Pneumatic Vent Gas Measurement

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Project Team

The project team included Brian Van Vliet of Spartan Controls and Michael D'Antoni, Michael Glackin, Abin Eldhose and Joshua Anhalt of GreenPath Energy.

Any opinions, findings, conclusions or recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of the reviewers or their agencies.

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About Spartan Controls

Spartan Controls Ltd. is the leading provider of process control, measurement and automation solutions to industries in Western Canada. Our unique partnership with Emerson Process Management and other leading solution providers, enables us to connect our customers with world-class technology, technical expertise and product services.

We are committed to environmental leadership within our community, our business operations and the industries we serve through education and the application of best practices and technology. Management of energy, emissions and environmental performance are key means of driving costs down and meeting regulatory compliance requirements.

Together with our principals, and with consideration for environmental impacts, Spartan strives to provide sustainable and profitable, performance improving solutions for customer assets across all industries served.

Abstract

Pneumatic device (pump and instrument) retrofits are a key means of achieving a 45 percent methane (25x Global Warming Potential) reduction by 2025 in Canada (Environment Canada and Climate Change Canada, 2017). Confidence in current published methane vent rates from pneumatic devices, including the reduction and associated carbon dioxide equivalent (CO2e) after retrofit, are key to determining the available opportunity for reducing methane emissions in upstream oil and gas operations.

In bench testing, a new measurement solution, the enhanced-Measurement Emission Accuracy Solution (e-MEAS^{TM}), supplied nitrogen gas to a given pneumatic device of interest with and without a positive displacement meter measuring the volume vented downstream of the pneumatic device via pipe away vent line. Emissions were measured in a repeatable manner and the data sets were overlaid and compared to determine measured vented volume differences.

Field measurements obtained, without backpressure effects, provided vent rate comparison examples and data differences were compared with emission rates published to date. Field measurements supported the application of field relevant emission factors to retrofit dynamically active pneumatic devices, specifically level controllers. The e-MEAS^{TM}, helped quantify the amount of gas supplied to each pneumatic device and provided several insights beyond those published in the literature to date. Using a calculated mass approach with a low-pressure volume bottle provided an alternate means to support quantification of the amount of pneumatic gas vented, while mitigating ambient pressure effects on vent rates.

Measured volumes supplied to pneumatic devices were compared to measured volumes vented from them. Sensitivity, proportional band (PB) adjustments and set point changes on pressure controller emission rates were studied to determine the impact on vent rates. Steady state vent rates were investigated as one of several forms of emissions from pneumatic devices. Analysis of the data collected in this study provided significant insight into pneumatic deivce operation and associated vent rates. The impact of output pressure and backpressure effects on transducers was studied. Chemical injection pumps used for wellhead and pipeline chemical injection were sampled to determine if vent rates differ significantly. Instrument and pump vent rates were studied to determine ambient temperature and pressure impacts.

This study provided much insight on pneumatic devices and their operating vent rates.

Executive Summary

Air emission inventories are becoming an increasingly important method of monitoring and reporting on industry emissions, for the public, governments and individual companies. Governments are using emission inventories to negotiate international treaties, establish air emissions policy measures and targets and develop emission forecasts. It is important that upstream oil and gas operators have access to effective emission monitoring technologies and, more importantly, emissions factors obtained from adequate quantity and duration field measurements. Reported facility emission reductions are more realistic when tracked using standardized methodologies and accurate emission factors with low uncertainty. Inaccurate emission factors can result in an imprecise portrayal of the emission profile of pneumatic devices used in the oil and gas industry. Pneumatic efficiency is a key focus area specific to chemical injection pumps and instruments used at upstream oil and gas sites. Clear targets and means of de-risking expected emission reductions with equipment retrofits are key to enabling vented methane reductions in the field.

The development of technically defensible and effective emission management policies and regulations is reliant upon good quality emission data. Analysis of high quality data identifies potential opportunities for emission reductions and can be used to quantify industry Greenhouse Gas (GHG) performance as well as track emission reductions achieved. There are opportunities in the upstream oil and gas sector for improvements in emission data quantification (emission factors, measurement technologies and methodologies), monitoring, data management and reporting. The goal of this study was to establish more accurate and repeatable means for determining emissions from pneumatic devices including chemical injection pumps and instruments.

Industry benefits from field verified emission factors that can be applied for equipment retrofits. Most current measurement techniques focus on measuring the amount of gas vented from, not supplied to, a pneumatic device. Measuring the upstream pneumatic supply does not impact device performance nor cause pneumatic device backpressure, which are a source of error in the current published data sets. The data is also not subject to error if the case of the pneumatic device is not pressure containing. The enhanced-Measurement Emission Accuracy Solution (e-MEAS^{TM}) quantified the volume consumed by measuring pressure reduction with temperature compensation from a known volume, pressure, temperature and quality gas. Better quantification of current methane emission rates from pneumatic devices, as well as the reduction and associated carbon dioxide equivalent (CO2e) after retrofit, has a direct monetary impact on operations. Establishing better margin of error on positive displacement measurement emission rates published to date reduced the risk associated with emission

uncertainty for such retrofits and provided a better level of certainty on measurements made and presented in published reports.

The e-MEAS[TM] measurements obtained also achieved better quantification of dynamic, transient and static emission contributions. This analysis provided insight into the amount of pneumatic gas consumed beyond steady state instrument vent rates. Specific to level controllers, quantifying the dynamic vent contribution drew attention to the potential additional volume available for GHG offset credits beyond steady state vent rate reductions. This is of importance in Alberta, Canada because about 40 percent of pneumatic instruments in service at upstream oil and gas sites are level controllers (GreeenPath Energy Ltd., 2017) and those devices are currently considered pneumatically efficient. Focus on vent reductions for these devices provides opportunity for greater than 0.5Mt CO2e per year in vented methane reductions in Alberta.

Current regulations are focused on emissions specific to a low vent steady state threshold of 0.17 meters cubed per hour (m3/hr.) or six standard cubic feet per hour (scfh). The emissions from pneumatic devices are more than just steady state. The steady state rate of gas consumption is not a good predictor of the total gas consumption as shown in (Allen, et al., 2015) and (Prasino Group, 2013). Consequently, the total consumption of a given control loop can be optimized by improving more than just steady state consumption. There are few details on just how to optimize pneumatic efficiency because the consumption in a pneumatic control loop, attributed to the final control element, is difficult to segment from the instrument. Furthermore, the pneumatic device's contribution to the total emission in the dynamic state is not well understood. By trending the gas consumption, the static and dynamic components of gas use for a pneumatic device could be separated. Giving consideration for the dynamics in a control loop provided reference for determining the uncertainty associated with a given emission factor. By gaining a detailed understanding of the dynamic gas consumption of pneumatic devices, it is possible for policy makers to implement outcome-based GHG regulations that are both practical and achievable. This study provides both producers and regulators with the necessary tools to better quantify GHG reductions from pneumatic devices.

Unless otherwise noted, vent rates in this report are presented in metric volumes of Fuel Gas Equivalent (FGE) per hour (m3/hr.), not Imperial volumes of nitrogen per hour (scfh), at International Standard Conditions for natural gas and similar fluids, which is 101.325kPa (14.7psi) atmospheric pressure and 15C (59F). Nitrogen and air are of very similar density and molecular weight, which means measured nitrogen vent rates, following the method provided in Appendix A of Alberta Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices (Alberta Environment and Parks, 2017), will be within two percent of each other. Measured nitrogen flow rates were converted to FGE using a multiplier of 1.27. FGE flow rates were converted to tonnes of CO_2e using 80 percent methane content in fuel gas, 0.17m3/hr. (1scfh) of pure methane equivalent to 4.2tCO_2e/year with continuous device operation. If the device is not in operation continuously, the carbon equivalent values would need to be reduced by the percentage of time not in operation.

Best Practices / Tangible Project Outcomes

Conclusion #1: Manufacturer Published Steady State Vent Rates are Not the Best Predictor of Emissions for Dynamically Active Control Loops

Steady state vent rates are only one component of emissions from pneumatic devices. In the case of level controllers, pumps or other devices used in active control loops, dynamic consumption is often a more significant element of total volume vented from the device. A plot of upstream nitrogen tank pressure vs. time, is used to observe the different vent rates associated with a level controller's operation where tank pressure is the inter-stage finite volume cylinder used to measure gas use. A plot of the flow rate vs. time using e-MEAS™ data was found to be more scattered and less conclusive on consumption trends than a plot of pressure vs. time, which is shown in Fig. i. The following was observed during bench testing:

- There is a large difference between steady state gas volume consumption and the volume of gas consumed in a dynamic dump event;
- Measured steady state consumption data aligned with manufacturer published data (<0.03m3/hr. FGE), while the volume associated with a dump event was two orders of magnitude larger (1.80-5.39m3/hr. FGE) which increased the average total consumption;
- The flat profile of steady state consumption could lead to misinterpretation that this is an intermittent vent device, not continuous;
- Five dump events occurred in total run time; and
- The level control period is shorter with lower pneumatic supply pressures.

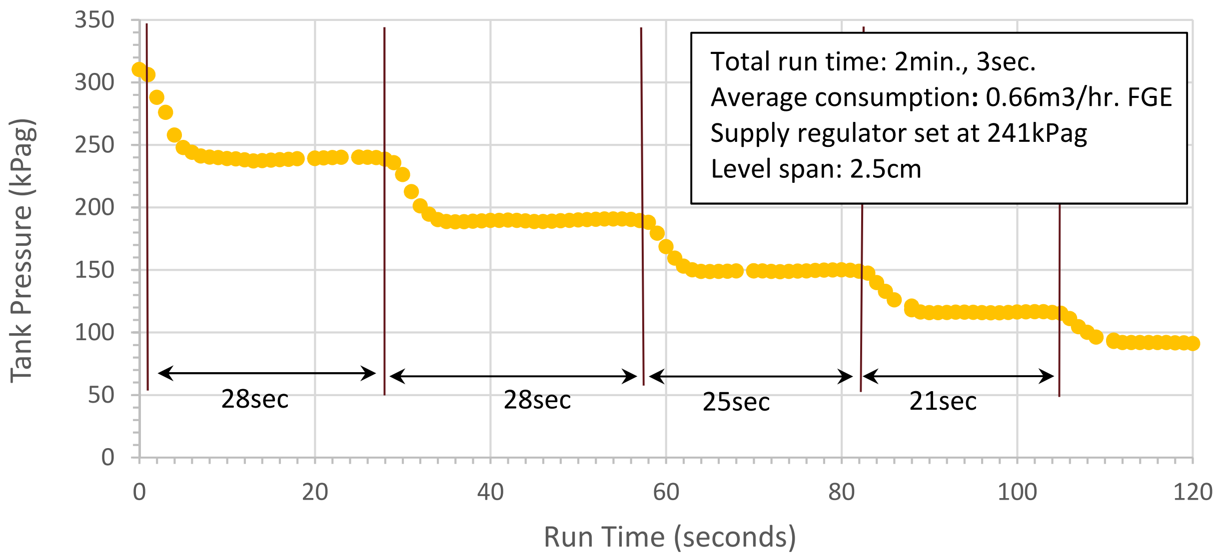

Fig. i: Fisher™ L2(Snap Relay) Bench Tested Level Controller Pneumatic Consumption

Field testing provided more insight into typical field vent rates. The average vent rate of 72 Fisher™ snap relay level controllers sampled was 0.46m3/hr. FGE. This includes both steady state, transient and dump valve consumption. The pneumatic consumption was also found to be higher when the level controller relay was in the transient state for longer periods of time. It was observed, as shown in Fig. ii, that dump events may not be especially frequent, but the controller could still be a candidate for pneumatic efficiency improvement. Note how the vent rate changes from steady state (flat) to transient (steeper) to nearly vertical (dump event). While the volume of gas needed to stroke a pneumatically actuated dump valve cannot be eliminated, unless switched to an electric or electrohydraulic actuator, the transient consumption can be eliminated. Implementation ready level controllers are available with relays that eliminate consumption associated with transient "simmer" states. Such relays output no pressure or full supply pressure, with no increase in vent rate between states.

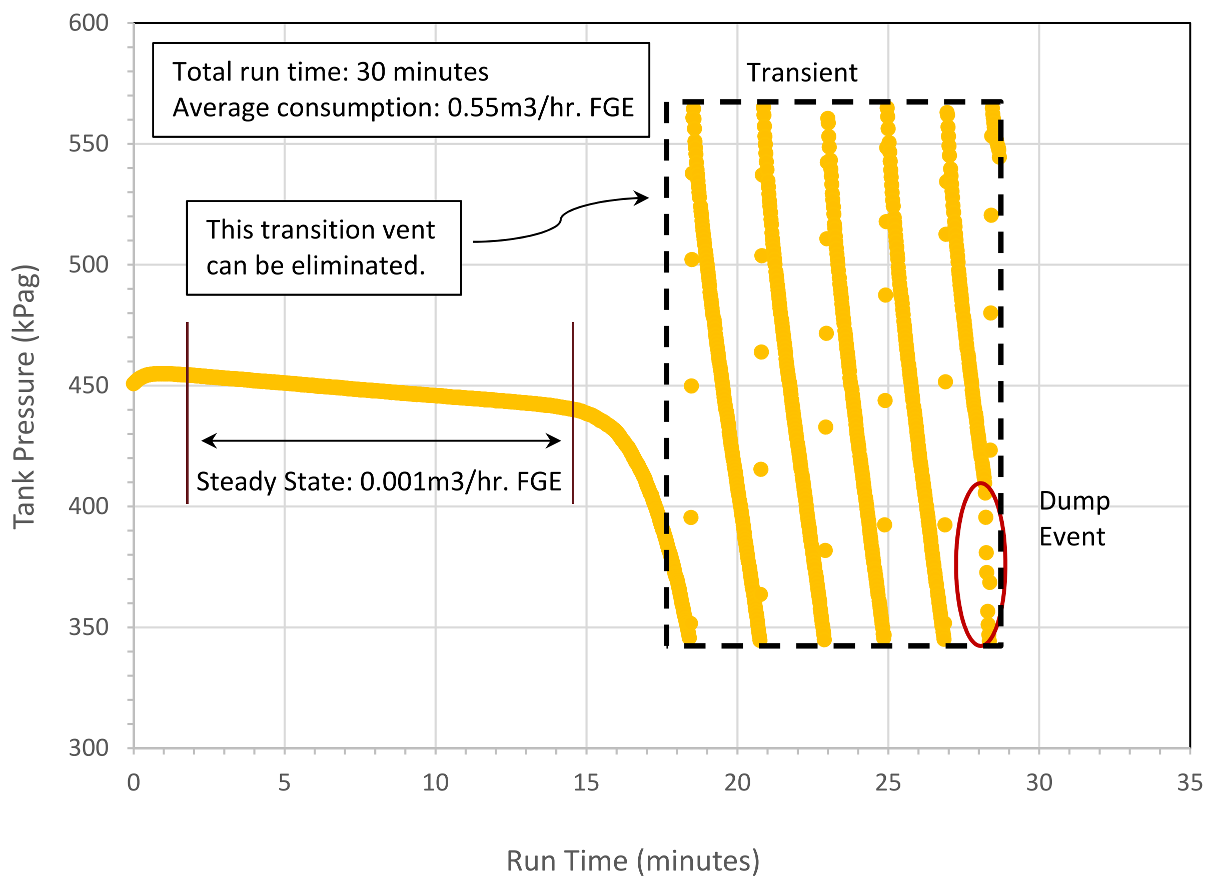

Fig. ii: Fisher™ L2(Snap Relay) Field Tested Level Controller Pneumatic Consumption

Conclusion #2: Level Controllers Dumping More Frequently than Once Every 15min are a Key Focus Area to Improve Field Instrument Pneumatic Efficiency

The average amount of fuel gas vented from Fisher™ L2 level controllers was 0.46m3/hr. FGE. This average is based on measurements gathered in the field using the e-MEAS™ on 72 Fisher™ L2 level controllers. Level controllers that did not dump in the measurement period vented an average of 0.19m3/hr. FGE. For level controllers actuating more frequently than once every 15min, the average vent rate was 0.75m3/hr. FGE.

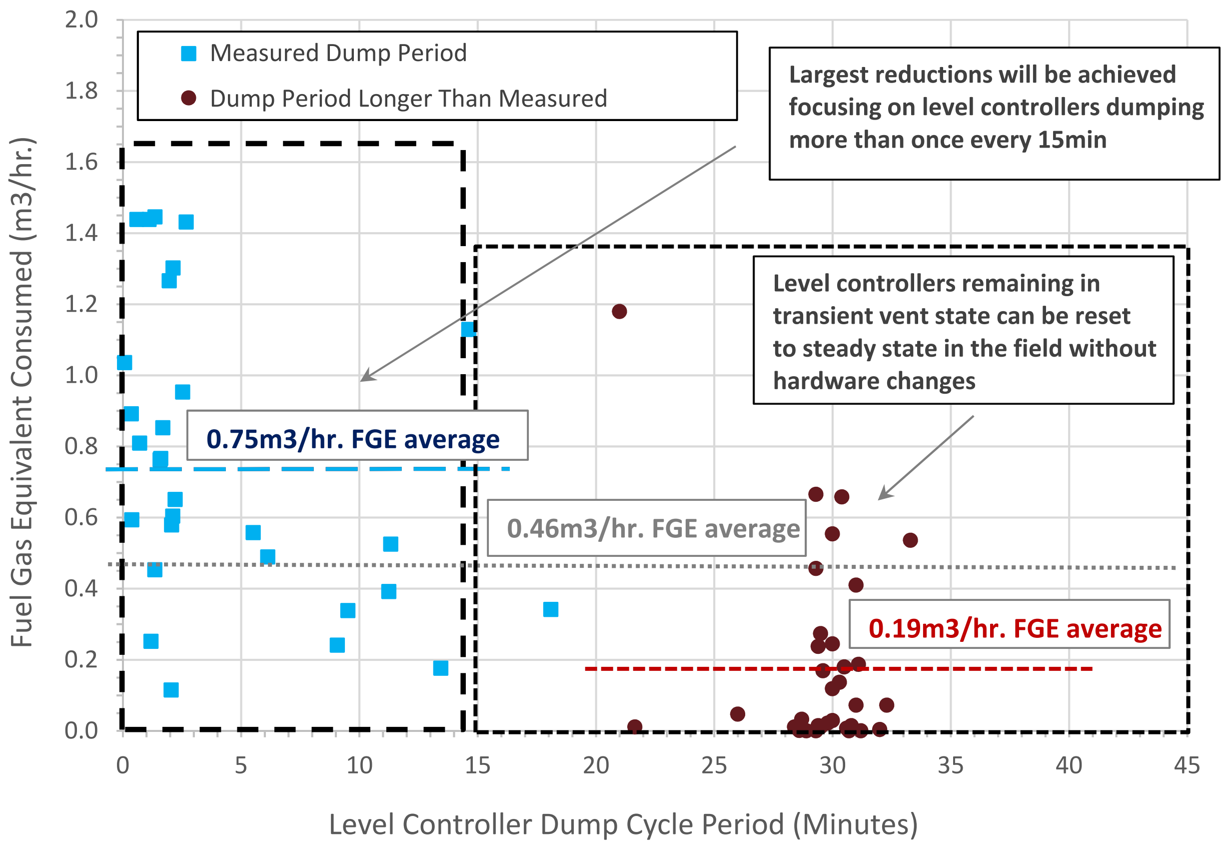

Fig. iii: Fisher™ L2 Level Controller Pneumatic Consumption vs. Dump Period

Level controllers that dump more than once every 15 minutes are typically found at sites that are newer, produce more liquids and are higher pressure than older sites that produce less liquids at lower pressure. There is a four-fold difference in vent rates, for these level controllers, depending on operation. This is important to recognize when applying a single emission factor to an instrument type. High outlier units that didn't dump in the sample period are level controllers that remain in the transient state and are unable to reset to the steady state vent rate. Those level controllers can be manually reset in the field by opening the instrument cover and temporarily applying force to the span levers or displacer rod.

