CANADA EMISSIONS REDUCTION INNOVATION NETWORK (CERIN) PUBLIC REPORT

1. PROJECT INFORMATION:

Project Title:	**Ventsentinel® Flow Metering – Phase 1 of 2**
Alberta Innovates Project Number:	G2020000010
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AI Project Advisor:	Bryan Helfenbaum

2. APPLICANT INFORMATION:

Applicant (Organization):	**Ventbuster Instruments Inc.**
Address:	Airdrie
Applicant Representative Name:	Robert Layher / Deanne Layher
Title:	CEO / President
Phone Number:	403-512-0902
Email:	info@ventbusters.com

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3. PROJECT PARTNERS

Thanks to the team, which included:

- Cenovus Energy Inc. (Owen Henshaw, Morgan Wrishko, Sean Hiebert)
- Bonavista Energy Corp. (Kendell Esau, Colin Hennel)
- Tangent Design Engineering (Chris Parker, Josh Abbott)
- Spartan Controls (Brian Van Vliet, Dean St. Amant)
- InnoTech Alberta (Neil Yaremchuk)
- PTAC (Larry Frederick, Brian Spiegelmann)

And supporting companies:

- GreenPath Energy Inc. (Joshua Anhalt)
- Carbon Management Canada Inc. (Kirk Osadetz)
- Align Energy Services (Shane LaCasse)
- CEI Control Services (Craig Andrew)

A. EXECUTIVE SUMMARY

Existing meters for measuring greenhouse gases (GHGs) emissions have been insufficiently accurate or prohibitively expensive. As a result, there is little information on flow rates from a variety of sources. It is important to know flow rates of these sources because they represent either methane being released to the atmosphere or negation of the same. New metering technologies, such as those offered by Ventbuster Instruments Inc. were tested to help fill this technological gap. Phase 1 of this project sought to determine the utility of the prototype Ventsentinel® and its accuracy over it calibrated flow range, at varying flow rates, both in laboratory situations and in actual field installations including exposure to low temperatures. Laboratory testing was carried out at InnoTech Alberta and field testing was carried out at Cenovus Energy's (Husky) field sites, CMC Research Institute southwest of Brooks, Alberta and Bonavista Energy's field sites.

Testing of the Ventsentinel® on the bench and in the field was carried out to determine if the measurements were accurate to within 10% of each other and to within 15% of the reference (standard) meter, and that they would remain accurate at cold temperatures. It was anticipated that these meters will be used for measuring gas flows where high quality information is required. Testing applications included, but were not limited to, air flow rates, atmospheric tank emissions and compressor packing vents. Testing was carried out to help facilitate accurate reporting and help operators make informed decisions towards deployment of emission mitigating solutions.

From bench testing at InnoTech Alberta, the Ventsentinel® was found to be immune to hysteresis effects, performed well with methane and air process media. Maximum relative error for low flow rates (0.5 to 7.0 Sm3/d) was 8.5% and for high flow rates (2.5 to 175.0 Sm3/d) was 6.1%. Relative error with methane process media was found to be lower than air by about 3.0%.

Inspection of the sensor from a Ventsentinel® used previously in the field measuring casing head gas on a Cenovus (Husky) Cold Heavy Oil Production with Sand (CHOPS) well in the Lloydminster region, showed that the integrity was not severely compromised despite scratches and fouling caused by impurities in the solution gas stream, as observed from images obtained under microscope.

Two compressor packing vents tested at a Cenovus site were found to be emitting enough gas to be tested with GreenPath's Hawk 9000 testing unit. A 1-inch Ventsentinel® was connected in series with this other meter for simultaneous comparative testing. The logged data for both completed tests showed small relative error and was a very positive result. There was very little variation in the flow rates from those vents though, which didn't provide opportunity to see how the Ventsentinel® would perform at higher field flow rates.

Higher field flow rates were tested on oilfield tanks at CMC Research Institute (LSD. 10-22-017-16 W4M) southwest of Brooks, Alberta. Controlled releases between 0 and 5,800 m3/d of methane from a high-pressure gas trailer were measured from the top of two atmospheric tanks at site. An Alicat Scientific Mass Flow Controller was used to control flow rates between 0 and 1,700 m3/d. Above 120 m3/d, the flow measured by the Ventsentinel® was found to be higher in most cases by 1-6x. Audible observations at site found that the flow heard at 1,700 m3/d was not much louder than was heard at 500 m3/d which made us unsure if the Alicat flow rates on the display were representative of the true flow rate through the meter. Key learnings from this first day of testing were that the Ventsentinel® metered flow rates, above it calibrated range at 720 m3/d, were reading higher than expected with increasing flow rates. Thus, a K factor was needed, determined, and applied to get measured results with 5.0% or less error.

Metering with Ventsentinel® technology provides opportunity to generate carbon offset credits if the measurement is representative of actual with minimal error. Adding the K factor correlation coefficient to the scaling equation provided measurements with 5.0% or less error.

B. INTRODUCTION

Oil and Gas Sector

Canada has set goals to achieve 45% methane emission reductions in the upstream oil and gas industry by 2025 and 75% reductions by 2030. To achieve this, oil and gas field venting limits have been applied to upstream assets. Site limits for new infrastructure put in service after Jan 1, 2021 in British Columbia and Jan 1, 2022 in Alberta are now significantly reduced. To achieve reduced emissions, the business-as-usual approach of using fuel gas to operate pneumatic instruments has been a focus area, which has required existing instruments in service to be reduced from high bleed to low bleed (steady state vent rate less than 0.17m3/h fuel gas). New sites need to conserve or control, which means going one step further and collecting remaining emission sources from assets such as atmospheric tanks, pneumatic instruments, pneumatic pumps, compressor packing vents, reducing and eliminating fugitive emission sources, eliminating emissions from surface casings, mitigating fuel gas blow through associated with combusted sources, converting pneumatic systems to be operated on non-GHG media such as air or nitrogen and use of electric and electrohydraulic control loops instead of pneumatic. Through this effort to reduce methane emissions, industry continues to focus on the aforementioned areas and is evaluating the most cost-effective means of reduction by knowing the magnitude of emission source and the cost to eliminate or mitigate it. Not knowing the magnitude of the achievable emission reduction presents a barrier to achieving improved environmental outcomes.

Knowledge or Technology Gaps

Proper metering of atmospheric point sources provides the information needed to improve outcomes. Atmospheric vent metering presents challenges. Flow meters available to industry today each have strengths and weaknesses. Flow meter accuracy and error are impacted by the following: cost; media phase; wet or dry gas; specific gravity; downstream backpressure; sensor range; meter turndown ratio, upstream and downstream straight pipe length (inlet and outlet runs), laminar or turbulent flow, etc. In the area of atmospheric point sources, back pressure certainly has a measurable impact on vent rates. If the pipe away vent line holds too much backpressure the measured flow rate will be lower than without the meter connected to it. Backpressure applied to an instrument will impact the operation of the device, which will impact how well the valve is able to adjust process flow needed for control. Backpressure applied to a compressor packing vent presents a safety concern. Too much differential across a flow meter on an atmospheric tank can cause it to exceed it maximum allowable working pressure or on pump out, with reverse flow through the meter, to pull a vacuum inside the tank that would exceed its min allowable working pressure.

In addition, specific to atmospheric tanks, the emissions are variable because the tanks breathe. Liquid flow into a vessel displaces the vapour within that same space and vice versa. Thermal expansion with an unchanging volume within a tank will cause some the vapour to be emitted from the tank. Some of the gas that was in solution will flash out and be emitted as well in a process called out-gassing because the tank pressure is lower than the vapour pressure of the lighter ends of the hydrocarbon mixture within the tank. For this reason, sampling a tank in a specific instance provides a snapshot of emissions associated with that asset, but that may not be representative of daily, monthly, or annual average rates. Installing continuous flow measurement on every atmospheric tank to gain insights that are better representing emissions from that point source type is not cost-effective.

Installing a flow meter on an atmospheric tank also presents challenges. Many of the atmospheric tanks in service today are not rated to pressures above 14.0 kPag. The roof of these tanks is often fixed, but not rated to support having a person stand on it. For that reason, use of an artificial lift is recommended, but adds another layer of complexity to measurement. Use of an artificial lift doesn't provide a secondary path of regress in the event of an incident. Furthermore, many atmospheric tanks are not connected to vapour recovery units and have just a gooseneck at the top of the tank to allow it to breathe and a thief hatch to allow excess pressure to be relieved from the tank. In the process of metering the volume from the tank, flow will take the path of least resistance. By quantifying the flow from the gooseneck, that will provide insight on flow rates, but may not be a closed system representative measurement if the thief hatch is leaking.

C. PROJECT DESCRIPTION

Technology Description

The Ventsentinel® uses patented flow channel technology and is designed as an economical low to ultra-low flow gas metering device used to measure flow rate, flow temperature, flow pressure, shut-in pressure, and is intended for ongoing measurement and reporting of vented emissions to atmosphere.

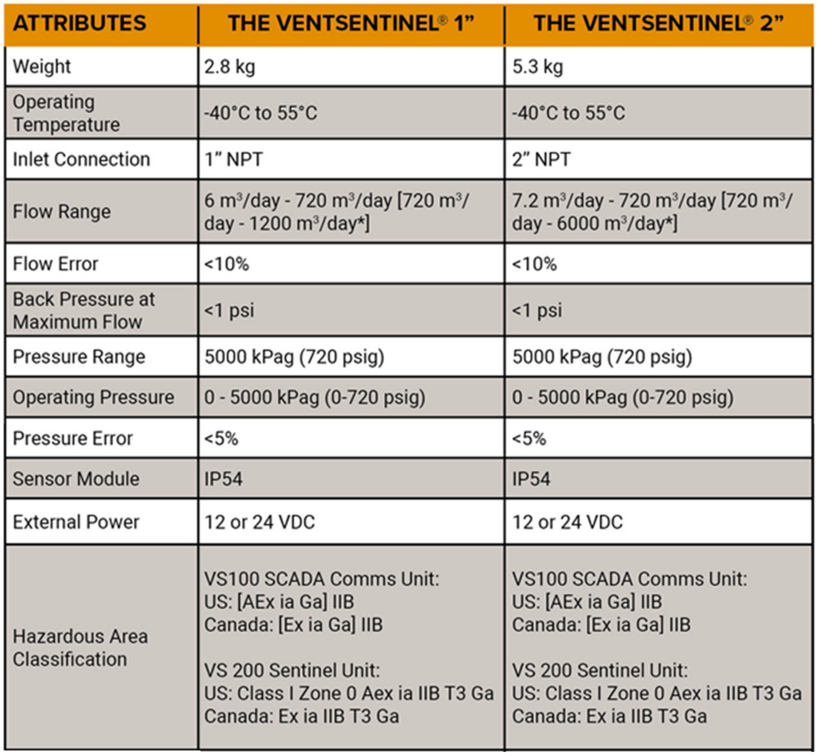
It was developed for installation on wellheads, production tanks, produced water tanks, relief valves, vented underground tanks, compressor seals, instrument air compressors, fuel gas lines, flare lines or incinerators. It is mounted in-line to any hydrocarbon point source to measure and record emissions accurately and in real time. This flow meter meets the requirements of AER Directive 017, 020 and 060 for gas measurement.

As a major concern and a requirement of many atmospheric vents, the unique Ventsentinel® design does not restrict gas flow, resulting in virtually zero backpressure. In addition, its design allows atmospheric vents to "breathe". This is particularly important with vented tanks where back pressures are not tolerable. The Ventsentinel® allows both positive and negative flows into and out of the tank which is ideal for operating safety.

It is designed to be installed in-line on the vent assembly and continuous measurements are transmitted to an IoT Platform via a "gateway" or SCADA communication device. The unit utilizes either supplied plant power or can operate with an external 12V @ 100 mA battery. Its flow range has been designed to meet all anticipated ranges from zero to 6,000 m3/d.

A summary of its attributes is provided in Table 1.

Table 1: Ventsentinel® Specifications



ATTRIBUTES	THE VENTSENTINEL® 1”	THE VENTSENTINEL® 2”
Weight	2.8 kg	5.3 kg
Operating Temperature	-40°C to 55°C	-40°C to 55°C
Inlet Connection	1” NPT	2” NPT
Flow Range	6 m^3/day - 720 m^3/day [720 m^3/day - 1200 m^3/day*]	7.2 m^3/day - 720 m^3/day [720 m^3/day - 6000 m^3/day*]
Flow Error	<10%	<10%
Back Pressure at Maximum Flow	<1 psi	<1 psi
Pressure Range	5000 kPag (720 psig)	5000 kPag (720 psig)
Operating Pressure	0 - 5000 kPag (0-720 psig)	0 - 5000 kPag (0-720 psig)
Pressure Error	<5%	<5%
Sensor Module	IP54	IP54
External Power	12 or 24 VDC	12 or 24 VDC
Hazardous Area Classification	VS100 SCADA Comms Unit: US: [AEx ia Ga] IIB Canada: [Ex ia Ga] IIB VS 200 Sentinel Unit: US: Class I Zone 0 Aex ia IIB T3 Ga Canada: Ex ia IIB T3 Ga	VS100 SCADA Comms Unit: US: [AEx ia Ga] IIB Canada: [Ex ia Ga] IIB VS 200 Sentinel Unit: US: Class I Zone 0 Aex ia IIB T3 Ga Canada: Ex ia IIB T3 Ga

* High flow limit calibration pending

Project Objectives

Phase 1 of this project was to determine the utility of the prototype Ventsentinel® product and its accuracy over its calibrated flow range, at varying flow rates, both in laboratory situations and in actual field installations including exposure to low temperature. Activities within this project included laboratory testing at InnoTech Alberta as well as field testing at Cenovus Energy (Husky) and Bonavista Energy sites in Western Canada.

