUCTION

The recently launched Global Methane Pledge, which now counts over 150 country participants, commits nations to seek improvements to their national inventories in parallel with developing action plans to contribute to an overall goal of reducing global methane emissions by at least 30% by 2030.[1] It is critical that these national action plans consider all sources of importance, or risk inefficient and ineffective mitigation actions. Programs such as the United Nations backed Oil and Gas Methane Partnership (OGMP 2.0)[2] are specifically designed to drive identification and reporting of all oil and gas methane sources as a central part of accelerating reductions, where goals of "near-zero"[3,4] methane emissions ultimately require mitigation of all observable sources.

Oil and gas sector methane sources can generally be categorized as vented, fugitive, or combustion sources. Vented sources include natural gas driven pneumatic equipment,[5−7] uncontrolled storage tanks designed to vent directly to atmosphere,[8−12] and process events such as liquid unloadings[13,14] or pipeline blowdowns,[15] whereas fugitive sources are generally defined as unintentional or unknown leaks or accidental releases and can include failed seals, leaking valves or fittings, open or leaking thief hatches on controlled tanks, etc.[16−18] Combustion sources arise through incomplete combustion of hydrocarbon gas in devices such as compressor engines[19−21] and flares.[22−27] Although many studies have focused on identifying, characterizing, or quantifying fugitive and vented methane sources, comparatively fewer have considered methane slip from combustion sources despite the fact that these sources can represent the largest portion of total upstream methane emissions in some regions.[28]

One potentially important combustion source at upstream oil and gas sites that to the authors' knowledge has not previously been the subject of in situ measurement studies is natural gas fired catalytic heaters. Such heaters are commonly used in cold climate production regions for space or spot heating by reacting fuel gas on a catalyst bed to safely release the enthalpy of combustion without a flame. These heaters are ubiquitous at upstream production sites in Canada, where

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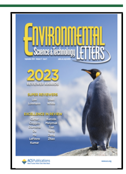

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multiple units are often present at a single site. These heaters are critical in maintaining equipment operability in cold temperatures but as with any combustion device, they have the potential to emit unburned hydrocarbons due to incomplete combustion. Although manufacturer literature suggests that combustion products should be limited to carbon dioxide and water vapor,[29] the limited literature on the efficiency of commercial catalytic heaters suggests that unburnt hydrocarbons can be an issue with this technology.[30] This is ultimately why the U.S. EPA recommended against domestic use of catalytic heaters in the 1970s.[31] A study investigating the feasibility of catalytic heaters for destroying hydrocarbon emissions from glycol dehydrators used in upstream oil and gas production reported methane conversion percentages as low as 45% due to insufficient oxygen transport to the surface of the catalyst pad.[32] Further, there have been anecdotal reports from oil and gas workers that catalytic heaters have triggered personal gas monitors as elaborated below.

Critically, potential methane emissions from catalytic heaters are also likely to be missed in current methane reporting and measurement studies. Since the emitted methane is comingled with hot exhaust gases, commonly used detection tools such as optical gas imaging (OGI) cameras will not be able to differentiate between a methane emitting heater and one where complete combustion is occurring. Moreover, due to their seasonal use, potential emissions will be missed in top-down measurement campaigns occurring solely in warmer months. Finally, it may also be the case that emission rates from individual heaters are too small to be detectable by remote measurement technologies despite their potential importance in aggregate.

The objectives of this study were to investigate emission characteristics of catalytic heaters used in the upstream oil and gas sector through direct in situ measurements of heaters installed at active production sites. Derived carbon conversion efficiency, methane destruction efficiency, and methane emission rate data, combined with equipment count and sizing data collected via parallel work, are used to estimate the contribution of catalytic heaters to a previously published total methane inventory.[28] These results are particularly relevant in the context of new Canadian oil and gas sector methane regulations under development[33] as well as international monitoring, measurement, reporting, and verification (MMRV) programs.