Dump valves that stroke less often and pass more fluid volume per dump event are also good for measurement of produced volumes. Fisher™ L2(snap, improved), Fisher™ L2e, Fisher™ L2(on-off) and Fisher™ L2sj level controllers used in the same service dump more volume per dump event and stroke less often, which is important to consider in Greenfield design as well as Brownfield pneumatic efficiency optimization.

Conclusion #3: Using a Low Vent Level Controller that Eliminates Transition Vent is a Key Means of Improving Field Instrument Pneumatic Efficiency

With level controller baseline performance being a Fisher™ L2 (snap acting), the retrofit to a more pneumatically efficient level controller was investigated. The baseline performance established a dump frequency of once every 30 seconds, a vessel level change of approximately 2.5cm and an emission rate of 0.66m3/hr. FGE of nitrogen. Fisher™ L2 level controllers can be retrofit without de-pressuring the separator or changing the displacer. Retrofit of the snap acting relay with an on-off relay involves replacement of that component in the controller and recalibration of the controller by adjusting the zero and span. Conversion to a Fisher™ L2sj involves replacement of the entire controller case and recalibration. Both retrofits can be done while the process remains live if one person does the retrofit while another manually opens the dump bypass valve to drain fluid as needed. By doing such, a vent rate of 0.12m3/hr. FGE was achieved using the Fisher™ L2sj, which resulted in a 0.54m3/hr. FGE reduction. It achieved this result by actuating once every 3.5 minutes, which is equivalent to approximately seven times the volume per dump event and well within the sensing length of the 30cm displacer. Baseline performance actuating less frequently would result in even lower emissions, which establishes 0.12m3/hr. FGE as an upper end for emission rates from the low vent Fisher™ L2sj model actuating a Fisher™ D3 dump valve.

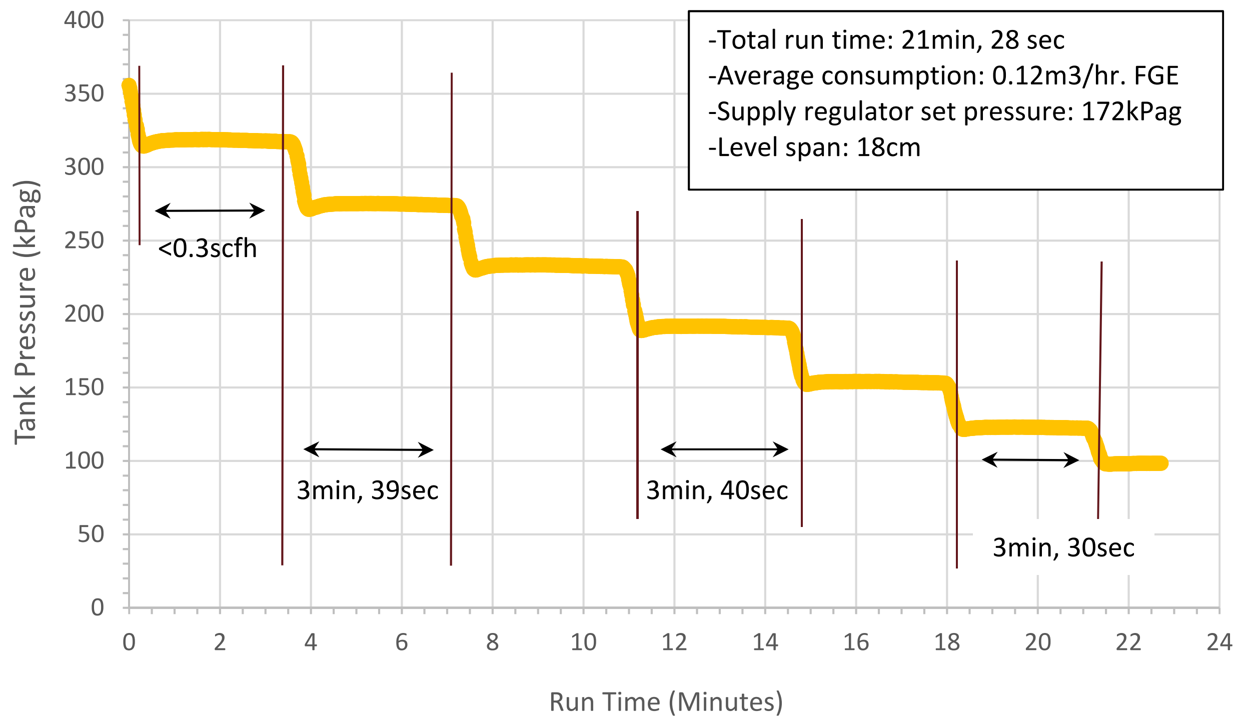

Fig. iv: Fisher™ L2sj (On-Off Relay) Bench Tested Pneumatic Consumption

Conclusion #4: Measured Volumes Supplied to Pneumatic Devices are Higher than Measured Volumes Vented from Them

In bench testing, the e-MEAS™ supplied nitrogen gas to a given pneumatic device of interest with and without a Hawk 9000 positive displacement meter (Hawk 9000) measuring the volume downstream of the pneumatic device via a pipe-away vent line. The emissions were measured in a repeatable manner that was overlaid and compared to determine relative accuracy specific to vented volumes. Measurements made with the e-MEAS™, without a positive displacement flow meter connected to the pneumatic device vent (exhaust) line, were most representative of the volume consumed by the pneumatic device in typical operation. The preferential order for vent rate measurement samples identified on page 57 the Alberta Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices also identifies measurement at device supply ports before vent ports (Alberta Environment and Parks, 2017). With the Hawk 9000 measuring the volume through a pipe away vent, the measured volume was on average within one percent of that measured by the e-MEAS™ and three and a half percent less than measured by the e-MEAS™ when the Hawk 9000 was not connected to the pneumatic device pipe-away vent line. These measured flow rates were closer to each other at low vent rates. More study is needed to quantify how close measured rates are to each other at high vent rates.

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Acronyms and Key Terms

AB	Alberta
AUPRF	Alberta Upstream Petroleum Research Fund
CO2e	Carbon Dioxide Equivalent
Cv	Valve Coefficient
D	Direct Acting
Dynamic vent	The amount of gas vented from a pneumatic device including the volume vented from the final control element controlled by the pneumatic device when the output is actively changing. If the device is active, this is a high vent device.
e-MEAS^{TM}	enhanced-Measurement Emission Accuracy Solution
FC	Fail Closed
FO	Fail Open
FGE	Fuel Gas Equivalent
Frequency	Quantity of occurences of a repeating event per unit of time (RPM, level control dump cycle events per 15min, etc.)
Gain	The change in output divided by the change in input
GHG	Greenhouse Gas
HMI	Human Machine Interface (Touch Screen)
l-g	Liquid-Gas
l-l	Liquid-Liquid
PD	Positive Displacement
Period	One cycle duration of time in a repeating event (1 level control dump cycle took fifteen minutes, etc.)
P&ID	Piping and Instrument Diagram
Proportional	Then amount of change in the controlled variable of a pneumatic controller Band required to run an actuator over its full stroke
Pneumatic Efficiency	A qualitative measure of pneumatic device operational task effectiveness for a given volume of gas i.e. chemical pump volume vented per stroke of chemical injected or level controller volume vented per dump cycle.
PTAC	Petroleum Technology Alliance of Canada

R	Reverse Acting
SCFH	Standard Cubic Feet Per Hour
SOV	Solenoid Valve
Static vent	The amount of gas vented from a pneumatic device when idle in normal operation. Operating with a static vent rates less that 0.17m3/hr. (6scfh) is a low vent device.
Transient vent	The amount of gas vented from a pneumatic device when on the verge of changing output from zero to full or vice versa. High frequency transient vent devices may be high vent devices.
UOG	Upstream Oil and Gas
GWP	Global Warming Potential
67CFR	Fisher™ 67C Series Instrument Supply Regulator used to provide a pneumatic supply at an even pressure to a variety of pneumatic and electro-pneumatic instrumentation

Introduction and Background

The purpose of this study is to accurately measure methane vent rates from various pneumatic devices commonly used in the upstream oil and gas industry (UOG) and compare these vent rates with published values. Priority was on placed on dynamically active devices such as level controllers and chemical injection pumps.

Accurate measurement and quantification of methane vent rates from pneumatic devices, before and after retrofit device implementation, is a bottom up approach for quantifying the methane emission reductions from pneumatic devices in UOG. Pneumatic device (pump and instrument) retrofits are a key means of achieving a 45 percent reduction in methane in Canada by 2025 (Environment Canada and Climate Change Canada, 2017).

Methane vent rates are typically measured downstream of a pneumatic device by attaching a positive displacement meter on the vent to atmosphere. However, this method establishes a backpressure on the pneumatic device, which can affect the operation of the device. In other words, any attempt to measure the vent rate will affect the vent rate itself.

To overcome this deficiency, Spartan Controls Ltd. fabricated a new measurement device, the enhanced-Measurement Emission Accuracy Solution (e-MEAS^{TM}).

For this study, the vent rates of eight different pneumatic devices were measured using the typical method and the e-MEAS^{TM}. Vent rates were measured on the bench at Spartan Controls Ltd. and in the field for steady state and dynamically active states. Example calculations for the e-MEAS^{TM} device are included in Appendix A. References are located in Appendix B Measurement from over 200 bench and field tests were made and are included in Appendix C. Manufacture published literature for devices tested in this study is found in Appendix D.

Pneumatic Devices Tested

It is estimated that there are about 100,000 instruments and 145,000 pumps in service in Alberta that are eligible for retrofit with more pneumatically efficient alternatives (Cap-Op Energy, 2013). Common pneumatic devices at UOG sites include Fisher^{TM} 546 and i2P-100 (1st Gen.) pressure transducers, Fisher^{TM} 4150 pressure controllers, Fisher^{TM} 2900, 2680, 2660 and L2 level controllers, Texsteam 5100, 5000, Morgan HD312 and Williams P125, P250 and P500 chemical injection pumps. For instruments, it is estimated that the percentage by instrument type is 20 percent transducers, 30 percent pressure controllers, 40 percent level controllers and 10 percent other (pressure switches, positioners, level switches, temperature controllers). This ratio is very similar to that reported in the Prasino Study with 19 percent transducers, 27 percent pressure controllers, 39 percent level controllers and 15 percent other (Prasino Group, 2013). Retrofits available for instruments are complete replacements such as the Fisher™ C1 for Fisher™ 4150 pressure controllers or the Fisher™ i2P-100 (2nd. Gen) for the Fisher™ 546 transducer. Retrofit kits are also available for instruments such as the Fisher™ i2P-100 (1st Gen) and the Fisher™ 2680, 2660 and L2 level controllers.

Previous Work

A number of previous studies have attempted to measure the vent rates of pneumatic devices (Prasino Group, 2013), (Allen, et al., 2015), (US Environmental Protection Agency, 1996), (Clearstone Engineering Ltd., 2014) and (Canadian Association of Petroleum Producers, 2017). In these studies, the vent measurements were gathered using flow meters connected to the pneumatic device pipe way vent port. While this method is non-invasive as it does not interrupt the pneumatic supply provided to the pneumatic device, the addition of a flow meter to measure the gas vented from a pneumatic device does introduce backpressure. This backpressure is not present during normal operation and impacts the set point of instruments, alters the dynamic performance and typically reduces the measured vent rate. The amount of backpressure present was not measured in the field and is an opportunity for further study. To be accurate, measuring the flow through the pipe away vent requires that the pneumatic supply doesn't have an alternate path to atmosphere (i.e. Out of the instrument case/cover gasket).

This study attempts to confirm the impact of downstream measurement on the vent rate. The Hawk 9000 positive displacement vent gas meter (Hawk 9000), commonly used for this purpose, measures volume very similar to the natural gas meter supplied to homes and businesses in western Canada.

This measurement technique does not interrupt the supply of pneumatic pressure and is consequently less invasive. For this reason, measuring the volume vented from the pneumatic device case has been the preferred means. However, the addition of a measurement device to the vent port of the pneumatic device introduces backpressure on the pneumatic device not otherwise present. Introducing backpressure, that would not otherwise be present during normal field operations, impacts the set point of instruments, alters dynamic performance and typically reduces the measured vent rate. Published data sets highlight variances between manufacturer published steady state vent rates and field measurements.

Fig. 1: Hawk 9000 Configured for Differential Gas Flow Measurement *(Calscan, 2018)*

Understanding the difference between rates requires knowledge of the means of measurement supporting published vent rate values, sources of error in measured values and dynamic contributions to total vent rates beyond steady state. Previously published field measurements such as those included in the Prasino Study (Prasino Group, 2013) were significantly lower than found in this field survey despite close correlation of Hawk 9000 with e-MEAS^{TM} measured vent rates.

Methodology

One e-MEAS^{TM} was fabricated by Spartan Controls Ltd. using patent US7,818,092 and CA2,637,653 (United States Patent and Trademark Office, 2017) and (Canadian Intellectual Property Office, 2017). This device (Fig. 2) is designed to deliver a pneumatic supply from a high-pressure nitrogen (1) bottle through a measurement solution (2), that used a solenoid valve (SOV) to fill the inter-stage volume bottle between 345kPag (50psig) and 586kPag (85psig). The e-MEAS^{TM} data logger tracked the pressure decrease and temperature changes as that gas was used by the downstream pneumatic device (3). The 67CFR model supply regulator kept the delivery pressure matched to that of the supply regulator at site which was typically between 207-241kPag (30-35psig). A material balance approach, based on these measurements was used to calculated the amount of pneumatic gas used. A simplified piping and instrument diagram (P&ID), shown in Fig. 2 for the volume bottle, highlights the operation of the inter-stage volume bottle.

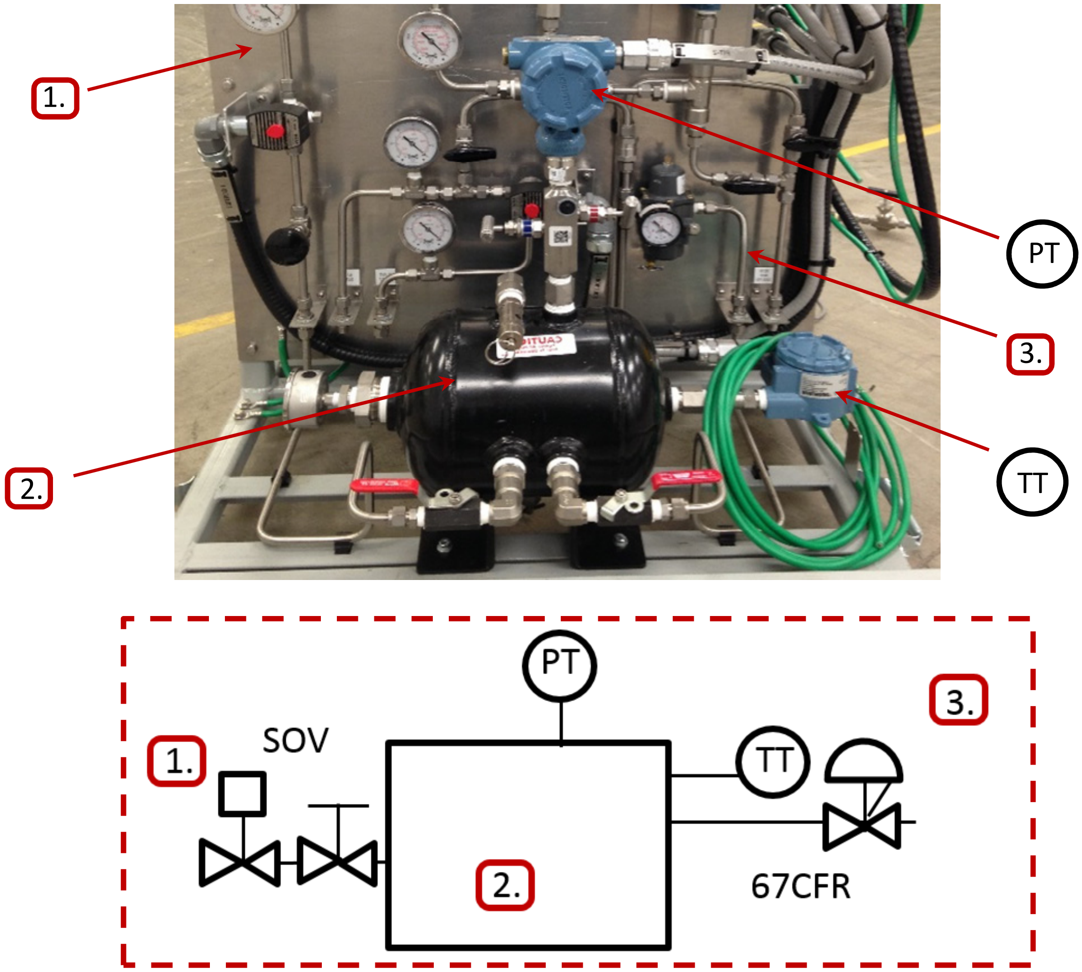

Fig. 2: e-MEAS™ Volume Bottle Measurement

As shown in Fig. 3, for both bench and field testing, nitrogen was supplied from:

(a) Large cylinder(s); to the

(b) e-MEAS™, which supplied nitrogen gas at a constant supply pressure; to

(c) Pneumatic device of interest, such as a level controller, pressure controller or transducer; with and without

(d) Hawk 9000 positive displacement vent gas meter measuring the volume vented downstream of the pneumatic device via pipe-away vent line.

Using the e-MEAS™ upstream, to measure the gas volume supplied to the pneumatic device being tested, allows the device to operate normally without backpressure effects. A side view of the e-MEAS™ is shown to provide dimensional reference for its width (77cm), height (100cm) and depth (122cm). Emissions were measured in a repeatable way that compared measured volumes using this configuration. The Hawk 9000 was only used downstream of the pneumatic device to quantify the amount of gas vented. This is consistent with how the flow meter has been used to date (Prasino Group, 2013). The Hawk 9000 was not tested in other locations such as the e-MEAS™ connection point (b) between the upstream pneumatic supply and the downstream instrument or pump.