Performance Metrics

The goal for the Ventsentinel® was to be able to measure atmospheric point sources with metered results repeatability within 10.0% and be within 15.0% of a reference flow meter. The meter would also remain accurate at cold temperatures as is typical to Canadian winters. To be able to provide flow rates in standard conditions, the flow meter also needed to be able to accurately measured temperature and pressure. To be a success, this meter needed to be able to obtain flow measurements with acceptable uncertainty representative of the emissions from the point sources measured.

D. METHODOLOGY

Bench Testing – InnoTech Alberta

The test setup consisted of pressure-regulated laboratory air or pure compressed methane supplied through a 1-inch Ventsentinel® in series downstream of Alicat Mass Flow Controllers (MFCs). Additional detail on the work completed at InnoTech Alberta is included in Appendix A.

Flow through the meters was varied between 0 to 180.0 Sm3/d and 0 to 7.0 Sm3/d. To ensure fully developed flow, 24-inches of straight 1-inch Sch. 40 pipe was installed upstream and 12-inches of straight 1-inch Sch. 40 pipe was installed downstream of the Ventsentinel®. Not shown in Figure 1 a diaphragm-type dry test meter (DTM) was installed downstream of the 12-inch straight section. The DTM was only incorporated early in the project where its function was to provide a secondary confirmation of the volumetric flow rate via manual recordings of the dial readouts. The MFCs and Ventsentinel® communicated with a data acquisition system to digitally record the flow measurements.

As noted by Tangent Design Engineering, the Ventsentinel® is calibrated to transmit flow data corrected to the standard temperature and pressure (STP) of 101.3 kPaa and 25°C. The Alicat MFCs were consistent in this setting; therefore, the flowrates from all three sensors were recorded at the same STP conditions.

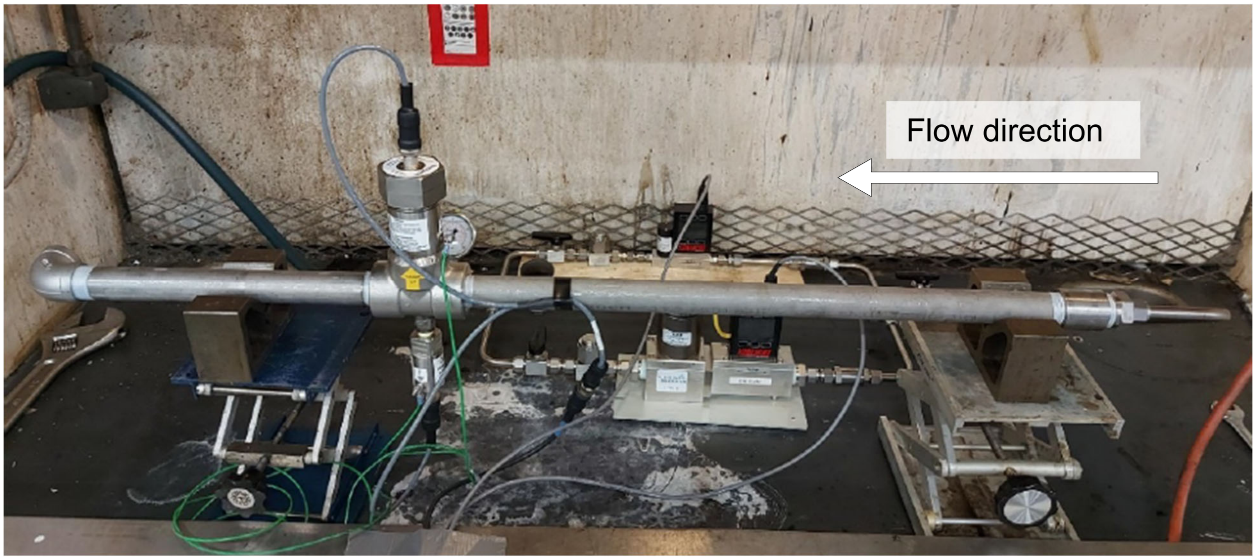


Figure 1: Flow Test Setup - Alicat Mass Flow Controllers and 1-inch Ventsentinel® installed in fumehood

Compressor Packing Vent Testing – Cenovus Energy

Spartan Controls and GreenPath met at site on October 18, 2021 to obtain flow measurements from multiple compressors for the day. Of the four (4) compressors tested, only two (2) were emitting enough gas to be tested with GreenPath's Hawk 9000 positive displacement flow meter.

As shown in Figure 2, a pipe away vent line was connected between the compressor packing vent on site and the 1 In. Ventsentinel® to have simultaneous testing.

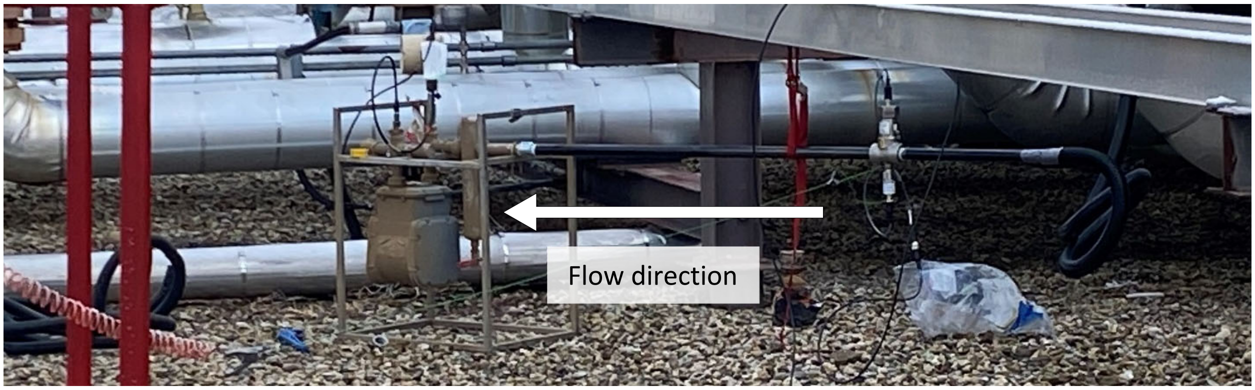


Figure 2: Flow Test Setup - Calscan Hawk 9000 and 1-inch Ventsentinel® installed at compressor station

Atmospheric Tank Testing – CMC Research Institute

Spartan Controls, Ventbuster Instruments and Align Energy Services met at site on Mar 3, 2022 to obtain flow measurements from two 100-barrel atmospheric storage tanks over a 24-hour period. A high-pressure natural gas source (mostly methane) was brought to site filled from the ATCO CNG station in Lethbridge. The high-pressure gas from the trailer went through a two-stage regulated pressure reduction and a finned heat exchanger before connection to a Alicat MFC that introduced the gas into the atmospheric tank and a set flow rate. The tanks were pre-fit by Align Energy Services with the needed inlet piping and pipe away vent connection and new thief hatches. Each tank was filled with 40 barrels of water/methanol mix to be representative of process fluid in the tank at operating sites.

The flow rates were adjusted with randomly selected flow rates between 0 and 1,700 m^3/d. Opening and closing a manual valve was also carried out to simulate dumping fluid into the process vessel from an upstream separator. With the Alicat MFC set at 11.6 m3/d, both flow meters were left overnight to trend the impact of ambient temperature on the Ventsentinel® flow measurements. The Alicat MFC was insulated under a tarp with an oil-bath heater to help maintain a more consistent warmer temperature because the Alicat was not rated for use with ambient temperatures that night.

As shown in Figure 3 and Figure 4, a pipe away vent line was connected between the top of the tank and the 2-inch Ventsentinel® to have simultaneous testing.

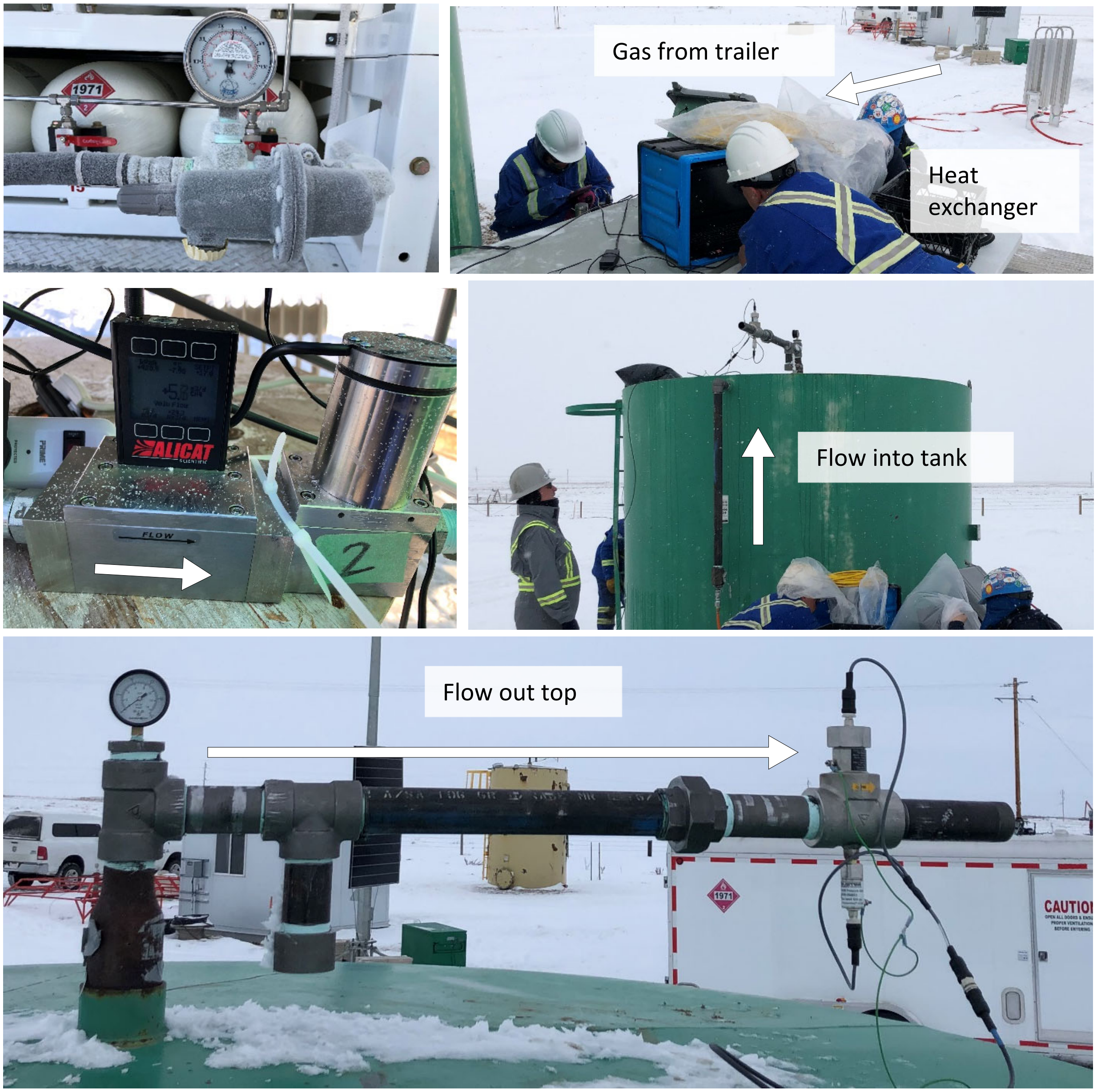


Figure 3: Flow Test Setup - Alicat Mass Flow Controller and 2-inch Ventsentinel® installed at CMC RI

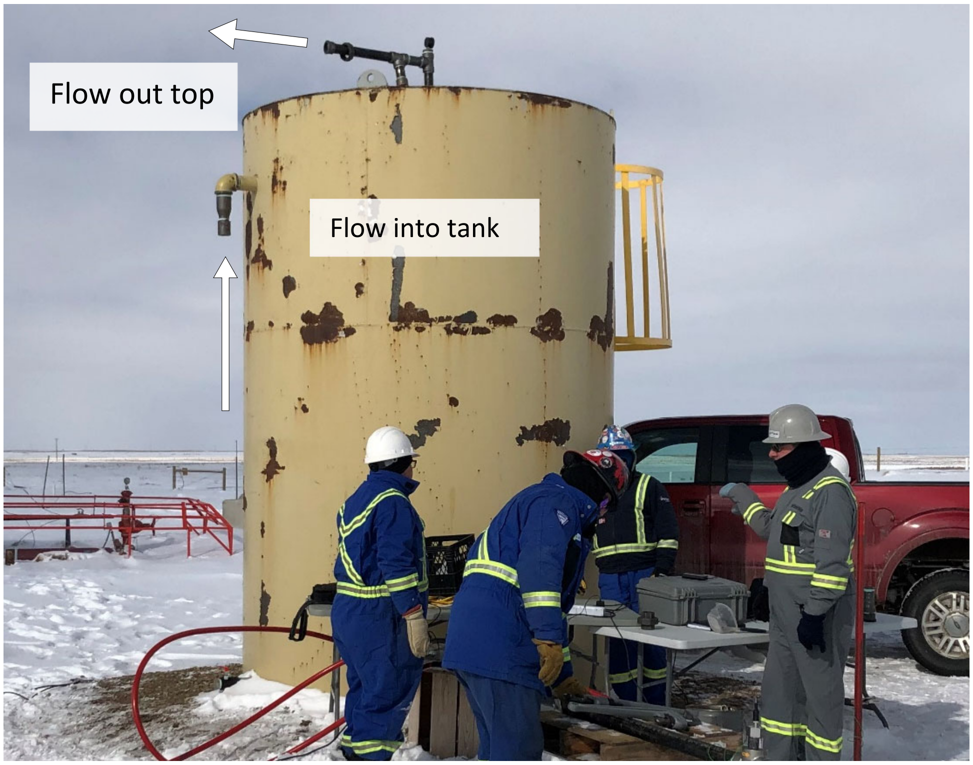


Figure 4: Flow Test Setup - Other 100bbl tank at CMC RI

Atmospheric Tank Testing – Bonavista

Spartan Controls and CEI met at site on April 28, 2022 to confirm scope of the installation. Due to the delay in the remote solar package construction, the install was moved to the following Monday.