■ METHODS AND MATERIALS

In situ measurements of the exhaust streams of 38 different catalytic heaters were completed at 7 distinct upstream oil and gas facilities (5 unique operators) in northeastern British Columbia, Canada, from late July to mid-August 2023. Exhaust composition measurements were made using a portable Fourier transform infrared (FTIR) gas analyzer (Gasmet, DX4000) equipped with a heated sampling probe, sampling lines, and measurement cell to facilitate combustion measurements and prevent condensation losses of the sample. Exhaust gases were sampled from inside the vent hood of each catalytic heater, at a point adjacent to or within the short duct penetrating the wall of the building (See Figure 1). Further measurement details are provided in the Supporting Information (SI).

The sampled heaters were all manufactured by Thermon under the Cata-Dyne brand, and included models MK24 × 48 (n = 25), W24 × 48 (n = 9), and W24 × 72 (n = 4). Survey data (detailed below) showed that this brand holds a 93% market share in British Columbia; in fact, Cata-Dyne is the generalized name in industry when referring to catalytic heaters. These models have a shared design with differences limited to the hazardous location certification of the associated electrical components and the size of the catalyst panels. The heaters all featured a crude thermostat control valve that could switch the fuel flow rate to approximately 30% if a desired set point temperature was reached (but still flowing to sustain the combustion reaction and thus the catalyst temperature) and back to 100% if the temperature fell below the set point.[34] However, operators at the measurement sites explained that to minimize downtime and ensure reliable heat output, catalytic heaters are always left on their highest set point (44 °C) and thus can be expected to run continuously when used in cold winter months. This is consistent with methodology documents from the Canadian Association of Petroleum Producers for estimating fuel consumption from catalytic heaters.[35] While all results included in the main body of this paper are from heaters operating at full fuel flow, a subset of heaters was also sampled when their thermostat control was lowered such that the fuel flow was reduced to the standby level of ∼30%. Fuel conversion in standby mode could be higher or lower than at full fuel flow depending on the unit (see SI, section S4), which likely reflects a trade-off between improved oxygen availability and reduced catalyst temperature at lower flow rates.

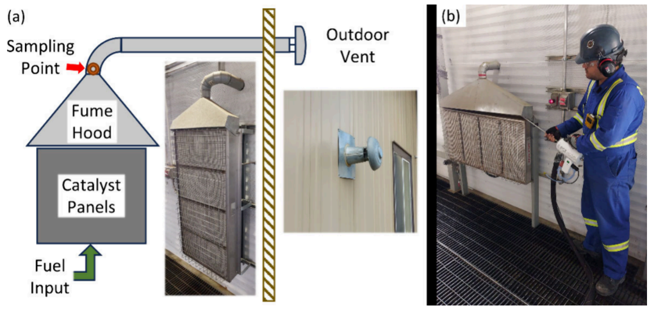

Figure 1. (a) Schematic of a catalytic heater showing the location of the sampling point within the fume hood, accompanied by pictures of a heater and the outdoor vent typically used. (b) Picture showing sampling of exhaust gases from a heater.

The mean volume fractions of the major components identified in the exhaust are included in the SI, Table S2 (the full list of retrieved species' volume fractions for each unit is available in the linked data repository). Carbon conversion efficiency (CCE, the percentage of carbon in the hydrocarbon fuel that is fully converted to CO_2) and methane destruction efficiency (MDE, the net percentage of methane in the fuel that is destroyed) were calculated using the methodology of Corbin and Johnson[36] which accounts for any CO_2 content in the fuel gas and corrects for the presence of hydrocarbons and CO_2 in the ambient air (see SI, section S2). Fuel gas compositions (SI, Table S3) were obtained either from gas chromatography (GC) analysis by a third-party laboratory (Bureau Veritas, Edmonton, AB) of samples taken by the ground team (23 heaters), from recent GC analyses provided by the producers (13 heaters), or by taking an average composition of these samples (2 heaters). Methane emission rates for each heater were calculated using these fuel compositions, the measured MDE, and the rated fuel flow rate of each model.

