Flare Tip Monitoring – Feasibility Study and Project Proposal Sketch

April 28, 2022

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1. SCOPE OF WORK

In Autumn of 2021, St. Francis Xavier University, working with funding from Natural Resources Canada (NRCan) and Energy Research and Innovation Newfoundland and Labrador (ERINL), conducted aircraft methane benchmarking measurements of oil and gas platforms in Newfoundland and Labrador. The study showed that methane emissions were in line with reported estimates, although Cenovus identified the possibility that the flared tip was combusting efficiently. The flare abord the Sea FPSO is older and is operating at the limits of efficiency, and at moments may not be combusting completely. Cenovus was interested in understanding the potential for drone measurements to take additional samples.

Thanks to a funding extension, St. Francis Xavier University was awarded with funds to investigate opportunities for drone flares tip combustion-efficiency measurements, to have project discussions with potential partners, and to devise a rough work plan.

2. OFFSHORE DRONE-BASED FLARE TIP MEASUREMENTS

Although drones are used in offshore oil and gas measurements and photography, they have not been used to date for flare combustion efficiency monitoring. Theoretically, a drone would fly into the flume downwind of the tip, and measure or collect. The typical drone payload limitation is about 3 to 6 kg, or somewhat less if battery time is important or winds are heavy which they are traditionally in offshore oil and gas environments in Newfoundland and Labrador. Once down-wind some tens of metres, or potentially 100 m, dispersion of gases would reduce the concentrations of methane and carbon dioxide products in air significantly, where anomaly are reduced to only some tens of ppmv methane in magnitude. Much higher concentrations of carbon dioxide are expected since the flare gases should convert methane into carbon dioxide at an efficiency of about 98%. We would expect concentrations of carbon dioxide to be in the hundreds of ppmv above background. A drone capable of making combustion efficiency measurements at the flare tip measurements would need to simultaneously measure methane and carbon dioxide. Small carbon dioxide sensors that are available, although not sold for drone-based work, would be very much within the competencies of the Flux Lab team to build. Small methane sensors with capability of resolving tens of parts per million methane, or less, with high noise ratio, are harder to find. One drone portable sensor developed at NASA JPL is licensed exclusively to a company called Seek Ops. Unfortunately, most of that company's activities are in the US and they do not perform carbon dioxide measurements. The only other small drone-based sensor is from the national research council, although it is in prototype form and is probably not yet ready for commercial work.

Another option is to use air core sampling. An air core consists of a long thin tube coiled for small size into which air is introduced at a known steady rate during flight. The air core stores a time-based chronology of the flight. When using an air core, it is important to use a length of tubing sufficient to hold the volume of air that will be introduced during the flight. After the flight has finished, the air stored within the core would be "played back" on a high-performance cavity ring down spectrometer capable of ppbv resolution and simultaneous measurement of carbon dioxide, methane (and ethane for Flux Lab's analyzer). If the flow rate of air into the air core is tuned to roughly match that of the spectrometer, the result is a record of air carbon dioxide and methane concentrations through time that is nearly equivalent to having put the analyzer in the air with the drone, since air does not mix laterally within the small diameter air core tube. This form of sampling is commonplace for balloon sampling, and truck sampling, but there is only one record in the peer review literature of an air core having been used with a drone. We believe that the air core system is well suited to the offshore environment, and flare tip work. The Synflex tubing used for air core sampling is lightweight, weighing only 18.5 g per meter and an air core of sufficient length to sample a 30-minute chronology would probably weight less than 1.5 kg.

There are two technical hurdles to overcome for drone air core sampling in Newfoundland and Labrador. The first hurdle is to reduce accessory weight. We would need to dispense with the large and heavy flow controller that is normally used as part of air core sampling, and to replace that with some other form of flow regulation that is reliable and will move air very slowly into the air core at a rate of 20-40 sccm to match the sampling rate of the spectrometer. The second hurdle relates to explosion risk. The air core system needs to be intrinsically safe in case it would accidentally fall on the deck of the FPSO in an inopportune location. This short feasibility study addresses both hurtles.