On May 5, 2022 the installation was completed, and the flow measurements began logging from the 400-barrel atmospheric storage tanks. Like testing at CMC RI, the Ventsentinel® was hooked up to the discharge piping at the top of the tank. This tank was in service as a production site. For that reason, a pressure vacuum relief valve will be installed to ensure that the operating pressure in the tank stays between its minimum and maximum allowable working pressures.

Figure 5: Ventsentinel® meter installed on 400-bbl tank with remote monitoring infrastructure to remotely data log the ongoing flow measurements and other measurement variables

E. PROJECT RESULTS

Bench Testing – InnoTech Alberta

The Ventsentinel® metered test results compared quite favourably with those of the Alicat MFC. Figure 6 shows the measurements from a test where the Alicat MFC and Ventsentinel® were subjected to random, intermittent air flow from 0 to 150.0 Sm^3/d. The Ventsentinel® responded well and tracks the step changes in the flow rate. In some occurrences, the Ventsentinel® underpredicted the flow rate by approximately 10.0 Sm^3/d when subjected to upward step changes to 50.0 Sm^3/d or less (i.e., Steps 1, 5, 8, 10, 11, 19). This resulted in large relative errors for these flow intervals. For all other step changes, the Ventsentinel® demonstrates good performance and comparable to the previously discussed air and methane tests. For these flow steps, acceptable relative errors within +/- 6.1% are seen.

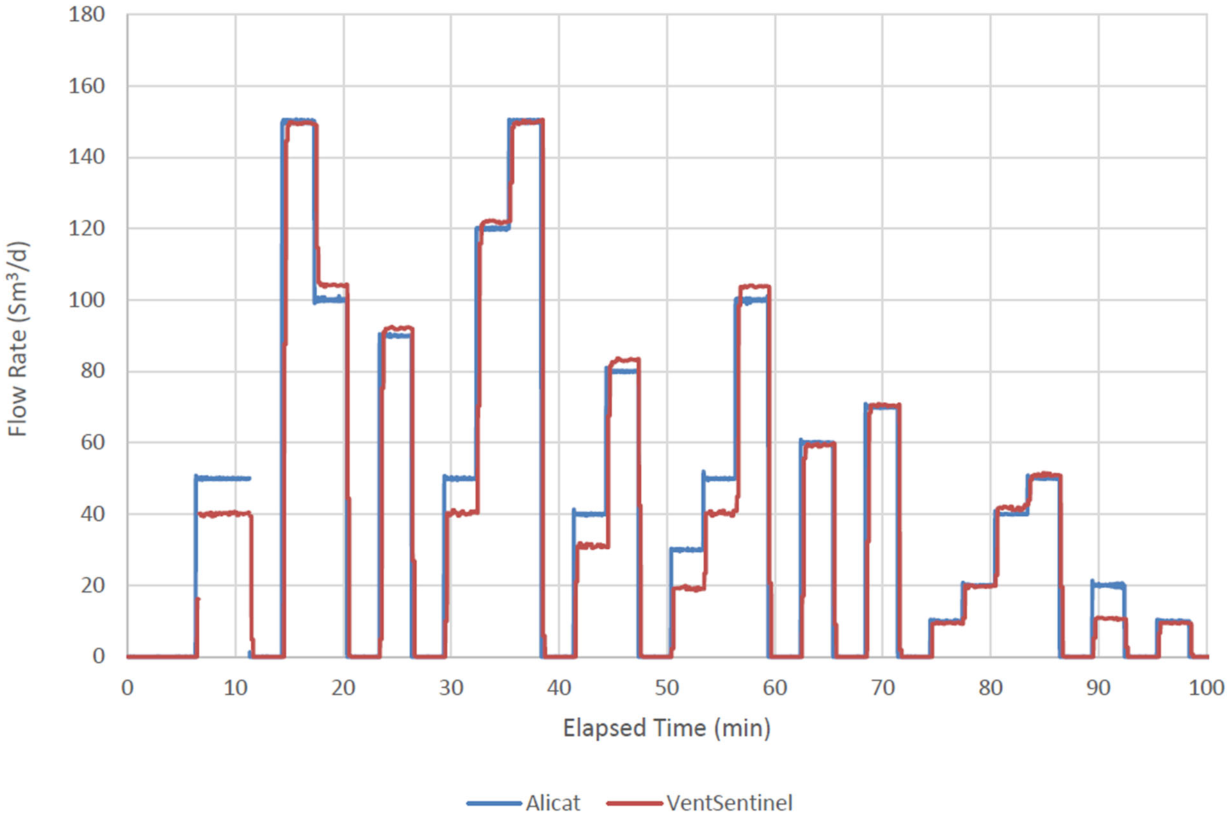


Figure 6: Standard measurements of air flow at random, intermittent rates

The Ventsentinel® was found to be immune to hysteresis effects, performed well with methane and air process media. Maximum relative error for low flow rates (0.5 to 7.0 Sm3/d) was 8.5% and for high flow rates (2.5 to 175.0 Sm3/d) was 6.1%. Relative error with methane process media was found to be lower than air by about 3%.

Inspection of the sensor from a Ventsentinel® used previously in the field measuring casing head gas on a Cenovus (Husky) Cold Heavy Oil Production with Sand (CHOPS) tank well in the Lloydminster region, showed that the integrity was not severely compromised despite scratches and fouling caused by impurities in the solution gas stream, as observed from images obtained under microscope.

Additional detail on the work completed at InnoTech Alberta is included in Appendix A.

Compressor Packing Vent Testing – Cenovus Energy

Instantaneous flow rates of the Hawk 9000 had wider variation than the Ventsentinel®, which is inherent with how a PD meter operates with X number of rotations in a specific period. That is not detrimental error on a compressor packing vent, which is known to be quite steady and more uniform.

Cumulative flow rates over a 30-minute period yielded Ventsentinel® flow rate that were really close to the Hawk 9000, which was a very positive result. Logged data for both completed tests on vented methane had small difference between each other as shown in Table 2 and Figure 7.

Table 2: Field Compressor Packing Vents Measured

Measured Flow Rate (m3/hour)	Ventsentinel®	Hawk 9000
Test 1	0.277	0.283
Test 2	0.300	0.283

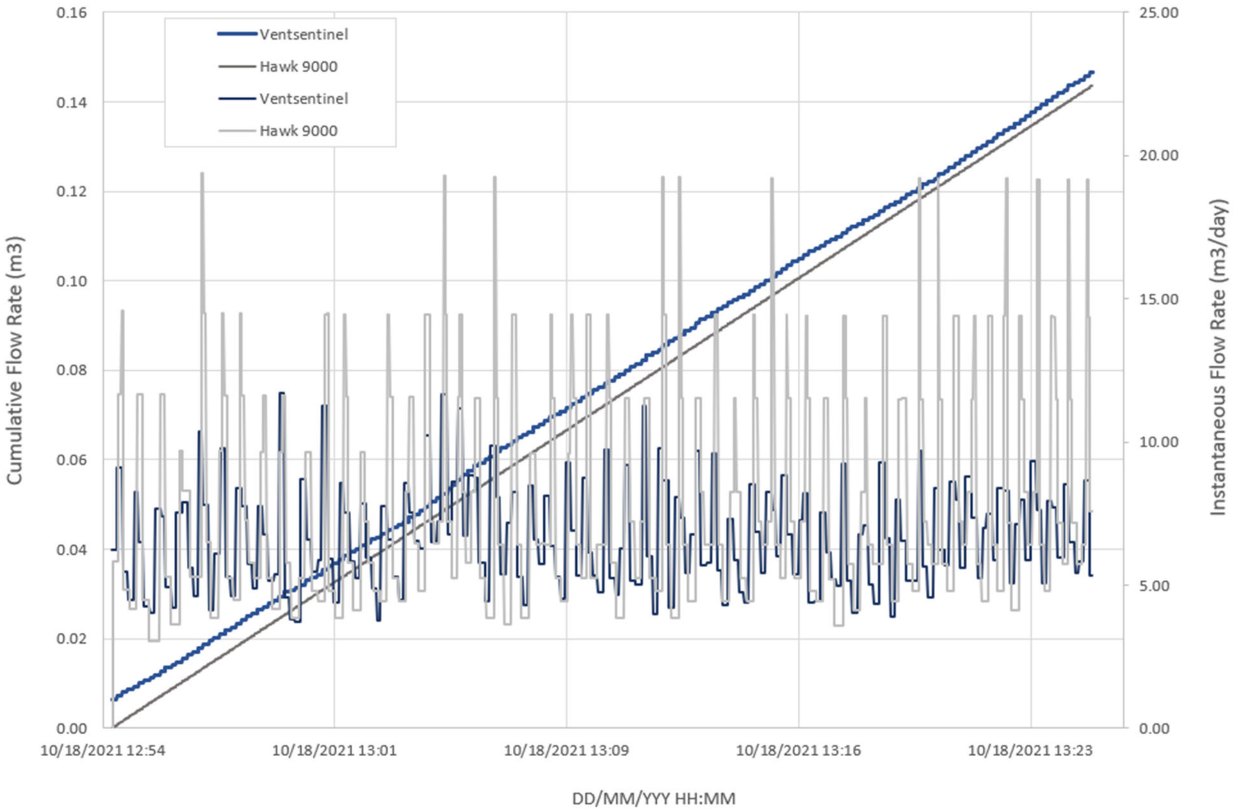


Figure 7: Ventsentinel® and Hawk 9000 compressor packing vent measurement (Test 1)

There was very little variation in the flow rate measured though, which didn't provide indication of how it the units would perform on dynamically active point sources nor at higher flow rates.

Atmospheric Tank Testing – CMC Research Institute

A weather front came through at 4:35pm, which resulted in a temperature drop of 4 degrees Celsius. Shortly after, some of the methane supply bottles from the trailer were almost depleted and were switched over to higher pressure bottles. That was observed with the Alicat temperature dip between 5:17pm and 5:45pm. The temperature recovered a bit and the Joule-Thompson effect was mitigated with the rebalance of the 2-stage pressure cut from the trailer gas supply. Proportionality is noted between CMC weather station measured ambient temperature and that of the Alicat MFC and Ventsentinel®. The lag effect in measured temperature is anticipated because of the relatively warm trailer gas and water/methanol solution in the atmospheric tank providing some heat transfer to the gas media. Temperature is important for proper conversion of measured process to standard conditions.

Figure 8: 100-barrel green tank process and ambient temperature measurement

Ventsentinel® flow measurements relative to the Alicat MFC the Ventsentinel® logged data were found to be high above 120.0 m^3/d. Instantaneous and cumulative averaged measured flow rates from the Ventsentinel® were very close to each other. As shown in Figure 9, good repeatability was observed with the manual valve opening and closing between 5:30pm and 6:30pm. One exception to measuring high above 120.0 m^3/d was observed at 5:15pm with the increase in Alicat MFC flow rate from 544.0 m^3/d to

1,019.0 m^3/d, which is when the trailers bottles were switched as described earlier. That measurement was considered an outlier and removed from the data set. A non-linear correction factor was needed to get proportionality. This is understandable as the prototype Ventsentinel® had not been calibrated above 720m^3/d on the bench due to limited air compressor capacity in the shop.

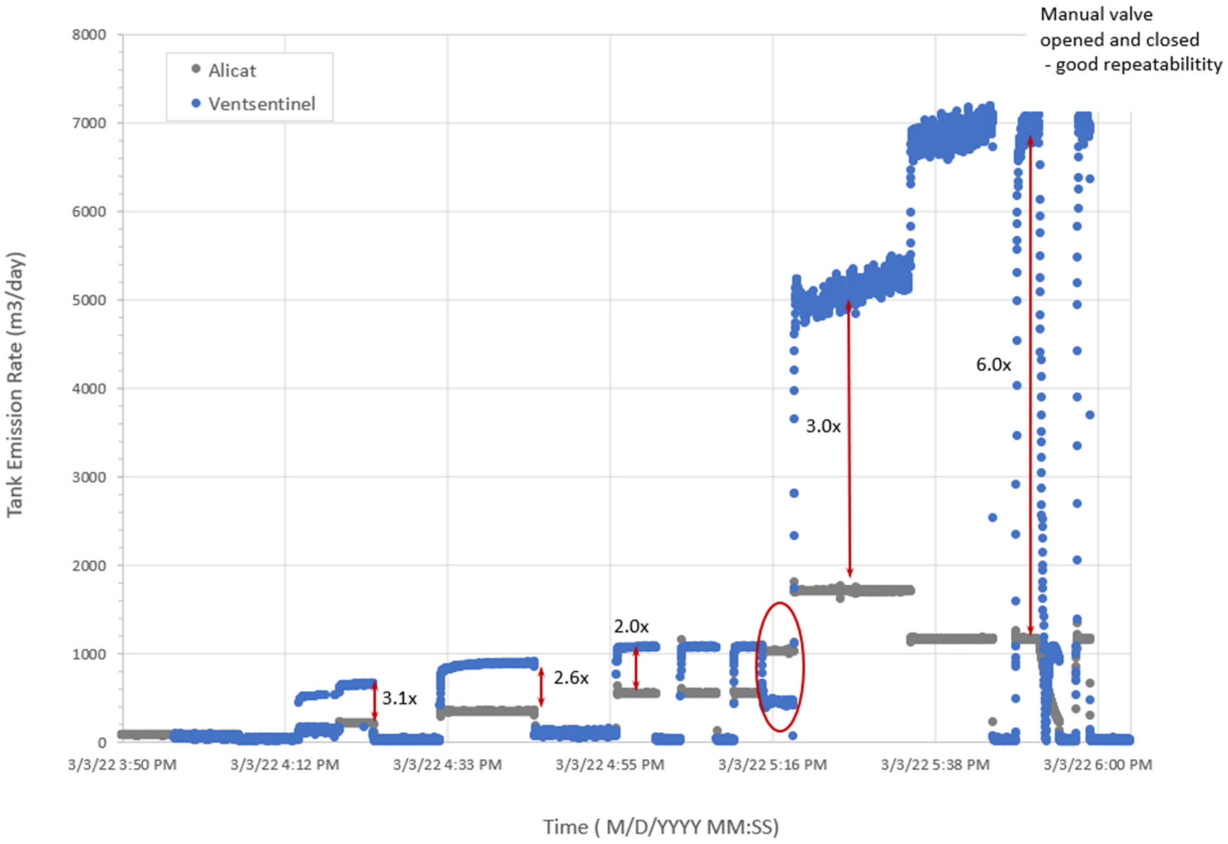


Figure 9: 100-barrel green tank process flow measurement

Audible observations at site found that the flow heard at 1,700 m3/d was not much louder than was heard at 500 m3/d, which made us unsure if the Alicat flow rates on the display were representative of the flow passing through the meter. Additional testing was needed with a meter rated for higher flow rates. That was carried out on the second tank on Day 2 with a NUFLO Scanner 2000 V-Cone differential pressure flow meter, but the data obtained from that meter was not consistent nor conclusive.