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In parallel to the emission measurements, as part of a separate project, subcontracted technicians from Montrose Environmental Ltd. counted and documented makes, models, and fuel type of catalytic heaters at 407 upstream oil and gas sites in British Columbia, comprising 198 facilities and 1986 individual wells as identified in industry reporting[37] across BC from July to November 2023. The technicians documented 2954 natural gas catalytic heaters during this survey as summarized in the SI. With these site-specific counts an estimated inventory of installed heaters was completed for the entire province based on the number of active facilities.

■ RESULTS AND DISCUSSION

Carbon Conversion Efficiency and Methane Destruction Efficiency of Catalytic Heaters. Example results for two of the 38 measured heaters are shown in Figure 2, which plots measured carbon dioxide, methane, and oxygen fractions in the exhaust as a function of time. Similar plots for all heaters are included in the SI. In most cases, the exhaust concentrations were steady as in Figure 2(a), as would be expected for a heater operating at steady state with an uninterrupted exhaust flow. However, in a few cases the steady data were interrupted by intermittent spikes in oxygen concentration aligned with drops in CO_2 and methane concentration as shown in Figure 2(b). This behavior is attributed to wind buffeting on the exit of the vent duct resulting in a pressure differential that temporarily reversed the flow in the exhaust duct. In a few extreme cases, the reversed flow was sustained causing combustion products to spill out around the exhaust hood and enter the room. This behavior was confirmed using an infrared optical gas imaging (OGI) camera (FLIR, GFx320) with an example video file included as part of the SI. Useful samples could not be obtained in these cases (which are thus not included in the analyzed sample of 38 heaters) since the combustion products quickly diluted into the surrounding air instead of being collected in the fume hood. Notably, this field observation would explain anecdotes of catalytic heaters being responsible for triggering gas alarms or personal gas monitors.

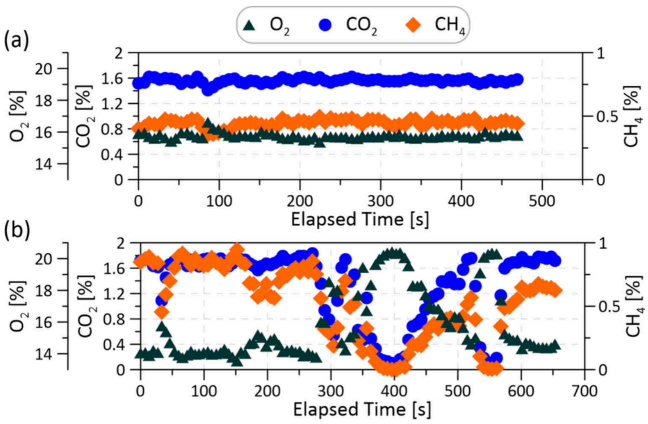

Figure 2. Example exhaust gas species fractions for two catalytic heaters, showing the measured time history of oxygen, carbon dioxide, and methane. (a) Typical result for a heater with stable exhaust flow. (b) Sampled unit with the least stable exhaust flow, including periods where oxygen concentrations spiked as exterior air flowed into the exhaust duct.

The calculated mean CCE and methane emission rate of all 38 sampled heaters is shown in Figure 3. Error bars indicate a 95% confidence interval on these means based on the observed sample variance, as illustrated in Figure 2, and the FTIR instrument's uncertainty (see SI, section S7). The mean CCE of all 38 heaters was 68 ± 4%. A one-way ANOVA analysis indicated that there was no statistically significant difference between the mean CCE of the three models of heaters for which measurements were completed ($F(2,35) = [1.86]$, $p = 0.17$). Over the complete sample set, the mean methane emission rate of the heaters was 0.28 [+0.04/−0.03] kg/h, with a mean emission factor of 235 [+31/−28] grams of methane per cubic meter of fuel input (natural gas).

