Evaluation of Surface Casing Vent Flows at Inactive Wells

Mary Kang, Civil Engineering, McGill University

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Executive Summary

Abandoned, inactive, and suspended oil and gas (AISOG) wells are a source of methane emissions to the atmosphere. This emissions source is currently underestimated in the Canadian National Inventory Report, partly due to a lack of representative direct measurement datasets. Emissions from AISOG wells can arise from wellhead infrastructure, surface casing vents and/or from the surrounding soil. Identifying the emitting component is key to improving emission estimates and designing effective repair strategies.

Through several complementary research projects, we are investigating drivers of emissions at sub-provincial, provincial, and national scales. In one study (Bowman et al. 2023), we found combined (wellhead and surface casing vent) methane emission rates to range from -5.0x10^1 to 5.2x10^6 mg/h with highest emissions from unplugged wells. We found that wells with high surface casing vent emissions usually exhibited low wellhead emissions, while wells with low surface casing vent emissions often had high wellhead emissions. Other on-going studies include national-scale database analysis of measurements and well attributes and geochemical analysis and characterization to elucidate the source of methane.

Our findings provide evidence that the AISOG methane emission estimates in the national inventory report is highly uncertain and establish the importance of conducting measurements of surface casing vent emissions separately. Moreover, there remain gaps in our measurement database that can conflate emission sources and drivers. Provincial databases of surface casing vent flows appear to be missing a substantial proportion of surface casing vent flows at AISOG wells. It is unclear if this finding can be extended to active wells. Preliminary analysis of geochemical data indicates large uncertainties in potential sources, emphasizing the need to include more advance geochemical techniques such as noble gases. Overall, our report summarizes how comprehensive characterization and analysis of AISOG well emissions is necessary to efficiently predict, monitor and mitigate methane emissions.

Best Practices/ Emissions Reductions/ Tangible Project Outcomes

Our study highlights the benefit of separately quantifying methane emissions from surface casing vents from other emissions at abandoned, suspended, and inactive oil and gas (ASIOG) wells. This component-level approach to methane emission quantification at AISOG wells is recommended as a best practice.

The component-level identification of methane emissions from AISOG wells is important for emissions reductions as they can be used to determine the appropriate strategy. Repair options for surface casing vent flows require subsurface interventions while other methane emissions may only require aboveground equipment maintenances and fixes, which can be easier and less costly. We have shared our measurement data with individual operators, including information on where the emissions are arising from. This information can be used directly by the operators to reduce methane emissions. Our data is also actively being shared with Environment and Climate Change Canada.

Overall, our study of AISOG well methane emissions in Canada provide necessary up-to-date data to policy makers, thereby helping improve national emission inventory estimates and leading to cost-effective emissions reduction mitigation strategies.

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1. Background

The oil and gas sector is the largest source of methane emissions in Canada, emitting 41% of the country's annual methane emissions in 2021 (Environment and Climate Change Canada, 2023). At oil and gas well sites, these emissions can be due to leaks from the wells or the surrounding infrastructure (e.g., batteries, storage tanks) (Seymour et al., 2022, Seymour et al., 2023). The focus of this report is on methane emissions from non-producing wells, including abandoned, inactive or suspended wells. We focus on emissions from the wells themselves and exclude other well site infrastructure.

At oil and gas wells, methane can be emitted from the aboveground wellhead infrastructure, the surface casing vent, or the soils surrounding the well (i.e., gas migration). Repair and methane emission reduction strategies differ substantially depending on the emitting component.

Repairing surface casing vent flows can be particularly challenging as subsurface interventions are needed. Therefore, in Bowman et al. (2023), we separately quantified these emissions.

Previously published direct measurements of methane emissions from abandoned, inactive, and suspended oil and gas (AISOG) wells in Canada do not include wells from Alberta, the main oil-and-gas-producing province in the country. The result is that provincial and national estimates of this source remain highly uncertain (Williams et al., 2021). In addition, the engineering, geological, and policy-based drivers of high methane emissions remain understudied (El Hachem and Kang, 2023). Therefore, to reduce uncertainties, improve inventory estimates and inform mitigation strategies, additional measurements of methane emission rates from AISOG wells in Canada, especially Alberta, and their analysis with broader datasets are needed.