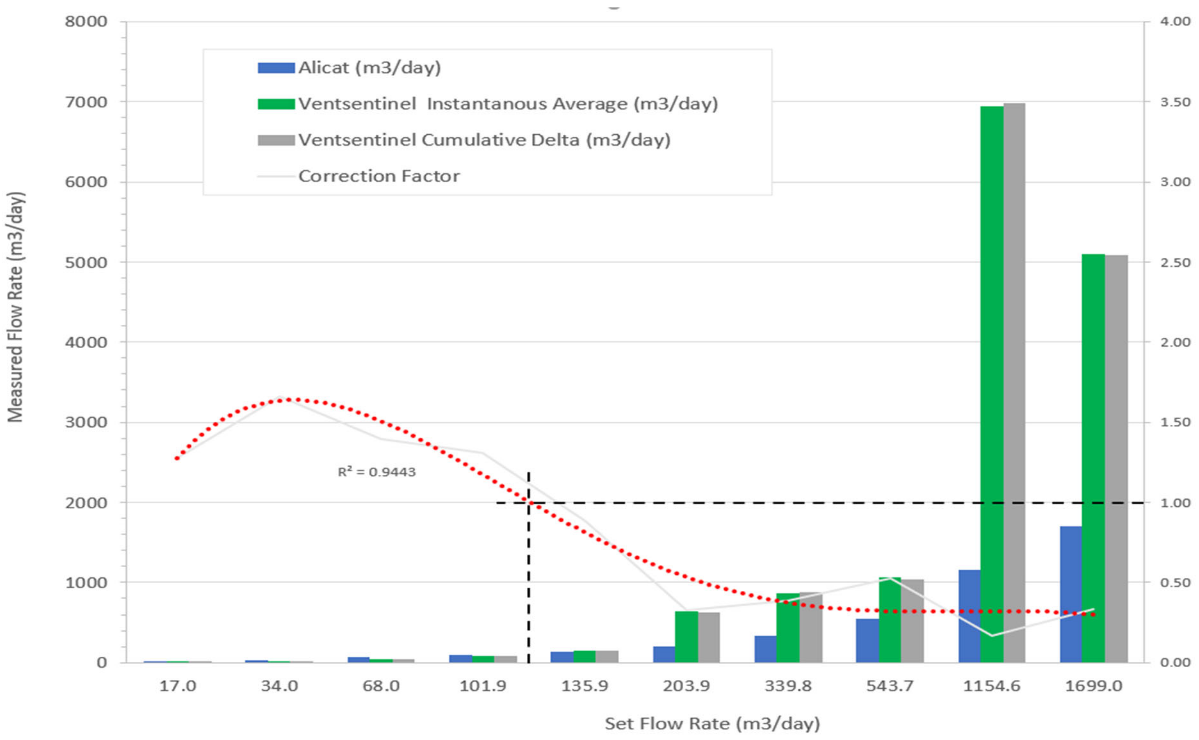


Figure 10: Measured vs. Alicat MFC Set Flow Rates

This 5th order polynomial was a good fit with an R^2 of 0.9443 showing good correlation. Even a 3rd order polynomial is a fair approximation to correct measured flow rates with an R^2 of 0.9062. This approach was taken on step further to determine a correction equation with 5% or less error relative to the Alicat measurements. Results using this equation are included in Table 3.

$$C = \left(1 + \frac{M-S}{S\ or\ M}\right)^{\left(\frac{M}{S}\right)} x\ M\ /\ \left(1 + \frac{M-S}{S\ or\ M}\right)\ x\ K$$

Where:

- C is the corrected measured flow rate (m3/d)
- M is the measured flow rate (m3/d)
- S is the set flow rate (m3/d)
- K is the adjustment factor that would be set with calibration testing up front
- S or M is shown in the denominator of the first term of the equation where at 120 m^3/d, S or M are interchangeable
    - S is used below 120 m3/d the Ventsentinel® was reading low
    - M is used above 120 m3/d the Ventsentinel® was reading high
- $M\ /\ \left(1 + \frac{M-S}{S\ or\ M}\right)\ x\ K$ in the above equation is only used with flow rates above 120 m^3/d

Table 3: Ventsentinel® Corrected Flow Rates

Alicat Set Flow Rate (m3/d)	Alicat Measured Flow Rate (m3/d)	Ventsentinel® Measured Flow Rate (m3/d)	Correction Factor	Corrected Ventsentinel® Measured Flow Rate (m3/d)	Relative Error (%)
17.0	17.8	13.3	N/A	17.1	0.6
34.0	34.0	20.5	N/A	35.7	5.0
68.0	68.0	48.7	N/A	69.0	1.5
101.9	101.9	78.0	N/A	102.8	0.8
135.9	135.9	153.5	1.4	131.3	-3.4
203.9	203.9	629.1	1.4	197.9	-3.0
339.8	339.8	884.0	1.4	329.0	-3.2
543.7	543.7	1033.8	1.4	542.2	-0.3
1154.6	1154.7	6830.8	1.4	1198.9	3.8
1699.0	1699.1	5089.3	1.4	1647.1	-3.1

The Ventsentinel® was left in service overnight with a set flow rate of 11.6 m3/d from the Alicat MFC. Results are show in Figure 11. The ambient temperature dropped as low as -20°C. The Alicat MFC was not rated to temperatures that low and was kept under a tarp with an oil bath heater. The Ventsentinel® measured process temperature was kept relatively constant between -4 °C and -7 °C the until 5:00am at which time the heater appears to have turned off and the temperature dropped to -12°C. It then turned on again and got the process temperature back up to -5°C by 9:00am. With some outliers, the instantaneous point flow measurements largely ranged between 0 and 40 Sm3/d. The temperature variation had little effect on the Ventsentinel® as shown by the linearity of the totalized volume. Despite the ambient and process temperature changes, the measured average flow rate by the Ventsentinel® was 11.3 m3/d with 2.4 percent relative error, which was a very positive result.

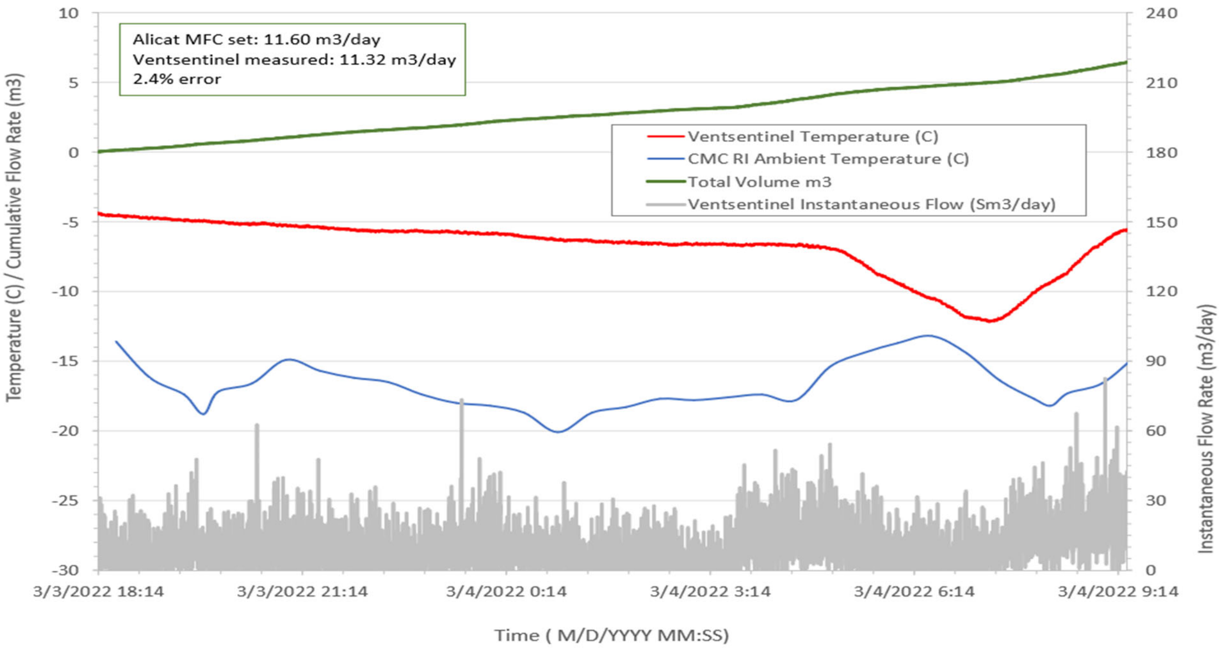


Figure 11: Ventsentinel® Measured vs. Alicat MFC Set Flow Rates with Ambient and Process Temperature

Similar to end of Day 1 testing, the Alicat MFC was set back to higher rates with flow to the green tank for repeatability to see how the Ventsentinel® responded. Good repeatability was observed, but still a proper scaling factor needed to be applied to higher flow rates.

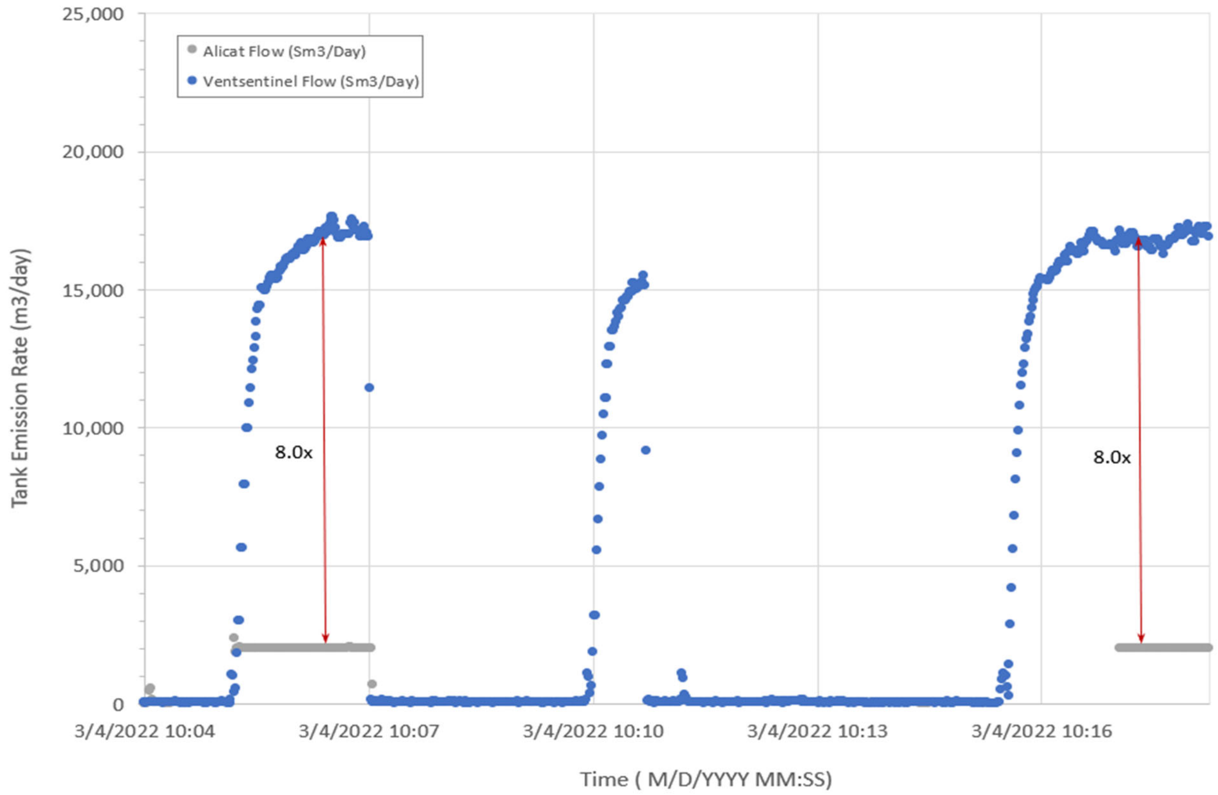


Figure 12: 100bbl green tank process flow measurement - Day 2

Testing with on the taller 100-bbl yellow tank on Day 2 showed similar results. Proportionality was observed, however the Ventsentinel® measured higher than actual at flow rates above 120 m3/d as shown in Figure 13.