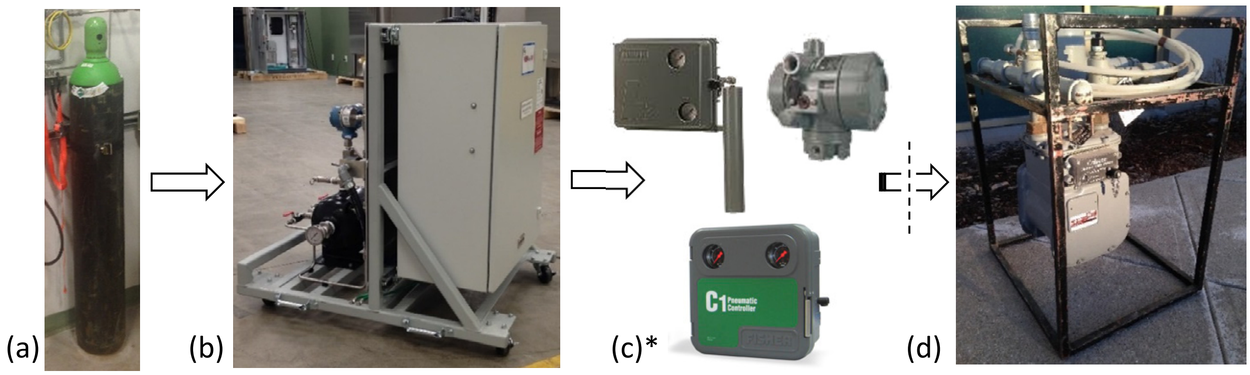

Fig. 3: Example Test Apparatus
**Images Used with Permission of Emerson Automation Solutions*

On the bench, a test procedure was followed for each device to test variable setting changes as shown in Table 1. Each test was carried out by first connecting the e-MEAS™ as described without the Hawk 9000 connected to the pneumatic device pipe-away vent line. Before disconnecting a given instrument, the test procedure was repeated with the Hawk 9000 connected to the vent port of the instrument.

Table 1: Bench Test Instrument Variable Settings

Device	Variable	Setting
Fisher™ i2P-100 (2nd Gen.) Transducer Fisher™ i2P-100 (1st Gen.) Transducer Fisher™ 546 Transducer	Input current	4mA
		8mA
		12mA
		16mA
		20mA
Fisher™ 4150 Pressure Controller Fisher™ C1 Pressure Controller	Set Pressure	0kPag
		Full bourdon tube range
	Proportional Band	1
		5
		10
Fisher™ L2(snap relay) Level Controller	Retrofit Type	L2(On-Off) relay
		L2sj controller case
		Improved L2 (I-I snap) relay
		Improved L2 (I-g snap) relay

Manufacturer published literature for each of these devices is included in Appendix D. A more detailed discussion on the function of each of these devices is included in the Discussion. Note that level controllers, the Fisher™ L2(snap) model, L2(On-Off) model and L2sj model were set on the most sensitive setting. The same displacer was left immersed in the process in all three level controller test situations.

The bench testing data collected in e-MEAS™ electronic data logs from device vent measurement was downloaded from the e-MEAS™ to a USB memory stick or direct to a laptop for analysis and vent rate calculation. The bench testing data collected in the Hawk 9000 was also downloaded from its electronic data log to a laptop. With both data sets downloaded, the vent rates could be compared.

Field measurements from randomly selected sites were sought for each device bench tested to compare measured pneumatic device vent rates using the e-MEAS™ and the Hawk 9000. For any given run, either the e-MEAS™, the Hawk 9000 or both are used. The field pneumatic devices were operated on a nitrogen pneumatic supply and were not isolated from the process for testing. All field measurements were obtained using the e-MEAS^{TM}, in the box of a pickup truck (Fig. 4) with the battery box and two nitrogen bottles, at upstream oil and gas sites such as well pads. The e-MEAS^{TM} was left loaded on the truck due to weight and size restraints. It was connected to the pneumatic device of interest for measurement by routing a flexible tubing line through the door or window of the building. The Hawk 9000 was not left on the truck like the e-MEAS^{TM}, but was positioned on the ground just outside the building.

Fig. 4: Loaded e-MEAS^{TM} In Use

Measured consumption trends were observed on volume tank pressure vs. time plots on the human machine interface (HMI) inside the front cover of the e-MEAS^{TM} to provide an on-site visual for the dynamic behaviour of the measured pneumatic device.

In the field, the operational settings of the instruments and pumps were not changed. The Hawk 9000 was also connected for some of the field samples in the same way the bench testing was performed. With and without the Hawk 9000, data was collected in e-MEAS^{TM} electronic data logs, representative of as-found operation. As was done for bench testing, the field testing data was downloaded from the e-MEAS^{TM} system and from the Hawk 9000 was downloaded to a laptop. Analysis of the field testing data was later analyzed for both.

The mass of nitrogen consumed was calculated using the ideal gas law (Eqn 1) with the pressure and temperature of nitrogen in the inter-stage volume bottle captured at one second intervals in the datalogger.

$$PV = zmRT$$

Where:

Variable	Description
P	Pressure (kPa(a))
V	Volume (m3)
z	Coefficient of compressibility
m	Mass (kg)
R	Ideal Gas Constant of Nitrogen (0.297 KJ/Kg/K)
T	Temperature (K)

Eqn 1: Ideal Gas Law

The ideal gas constant of nitrogen was determined dividing the universal ideal gas constant (8.3145 kJ/K/kmol) by the molecular weight of nitrogen (28.013kg/kmol). The rationale for determining the sample frequency was to balance sampling frequency with datalogger memory. Sampling more frequently than once per second shortens the total period that data can be collected. Not sampling frequently enough makes it more difficult to quantify the dynamic effects and vent rate variance. Sampling once per second was the compromise.

The average mass flow rate was determined by taking the calculated difference in mass of nitrogen in the volume bottle between the full state (586kPag; 85psig) and the empty state (345kPag; 50psig), and dividing by the amount of time it took to go between states. The temperature and gauge pressure were logged and the volume of the inter-stage volume bottle was known. The atmospheric pressure was obtained from Environment Canada (Government of Canada, 2017) specific to location, date and hour of measurement. The coefficient of compressibility for nitrogen volume bottle pressures between 345kPag (50psig) and 586kPag (85psig) was found to be 0.998 and not included in the calculations because it was only 0.2 percent lower than 1 and found to contribute to less than 0.05g difference in mass of nitrogen consumed per inter-stage volume bottle fill event.

Unless otherwise noted, vent rates in this report are presented in Metric volumes of Fuel Gas Equivalent (FGE) per hour (m3/hr.), not Imperial volumes of nitrogen per hour (scfh), at International Standard Conditions for natural gas and similar fluids, which is 101.325kPa (14.7psi) atmospheric pressure and 15C (59F). Volumetric flow rates of nitrogen were determined using the calculated mass and dividing by the density of nitrogen at standard conditions. The density of nitrogen used was 1.187kg/m3 (g/L) at 101.325kPa and 15C (Wichneweski, 2017), which is similar to the density of 1.185kg/m3 calculated using the ideal gas constant for nitrogen of 0.2968 (Cengel & Boles, 2002). Nitrogen and air are of very similar density and molecular weight, which means measured nitrogen vent rates, following the method provided in Appendix A of the Alberta Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices (Alberta Environment and Parks, 2017), will be within 2 percent of each other. Measured nitrogen volumetric flow rates were converted to FGE using a multiplier of 1.27. FGE volumetric flow rates were converted to tonnes of CO_2e using 80 percent methane content in fuel gas, continuous pneumatic device operation and 0.17m3/hr. (1scfh) of pure methane being equivalent to 4.2tCO_2e/year. If the device is not in operation all the time, the carbon equivalent values would need to be reduced by the percentage of time not in operation.

The e-MEAS™ functioned well in the field and, as shown in the Alberta Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices, Appendix C: Field Vent Rate Sample and Emissions Factor Development, is an accepted means of total pressure loss measurement for pre-and post-retrofit measurement of the pneumatic device(s) to quantify the amount of gas vented (Alberta Environment and Parks, 2017).

Results and Discussion

The intent of the field measurements in this study was not to sample enough to form a representative sample of vent rates, but to determine if what was observed through bench testing could also be observed in the field. To be considered a representative sample, enough pneumatic devices of a given type need to be measured.

$$n = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1+\left(\frac{z^2 \times p(1-p)}{e^2 N}\right)}$$

Where:

Variable	Description
n	Sample Size
N	Population Size
e	Margin of Error (as a decimal)
z	Confidence Level (as a z-score)
p	Percentage Value (as a decimal)

Eqn 2: Sample Size Formula

For example, it is estimated that there are between 5,000 and 40,000 (N) Fisher™ L2 level controllers in operation in Alberta. To develop a statistically valid emission factor, approximately 72 devices (n) would need to be sampled. This assumes a margin of error of 0.115 (e), a confidence level of 95% (z = 1.96) and conservative p value of 0.5 (yields largest sample size). While not the main objective, enough Fisher™ L2 level controllers were sampled in the field to be statistically representative of the installed population.

Applying this logic to the 5100-series pneumatic pump, with an increased margin of error to 0.192 (e), a sample of 26 would be statistically relevant for a population (N) as small as 2,000 or as large as the total estimated chemical injection pump population of 150,000 in Alberta (Cap-Op Energy, 2013). The average vent rate of the Fisher™ L2(snap relay) is 0.46m3/hr. FGE. This is higher than the published steady state vent rate of <0.03m3/hr. for the same device. (Emerson Automation Solutions, 2017). Greater detail is explored in the discussion to explain the difference. A summary of the e-MEAS™ measured nitrogen vent rates from the field devices is included in Table 2.

Table 2: Comparison of Pneumatic Device Field Vent Rates (m3/hr., FGE)

Pneumatic Device Type	**Pneumatic Device Make & Model**	**Number of Field Samples**	**Average Vent Rate**	**Standard Deviation**	**95% Confidence Interval**	**Prasino Report Average Vent Rate[1]**	**Manufact. Steady State Vent Rate[2]**
Pressure Controller	Fisher™ 4150	3	0.92	0.68	1.69	0.42	1.51
Pressure Controller	Fisher™ C1	2	0.11	0.0	0.0	0.07	0.16
Level Controller	Fisher™ L2(snap)	72	0.46	0.05	0.10	0.26	<0.03
Transducer	Fisher™ i2P-100 (1st. Gen)	4	0.72	0.13	0.40	0.22	0.13-0.37
Pressure Switch	Fisher™ 4660	6	0.16	0.05	0.12	0.02	< 0.18
Level Switch	SOR 1530	7	0.71	0.58	0.54	0.05	0.14
Chemical Injection Pump	Bruin 5015	11	1.30	0.20	0.46	------	Chemical volume specific
Chemical Injection Pump	Bruin (Texsteam) 5100	26	0.97	0.44	0.18	0.97	Chemical volume specific

[1]m3/hr. fuel gas equivalent values converted from scfh of nitrogen by dividing by 35.3 and multiplying by 1.27.

[2]41-207kPag output in m3/hr. of air converted to fuel gas equivalent by multiplying by 1.29.

Only the Fisher™ L2 and 5100 model chemical injection pumps have enough field samples to be statistically significant.

Table 3 shows pneumatic device vent rates that were determined using both the e-MEAS™ upstream of the pneumatic device and the Hawk 9000 downstream (column 1), only the e-MEAS™ upstream of the pneumatic device (column 2) and only the Hawk 9000 downstream of the pneumatic device (column 3). In bench testing, the e-MEAS™ supplied nitrogen gas to a given pneumatic device of interest with and without the Hawk 9000 positive displacement (PD) meter measuring the vented volume downstream of the pneumatic device via pipe away vent line. In this way, the vented volumes were measured in a repeatable manner that was overlaid and compared to determine measured variance specific to vented volumes. Measurements made with the e-MEAS™ were higher when the vent exhaust was not connected to the positive displacement meter. This difference in measured vent rates confirmed the expected influence of placing backpressure on the device (in the form of a PD meter). The preferential order for vent rate measurement samples identified on page 57 of the Alberta Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices also identifies measurement at device supply ports before vent ports (Alberta Environment and Parks, 2017).

A plot of the total vent rate measurements in Fig. 5 highlighted how the population of field instruments sampled per Table 2 was quite well distributed. The population sampled had an average vent rate of 0.64m3/hr. FGE.

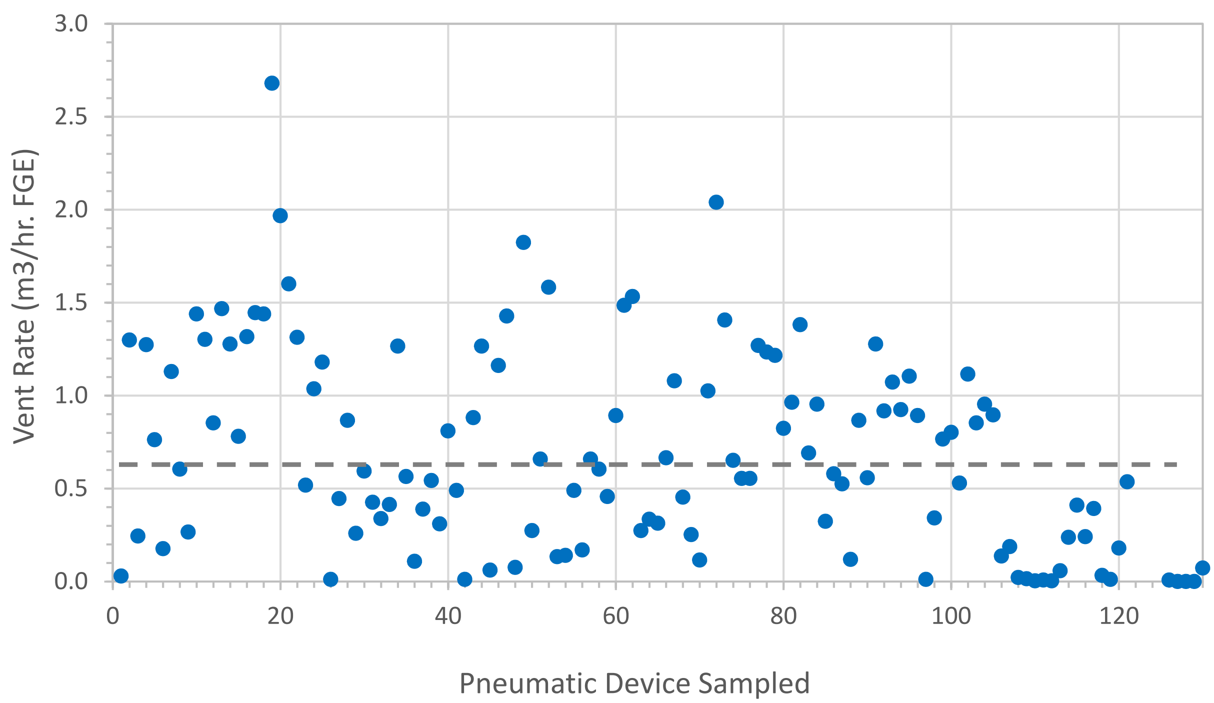

Fig. 5: Vent Rates for Field Pneumatic Devices Sampled

As shown in Table 3, with the Hawk 9000 measuring the volume through a pipe-away vent, measured volume was on average within one percent of that measured by the e-MEAS™ (column 1), but three percent less than measured by the e-MEAS™ without the PD meter downstream of the pneumatic device (column 2).

Table 3: Bench and Field Testing Measurement Sample Data (m3/hr., FGE)

Sample	e-MEAS™ with Hawk 9000 (1)	e-MEAS™ without Hawk 9000 (2)	Hawk 9000 (3)
1	0.054	0.054	0.054
2	0.054	0.050	0.054
3	0.076	0.076	0.065
4	0.076	0.076	0.068
5	0.097	0.097	0.086
6	0.086	0.072	0.094
7	0.097	0.097	0.094
8	0.097	0.108	0.108
9	0.111	0.119	0.122
10	0.119	0.119	0.122
11	0.097	0.101	0.128
12	0.129	0.133	0.131
13	0.129	0.133	0.131
14	0.140	0.140	0.137
15	0.144	0.144	0.146
16	0.151	0.155	0.155
17	0.201	0.209	0.192
18	0.270	0.263	0.234
19	0.827	0.892	0.744
20	0.798	0.798	0.788
21	1.356	1.413	1.406
Total	**5.240**	**5.380**	**5.192**
Percent	**97.4%**	**100%**	**96.5%**

Insufficient data was gathered at vent rates above 0.27m3/hr. FGE with both measurement devices to analyze if the measured vent rates have greater differences at high vent rates than low vent rates. More work is necessary to determine differences.

The operational characteristics of a pneumatic control loop have a significant impact on vent rates. As shown in Fig. 6 below, every control loop has three basic elements, the sensing element or Measurement, the Controller and the Final Control Element.