3. AIR CORE FEASIBILITY EXPERIMENT

Although drones are used in offshore oil and gas measurements and photography, they have not been used to date for flare combustion efficiency monitoring. Theoretically, a drone would

In this study, we used at 40 m air core along with a miniature air pump, the activation energy of which falls below the threshold at which intrinsic safety rules come into effect. In other words, the pump is so small that it does not generate spark sufficient to ignite a plume of natural gas, especially if an amperage protection circuit is in play. The pump is also small enough to be regulated extremely well or low flow conditions by only voltage regulation. The pump was selected based on discussions with manufacture KNF which makes high-quality pumps for high duty cycle scientific and industrial applications in hazardous and non-hazardous environments. We conducted tests in which a Synflex tube was married to only the micropump and a small power supply of 0-1 V. We first conducted an experiment to determine the voltage at which the flow would be 25 sccm, and to assess its variability over time. We used a laboratory power supply capable of small changes in voltage. The figure below shows flow as a function of voltage. We determined that 0.6 provided the correct flow rate, and we were happy to find that the flow was very stable for hours so long as we had sufficient air core backpressure at the pump outlet. At 0.6 V, the pump consumed only 0.01 W of energy, which could be supplied over the timeframe a 10 - 30-minute drone flight with a small watch-type battery.

For context, the energy consumption of the micro air core pump is about 1-2 orders of magnitude lower than a cellphone transmitting and receiving on a cellular network.

Figure 1. Flow rate into a 40 m air core as a function of voltage for a KNF micropump.

We tested an air core system using compressed air (about 2 ppmv methane), and a 4 ppmv methane air standard, to introduce variable concentration chronologies of air into the air core. We arranged for the spectrometer to be sampling the variable concentrations at the same time they were introduced into the air core. Subsequent to the 15-minute chronologies, we played back the air core record on the analyzer. We used two air core flow rates – 0.6 V which resulted in a flow of 22 sccm, and 0.7 V which resulted in a flow just over 40 sccm. Since the low lower of the flow rates was beneath that of the spectrometer, we expected that fluctuations recorded by the air core record would be damped relative to that of the spectrometer direct sampling. The higher flowrate condition resulting from the higher voltage input, was faster than that of the analyzer, so we expected that the air core record might deliver even more fidelity than the direct spectrometer measurement. We used low concentrations of methane and carbon dioxide, and relatively fast pulses of 5 seconds to 3 minutes, in order to test the limits of resolution. In the field we would expect higher concentrations, and several minutes of hovering time. It is important to note that methane and carbon dioxide concentrations were recorded simultaneously in the test by the same spectrometer. We also recorded ethane values simultaneously, but those are not reported here. The figure below shows the results of these lab-based air core fidelity tests where we have tried to completely overlap the direct recording, and the air core record.