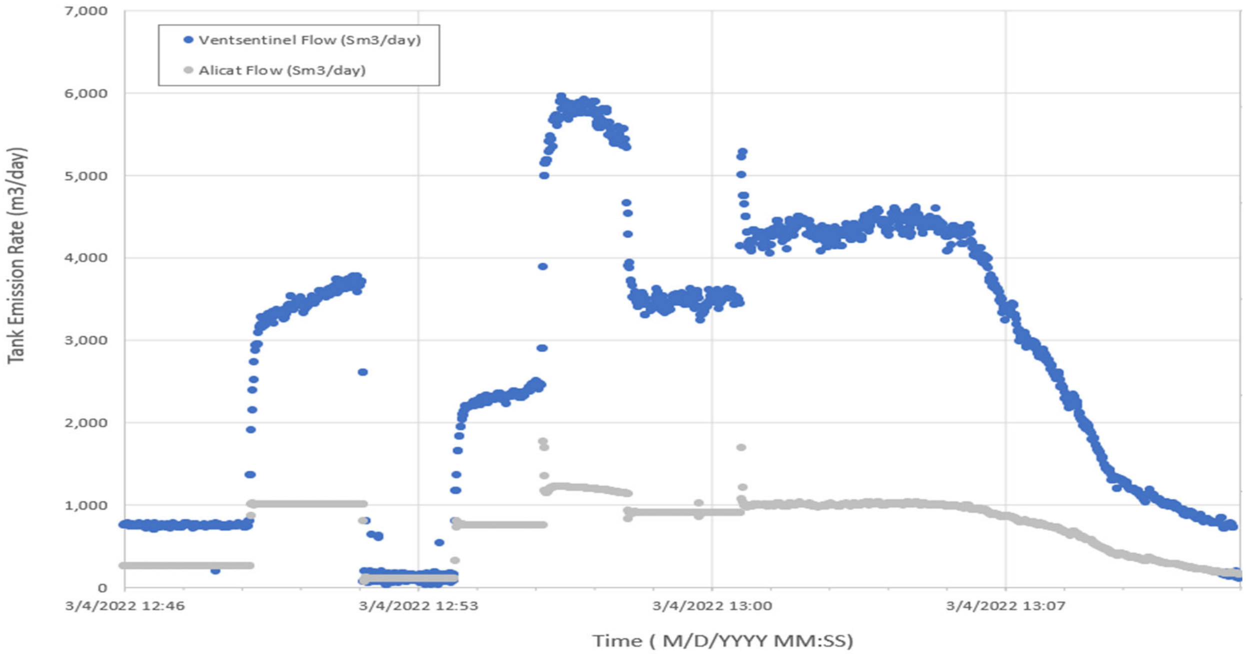


Figure 13: 100-bbl yellow tank process flow measurement - Day 2

Atmospheric Tank Testing – Bonavista

Preliminary qualitative insights have been gathered from site as shown in in Figure 14. More data will be gathered from this site with it staying in service as a permanent meter installation and will be included in the Phase 2 update to this report.

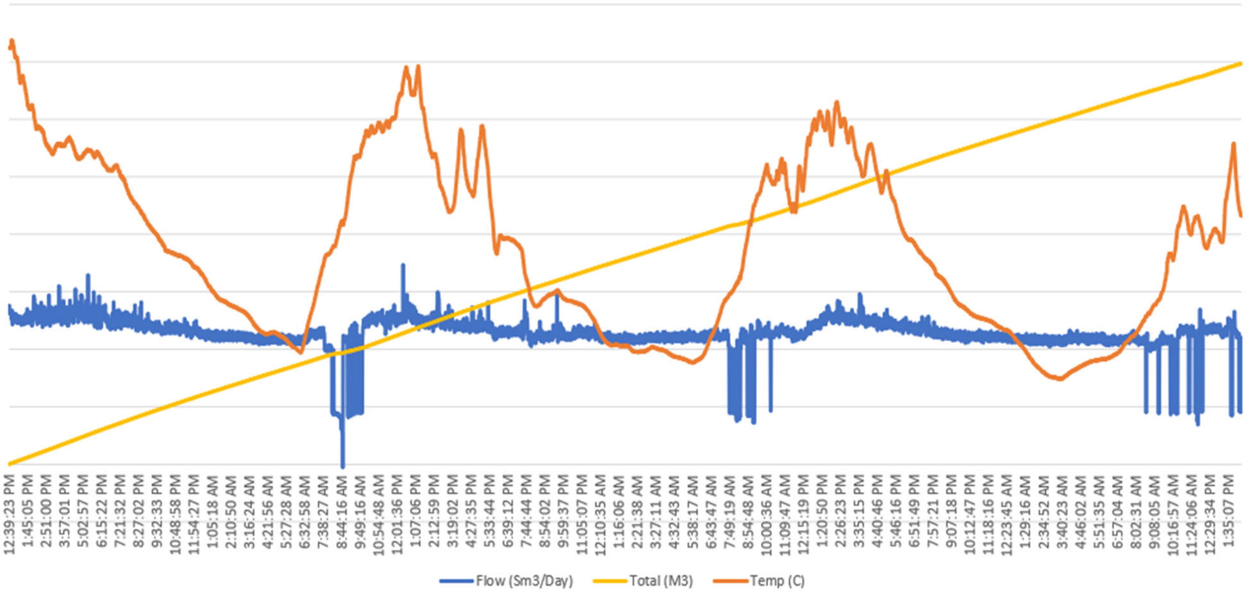


Figure 14: 400-bbl Ventsentinel® instantaneous and cumulative flow rates with process temperature

F. KEY LEARINGS

Project Scope

- Developing a new measurement technology is challenging.
- There is uncertainty in all measurements. The Hawk9000 wasn't suited for measurement of some of the compressor packing vents and the Alicat MFC was unable to set and maintain higher flow rates. At high flow rates, the Ventsentinel® measured high by several multiples until scaled properly.
- Any field measurement is only able to provide insight on what is happening if the duration is long enough to be considered representative.
- Atmospheric tanks are very dynamic and subject to emit dynamically active volumes depending on ambient conditions, the amount of light ends in the liquid stored in the tank, the liquid flow rates in and out of the tank and the ambient pressure and temperature. The Ventsentinel® allows tanks to "breathe" and does not induce a backpressure.
- Bench tests only go so far. Field efforts are essential to ensure the needed durability, accuracy and reliability is built into the design of a flow meter. Important factors such as how well the flow meter is grounded are paramount. Other factors such as suitability to different media is important. The Ventsentinel® does not need to be recalibrated, where others do.
- The measurement needs to be fit-for-purpose and cost effective – there are often considerations that are missed when flow meters are deployed in the field and that only adds cost to field deployment. The Ventsentinel® is designed to be deployed on virtually all atmospheric vents.
- Atmospheric point source measurements need to be obtained with view to the broader assembly and ease of use.

Broader Impacts

- It's important to be mindful of some of the limitations and caveats; when carrying out a HAZOP prior to installation of flow meters on atmospheric point sources, what could happen and is there risk or negative consequence associated with that?
    - Connecting a flow meter without a drip leg in the upstream piping; liquid in the process may be detrimental to obtaining reliable field measurements.
    - Specific upstream and downstream pipe lengths are beneficial to obtaining good field data but may be difficult to obtain in all measurement situations.
    - Leaky gaskets in the process piping connection.
    - Being cognization of other point sources that are part of the pressure boundary – flow will take the path of least resistance (PVRVs, thief hatches, ERVs, compressor crankcase, etc.).
- Achieving 45% methane reductions in the upstream oil and gas industry by 2025 and 75% by 2030 is a considerable task. Being able to achieve that outcome requires focus on all forms of atmospheric point sources through regulations, policies, and approval and permitting processes

that are Specific, Measurable, Achievable, Reasonable and Timely (SMART) and predictable because uncertainty equals risk.

- Being able to optimize performance and/or verify compliance requires a good understanding of the baseline. Without such an analysis cannot be carried out, retrofit options cannot be evaluated nor can solution be implemented.
- Not all point source emissions are problematic, including atmospheric tank emissions and compressor packing vents as were field measured in this project. Similar to other atmospheric point source emission sources including, but not limited to, instruments, pneumatic pumps, cactus dryers, surface casing vent flow, engine blow-by, crankcase vents, blowdown valve leaks, valve packing leaks, flange gasket leaks, non-combusted flare volumes, the focus needs to be first on the ones that emit most often or emit the largest magnitude volumes. Tackling those first will be the most cost-effective and provide the greatest gains near term to help waste less and reduce GHG emissions.
- As learned through the Ventsentinel® efforts, there are a variety of approaches that will be considered fit-for-purpose and a good, better, best approach that merits having continuous emission monitoring of some point sources and sampling other point sources on a less frequent basis to provide needed insight.

G. RECOMMENDATIONS AND NEXT STEPS

The near-term plan for the commercialization of the Ventsentinel® is to continue using it at more field sites to make use of a proven technology, improve its performance and make it easier to implement. It is easy to repeat installs that have been done before and future deployments become much more cookie cutter.

Having access to a bench test facility that can provide air and/or methane flow rates up to 7,000 m3/d would be invaluable. Not having access to such keeps testing with higher volumes limited to field applications. As such, the Ventsentinel® is currently undergoing a “calibration project” to fine tune the accuracy to the meter and to extend its calibration range of the 1-inch unit from 0 to 1,200 m3/d and the 2-inch unit from 0 to 6,000 m3/d. The testing carried out at CMC RI was invaluable. Seeing how things hold up (including human tenacity) as the temperature drops below -15°C with a fierce windchill is the real deal. There is no bench test that can replicate that easily.

The learnings from field deployment are invaluable. Per additional support received from CanERIC, next steps to be completed near term are further testing at InnoTech Alberta in applications that include instrument air where the downstream pressure in many applications is 345 to 690 kPag, not atmospheric. Included in that will be a complementary field install to see how well the Ventsentinel® is able to quantify air flow rates. Such is needed to quantify the volume of fuel gas that has not vented in pneumatic systems if carbon offsets are to be generated.

The long-term plan for commercialization of the Ventsentinel® requires more probability that more continuous flow measurements will be needed at upstream oil and gas sites. This patented flow channel technology of the Ventsentinel® has its place in the market to help quantify atmospheric point sources. Greater adoption of its use will increase the scale or deployment and improve its cost-effectiveness.

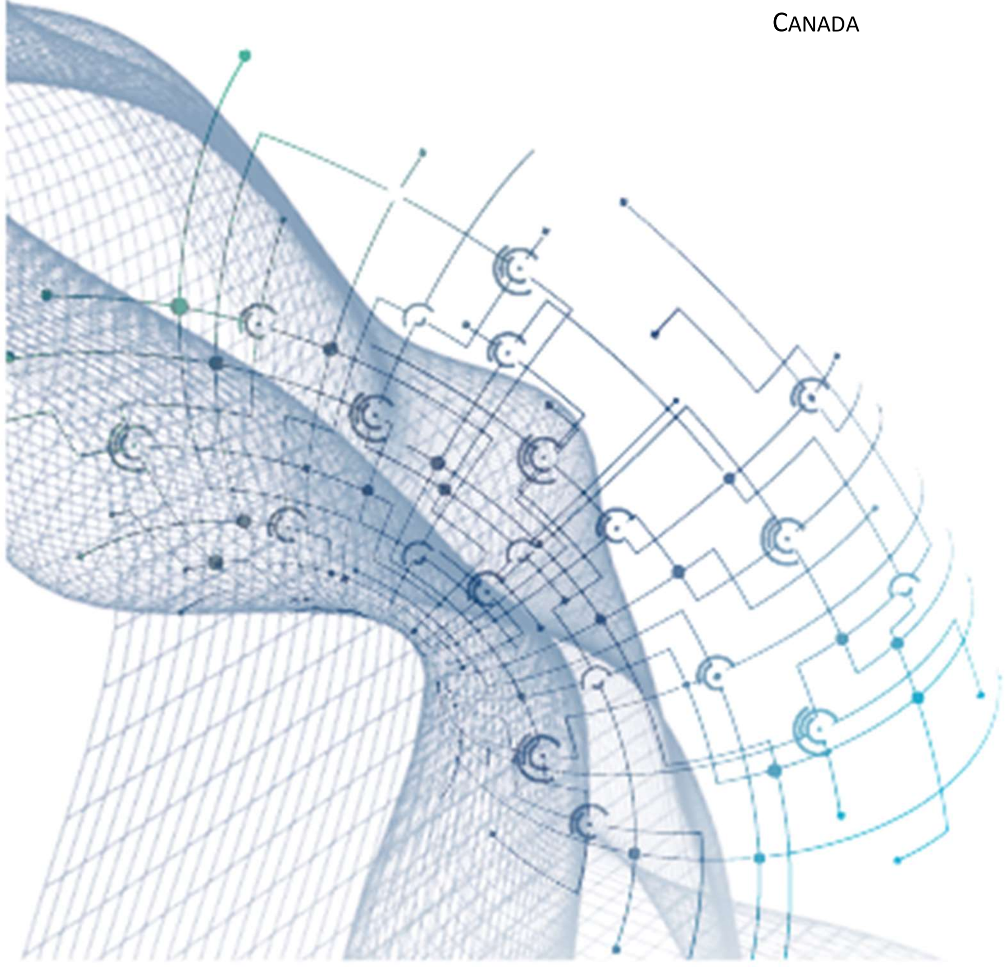
Appendix A: Ventsentinel® Lab Testing

Ventsentinel® Lab Testing

Neil Yaremchuk

Report Prepared for
CENOVUS ENERGY
BY INNOTECH ALBERTA INC.