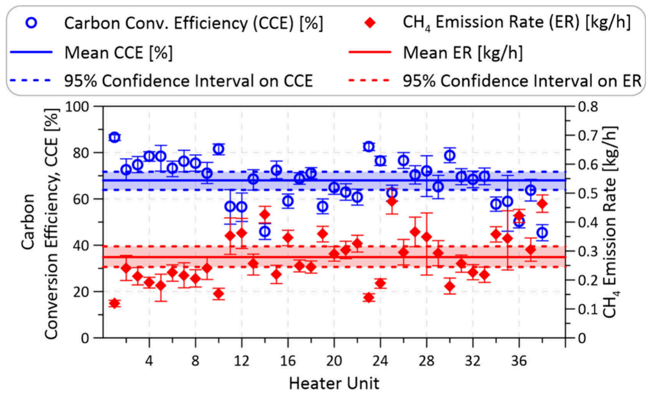

Figure 3. Carbon conversion efficiency (blue dots) and methane emission rate (red diamonds) of all catalytic heaters when operating at 100% fuel flow rate. Error bars represent 95% confidence bounds on the individual mean values. Dashed lines and shaded regions denote the 95% confidence interval on the derived mean CCE and emission rate.

Interestingly, the overall mean MDE of the heaters (61 ± 5%; see SI, section S3) was lower than the CCE. This difference is likely due to a higher light-off temperature of methane (i.e., the minimum temperature required to maintain the combustion reaction on a catalyst) compared to most other hydrocarbons found in natural gas.[38] Similar preferential combustion of higher hydrocarbons has been observed in detailed experiments on gas flares.[22] The noted difficulty in destroying methane through catalytic combustion warrants caution in using this technology for mitigating natural gas vented emissions.

Implications for Methane Inventories. Equipment survey data for 407 sites in BC were used to derive the mean natural gas use on a per facility type basis (as defined in the Petrinex reporting database) and subsequently total methane emissions for all installed catalytic heaters in the province. Within these 407 sites, 3593 heaters were inventoried, 2954 of which were natural gas fired and 639 propane fired. Of the natural gas heaters in the sample, 155 units could not be fully identified by model number, so were instead assigned the mean rated fuel flow rate from the remaining 2799 units (0.56 m^3/h). From these data, mean heater counts and natural gas consumption values were derived for each facility type or offsite well in the province as detailed in Table S4 of the SI. Considering only the natural gas fired units and scaling to the populations of each facility and well type in the province, we estimate that installed natural gas fired catalytic heaters in BC consume 7835 m^3/h when operating.

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Using the previously calculated mean emission factor of 235 g_{CH4}/m^3_{fuel}, this installed capacity translates to a potential monthly methane emission rate of 1.34 kt/mo. Based on temperature records from 2014 to 2023 for the town of Dawson Creek, BC,[39] the major oil and gas producing region of BC will be subject to daily *average* temperatures below 0 °C for 156 days of the year (generally Nov-Mar) and overnight low temperatures below freezing for 202 days of the year (generally Oct-April). Assuming the inventoried natural gas catalytic heaters are operated continuously for 156−202 days of the year and not at all at other times, then on an annual basis they would be expected to emit 6.9−8.9 kt/y of methane. This represents 4.8−6.2% of the total oil and gas methane inventory (144.5 kt) in BC in 2021 as derived by Johnson et al.[28] Most importantly, this represents a seasonal source that would not be captured in measurement studies performed exclusively in summer months.