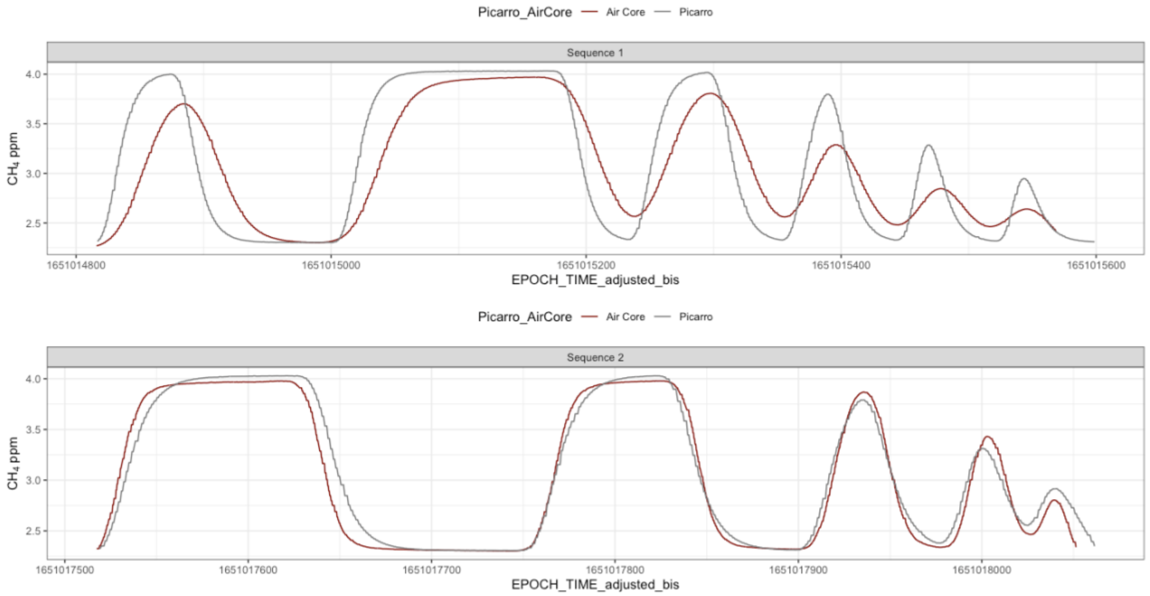


Figure 2. Methane record from air core and direct spectrometer readings for low flow air core (top panel) and high flow air core.

The results are as expected. For longer duration pulses (similar to hovering for a period of time in the plume), the low flow air core did match the equilibrated concentration of the direct spectrometer measurements. But during shorter-duration pulses, the low flow air core did not have sufficient sample volume inside to match the spectrometer record in terms of equilibrated concentration. In the high flow condition, the air core adjusted concentration was sometimes even faster than direct measurements into the analyzer, indicating that the high flow condition also makes up for small amounts of mixing that might occur as air is drawn into the air core.