The objectives of the project being reported here are:

1. Characterize methane emissions from abandoned, suspended, and inactive oil and gas (AISOG) wells in Alberta and Saskatchewan.
2. Determine geochemical composition that can elucidate the source of gases released.
3. Compare measured emissions to wider measurement datasets.
4. Provide data and analysis that can be used to design cost-effective mitigation strategies.

Bowman et al. (2023) addresses objectives 1, 3 and 4. We are currently working on preparing another paper focusing on geochemical composition of the released gases. In addition, we are also preparing another paper that is focused on analyzing the wider measurement dataset with new measurements conducted in 2023 with other funding.

2. Methodology

We conducted field campaigns in Alberta and Saskatchewan between Fall 2021 and Summer 2022 (Bowman et al., 2023) with funding from this project. The static chamber methodology was used to derive emission rates, as described in Kang et al. (2014). In addition, we collected gas samples from inside the static chambers placed on both sources and analyzed their geochemical composition to investigate the source of released gases, which is currently being analyzed for a manuscript in preparation. With other funding sources (Tab. 1), additional field campaigns were conducted in British Columbia, Ontario and Quebec between 2018 and 2021 and in Alberta, Saskatchewan, Ontario and Quebec in Summer 2023. This broader data set is currently being analyzed for a manuscript in preparation.

3. Data

Bowman et al. (2023) made measurements at 238 wells with 192 emission rate measurements of surface casing vents and 193 measurements of wellhead infrastructure (non-surface casing vent) (Tab. 1). An additional 71 surface casing vent and 54 wellhead methane flow rates were measured at 68 well sites during a field campaign to Alberta and Saskatchewan in Summer 2023 (Tab. 1). We did not separately measure emissions at surface casing vents at wells measured in British Columbia, Ontario, and Quebec.

As for gas samples, 183 surface casing vent flow and 122 wellhead gas composition data were analyzed at McGill University, and 50 duplicates of surface casing vent flow samples were analyzed at University of Calgary for quality assessment and control purposes (Tab. 1). We present preliminary results of the 183 surface casing vent flow samples in the results section of this report. This geochemical data is also currently being analyzed for a manuscript under preparation.

In addition, more than 600 samples from 72 surface casing vent flows and 121 wellheads are in the queue to be analyzed at McGill University and 58 additional samples are currently being analyzed at University of Calgary.

Table 1: Number of measurements collected in our field campaigns (in red: the samples are yet to be analyzed, in orange: the samples are partially analyzed).

	Funded by	Methane flow rate measurements	Gas composition analysis (McGill)	Gas composition analysis (UofCalgary)
Summer 2023 campaign (AB-SK)				
SCV	Clean Economy Fund	71	72	29
wellhead		62	57	29
well sites		68	68	38
Summer 2023 campaign (ON-QC)				
wellhead	NOVA (NSERC/FRQNT)	58	64	0
well sites		60	62	0
Summer 2022 - Fall 2021 campaign (AB-SK)				
SCV		202	182 *	50
wellhead	PTAC/CRIN and McGill	189	122	0
well sites		250	249	50
Winter 2021 - 2022 (ON)				
wellhead	ECCC, NRCan	82	76	0
well sites		82	82	0
Summer 2021 campaign (AB-BC)				
wellhead	ECCC, FRQNT and NFRF	67	73	0
well sites		67	67	0
Summer 2021 (QC)				
wellhead	ECCC, McGill	20	20	0
well sites		20	20	0
Fall 2020 (ON)				
wellhead	ECCC, McGill	36	23	0
well sites		37	37	0

* : samples corresponding to the results presented in 4.2.

4. Results

4.1. Methane flow rates

We found combined methane flow rates from surface casing vents and non-surface casing vent infrastructure ranging from -5.0x10^{1} to 5.2x10^{6} mg/h (Figure 2, Bowman et al. (2023)). On average, unplugged wells emitted 95 and 225 times more than unplugged wells in Alberta and Saskatchewan respectively. Investigating emissions from wells with various fluid production types, we found that average gas well emissions were higher than for other categories (e.g., oil, injection, disposal, storage and other). Finally, we found notable variations in emissions across provincial and sub-provincial geographic regions, with highest emissions found in Grande Prairie, Alberta, followed by Medicine Hat and Lloydminster, Alberta. Lowest emissions were found in the Estevan, Saskatchewan, region.