Energy Services
250 Karl Clark Road
Edmonton, Alberta T6N 1E4
CANADA



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Contract No. C2021000968

April 2022

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NEIL YAREMCHUK

1.0 INTRODUCTION AND OBJECTIVES

Existing meters for measuring GHG emissions are either insufficiently accurate or prohibitively expensive. As a result, there is little information on flow rates from a variety of sources. It is important to quantify flow rates of these sources because they represent potential areas or equipment that are releasing methane. New metering technologies, such as those offered by Ventbuster Instruments, may fill this gap. With support from the Canadian Emissions Reduction Innovation Consortium (CanERIC) and the Petroleum Technology Alliance Canada (PTAC), the objective of this project was to evaluate the accuracy and utility of the Ventsentinel® product under mild service conditions and known gas compositions. This also allows the meter supplier and designers an opportunity to generate diagnostics data during the tests and adjust the design if desired. Finally, a Ventsentinel® flow assembly that was previously put into service to measure gas flow from a Cold Heavy Oil Production with Sand (CHOPS) wellsite was to be imaged under a microscope to provide visual insights on the integrity of the sensor after field deployment.

2.0 FLOW TEST APPARATUS

As shown in Figure 1, the test setup consists of pressure-regulated laboratory air or pure compressed methane supplied to two Alicat Mass Flow Controllers (MFCs) installed in a parallel flow pattern. The two units allow for a high-flow range up to 180 Sm^3/d and low-flow range up to 7 Sm^3/d. Specifications of the two MFCs are shown in Table 1. A 1” Ventsentinel® flow meter assembly is installed downstream of the MFCs. To ensure fully developed flow, 24” of straight 1” Sch. 40 pipe is installed upstream and 12” of straight 1” Sch. 40 pipe is installed downstream of the Ventsentinel®. To ensure proper operation of the sensor, the ground wiring from the flow meter assembly was connected to a reliable ground source within the lab. Not shown in the Figure 1 a diaphragm-type dry test meter (DTM) was installed downstream of the 12” straight section. The DTM was only incorporated early in the project where its function was to provide a secondary confirmation of the volumetric flow rate via manual recordings of the dial readouts. The MFCs and Ventsentinel® communicate with a data acquisition system to digitally record the flow measurements.

For accurate measurement from the Alicat MFCs, the devices rely on the user to input the composition of the flowing gas into the device’s settings and allows the specific heat capacity of the gas to be known. In this study the manufacturer-supplied presets of Air (Clean Dry) and Methane were used. A very interesting feature of the Ventsentinel® is that it does not require this input; therefore, the sensor was applied “as-is” and no hardware or software modifications were required by InnoTech Alberta lab staff.

As noted by Tangent Design Engineering, the Ventsentinel® is calibrated to transmit flow data corrected to the standard temperature and pressure (STP) of 101.3 kPaa and 25°C. The Alicat MFCs were consistent in this setting; therefore, the flowrates from all three sensors were recorded at the same STP conditions. The DTM measures the cumulative volume of flowed gas at actual conditions. DTM flow rates are determined by visually recording the beginning and end cumulative volumes over a measured time interval and calculating the average, actual flow rate. The outlet of the DTM is vented directly to atmosphere in the fumehood and the pressure drop though the meter is negligible; therefore, it can be assumed that gas flow is at atmospheric pressure. This value is measured and recorded by the Alicat MFCs and compared against an in-house barometric pressure transmitter for confirmation. The Alicat MFCs were also used to measure and record the temperature of the flowing gas which is compared against a handheld thermocouple reader for confirmation. Combined with the ideal gas law, these measurements are then used to convert the average, actual DTM flow rate measurement to consistent STP conditions.

Figure 1: Flow test setup with two Alicat Mass Flow Controller and 1" Ventsentinel® installed in a fumehood.

Parameter	**Specification**
Model Number (High-Range MFC)	MCR-100SLPM-D-X/CM,CIN
Model Number (Low-Range MFC)	MC-5SLPM-D-X/CM,CIN
Flow Range (High-Range MFC)	0.5 to 100 SLPM
Flow Range (Low-Range MFC)	0.025 to 5 SLPM
Accuracy	± (0.8% of reading + 0.2% of Full Scale)
Repeatability	± 0.2% Full Scale
Zero Shift and Span Shift	0.02% Full Scale / ºCelsius / Atm

Table 1: Specifications of the two Alicat Mass Flow Controllers used in the flow tests

3.0 FLOW TESTING

3.1 ERROR DEFINITIONS

For this study, relative error is presented in the classical terminology of:

$$Relative\ Error = \frac{|Measured\ Value - Real\ Value|}{Real\ Value} \times 100\%$$

Also, for this study, the Alicat MFCs are the considered the “gold standard” that which the Ventsentinel® is compared against. Therefore, the Ventsentinel® measurement is defined as “measured” and the Alicat MFC as “real”. The DTM was incorporated in the project as secondary confirmation or “sanity check” of the Alicat MFC measurement; therefore, the Alicat measurement is defined as “measured” and the DTM as “real” in that comparison.

3.2 AIR – HIGH FLOW RATES

Figure 2 shows a step-up/step-down flow sequence using the high-range MFC and laboratory-supplied air. DTM measurements are shown only for lower rates, as higher rates were difficult to reliably measure. The figure shows that all three flow meters track the step changes well from 0 to 180 Sm^3/d. There is a slight, 10-second lag in the response from the Ventsentinel® which is result of the device’s internal data processing and intentional as part of the sensor design. For field applications with long or continuous measurement periods, this 10 second delay would be negligible. Table 2 shows the relative error when the different flow meters are compared. The table indicates that the Alicat MFC is producing reliable flow rate measurements as they compare closely with the DTM measurements (within +/- 1.6% error). The Ventsentinel® shows reasonably good performance where, when compared against the Alicat MFC, the measurements were within +/- 6.1% error. The step-up/step-down method is used to determine if the sensor is affected by hysteresis. Negligible hysteresis error is present as Step 3 (~80 Sm^3/d upward) and Step 6 (~80 Sm^3/d downward) errors are highly comparable at 4.4% and 4.6%, respectively.

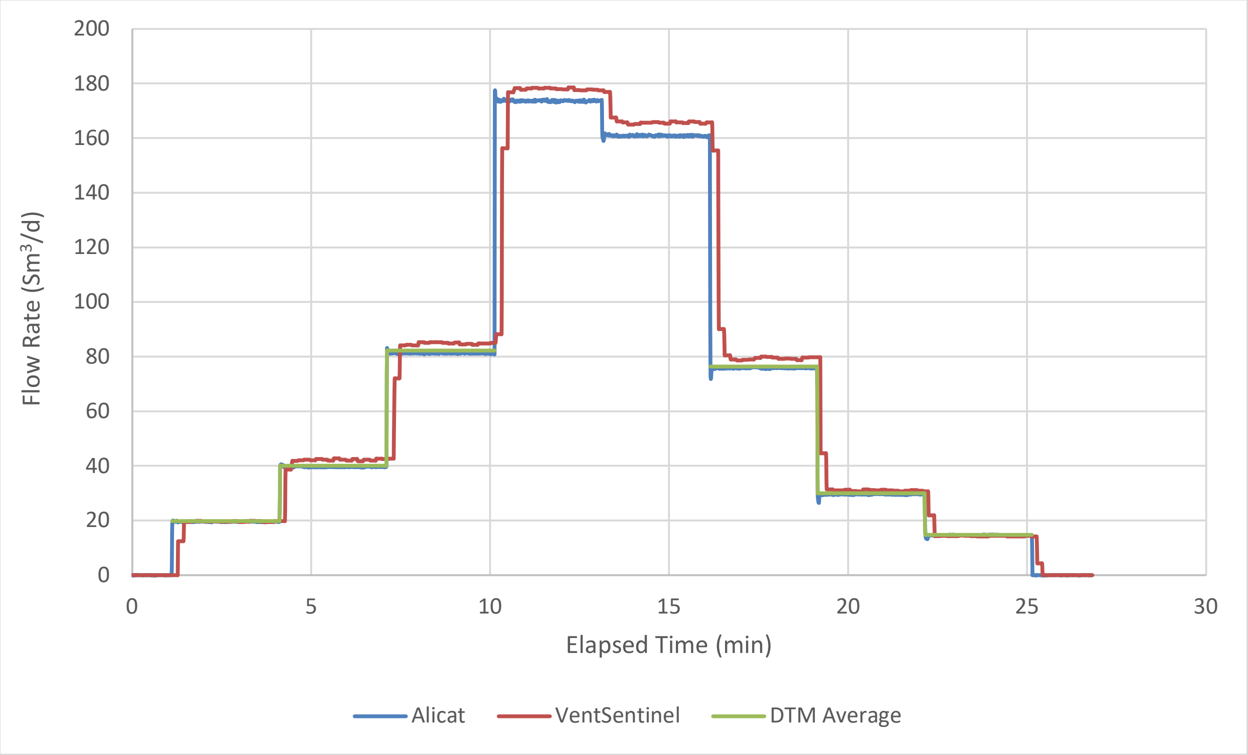

Figure 2: Standard measurements of high-rate air flow from the three different gas meters.

Step	Flow Rate Alicat (Sm^3/day)	Rel. Error Alicat-DTM (%)	Rel. Error VS-Alicat (%)
1	19.7	0.8%	0.2%
2	39.6	1.1%	6.1%
3	81.2	1.3%	4.4%
4	173.7	N/A	2.5%
5	160.9	N/A	3.1%
6	75.8	0.8%	4.6%
7	29.6	1.6%	5.0%
8	14.7	1.1%	2.3%

Table 2. Relative error in the standard measurements of high-rate air flow.

3.3 AIR – LOW FLOW RATES

As shown in Figure 3, the meters were also subjected to low-rates of laboratory-supplied air flow. The step-up/step-down flow sequence was performed using the low-range Alicat MFC. Again, all three meters consistently track the step changes from 0 to 7 Sm^3/d. As expected, the 10-second lag in the Ventsentinel® measurement is again observed. At the highest flowrate step (7 Sm^3/d), the Ventsentinel® measurement signal becomes significantly more “noisy” but is immediately corrected once the downward sequence begins. Table 3 shows the relative error when the different measurements are compared. The Alicat MFC to DTM compared less closely at low air rates as the relative error increased to +/- 2.5%. It can be noted that the DTM readings become less reliable at very low rates due to minimal dial movements and the Alicat MFC should be trusted in providing the more accurate measurement. The Ventsentinel® performance declined slightly at the lower flow rates, when compared against the Alicat MFC, as the measurements increased to within +/- 8.5% error. Similar to the high flow rates, it can be seen that there is negligible hysteresis error as the errors of Steps 4 and 6 (3.5 to 4 Sm^3/d) as well as Steps 3 and 7 (1.5 to 2 Sm^3/d) compare very closely.

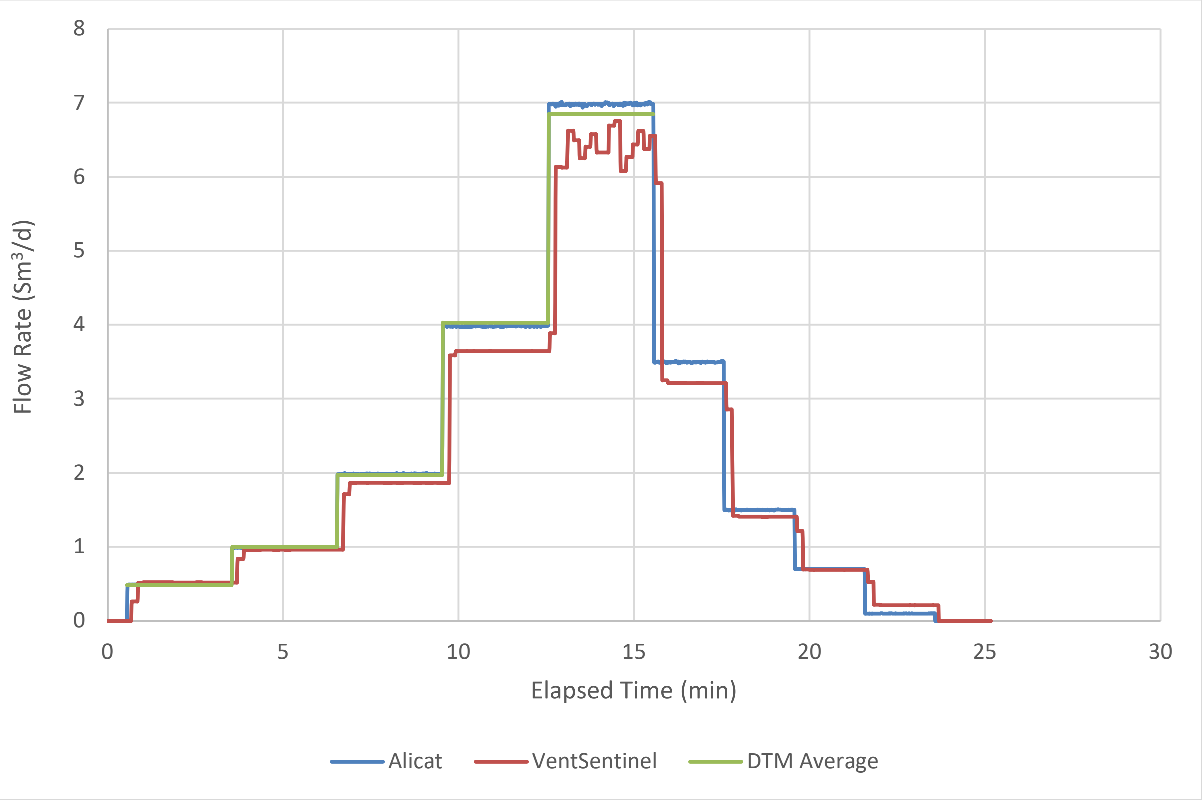

Figure 3: Standard measurements of low-rate air flow from the three different gas meters.

Step	Flow Rate Alicat (Sm^3/day)	Rel. Error Alicat-DTM (%)	Rel. Error VS-Alicat (%)
1	0.5	2.5%	5.4%
2	1.0	0.9%	2.8%
3	2.0	0.7%	6.1%
4	4.0	1.2%	8.5%
5	7.0	1.9%	8.2%
6	3.5	N/A	8.0%
7	1.5	N/A	6.0%
8	0.7	N/A	1.3%

Table 3. Relative error in the standard measurements of low-rate air flow.