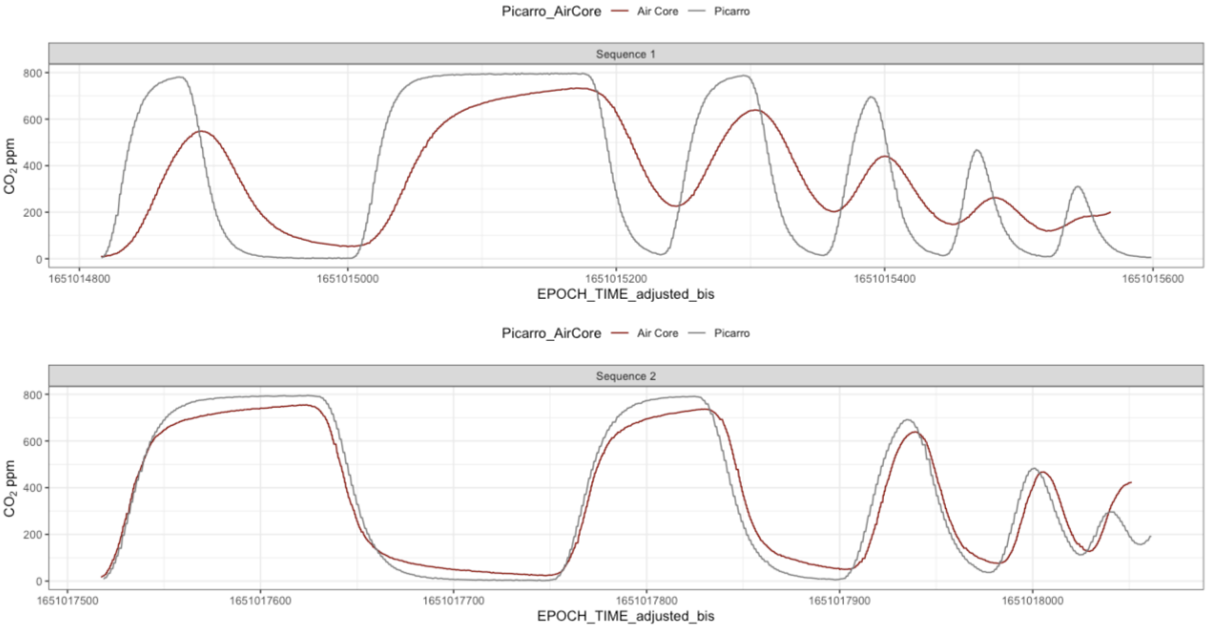
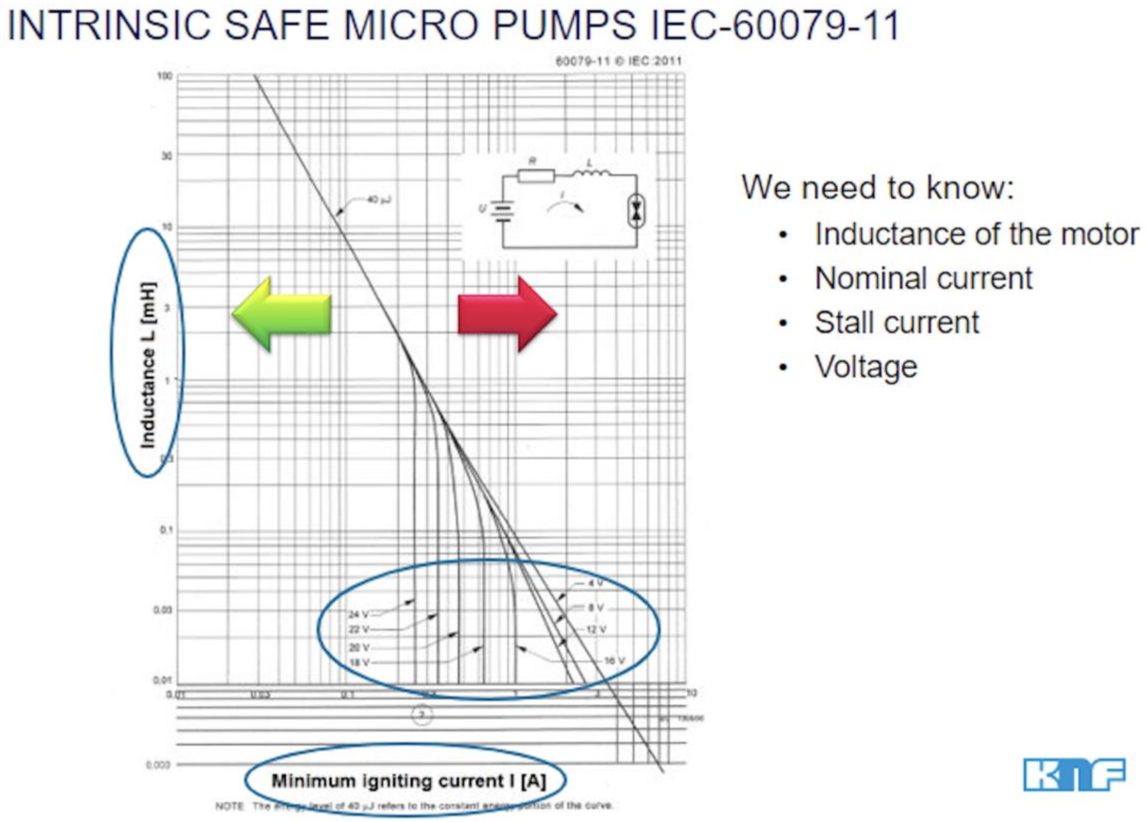


Figure 3. Carbon dioxide record from air core and direct spectrometer readings for low flow air core (top panel) and high flow air core.

The results for carbon dioxide were like those of methane, where the low flow air core damped the concentration chronology, and where the high flow air core preserved the chronology with high fidelity. However, the high flow rate air core is not necessarily better or more useful. We do have the capacity to hover in the plume for >3 minutes with a drone, which will help the spectrometer measure carbon dioxide and methane ratio at full equilibration. In practice the low flow rate air core would be half as long and heavy, and a smaller more nimble package might be advantageous for practical considerations like flight duration, wind profile, and other factors. We can also have multiple air cores available for repeat flights during good weather conditions. As conditions degrade, flights might be easier and faster with the smaller air core.

We had discussions with Matthew Tank and Jeffrey Dziedzic at KNF, the pump manufacturer. Looking at the KNF NMP03 pump range as a whole, the -M and -L motors meet the standard when run at their nominal voltages, the -B motor is under the limit, but near the threshold and must be tested. The -S motor is OK only when the current is controlled to 150 mA. We would prefer to use the -B motor because it offers the best opportunities for flow control, but if this introduces uncertainty, we are very confident that the -M and -L variants (all have different voltage inputs) would be suitable for this work and would provide results matching, or better than the lower end -S variant we used for our tests. We could also use the -S and limit incoming amperage.