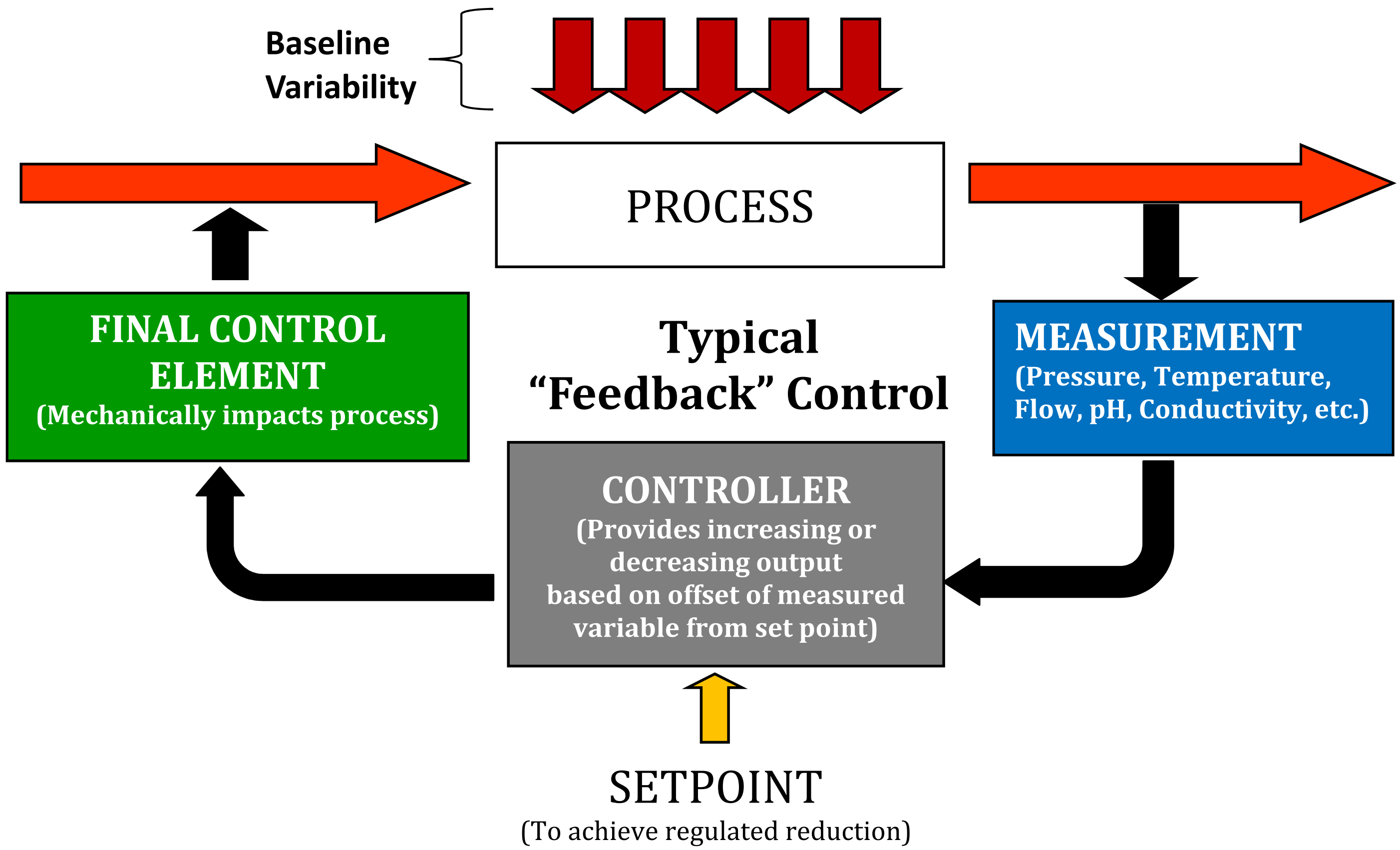

Fig. 6: Control Loop Elements

In the case of pneumatic positioners and pressure, level and temperature controllers, the function of Measurement and Controller are both done in a single instrument.

Pressure Controllers

Pressure controllers are used upstream or downstream of the final control element to maintain backpressure or reduce pressure. The fail position of the actuator, open or closed, on the final control element impacts the output of the controller. For example, a pressure controller upstream of a fail closed (FC) valve will need to increase its output pressure if the sensed pressure is too high. This allows more flow to pass through the final control element which will reduce the upstream process pressure. If the final control element is fail open (FO), the output would need to decrease when the measured pressure is too high to achieve the same action. Correspondingly, the controller would need to be direct (D) acting on a fail closed valve and reverse (R) acting on a fail open valve when used for backpressure control. Conversely, if the pressure controller is used to achieve pressure reduction downstream of the final control element, the controller would need to be reverse acting on a fail closed valve and direct acting on a fail open valve. Understanding the action of the controller doesn't impact its vent rate, but does impact the orientation of its internal nozzle-flapper assembly and the configuration of the low vent replacement.

As shown in Fig. 7, the process pressure acts on the bourdon tube sensing element, which is coupled to a nozzle-flapper assembly.

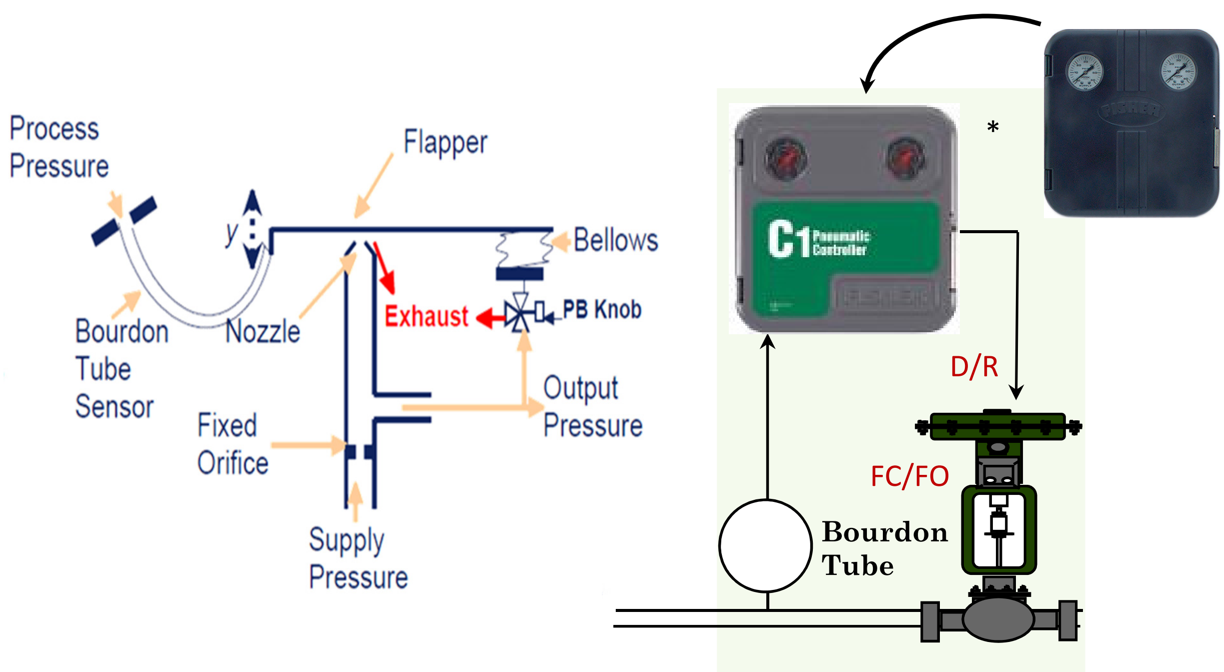

Fig. 7: Pressure Controller Operation Illustration

**Images Used with Permission of Emerson Automation Solutions*

The extension or retraction of the bourdon tube provides resistance to the amount of flow that can be vented across the nozzle which in turn affects the supply pressure to the actuator coupled to the final control element. The stiffness of the flapper can be adjusted to change the sensitivity of the controller to changes in sensed process pressure. If the flapper is relatively free moving, it is very sensitive to process changes. Conversely if the flapper is relatively stiff, it takes a larger change in process pressure to have the equivalent effect on the pneumatic output. Another way of referring to the sensitivity of an instrument is to think of its gain. Small process changes that result in large output changes from the instrument infer that the controller has high gain and, conversely, large process changes that result in only small output changes from the instrument infer that the instrument has low gain. Adjusting the sensitivity of the controller requires changing the proportional band dial where the proportional band is defined on a scale of 1-10 and in simple terms is inversely proportional to the gain of the controller. For example. with the proportional band knob set at 1, the device is most sensitive and at 10, it is least sensitive.

The impact of sensitivity/proportional band (PB) adjustments and set point changes on pressure controller emission rates were investigated. As shown in Fig. 8, it was found that for Fisher™ C1 Pressure Controllers, the steady state vent rate was not impacted by proportional band adjustments when changed between 0, 5 and 10. The changes in set pressure on either end of the 207kPag (30psig) bourdon tube range only resulted in less than 0.03m3/hr. variance in vent rates. The measured vent rates with and without the downstream Hawk 9000 PD meter downstream were within 0.004m3/hr. nitrogen. All measured nitrogen values were lower than the manufacturer published steady state vent rate of 0.17m3/hr. FGE. Note that that the steeper drop in the inter-stage volume bottle pressure on recharge is attributed to pressure equalization in the e-MEAS™ after the loading solenoid closes again. It is internal to the operation of the e-MEAS™ and not impactful to the operation of the pneumatic device.

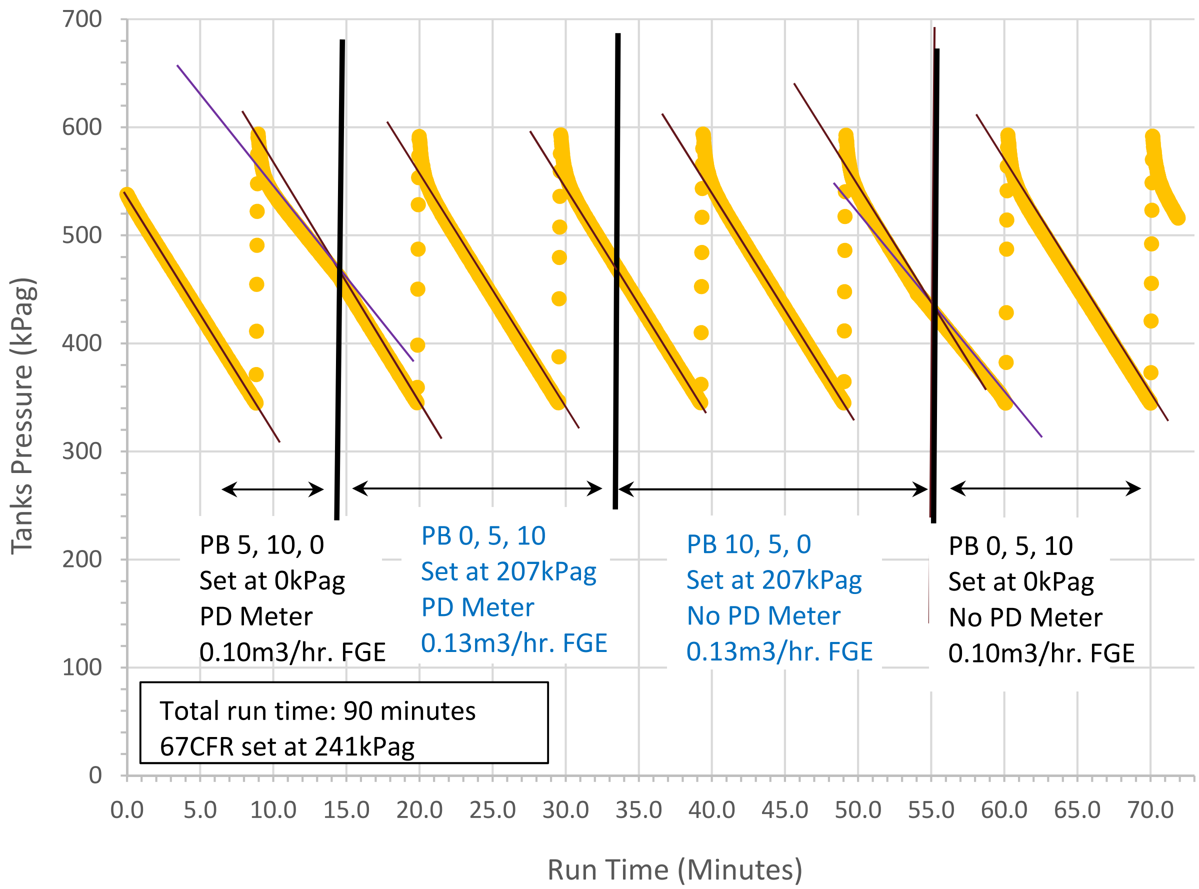

Fig. 8: Fisher™ C1 Pressure Controller e-MEAS™ Bench Tested Pneumatic Consumption

The vent rates of four Fisher™ 4150 pressure controllers were measured in the field. Fig.9 data indicates that the vent rate varied over the period of measurement. The proportional band was not adjusted, thus the change in controller consumption can only be attributed to process changes, changes in output pressure to operate the control valve and the volume required by the control valve to throttle the process as needed. The measured total vent rate of 1.53m3/hr. FGE is similar to the published steady state vent rate of 1.51m3/hr. FGE.

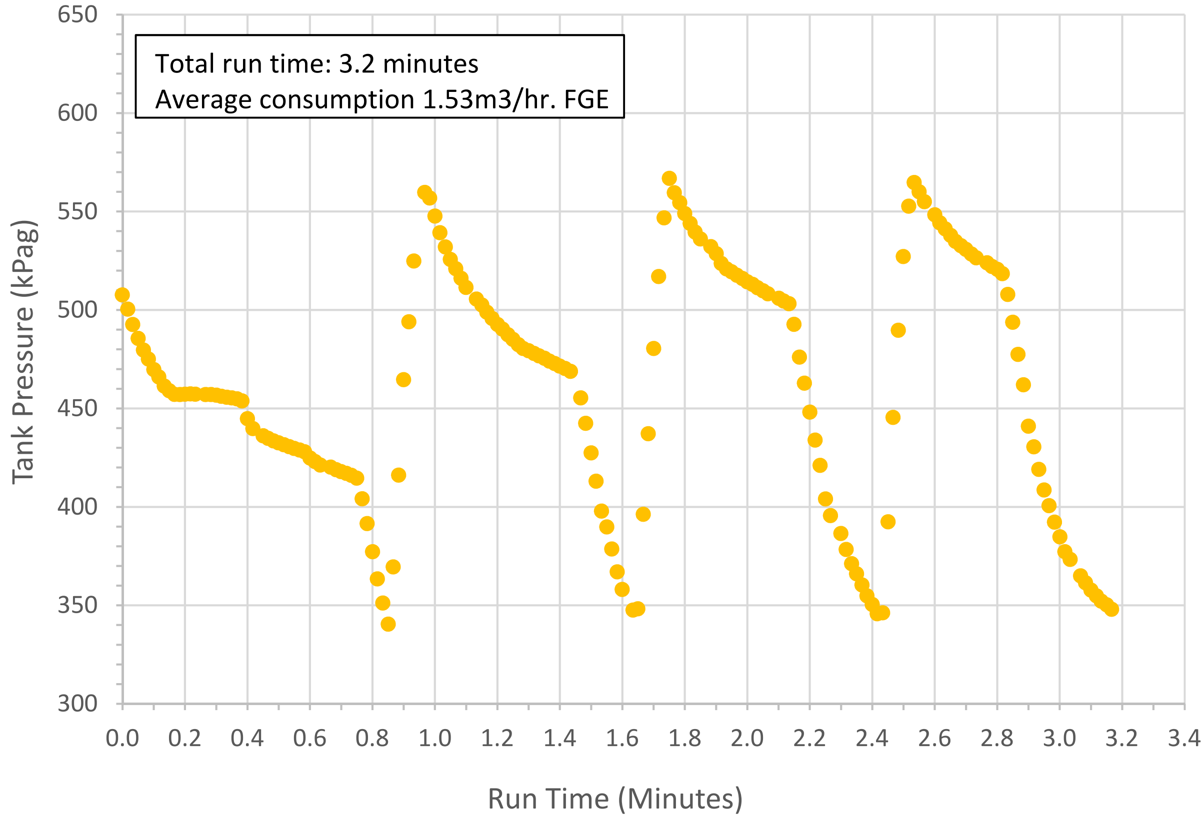

Fig.9: Fisher™ 4150 Pressure Controller e-MEAS™ Field Tested Pneumatic Consumption

Level Controllers

The pneumatic operation of level controllers was studied in detail. In a level control loop, liquid produced from the wellhead enters the separator at varying rates. The rates are impacted by the non-homogenous nature of the reservoir, the ratio of gas and liquid in the well bore and the presence of plunger lifts. The separator may be 2-phase (gas-liquid separation) or 3-phase (gas, oil/condensate and water separation). One line is used to let the gas exit the vessel and one or two liquid dump lines are used to let liquid exit the vessel. The conventional means of ensuring no liquid goes out the top of the vessel with the gas and that no gas goes out the dump lines, requires that the liquid level be controlled to a height range in between those two boundary conditions. In the case of a 3-phase separator, a level controller is also used on the oil/condensate-water interface to ensure the water level never rises high enough to overflow the weir and contaminate the oil/condensate on the other side.

Separators may be oriented vertically or horizontally. For a fixed change in liquid level, vertical separators require less volume than horizontal separators and consequently dump more frequently because the surface area to volume ratio is much lower than found in horizontal separators. As shown in Fig. 10 below, the level controller has a displacer immersed in the process that has a buoyant force acting on it within the confines of the separator.

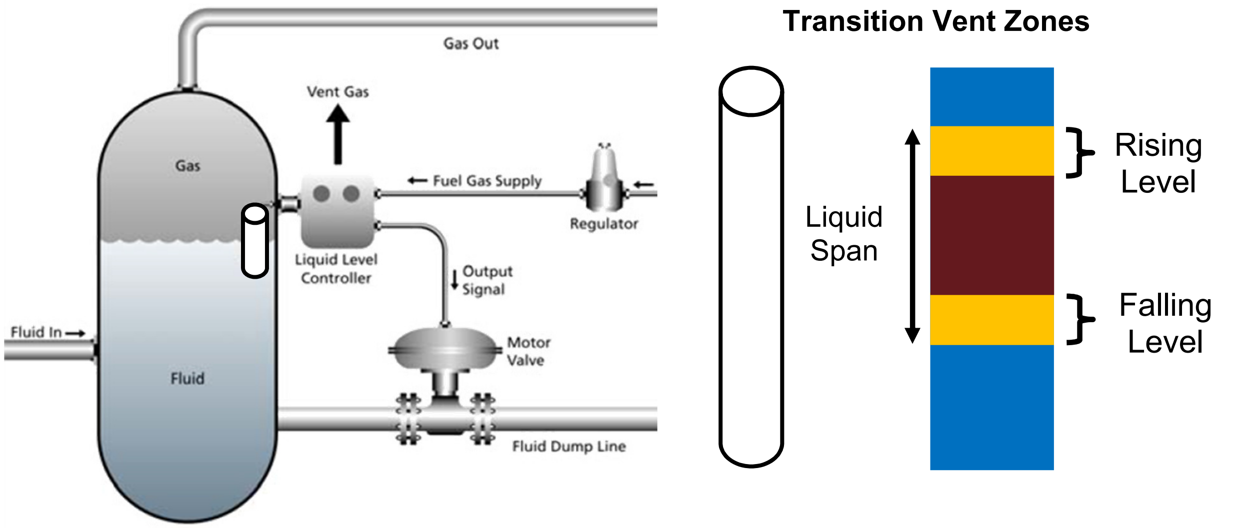

Fig. 10: Level Controller Illustration

The buoyant force acting on the displacer is proportional to the volume displaced by the immersed displacer and the density of the fluid acting on it. Lighter fluids exert less buoyant force, which is important to consider when designing upstream oil and gas separators. The change in force acting on the displacer is impacted by the differential specific gravity of the media acting on both sides (i.e. the difference in the fluid and gas densities in the illustration provided). Where the differential specific gravity is larger, more upward force is exerted on the displacer and less level change will be required, in addition to the spring force in the controller used to adjust the zero or target vessel fluid level, to overcome the pneumatic force applied to surface areas in the level controller relay.   When less level change is desired in a vessel, the difference in the buoyant force exerted on the displacer is reduced and the level controller needs to be more sensitive. The level controller can achieve more sensitivity by having a higher gain relay, using a longer connecting rod and/or by operating on a lower pneumatic supply pressure. In this way, a smaller change in buoyant force needs to act on the displacer to provide an equivalent moment near where the spring force is applied and/or overcome a lower pneumatic pressure acting on the level controller relay surface area(s).