3.4 METHANE – HIGH FLOW RATES

Figure 4 shows the Alicat MFC and Ventsentinel® measurements when exposed to low rates of the pure, cylinder-supplied methane. Since the Alicat MFC was proven to be reliable in the air flow test and to improve the safety of the test apparatus, the DTM was not included in subsequent tests. Figure 4 shows that both meters consistently track the stepwise increases and decreases in the flow rate changes from 0 to 15 Sm^3/d. The rate control of the Alicat MFC was less stable than that of the air tests. This is especially notable on Step 3 (15 Sm^3/d) where the controller and Alicat measurement is oscillating. This oscillation is also observed by the Ventsentinel® and accredits the sensor's impressive sensitivity. These control oscillations are likely at fault for the perceived poor performance of the Ventsentinel® at Step 4 (7.5 Sm^3/d). It is recommended that this data point be excluded. Table 5 shows the relative error of the Ventsentinel® measurement when compared against the Alicat MFC. Excluding the erroneous Step 4, the Ventsentinel® shows very good measurement performance as the relative error is within +/- 3.1%. There is also no notable evidence of hysteresis error.

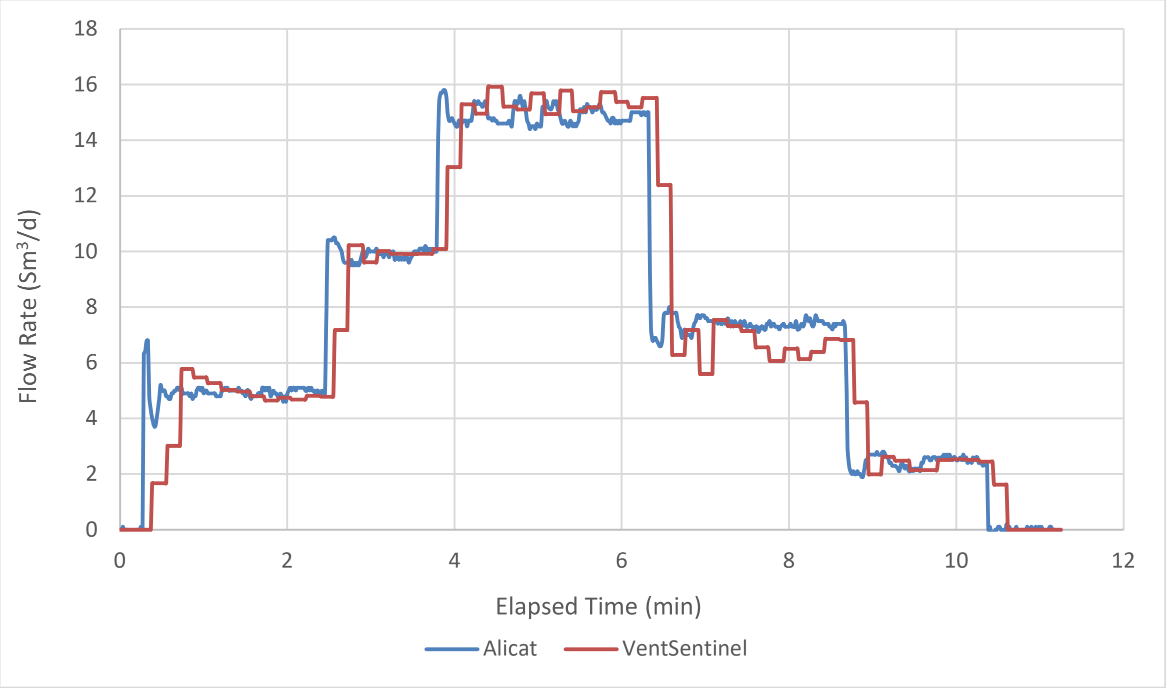

Figure 4: Standard measurements of low-rate methane flow with two different gas meters.

Step	Flow Rate Alicat (Sm^3/day)	Rel. Error VS-Alicat (%)
1	5.0	2.9%
2	10.0	0.7%
3	15.0	3.1%
4	7.5	9.9%
5	2.5	1.1%

Table 4. Relative error in the standard measurements of low-rate methane flow (NOTE: Step 4 is erroneous and can be excluded)

3.5 METHANE – LOW FLOW RATES

As shown in Figure 5, the Alicat MFC and Ventsentinel® were also subjected to low rates of the pure, cylinder-supplied methane. With the exception of Step 1, both meters track the step changes from 0 to 3 Sm^3/d very well. A peculiar occurrence is observed on Step 1 (0.5 Sm^3/d) where, after approximately 20 seconds of stable, accurate measurement, the signal jumps to over double the rate before slowly stabilizing. After which, the flow meter behaves excellently for the remaining step changes. Table 5 shows the relative error of the Ventsentinel® measurement when compared against the Alicat MFC. Excluding the anomaly in Step 1 from the calculations, the Ventsentinel® produced very good quality measurements again where the relative error is within +/- 5.1%. In general. Comparing the relative error of the measurements at the same range of the flow rates of air vs. methane, the Ventsentinel® appears to perform similarly and adequately well with both medias.

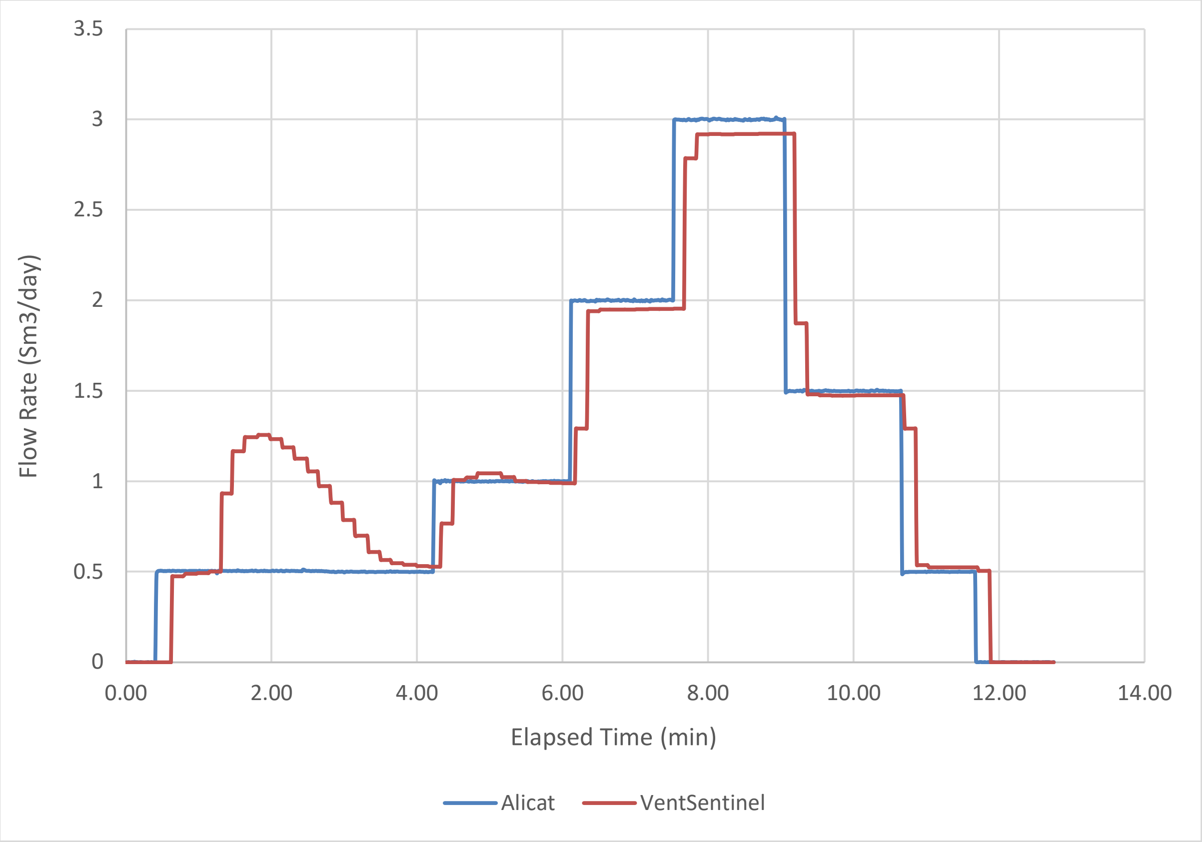

Figure 5: Standard measurements of low-rate methane flow with two different gas meters.

Step	Flow Rate Alicat (Sm^3/day)	Rel. Error VS-Alicat (%)
1	0.5	3.1%*
2	1.0	1.2%
3	2.0	2.6%
4	3.0	3.4%
5	1.5	1.6%

6	0.5	5.1%

Table 5. Relative error in the standard measurements of low-rate methane flow. (*NOTE: Measurement anomaly is excluded from calculation for Step 1).

3.6 AIR – INTERMITTENT FLOW RATES

Figure 6 shows the measurements from a test where the Alicat MFC and Ventsentinel® were subjected to random, intermittent air flow from 0 to 150 Sm^3/d. It can be seen that the Ventsentinel® responded well and tracks the step changes in the flow rate. Table 6 shows the difference in the measured flow rate and the relative error of the Ventsentinel® measurement when compared against the Alicat MFC. In some occurrences, the Ventsentinel® underpredicted the flow rate by approximately 10 Sm^3/d when subjected to upward step changes to 50 Sm^3/d or less (i.e. Steps 1, 5, 8, 10, 11, 19). This results in large relative errors for these flow intervals. For all other step changes, the Ventsentinel® demonstrates good performance and comparable to the previously discussed air and methane tests. For these flow steps, acceptable relative errors within +/- 6.1% are seen.

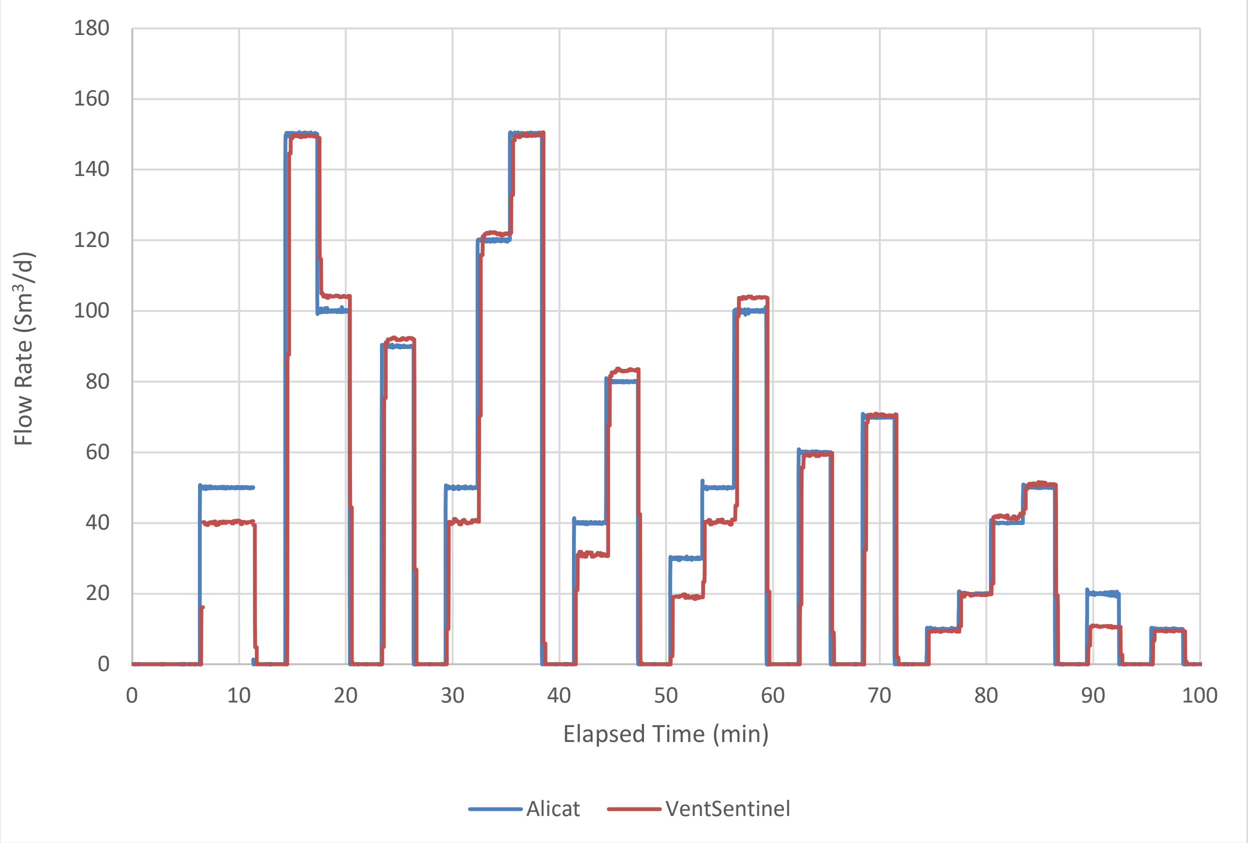

Figure 6: Standard measurements of air flow at random, intermittent rates.