INTRINSIC SAFE MICRO PUMPS IEC-60079-11

We need to know:

- Inductance of the motor
- Nominal current
- Stall current
- Voltage

Figure 4. KNF micro-pump intrinsic safety phase plot, provided by KNF.

Although this is a new prototype method, these results give us confidence that we can assemble a system of <2 kg that records at sub-ppmv level for 30 minutes where carbon dioxide and methane are measured simultaneously for determining combustion efficiency based on feedstock gas composition and relative abundance of both gases in the plume. There is high potential for a 15-minute system that weighs <1 kg even at high fidelity. Drone payloads could be lower, or higher depending on intended flight duration and resolution. This system would be highly useful for drone sampling of flare tips on offshore production platforms. The only uncertainty relates to the pump, and whether we need specific clearance for devices whose activation amperage falls under / outside of the safety standards.

4. PROJECT PARTNER DISCUSSIONS

We had conversations with a Newfoundland and Labrador-based company called AltoMaxx, who are an existing drone provider to Cenovus, and a provider of drone training and hardware across Canada. They had done previous photography projects at Sear Rose. We discussed the limitations of drone flare plume sampling, and the only real limitation is distance from the hot core. But, >50 m downwind and payload is no problem. They use an intrinsically safe DJI Matrice 300 for this work. They are comfortable with the work. AltoMaxx seems to have careful high competency people on staff and could probably be trained to use our spectrometer (the same we used for aircraft work) if we could ship it to the platform, but it is potentially better on a first visit to have a

StFX person available for some period of time at the start of a campaign, for training and for determining flight patterns and interpreting data immediately as it flows in from the spectrometer. There seems to be good potential for collaboration with AltoMaxx on a project, and they are willing, either as lead or subcontractor. They would do the flying, and we would prepare the air cores, perform the measurements, and results interpretation.

Cenovus will also connect us with Aker Solutions, another company that would link well into a project where they could handle the offshore safety issues for the project. They are apparently well equipped for this role and would reduce the need for StFX logistics and coordination.

5. PROPOSED PROJECT

Cenovus has communicated that two time periods might be appropriate for this work, to capture the flare in high and low conditions and before re-fitting next year. June and September would seem to work and offer good flight opportunities. A sampling campaign would be 1-3 weeks in length and would aim to capture repeated samples of flare gas when the weather conditions are appropriate, and ideally in high and low flaring states.

We propose that Aker should take the lead given their expertise in logistics, with both AltoMaxx and St. Francis Xavier University as subcontractors. The work program would be laid out as follow:

May-June

- Aker – Formal proposal, agreements, permissions, safety requirements, logistics (in collaboration with St. Francis Xavier University
- St. Francis Xavier University – Prepare hardware

Late June

- Field campaign – AltoMaxx and St. Francis Xavier University (1 each) onsite until we can retrieve 3 air core repeats in high and low flare situations (2), and in higher and lower wind (2). In combination, this equates to 12 air cores, or up to 3-6 hours total of flight time assuming 15 – 30-minute flights. We expect that these samples can be collected in 2 good days, but that it may take 2 weeks to get 2 good days.

July-August

- Data interpretation and initial reporting at St. Francis Xavier University, including to inform upcoming field campaigns. Should we have done anything differently?

September

- Field campaign – Repeat of June campaigns, incorporating any learnings. AltoMaxx staff only, with St. Francis Xavier University on the phone

October-November

- Data interpretation and final reporting at St. Francis Xavier University. Final report delivered to Cenovus November 30, 2022.
- Update to project partners

- Project post-mortem to discuss the prototype sampling approach and results

6. CONCLUSION

This project has allowed us to determine that the project is feasible, including within a short timeframe. The only possible hiccup relates to intrinsic safety certification, which is not expressly provided for the KNF micropumps that we would use, but they fall underneath the limits and thus should be permissible to use.

This project was supported by Natural Resources Canada's Emissions Reduction Fund (Offshore Research, Development and Demonstration Program), which is managed by Energy Research & Innovation Newfoundland & Labrador.