In Alberta, it is industry's preference to use level controllers that maintain a tight level band with high gain snap acting relays. The preference for high gain relay level controllers may have resulted from cost restraints in vessel fabrication and using level switches/floats with restricted spans for level control. Operational concerns such as avoiding trip of the high-high level shutdown above this level controller may have also factored into that decision as well. Using an on-off action, lower gain, relay in a level controller results in a wider range of fluid heights in the vessel. This may be fit-for-purpose on liquid-gas interface with larger differential specific gravity acting on the displacer, but will not be suitable for liquid-liquid interface because the smaller differential specific gravity won't provide enough buoyant force on the displacer to cause a dump event.

Displacer sensing level controllers operate in three modes, steady state, transient and full output. Where the level controller does not provide an output pressure to the dump valve actuator, it remains in steady state and the amount of gas vented is only the leakage across the seat of the relay. Referring to published manufacturer vent rate specifications, older level controllers, such as the Fisher™ 2900, are high vent (>0.17m3/hr.) in steady state and newer level controllers, such as the Fisher™ L2sj and Fisher™ L2, are low vent (<0.03m3/hr.) in steady state (Emerson Automation Solutions, 2018).

Where enough buoyant force acts on the displacer to cause the controller to be on the verge of full pneumatic supply output to the dump valve, and the controller has a high gain or snap acting relay, it will be in transition state and will be venting much more gas to the environment than it did in the steady state. For example, this is true of the high gain Fisher™ L2(snap). The transient vent rate directly contributes additional emissions to the volume needed by the actuator to open the dump valve and to the amount of gas the level controller consumes only in steady state operation. The controller may remain in the transition state for longer periods of time if the liquid enters the separator at a low rate. In such cases, the transient vent is a greater fraction of the total gas vented from a level controller with low rates of level change in the vessel. Level controllers may also remain in the transient state unable to reset to the steady state vent rate. Those level controllers can be manually reset in the field without hardware changes by opening the instrument cover and temporarily applying force to the span levers or displacer rod.

As the differential specific gravity becomes smaller, a greater amount of level change will be required to have enough additional buoyant force to cause a dump event. Allowing more height difference between the process connection to the level controller and the process connection to the dump valve provides:

- Increased flexibility in the use of the available displacer sensing length;
- Reduced controller gain (more pneumatically efficient level controller);

- Reduced number of dump cycles; and
- Reduced GHG emissions from level control loop operations.

Opening and closing the dump valve less frequently and dumping more volume per event will not cause the dump valve trim to wear out faster than it would dumping less volume more frequently. The duration of exposure to a potentially trim damaging cavitating process is the same in either case, and is still much shorter than it would be if the level controller provided a throttling output to the dump valve. A comparison is provided for two bench tested level controllers in Fig. 11 and Fig. 12, which shows that steady state vent rates are not the best predictor of emissions for dynamically active control loops.

Steady state vent rates are only one component of emissions from pneumatic devices. In the case of level controllers, pumps or other devices used in active control loops, dynamic consumption is often a more significant element of total emissions from the device. A plot of upstream tank pressure vs. time, is essential to observing the different vent rates associated with a level controller's operation. Note the following, from bench testing:

- There is a large difference between steady state consumption and the volume of gas consumed in a dump event. The inter-stage volume bottle pressure drops much faster through a transient and dump event than it does in steady state.
- Steady state aligned with manufacturer published data (<0.03m3/hr. FGE for Fisher™ L2 and <0.01m3/hr. FGE for Fisher™ L2sj) and the volume associated with a dump event was two orders of magnitude larger (1.80-5.39m3/hr. FGE).
- The flat profile of steady state consumption could lead to misinterpretation that this is an intermittent vent device, not continuous.
- The dump cycle period is shorter with lower pneumatic supply pressures and the steady state vent rate is lower.
- The dump cycle period is about seven times longer with the Fisher™ L2sj than the Fisher™ L2snap and the pressure decreases per dump event smaller by about 7kPag.

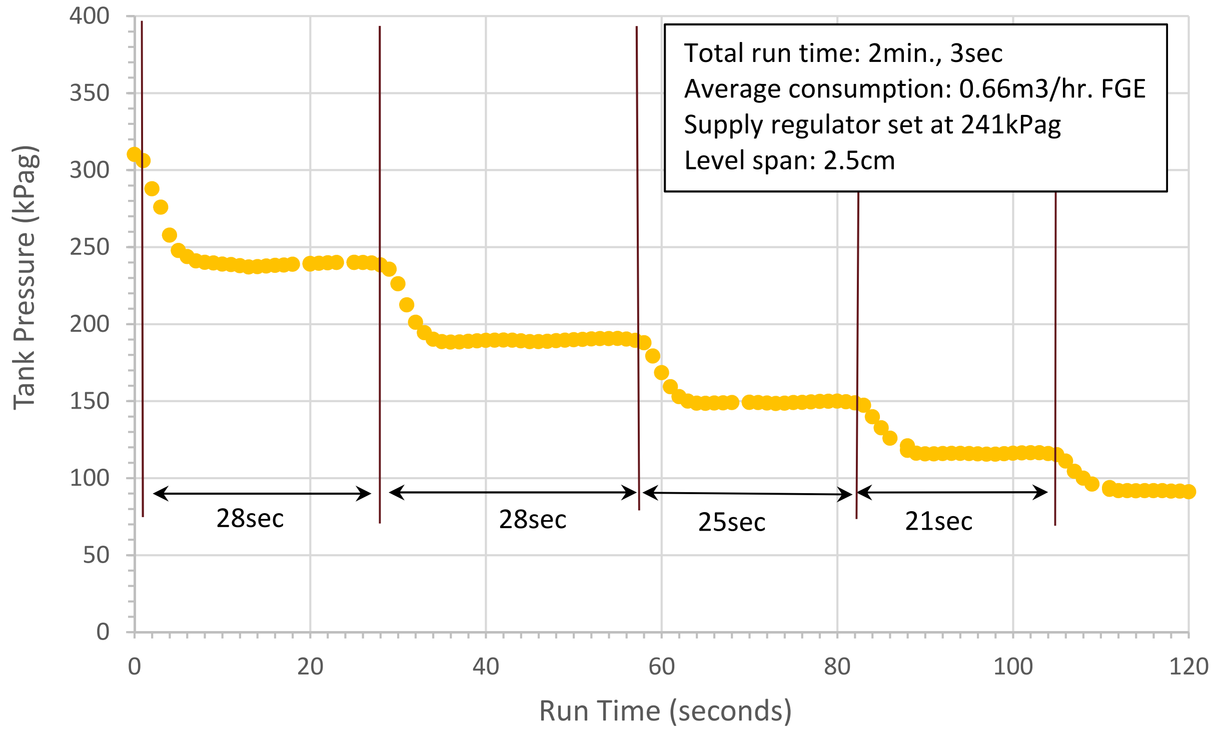

Fig. 11: Fisher™ L2(Snap Relay) Level Controller Bench Tested Pneumatic Consumption

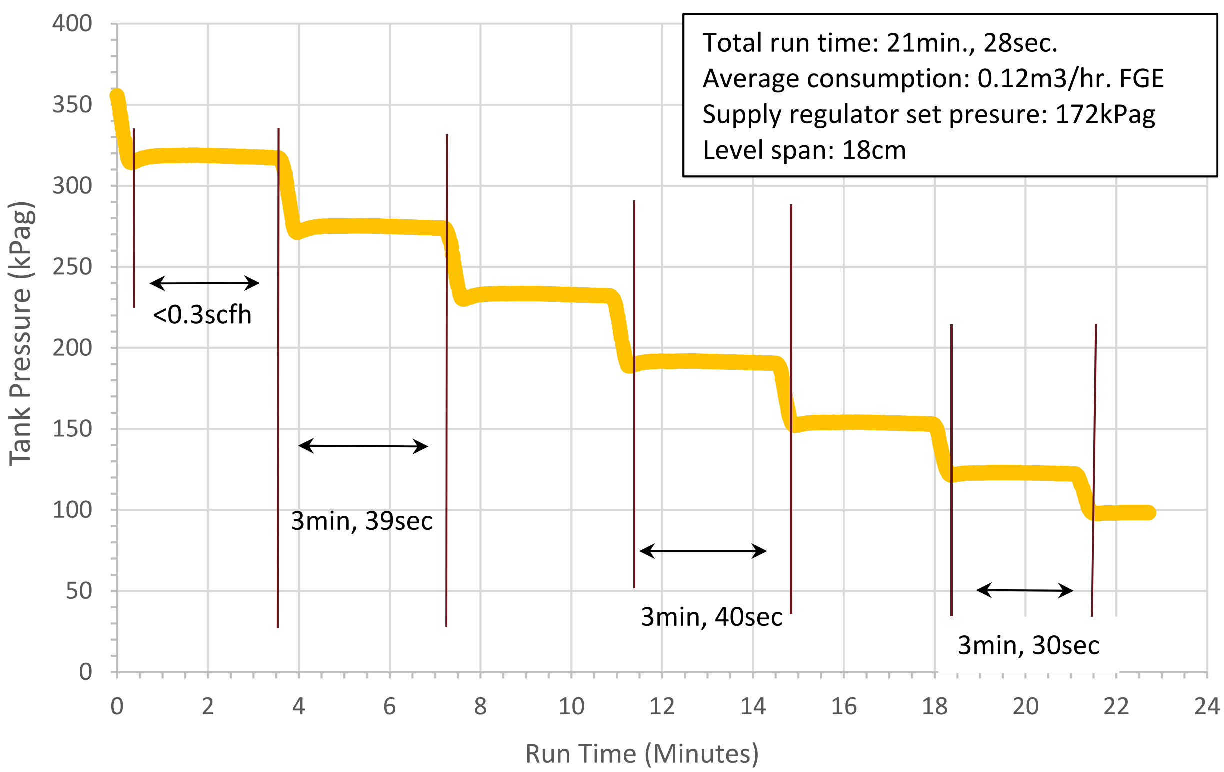

Fig. 12: Fisher™ L2sj (On-Off Relay) Bench Tested Pneumatic Consumption

Field level controllers such as the Fisher™ L2 were retrofit with lower emission improved snap acting relays (reduced transient vent) and the Fisher™ L2sj without shutting in the well nor de-pressurizing the separator to change out the entire level controller. Not shutting in production or limiting the duration while performing pneumatic device retrofits helps mitigate the impact on well production and eliminates the fuel gas that would otherwise go to flare on a blowdown event.

Field testing provided more insight into the consumption during transient state. It was observed, as shown in Fig. 13, that the dump frequency may not be considered frequent, but the controller could still be a candidate for pneumatic efficiency improvement. Note how the vent rate changes from steady state (flat) to transient (steeper) to nearly vertical (dump event) and back to transient. The measurement was stopped before the level controller was back in steady state. While the volume of gas needed to stroke a pneumatically actuated dump valve cannot be eliminated, unless switched to an electric or electrohydraulic actuator, the transient consumption can be.

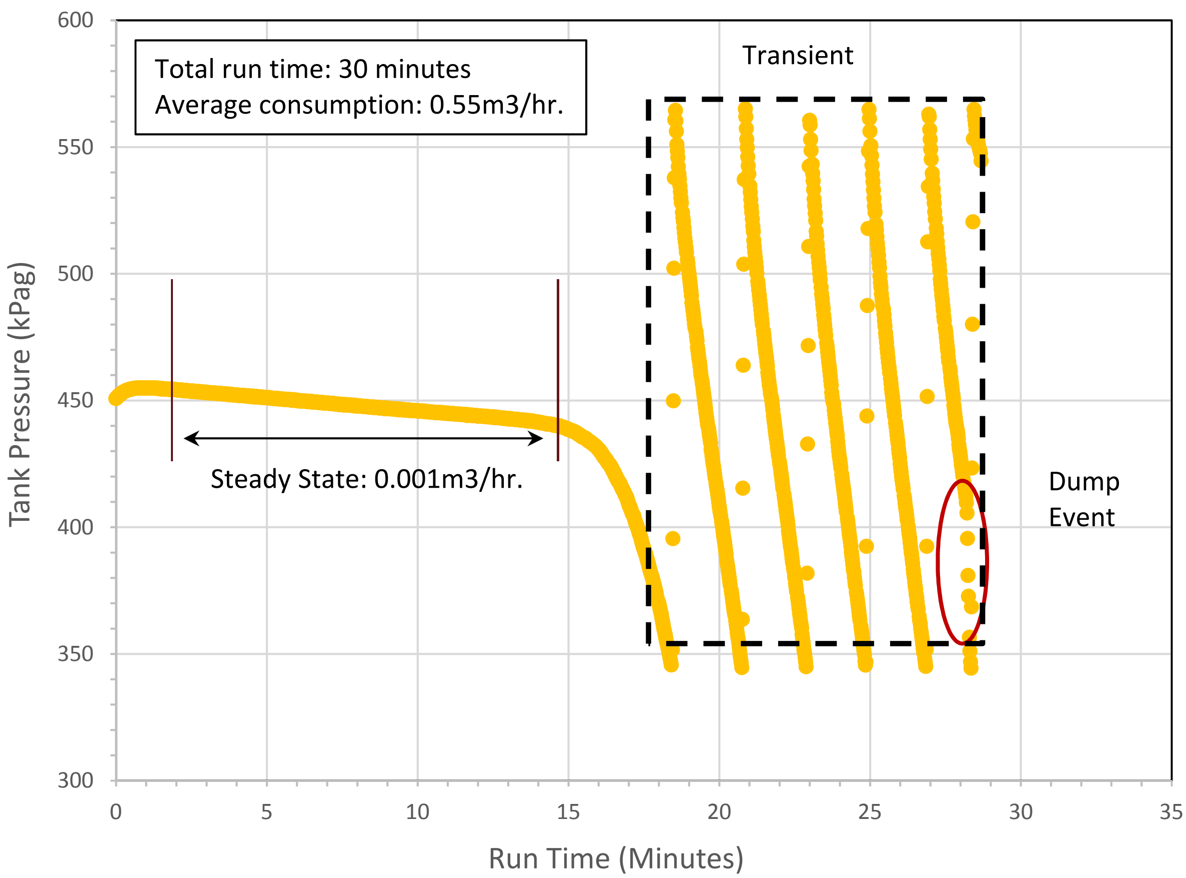

Fig. 13: Fisher™ L2(Snap Relay) Level Controller Field Tested Pneumatic Consumption

Plots of the Vent Rate (m3/hr.) vs. Run Time are not the preferred means of showing pneumatic device consumption in this study. Fig. 14, provides a visual for the same measurement data using a rolling average of vent rates over five sample measurements. A rolling average was used in the plot to minimize the calculated flow rate variance determined in one second increments. Note how much harder it is to determine where the dump event happened. The flow rate appears to vary in the transient state, but it is known looking at Fig. 13 that the vent rate of the level controller, while in the transient state, didn't in fact change. The inter-stage volume bottle refill events are the reason for the increase in measured vent rate. In this case, only the highest vent rate is attributed to the dump event.

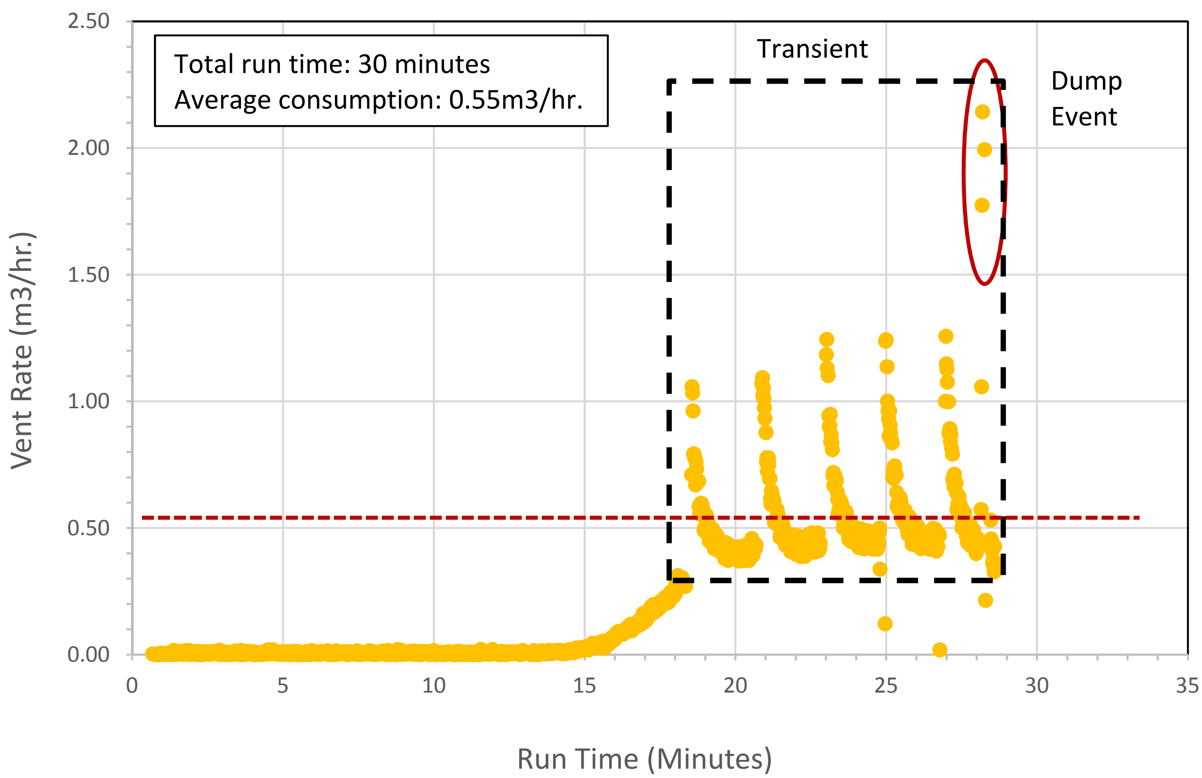

Fig. 14: Fisher^{TM} L2(Snap Relay) Level Controller Field Tested Vent Rate vs. Time

Implementation ready level controllers such as the Fisher™ L2sj use a relay that eliminates consumption associated with transient "simmer" states and has an open or closed response, with no increase in vent rate between open and closed states attributable to the level controller. These level controllers do so because the gas flow through the relay can only be in one of two flow paths – steady state or full output. Eliminating the ability of gas to pass through both flow paths at the same time eliminates the amount of gas vented through transition.