Step	Flow Rate Alicat (Sm^3/day)	Difference VS-Alicat (Sm^3/day)	Rel. Error VS-Alicat (%)
1	50.0	-9.9	24.6%
2	150.0	-0.5	0.3%
3	100.0	4.2	4.0%
4	90.0	2.1	2.2%
5	50.0	-9.6	23.9%
6	120.0	1.8	1.5%
7	150.0	-0.3	0.3%
8	40.0	-8.9	28.6%
9	80.0	3.0	3.6%
10	30.0	-10.9	56.8%
11	50.0	-9.7	24.1%
12	100.0	3.5	3.5%
13	60.0	-0.7	1.1%
14	70.0	0.5	0.7%
15	10.0	-0.6	6.1%
16	20.0	-0.3	1.6%
17	40.0	1.7	4.1%
18	50.0	0.9	1.9%
19	19.9	-9.2	87.1%
20	10.0	-0.6	5.9%

Table 6. Difference and relative error in the standard measurements of air flow at random, intermittent rates

4.0 SENSOR MICROSCOPY

Tangent Design Engineering supplied InnoTech Alberta with a new sensing element (printed circuit board) and V300 flow unit assembly (shown in Figure 7 and contains a printed circuit board) that was previously put into service to measure gas flow at a Cold Heavy Oil Production with Sand (CHOPS) wellsite. As shown in Figure 8, the sensor was received as it was taken out of service (i.e. uncleaned). The sensor was completely functional onsite despite the organic fouling that had accumulated on various areas of the circuit board surface. This fouling made integrity assessments difficult with initial images; therefore, the surface was cleaned with dish soap and water for further imaging. Figure 9 shows a 100X magnification image of the sensor where it appears that all the conductors appear to be intact but diagonal scratches were formed on the polymer surface (assumed from service flow). The 500X magnification of various sets of conductors are shown in Figures 10 to 12 where it appears that the integrity remains intact.

Figure 7: Used and cleaned V300 flow unit.

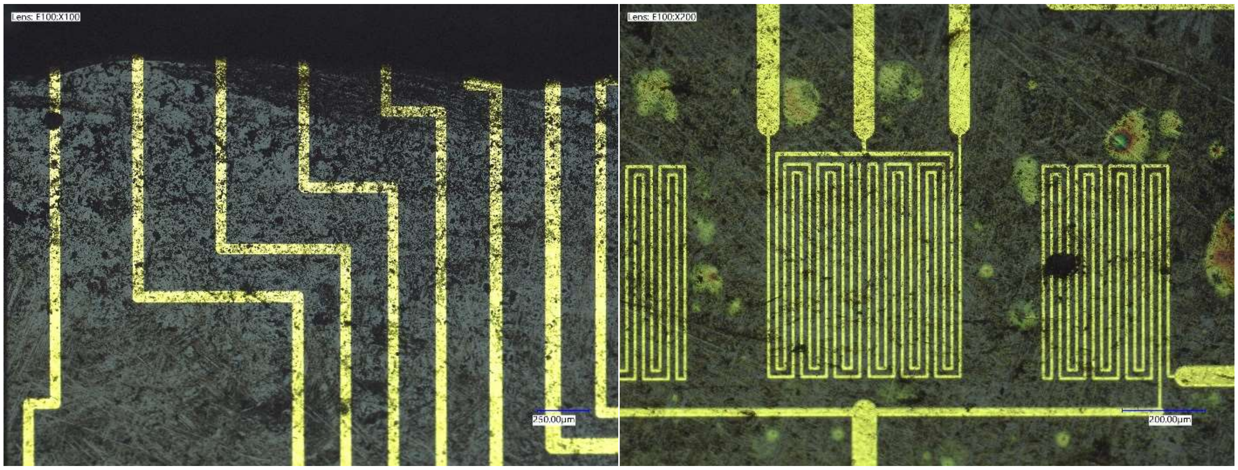

Figure 8: 100X magnification of used, uncleaned sensor (fouled with organics).

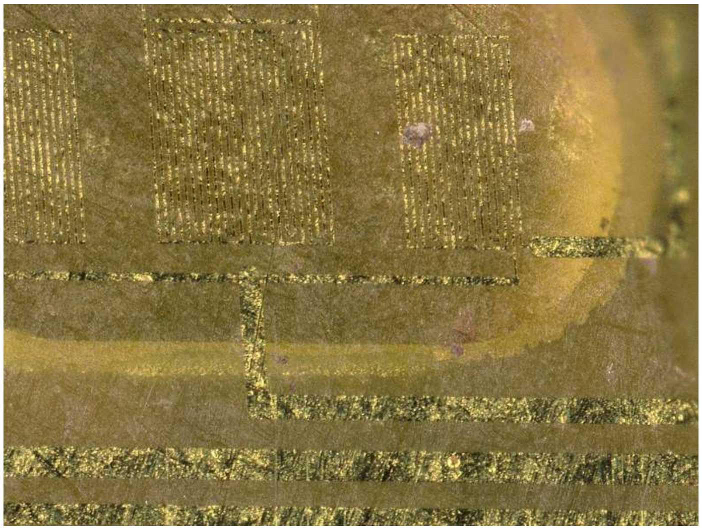

Figure 9: 100X magnification of used, cleaned sensor

Figure 10: 500X magnification of top, thick conductors

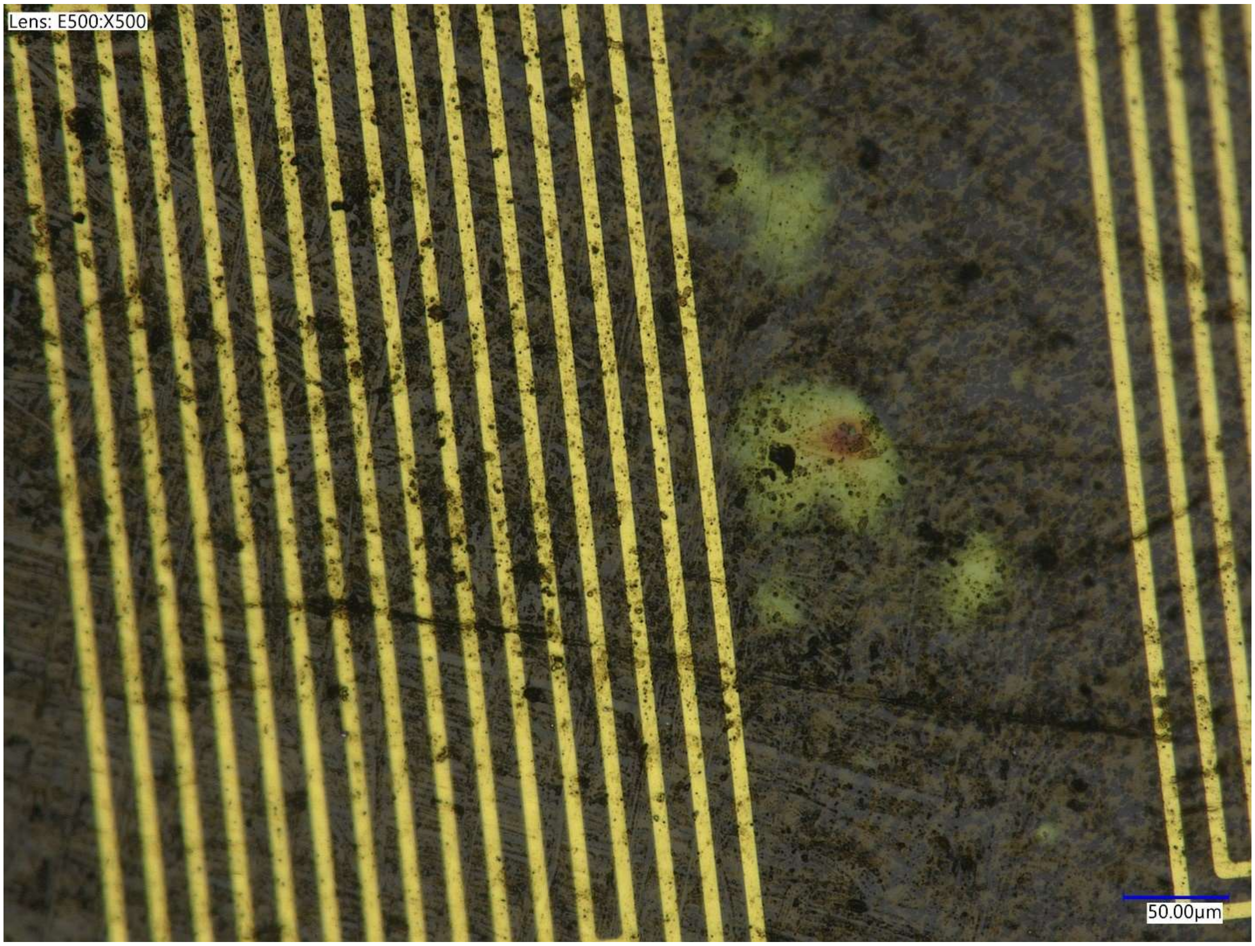

Figure 11: 500X magnification of left set of conductors

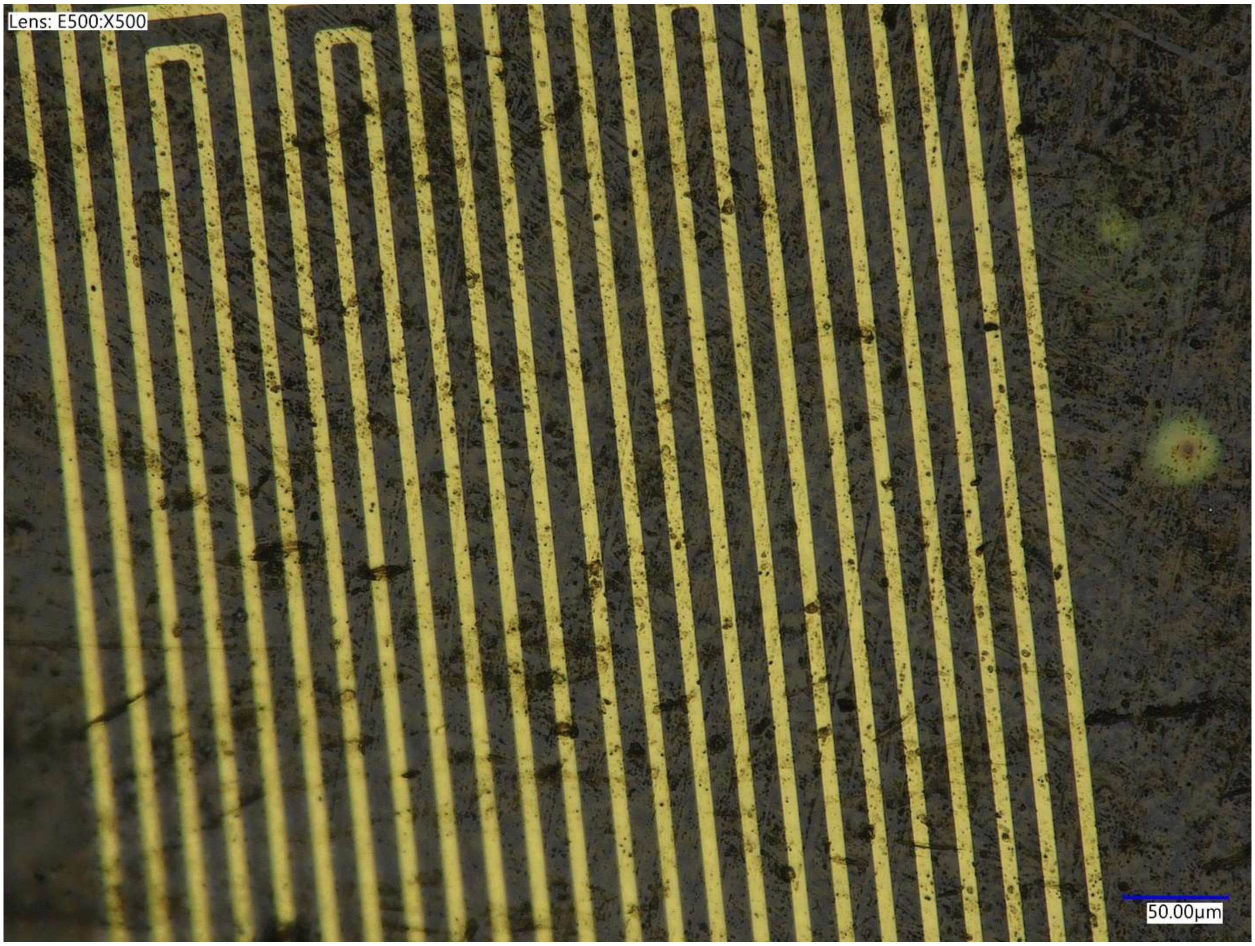

Figure 12: 500X magnification of center set conductors

5.0 CONCLUSIONS

The objective of this project was to evaluate the accuracy and utility of the Ventsentinel® product under mild service conditions and known gas compositions. This also allowed the meter supplier and designers an opportunity to generate diagnostics data during the tests and adjust the design if desired. Finally, a Ventsentinel® flow assembly that was previously put into service to measure gas flow at a CHOPS oil and gas wellsite was to be imaged under a microscope to provide visual insights on the integrity of the sensor after field deployment. From this study, the following conclusions were made:

- For high-rates of air flow (15.0 to 175.0 Sm^3/d) the relative error of the Ventsentinel® flow meter was between +/- 0.2 and 6.1%.

- For low-rates of air flow (0.5 to 7.0 Sm^3/d) the relative error of the Ventsentinel® flow meter was between +/- 1.3 and 8.5%.

- For high-rates of methane flow (2.5 to 15.0 Sm^3/d) the relative error of the Ventsentinel® flow meter was between +/- 0.7 and 3.1%.

- For low-rates of methane flow (0.5 to 3.0 Sm^3/d) the relative error of the Ventsentinel® flow meter was between +/- 1.2 and 5.1%.

- The flow meter appears to be immune to hysteresis effects.

- Comparing the relative error of the measurements at the same range of the flow rates of air vs. methane, the Ventsentinel® appears to perform similarly and adequately well with both medias.

- Aside from clouding on the surface of the sensor (due to scratches and/or fouling) the integrity of sensor did not appear to be severely compromised by field deployment. This is observed from microscopic images obtained from the cleaned sensor surface.