In Alberta, surface casing vent emissions ranged from -1.9x10^{1} mg/h to 5.2x10^{6} mg/h and were higher than non-surface casing vent emissions, ranging from -2.0x10^{2} to 9.8x10^{5} mg/h. In Saskatchewan, the opposite trend was found, with surface casing vent and non-surface casing vent emissions ranging from -4.9 mg/h to 3.2x10^{2} mg/h and -7.2x10^{1} to 1.8x10^{5} mg/h, respectively (Figure 3, Bowman et al. (2023)). The average methane emission rate from surface casing vents in Alberta was three orders of magnitude higher than in Saskatchewan. Another interesting trend we found in both provinces was that wells with high surface casing vent emissions usually exhibit low non-surface casing vent emissions, with the opposite trend being true as well. We compared our measurements to the Alberta Energy Regulator Vent Flow and Gas Migration Report and found that 50% of wells we identified as emitting were not listed on the database and 18% were recorded as remediated or died out.

4.2. Gas composition analysis of surface casing vent flows

Based on 182 samples from surface casing vents analyzed thus far (marked with * in Tab. 1 and Tab 2.), the gas composition indicate that the gas is mainly from mixed thermogenic/microbial origin. The $\delta^{13}C$-CH_4 composition of methane emissions from surface casing vents had a mean of -52.6 and a median of -47.83‰. Typically, thermogenic methane sources are enriched in ^{13}C (i.e., higher $\delta^{13}C$-CH_4 values) and microbial sources are depleted in $\delta^{13}C$ (i.e., lower $\delta^{13}C$-CH_4 values) (Schoell, 1988). The stable carbon isotopic signature of atmospheric methane is typically in the -47‰ range (Schoell, 1988). 29 out of 182 measurements were below the microbial $\delta^{13}C$-CH_4 limit of -63‰. Although the $\delta^{13}C$-CH_4 values of the samples analyzed thus far do not indicate a thermogenic origin, we detected C_2H_6/CH_4 ratios exceeding 0.01, indicative of thermogenic origins, in 32 out of 182 samples.

Table 2: Geochemical parameters measured from samples collected during our field campaigns (in red: the samples are yet to be processed)

	McGill University				University of Calgary	
Instrument	**CRDS (Picarro G2210i)**	**CRDS (Picarro G2204)**	**GC-FID**	**GC-IRMS**	**GC-TCD, GC-FID**	**GC-IRMS**
Parameters	**CH_4, C_2H_6, CO_2, d^{13}C-CH_4**	**CH_4, H_2S**	**CH_4, C_2H_6, C_3-C_6**	**d^{13}C-(CH_4, CO_2, C_2-C_5), d^{2}H-(CH_4, C_2-C_5)**	**He, H_2, O_2, N_2, CO_2, CH_4, C_2-C_6**	**d^{13}C-(CH_4, CO_2, C_2-C_5), d^{2}H-(CH_4, C_2-C_5)**
Summer 2023 campaign (AB-SK)	YES	YES	YES	YES	YES	YES
Summer 2023 campaign (ON-QC)	YES	YES	YES	YES	NO	NO
Summer 2022 - Fall 2021 campaign (AB-SK)	YES *	YES	NO	NO	YES *	YES
Winter 2022 (ON)	YES	YES	NO	NO	NO	NO
Summer 2021 campaign (AB-BC)	YES	NO	NO	NO	NO	NO
Winter 2021 (ON)	YES	NO	NO	NO	NO	NO
Summer 2021 (QC)	YES	NO	NO	NO	NO	NO
Fall 2020 (ON)	YES	NO	NO	NO	NO	NO

* : samples corresponding to the results presented in 4.2

5. Discussion

In this study, 11% of all abandoned wells we measured emitted methane at more than 10^4 mg/h, defined as high-emitters, including one measured emission rate that exceeded the highest previously published emission rate from abandoned wells (Etiope et al., 2023). Our findings provide evidence that emissions from abandoned oil and gas wells are currently being underestimated, and that available datasets may be missing some of the highest emitters. This raises the concern of gaps in the abandoned wells dataset, contributing to uncertainty in emission estimates in Canada and elsewhere. Therefore, additional field measurement campaigns are needed, to capture a wider sample of well characteristics, including well status and type, as well as measure wells in other geographical regions. However, a major barrier to obtaining representative samples is getting access to well sites, thus collaborations that enable site access are important.