Dump valves that stroke less often and pass more volume per dump event are also good for measurement of produced volumes. Improved Fisher™ L2 snap acting relays have also been installed in the field that reduce the transient vent rate and dump frequency while maintaining the gain needed to control the fluid level to a narrow enough band on almost any liquid-liquid or gas-liquid interface. Fisher™ L2(snap, improved), Fisher™ L2e, Fisher™ L2(on-off) and Fisher™ L2sj level controllers used in the same service all accomplish that, which is important to consider in Greenfield design as well as Brownfield pneumatic efficiency optimization. This is an opportunity that bears further examination.

Dumping more volume less frequently also provides better conditions for the flow meter downstream of the dump valve, typically a turbine meter, to measure flow more accurately. By passing volume for a greater duration in the range the flow meter was designed to operate, the inertial effect of the turbine is mitigated and the measurements will be more accurate. Conversely, by controlling the level to less than 5cm of span, the flow meter is exposed to frequent, but brief periods of flow. The meter may never see flow rates in the range it was designed to measure accurately nor measure a flow rate that is representative of the total amount of flow that passed through the dump valve line. A narrower level span has the potential to increase the volume of gas carry under in the separator. If the tank is dumping more frequent because of a narrow span, the produced fluids will have less time for gases to come out of solution. These issues related to level control, pose a whole other set of challenges if these process flow measurements are used to determine the productivity of the UOG well. More certainty of produced flows may be available with truck out volumes from on site storage tanks, but those tanks may not be located at the wellhead. If used downstream, the tank volume would be from several different wellheads and not specific to a given well. Proper measurement of produced volumes is an area for further improvement and is not the focus of this study.

The vent rates from all Fisher™ L2 level controllers were analysed as a population as well. The measured flow rates are presented in three groupings: one that includes level controllers that dumped on average more frequently than once every 15min; one that includes level controllers that didn't dump between 15min and the full duration of measurement (up to 37 minutes); and one that includes all level controllers measured. The average flow of gas released to atmosphere from Fisher™ level controllers was 0.46m3/hr. of FGE. This average is based on measurements gathered in the field using the e-MEAS™ on 72 Fisher™ L2 level controllers.

Water level control was 0.48m3/hr. FGE and condensate level control was 0.41m3/hr. FGE, which showed that the emission difference between controllers used in liquid-gas interface and liquid-liquid interface was minimal. The measurement of 0.19m3/hr. FGE average is specific to level controllers that did not dump in the measurement period. When targeting level controllers actuating more frequently than once every 15min, the average emission rate was 0.75m3/hr. FGE +/- 0.14m3/hr. FGE.

This targeted population will be found at sites that are newer, produce more liquids and are higher pressure than older sites that produce less liquids and are lower pressure. This vent rate span has a four-fold difference in vent rates, which is important to recognize when applying a single emission factor to an instrument type.

Level controllers that did not dump in the period of sampling had a vent rate higher than manufacturer published vent rates because the population sampled included units that were: operating in transient, not steady state; and may have been on the verge of dumping, as shown in Fig. 13 above; and showed signs of wear and tear. Manufacture published vent rates are for controllers in new condition, not controllers that have been in service with a wet fuel gas pneumatic supply nor o-rings that show signs of wear as part of regular use. Field instruments need to be maintained. Some scatter in the measurements can be attributed to the difference in the size of the actuator used on the dumps valves. Larger actuators use more gas to fully stroke than smaller actuators, which are part of the total volume vented. As shown in Fig. 15, level controllers dumping more frequently than once every 15min. are a key focus area to improve field instrument pneumatic efficiency. It is recommended that the measured vent rate of 0.75m3/hr. FGE for these randomly selected (a sample of 32) Fisher™ L2 snap acting level controllers dumping at least as frequently as once every 15 minutes be accepted as an emission factor for this subset of the larger installed Fisher™ L2 snap acting level controller population.

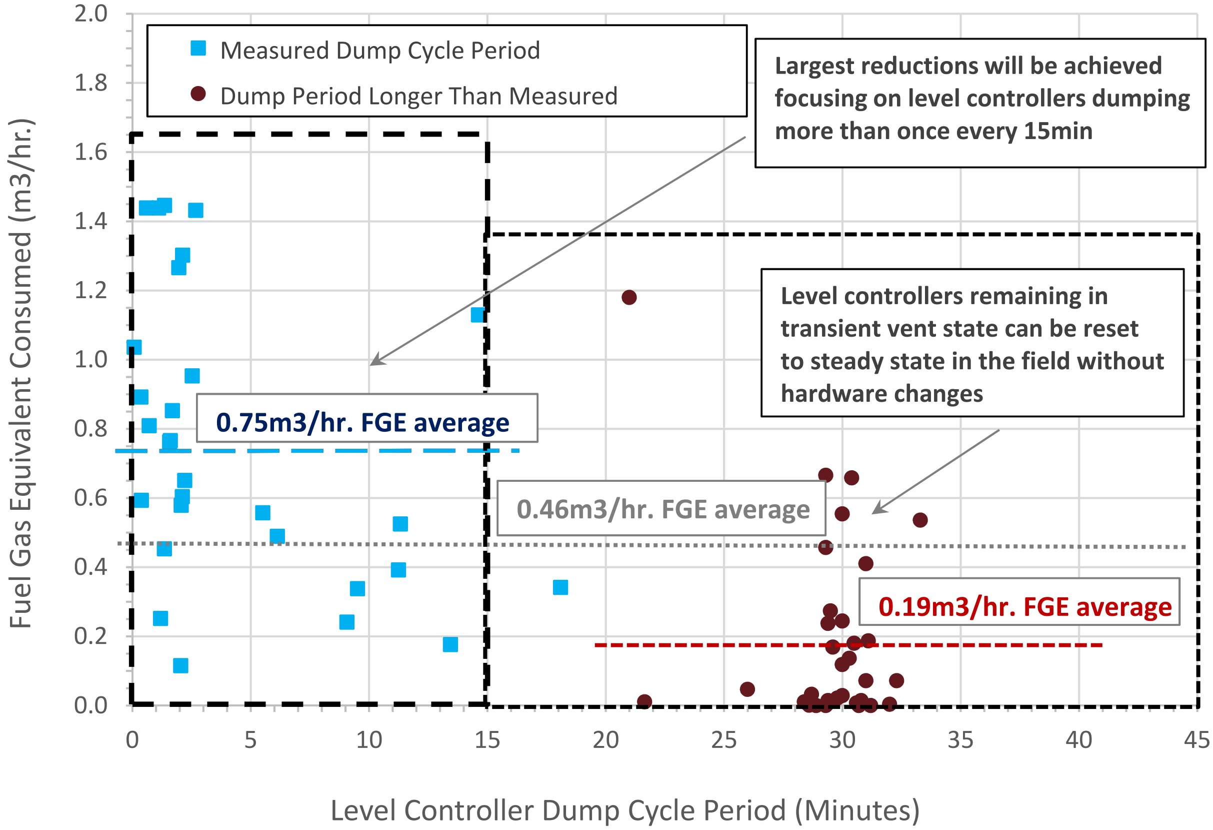

Fig. 15: Fisher™ Level Controller Pneumatic Consumption vs. Period

The sampled Fisher™ L2(snap) level controllers vented and average of 0.46m3/hr. FGE. Reduced volumes vented can be achieved when replaced with more pneumatically efficient level controllers or compatible relays. For example, vent rates of 0.12m3/hr. FGE were achieved with the Fisher™ L2sj level controller. Using measurements from this study, Fisher™ also took steps to redesign and improve the pneumatic efficiency of the L2 snap acting relay while providing enough relay gain to control the level within a narrow level band in separators if required. Due to significant difference in buoyant forces between a gas-liquid interface and the condensate-water interface, new relays have been made specific for each type. The difference between 0.46m3/hr. and 0.12m3/hr. is 0.34m3/hr., which is approximately 40 tonnes of CO2e/yr. A retrofit population as small as 12,500 would achieve a 0.5MT CO2e reduction, which is well within the estimated population of installed Fisher™ L2 level controllers in Alberta. If the targeted population is Fisher™ L2 level controllers that only dump once every 15min, the difference would be 0.63m3/hr. FGE, which is approximately 75 tonnes CO2e/yr. A retrofit population as small as 6,700 would achieve a 0.5MT CO2e reduction.

The sampled level data was also considered as a full population and not a population that dumped more or less frequently than once every 15 minutes. As shown in Fig. 16, a log plot provides opportunity to determine vent rates specific to any dump cycle period between one second and 35 minutes. While the R^2 coefficient is only 0.46, it provides a better sense for how the vent rate decreases with longer dump cycles. Many outliers can be seen above and below this trendline. Outliers above the trendline near a 30-minute measurement sample are predominantly level controllers venting continuously at a rate more consistent with the otherwise higher temporary transient vent rate in a typical dump cycle.

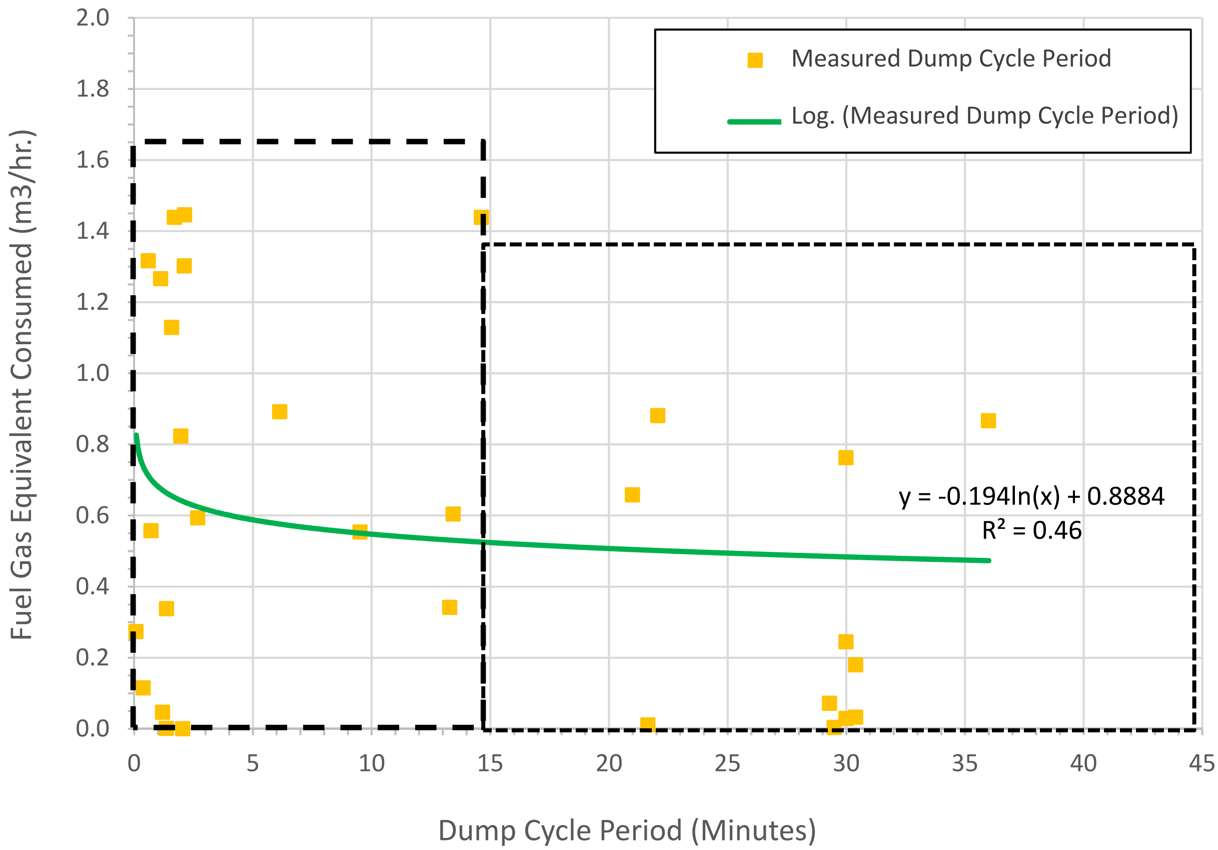

Fig. 16: Fisher^{TM} Level Controller Pneumatic Consumption vs. Dump Period

Taking the integral of the trendline equation between one second (0.167 minutes) and 30 minutes would provide the total vented volume of the population. Dividing that by 29 minutes and 59 seconds would provide an alternate means of determining an average vent rate of the population.

Testing other make and model level controllers is an area for further study. Conclusions cannot be drawn from only Fisher™ level controllers and applied to other manufacturer's level controllers. While the dynamic impact was better quantified for Fisher™ L2 level controllers, insufficient quantities of other pneumatic instruments were sampled in this study to be representative of their respective installed populations nor the anticipated vented rate when dumping once every 15 minutes or more frequently.

Transducers

The vent rates from transducers were also measured for comparison of older style Fisher™ 546 transducers to newer 1st Gen Fisher™ i2P-100 and 2nd Gen Fisher™ i2P-100 transducers. As shown in Fig. 17, transducers receive a 4-20mA input signal and provide a proportional pneumatic output pressure. The output pressure span is most often 41-207kPag (6-30psig), but it can be 21-103kPag (3-15psig), 14-228kPag (2-33psig) or customized to output an alternate pressure span.

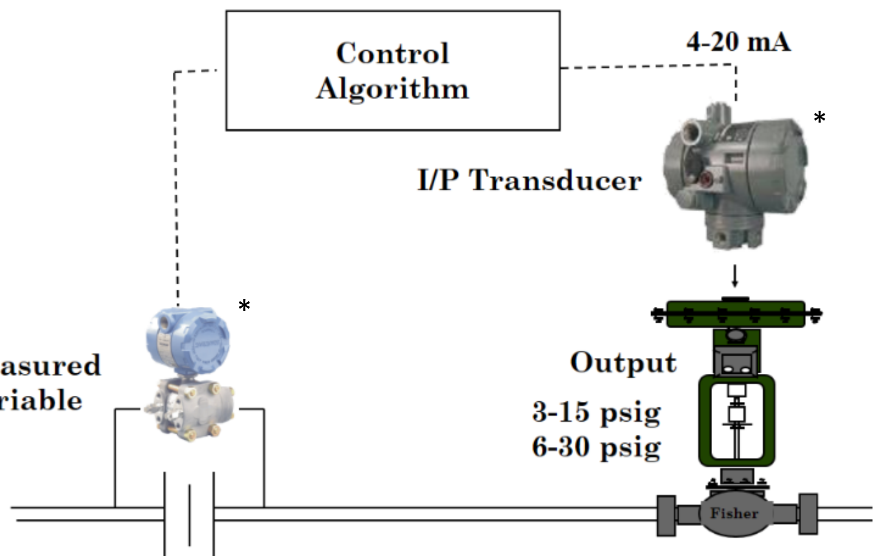

Fig. 17: Electro-Pneumatic Pressure Control
**Images Used with Permission of Emerson Automation Solutions*

Shown in Fig. 18 are the differences in operation of the old high vent Fisher™ 546 mechanical transducer (left) and the redesigned Fisher i2P-100 (2nd Gen.) low vent transducer (right). The Fisher™ 546 uses a torque motor, nozzle-flapper and pneumatic relay. Its high-capacity transducer relay vents more gas from its fully pressured casing. The FisherTM i2P-100 (2nd. Gen) low vent transducer uses a redesigned converter module and two moving coils.

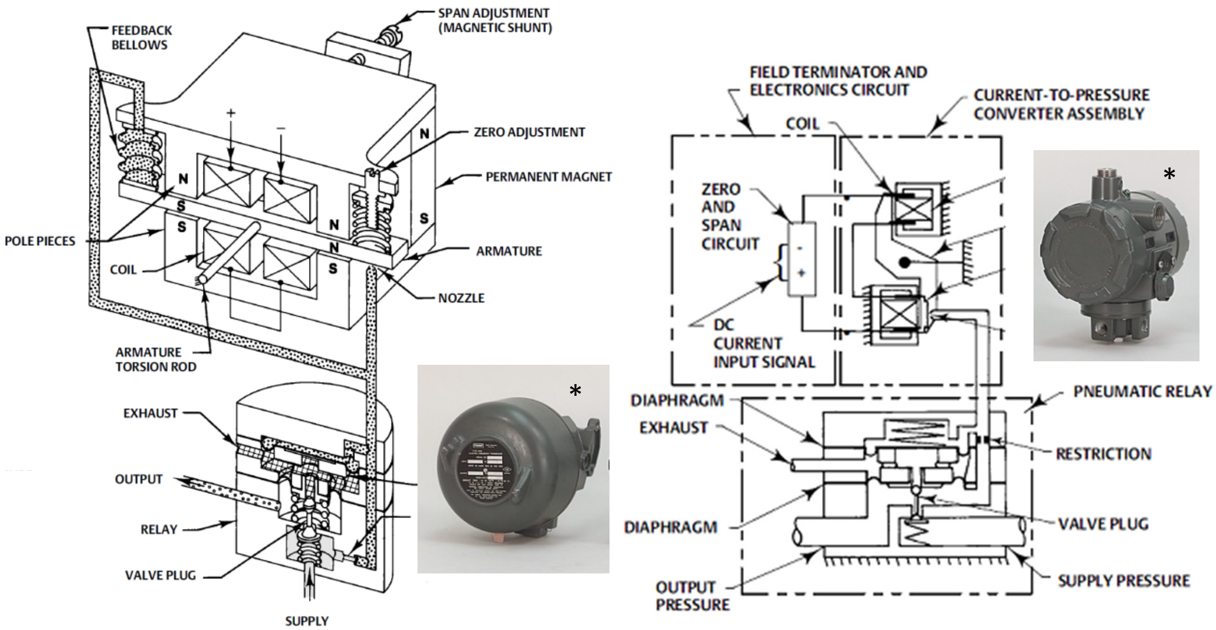

Fig. 18: Fisher™ 546 (left) and i2P-100 (2nd Gen.) (right) Internal Components
**Images Used with Permission of Emerson Automation Solutions*

The integral relay provides the high capacity necessary to drive pneumatic actuated final control elements, while pressuring only a portion of the transducer internals to help reduce the volume of gas vented.

Testing was completed for a variety of mA input signals using the e-MEAS™ and the Hawk 9000. The first test was done with 0mA supplied to the 546 transducers for comparison of the vent rate using the e-MEAS™ upstream and the Hawk 9000 downstream. As shown in Fig. 19, the Hawk 9000 cumulative vent rate (brown line) is approximately linear, but there are significant instantaneous flow rate variances (yellow line) that correspond directly to the number of rotations of the Hawk 9000 per sample. The volume collected in the meter below the threshold that would cause meter to rotate cannot be quantified as an instantaneous flow rate. It was not determined what that minimum flow threshold is.