Alternative Heating Solutions. At larger facilities, individual catalytic heaters are sometimes replaced by central heating using a heat medium burner also operating on natural gas. These central systems heat glycol or oil and distribute the heated medium using a network of pipes and pumps. Three heat medium burners were sampled during the catalytic heater measurement campaign, using the same methodology to determine CCE. As detailed in SI section S5, the mean CCE of these burners was 99.6%, which is significantly higher than the CCE achieved by the catalytic heaters. Considering fuel flow rates for rated burner output, the heaters had a mean methane emission rate of 0.03 kg/h or 0.55 g_{CH4}/m^3_{fuel}. Assuming to first order that heat loss from the lines used to transport heated fluid from the burner to the radiator(s) is balanced by inefficiencies of the catalytic heaters due to uncombusted fuel, then this type of central heating system would represent a ∼ 425 times reduction in methane emissions (i.e., 0.55 g_{CH4}/m^3_{fue} for central heating versus 235 g_{CH4}/m^3_{fuel} for an average catalytic heater). This simplified comparison also assumes that central heating systems do not include other methane emitting equipment such as pneumatic pumps. Further, at sites with a reliable electricity supply, hazardous location electric space heaters are commercially available from multiple vendors which could be a cost-effective, zero emission solution. Where feasible, replacement of catalytic heaters would have an important additional advantage of eliminating possible safety concerns from the risk of hydrocarbon-rich heater exhaust backflowing into buildings. In the short term, this safety concern could be more rapidly addressed by investigating improvements to the exhaust ductwork to promote outflow.

Regulatory Implications. Both for regulations under development and emerging MMRV efforts such as OGMP2.0 focused on comprehensively identifying and mitigating methane emission sources and reconciling bottom-up and top-down estimates, the present results reveal a new or previously hidden/neglected source that in cold climates can be an important contributor to overall emissions. For greater context, the present results in BC suggest that methane emissions from catalytic heaters are likely 3.8−5.0 times greater than the total expected methane emissions from all abandoned wells in the province (1.8 kt)[40] which have recently been the focus of expensive mitigation efforts with mixed success.[41] More generally, the average carbon conversion efficiency of only 68% in the present catalytic heater sample warrants caution for potential applications in destroying methane. Recently announced draft regulations by the federal government of Canada allow for the destruction of small quantities (<60 m^3/d) of methane using catalytic combustors, as long as the carbon conversion efficiency is at least 85%.[33] While units designed specifically for the destruction of hydrocarbons might be expected to achieve better conversion efficiency, the results from this work highlight the importance of verified performance data under field conditions. Since protocols[42,43] for measuring nitrogen oxide (NO_x) levels in the exhaust of stationary engines included in the Multi-Sector Air Pollutants Regulations (MSAPR)[44] use similar FTIR instrumentation as this study, the technical ability to include the combustion performance of catalytic heaters in methane emission surveys could therefore already exist on these same oil and gas sites.

■ ASSOCIATED CONTENT

Data Availability Statement

Data to replicate Figures 2 and 3 in the main text and additional figures and tables in the Supporting Information can be accessed via the Carleton University dataverse at 10.5683/SP3/SNRTXP.

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.estlett.4c00453.

Measured data/results for individual heaters, results of sampled heat medium burners, equipment count survey results and inventory estimate, FTIR uncertainty analysis, and time history data for measured catalytic heaters (PDF)

Supplementary video file of backflow of exhaust into a building (MP4)

■ AUTHOR INFORMATION

Corresponding Author

Matthew R. Johnson − *Energy & Emissions Research Laboratory, Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, ON K1S 5B6, Canada*; orcid.org/0000-0002-3637-9919; Email: Matthew.Johnson@carleton.ca

Authors

Simon A. Festa-Bianchet − *Energy & Emissions Research Laboratory, Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, ON K1S 5B6, Canada*; orcid.org/0000-0002-6491-0439

Milad Mohammadikharkeshi − *Energy & Emissions Research Laboratory, Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, ON K1S 5B6, Canada*; orcid.org/0009-0008-4077-7398

David R. Tyner − *Energy & Emissions Research Laboratory, Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, ON K1S 5B6, Canada*; orcid.org/0000-0002-6500-9888

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.estlett.4c00453

Author Contributions

Conceptualization: D.R.T., M.R.J.; investigation: S.A.F.B., M.M.; formal analysis: all authors; writing−original draft: S.A.F.B., M.R.J.; writing−review and editing: all authors; supervision and funding acquisition: M.R.J.

Notes

The authors declare no competing financial interest.

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