We found that high non-surface casing vent emissions often correspond to low surface casing vent emissions and possibly subsurface leakage and groundwater contamination. In other words, the highest emitting wells with leaks coming predominantly from wellhead infrastructure may not be the wells with the most subsurface leakage. Therefore, it is important that well integrity issues as indicated by surface casing vent flows and gas migration are repaired prior to plugging and abandonment as currently required in Canadian provincial regulations.

Source attribution of emissions can also be investigated using geochemical analysis of emissions. From our samples of surface casing vent flows, we found δ^{13}C-CH_4 values indicating a predominantly mixed thermogenic/microbial origin of the gas in the samples analyzed thus far. Ethane to methane ratios of 18% of the samples were in the thermogenic range, whereas 16% of samples had δ^{13}C-CH_4 in the microbial range. We are currently conducting a project analyzing a large dataset of geochemical data retrieved from wells across five Canadian provinces. However, although we may be able to provide insight into differences in sources of emissions from the wellhead and surface casing vents, advanced geochemical analysis (possibly involving noble gases) may be needed to narrow down the source of the emitted methane.

6. Conclusions

Our measurements of surface casing vent and non-surface casing vent methane flow rates in Alberta and Saskatchewan provide evidence that AISOG wells remain an uncertain source of methane emissions in Canada. We found emission rates higher than previously published emission rates in Canada and the U.S., indicating that AISOG well methane emission estimates in the Canadian National Inventory Report are highly uncertain. Component-level measurements separately accounting for emissions from surface casing vent and non-surface casing vent methane flow rates are useful for both for improving the Canadian National Inventory Report and providing actionable data to operators. Further geochemical analysis of emissions is likely to provide more insight into various sources of leakage. This is necessary to efficiently monitor emissions and identify subsurface leakage processes, thereby efficiently adapting/developing mitigation strategies.

7. Recommendations

One recommendation for future research is to strategically conduct direct measurements on AISOG wells that can better capture the full distribution of methane emission rates and fill gaps in emission rates datasets. To do this, it is important to understand which well attributes should be considered when assessing representativeness of a dataset. We are currently working on publishing a paper analyzing ~500 methane emissions measurements of non-producing wells across five provinces in Canada, (e.g., British Columbia, Alberta, Saskatchewan, Ontario and Quebec). In this paper, we are analyzing the role of well attributes on methane emissions, which may be used in designing future measurement studies.

Another key recommendation is to conduct multiple and/or continuous measurements at the same wells at multiple time scales to understand temporal variation in methane emission rates at AISOG wells. We have received funding from AUPRF to study temporal variability and are preparing for a field campaign in 2024.

Although the geochemical parameters that we analyzed provide some insights into the source of the emitted methane, on-going analysis indicate that the geochemical parameters we are analyzing will give many inconclusive results and additional information is needed. Therefore, we recommend collecting advanced geochemical information such as noble gases (Darrah et al., 2014). Such advanced geochemical information will help operators design effective surface casing vent flow mitigation strategies.

The studies presented in this report focused only on non-producing wells. It is unclear if the findings here on non-producing wells can be extended to surface casing vents and other emissions from active wells.

Finally, there may be opportunities to develop new measurement methods including simultaneous deployment of multiple methods and low-cost sensors to reduce costs, better detect high emitters, and evaluate temporal variability in emission rates. These opportunities can be achieved with new collaborations with industry and other partners. A critical component of such collaborations is the demonstration of methods through controlled release testing.

8. Applications (including extension to specified audiences)

In future projects, a workshop with field trials and demonstration of multiple surface casing vent flow methods would be beneficial. These demonstrations can be useful for industry to build credibility of their methods and services and to strengthen confidence in provincial and other datasets.

9. References

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