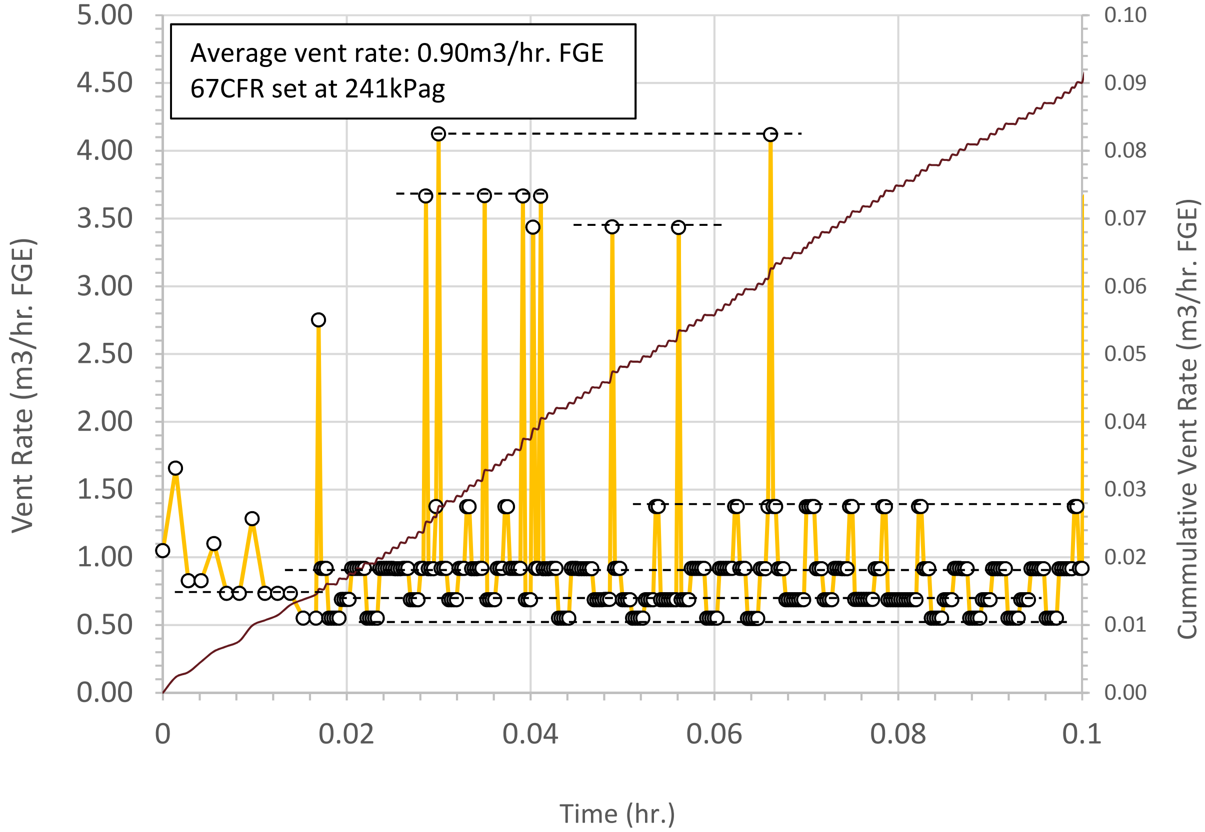

Fig. 19: Fisher™ 546 Transducer Bench Tested Pneumatic Consumption Using Hawk 9000

Operation of this style PD meter is better understood by working through hypothetical low and high flow examples. Consider that the low vent rate from the pneumatic device is enough to rotate the PD component of the Hawk 9000 1.1 +/-0.1 times in a five second period of measurement. The data log sample frequency is once per second. For the first four seconds, no volume registers, but the volume associated with rotation at the fifth second would be captured. Conversely in a high vent dynamic state, the pneumatic device measures enough to rotate the PD component 5.8 +/- 0.5 times per second. Over a ten second sampling period, the meter would catch instances of five rotations per second and instances of six rotations per second, but it would not measure the rate of volume change between those two vent rates. Similar min thresholds of measurement are observed in Fig. 19 by the dashed lines overlaid on the plot.

When comparing the consumption curve using the e-MEAS™, as shown in Fig. 20, it is more apparent how consistent the vent rate of the Fisher™ 546 transducer is by the parallel and repeated slope of the pressure curve over several volume bottle refill events. Note that the measured vent rate of the Fisher™ 546 transducer, with the same input of 0mA and, without the Hawk 9000 was 0.89m3/hr. FGE using the e-MEAS™. 0.89m3/hr. FGE is 0.06m3/hr. FGE higher than the e-MEAS™ measured when the pipe away vent connection was connected to the Hawk 9000 downstream of the transducer. 0.89m3/hr. FGE is 0.15m3/hr. FGE higher than measured by the Hawk 9000 when connected to the vent exhaust. These results indicate the vent rate was reduced when the Hawk 9000 was connected to the pneumatic device pipe-away vent line.

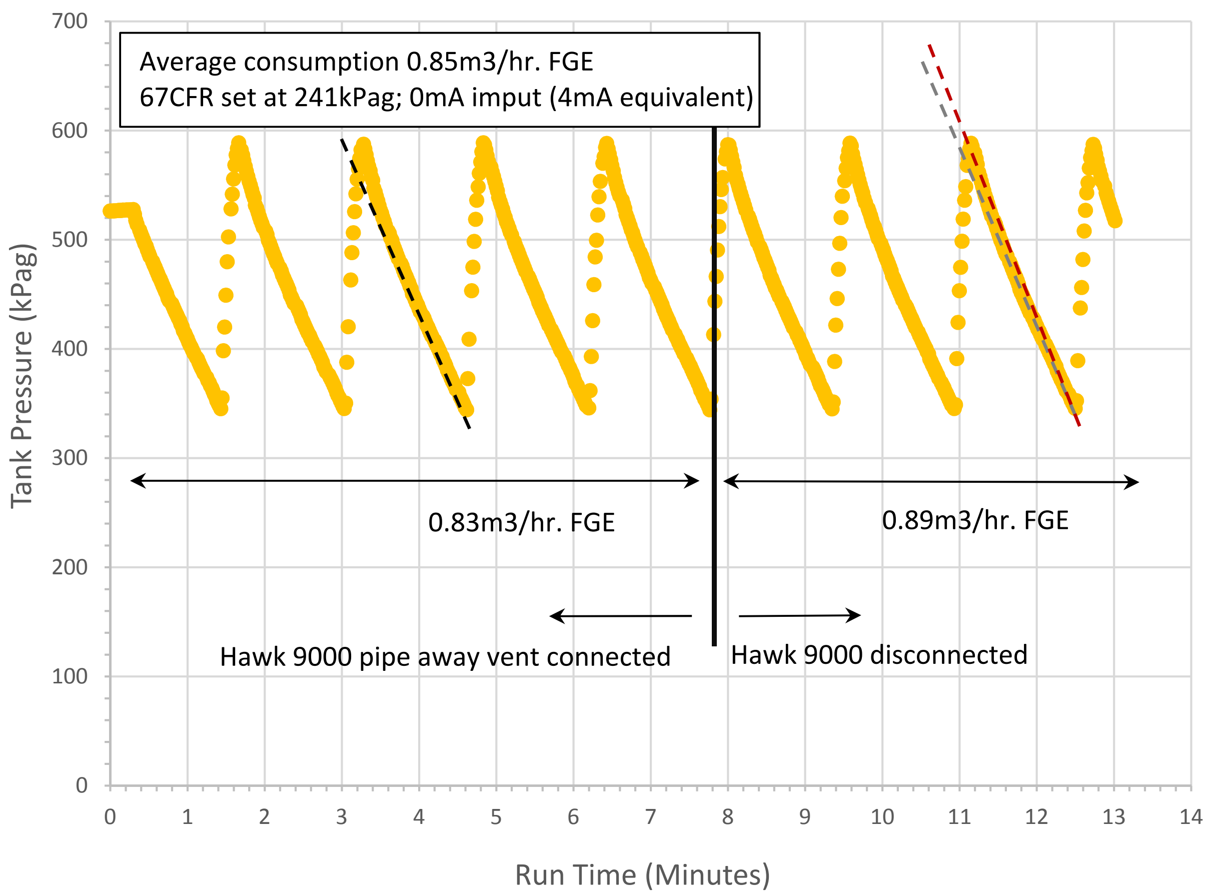

Fig. 20: Fisher™ 546 Pneumatic Consumption Bench Tested using e-MEAS™

The slope of the tangents (black, grey and red dashed lines) overlaid on the tank pressure curve illustrate the difference in vent rates. The grey and black lines are the same slope and the tangent color was changed from black to grey to provide greater contrast for visual comparison to the slope of the red line. By comparing the two tangents, the slope of the measurement with the

Hawk 9000 disconnected is observed to be slightly steeper, which is representative of the higher measured vent rate.

Testing completed on the Fisher^{TM} 546 transducer and i2P-100 (1st Gen) shown in Fig. 21 highlights three additional important vent effects.

- First, unlike the Fisher^{TM} i2P-100 transducer, the vent rate specific to the mA input was not linear for the Fisher^{TM} 546 transducer. As the mA input increased the output from the transducer increases and the vent rate to atmosphere decreases. This behaviour is explained knowing the entire casing of the Fisher^{TM} 546 transducer is pressure-containing where only a portion of the Fisher^{TM} i2P-100 transducer is. For the Fisher^{TM} 546 transducers, having greater output pressure means all the gas within the transducer case becomes pressured closer to the supply pressure. With that much pressure applied in the transducer case, the nozzle armature assembly has less differential pressure across it and it vents less gas to atmosphere. Conversely, with low mA input direct acting 546 transducers, more gas is vented because there is greater differential pressure across the nozzle armature assembly.

- Second, increasing backpressure on both model transducers effectively shifted the output pressure from the transducers by the amount of backpressure applied to the vent port. Pressure transmitters were installed on both the pipe away vent and the output lines. The amount of backpressure applied to the pipe away vent was adjusted with a manual valve downstream of the pipe away vent pressure transmitter. This in turn resulted in a proportional offset through the full output range of the transducer and a reduced measured vent rate. This comparison provided very conclusive backpressure impacts on both instrument performance and vent rates.

- Third, the vent rate of the Fisher^{TM} i2P-100 transducer is lower than the Fisher^{TM} 546 transducer through its entire output range.

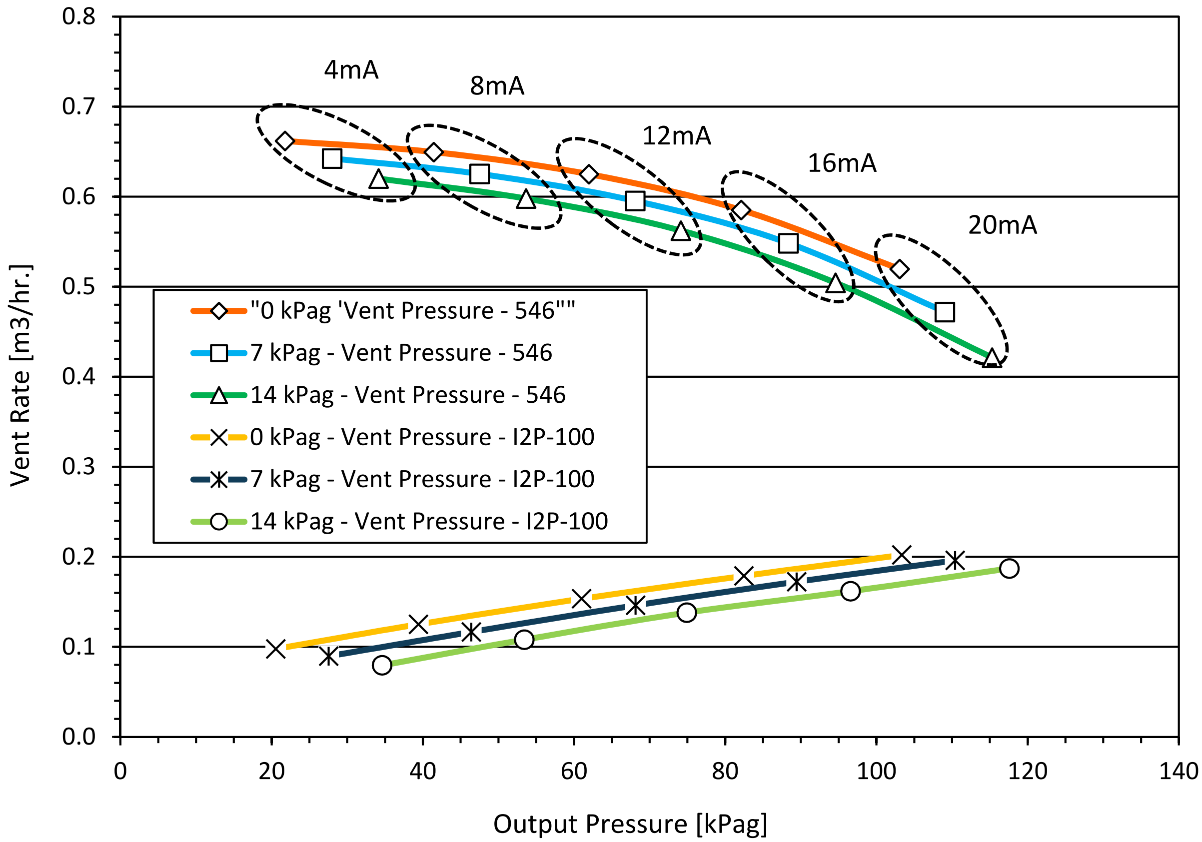

Fig. 21: Bench Tested FGE Flow Rate vs. Output Pressure Fisher™ 546 vs. i2P-100 (1st Gen.)

The vent rates measured when converted to air from m3/hr. FGE correspond closely with what has been published by Fisher™ in the bulletin form (Fisher Controls, 2017) and included in Table 4.

Table 4: Fisher™ i2P-100 Transducer Published Steady State Vent Rates (m3/hr., FGE)

Model	**21-103kPag Output (138kPag Supply)**	**Vent Rate (m3/hr.)**	**Model**	**21-103kPag Output (138kPag Supply)**	**Vent Rate (m3/hr.)**	**Vent Rate Reduction (m3/hr.)**
Fisher™ i2P-100 (1st Gen.)	21	0.11	Fisher™ i2P-100 (2nd Gen.)	21	0.05	**0.06**
	62	0.16		62	0.07	**0.09**
	103	0.23		103	0.09	**0.14**

The vent rate of the Fisher™ i2P-100 (1st Gen.) transducer was also compared to the Fisher™ i2P-100 (2nd Gen.) transducer with and without the Hawk 9000. As shown in Fig. 22, it is harder to correlate changes in input current with changes in transducer vent rates shown in Table 5 than it is looking at the slope of pressure vs. time for the inter-stage pressure tank in the e-MEAS™.

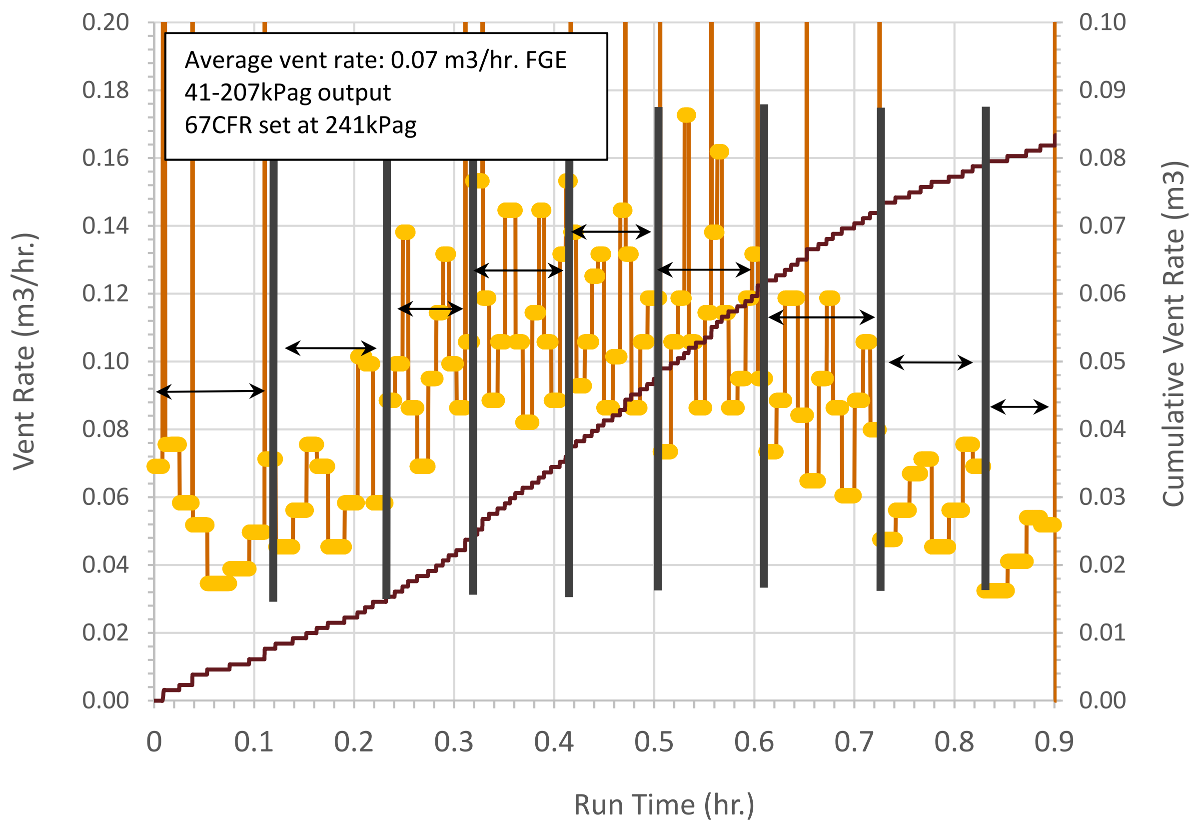

Fig. 22: Fisher™ i2P-100 (2nd Gen.) Bench Tested Transducer Vent Rate with Hawk 9000

Table 5: Fisher™ i2P-100 (2nd Gen.) Bench Tested Transducer Vent Rate with Hawk 9000

mA Input	**4**	**8**	**12**	**16**	**20**	**16**	**12**	**8**	**4**
Output Pressure (kPag)	41	82	124	165	207	165	124	82	41
Vent Rate (m3/hr. FGE)	0.05	0.06	0.09	0.12	0.14	0.13	0.10	0.07	0.05

By comparing Fig. 23 to Fig. 24, it was clear that the 2nd Gen. Fisher™ i2P-100 transducer was more pneumatically efficient with an average vent rate reduction of over 0.16m3/hr. Saving 0.16m3/hr. is consistent within 0.03m3/hr. of what has been published by Fisher™ in bulletin form (Fisher Controls, 2017) similar to Table 4 for 41-207kPag output. Like the slope tangents provided for the Fisher™ C1 pressure controller and the Fisher™ 546 pressure transducer, it was easy to see where the vent rate changed because of the change in slope of the tank pressure vs. time.

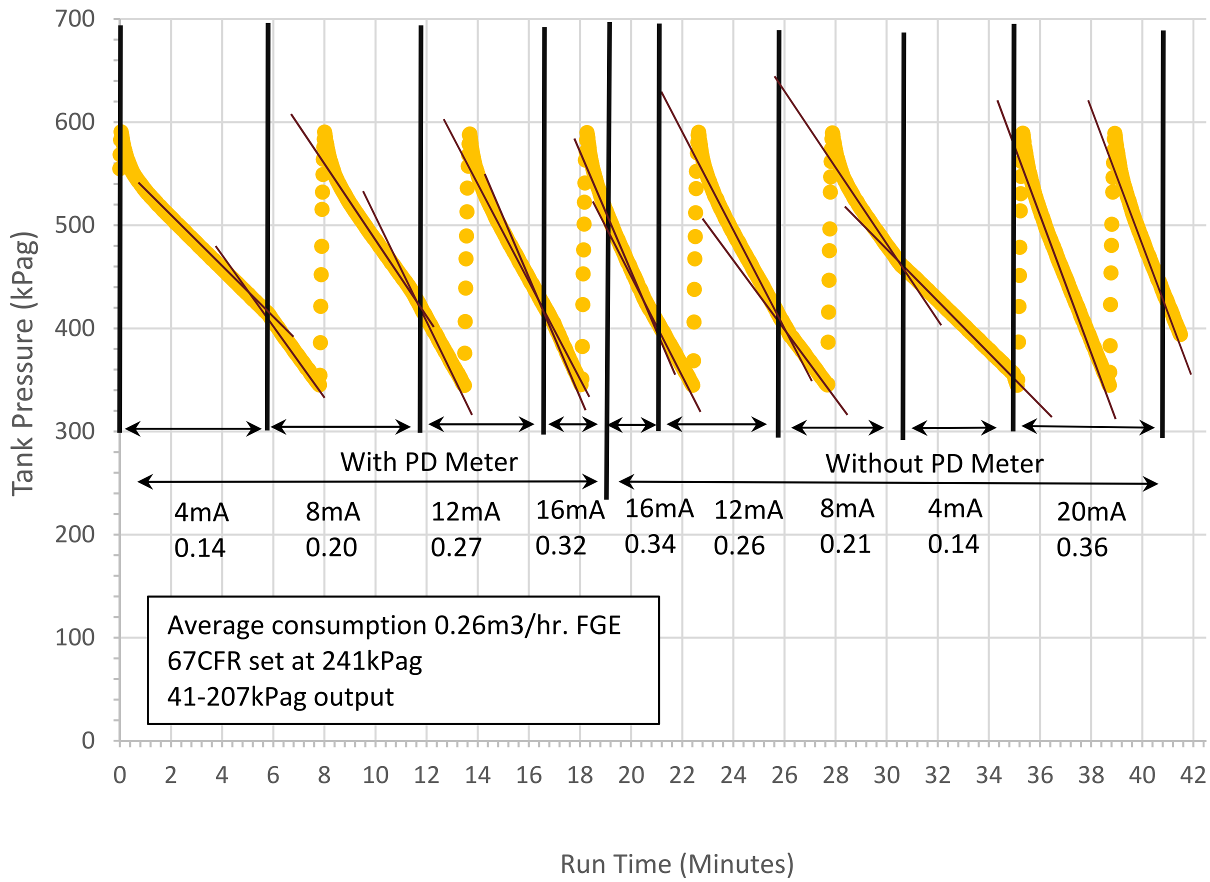

Fig. 23: Fisher™ i2P-100 (1st Gen.) Bench Tested Pneumatic Consumption

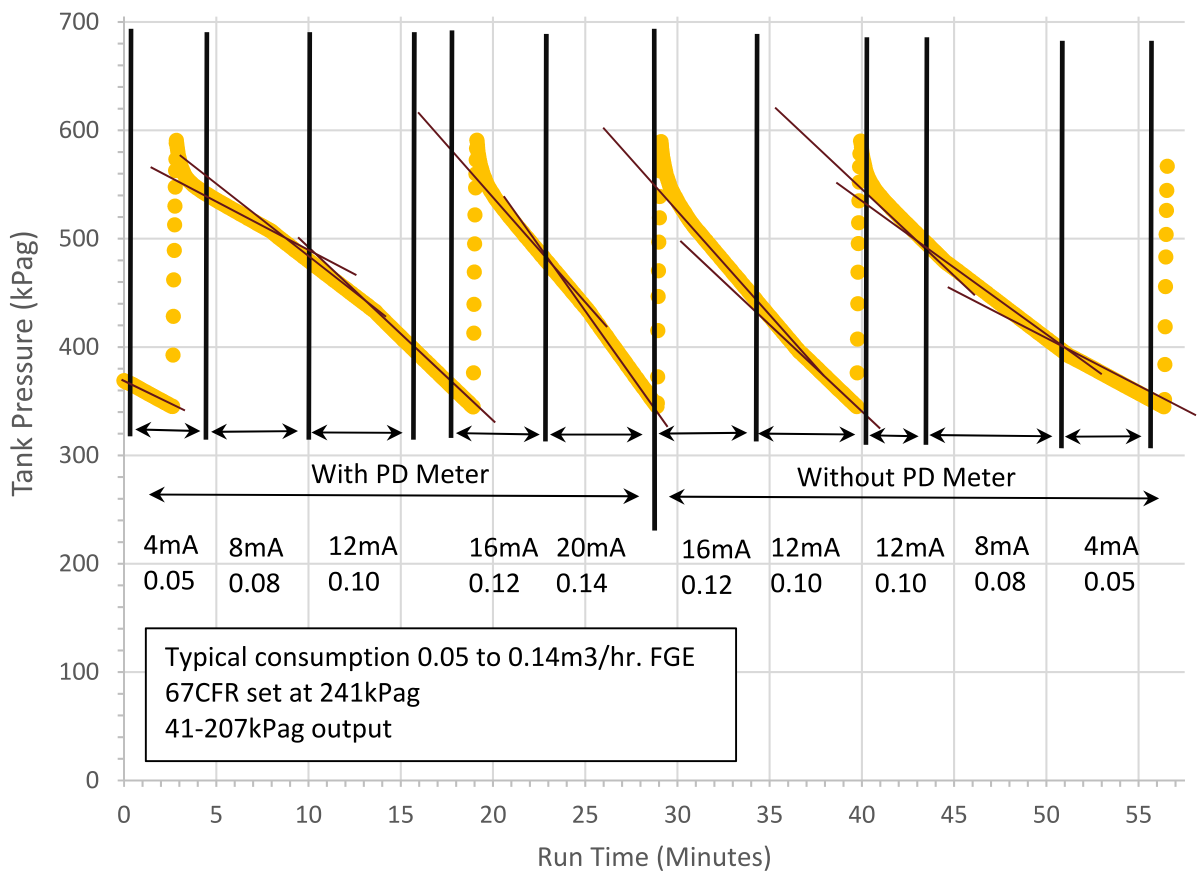

Fig. 24: Fisher™ i2P-100 (2nd Gen.) Bench Tested Pneumatic Consumption

Table 6: Fisher™ i2P-100 Transducer Published Steady State Vent Rate (m3/hr., FGE)

Model	**41-207kPag Output (241kPag Supply)**	**Vent Rate (m3/hr.)**	**Model**	**41-207kPag Output (241kPg Supply)**	**Vent Rate (m3/hr.)**	**Vent Rate Reduction (m3/hr.)**
Fisher™ i2P-100 (1st Gen.)	41	0.13	Fisher™ i2P-100 (2nd Gen.)	6	0.06	**0.07**
	124	0.25		18	0.10	**0.15**
	207	0.37		30	0.15	**0.22**

Five Fisher™ i2P-100 (1st Gen.) transducer measurements were gathered in the field using the e-MEAS™. With one high outlier removed, the average was 0.83m3/hr. FGE, which is still higher than manufacturer published vent rates shown in Table 6. It was recognized that four transducers are not enough to be a statistically representative sample of the transducers installed in the field. A larger number of field measured transducer vent rates would be needed to assert how much higher the steady state vent rate of Fisher™ i2P-100 transducer is above the manufacturer published values with care not to include transducers with changing output pressures and associated dynamic contributions in the field sample. The higher than average vent rate supports the assertion that instruments need to be maintained to ensure operation within manufacturer's published vent rates and that there are more contributions to the measured total pneumatic consumption than the gas vented by the instrument in steady state operation. For these four field measured transducers, one possible explanation for the higher measured vent rate is that actuators on the final control elements were pressuring and depressuring to throttle the control valve during the measurement, which added an element of dynamic consumption to the measured total vent rate.

Chemical Injection Pumps

In addition to instruments, pneumatic chemical injection pumps were also sampled with the e-MEAS™. The 5100-series model as shown in Fig. 25 (GE Oil & Gas, 2018) is a very common chemical injection pump used at well sites in the Western Canadian Sedimentary Basin.

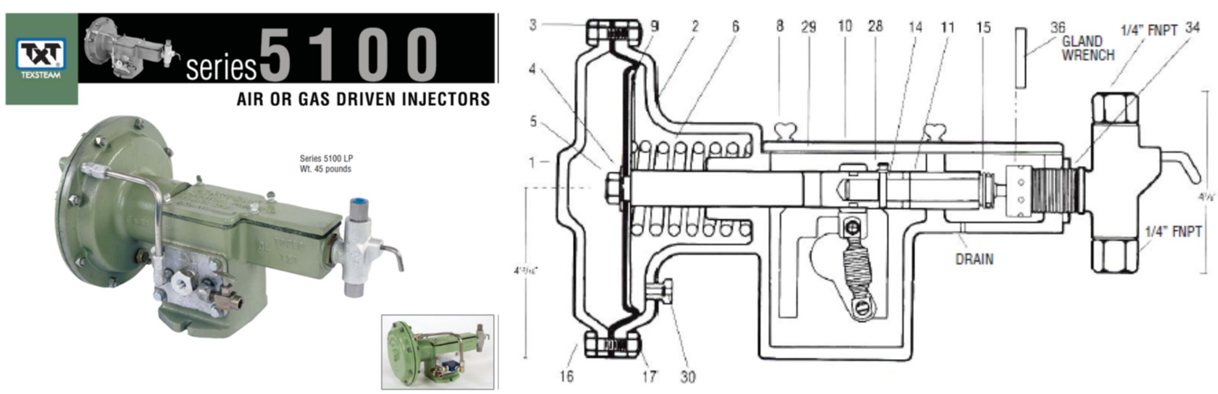

Fig. 25: Illustration of Texsteam 5100 Series Chemical Injection Pump *(GE Oil & Gas, 2018)*

This style of diaphragm pump is spring return, single acting and plunger-type. The volume of chemical injected is controlled by the pump speed, stroke length and plunger size. Gas consumption metrics are published specific to plunger size, stroke length and injection pressure where increasing any of those three values results in increased volumes of vented gas.

Studying the pressure curves of pneumatic pumps provided insight into the characteristics of their performance. Like level controllers, the stroke frequency could be easily observed and, if required for further study, directly correlated to the vent rate. Fig. 26 and Fig. 27 provide insight into their sinusoidal type consumption and the dynamic nature of pump vent rates. Even in the forward-stroking state, the pump is venting gas.

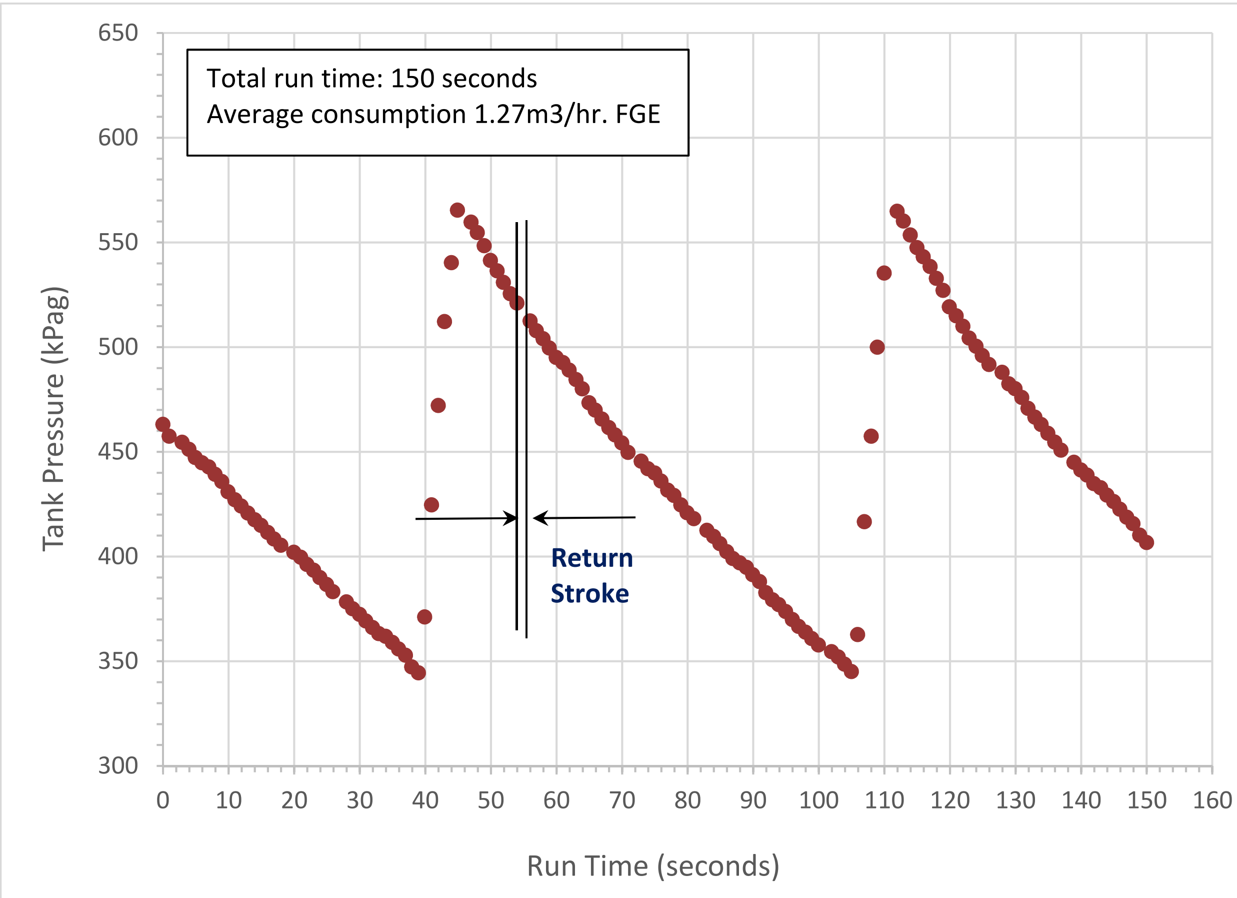

Fig. 26: Bruin 5015 Field Tested Pneumatic Consumption

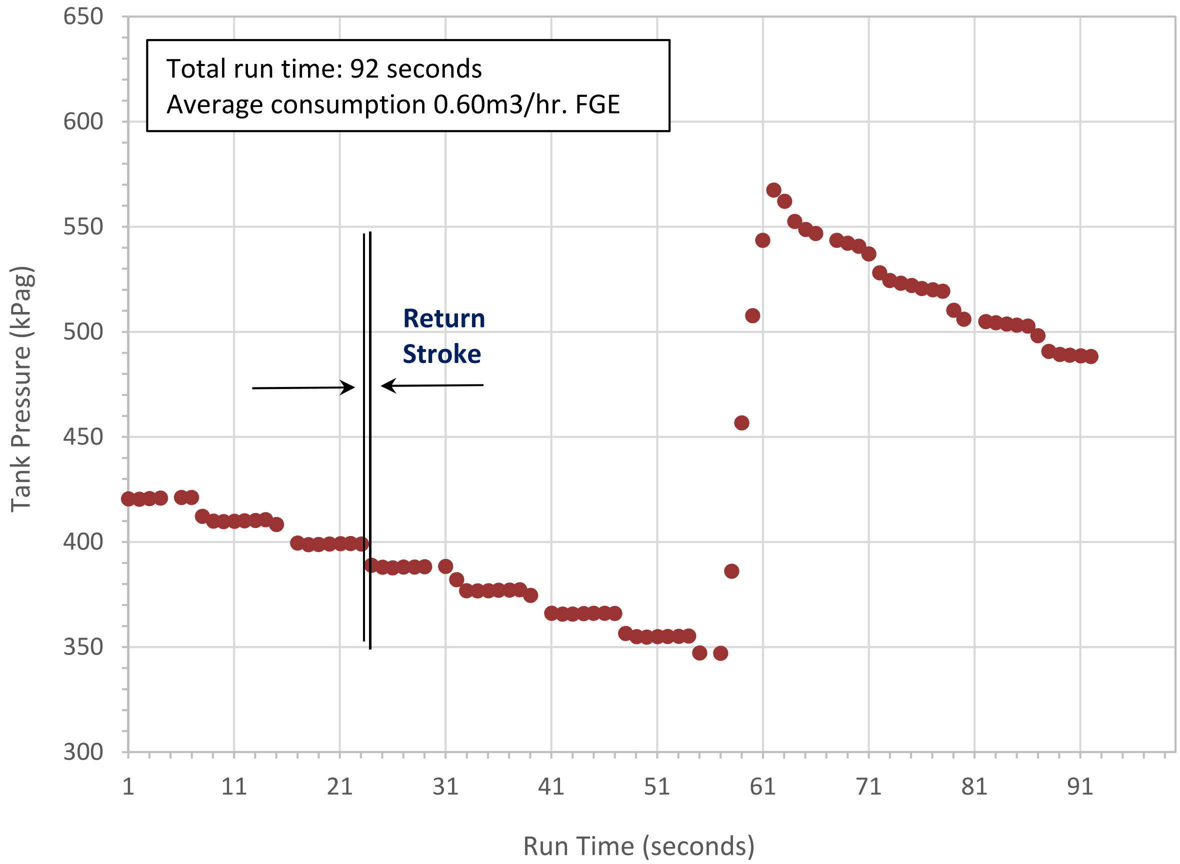

Fig. 27: Texsteam 5100 Field Tested Pneumatic Consumption

A total of 27 model 5100 chemical injection pumps used for wellhead and pipeline chemical injection were measured and found to have an average vent rate of 0.97m3/hr. +/- 0.18m3/hr. FGE. As shown in Fig. 28, the measured vent rates were normally distributed with 85% of the pumps samples venting between 0.61m3/hr. FGE and 1.32m3/hr. FGE. When comparing the vent rate difference between pumps used for chemical injection at the wellhead or the pipeline, the average vent rates were 0.94m3/hr. FGE and 1.09m3/hr. FGE respectively, which is well within the 95% confidence interval of the pumps as a single population described above. 0.97m3/hr. of fuel gas is about 115tonnnes of CO2e/yr. (0.97 x 0.8 x 4.2 /0.3048^3), which alongside pneumatic instruments, provide a significant opportunity for GHG reduction.

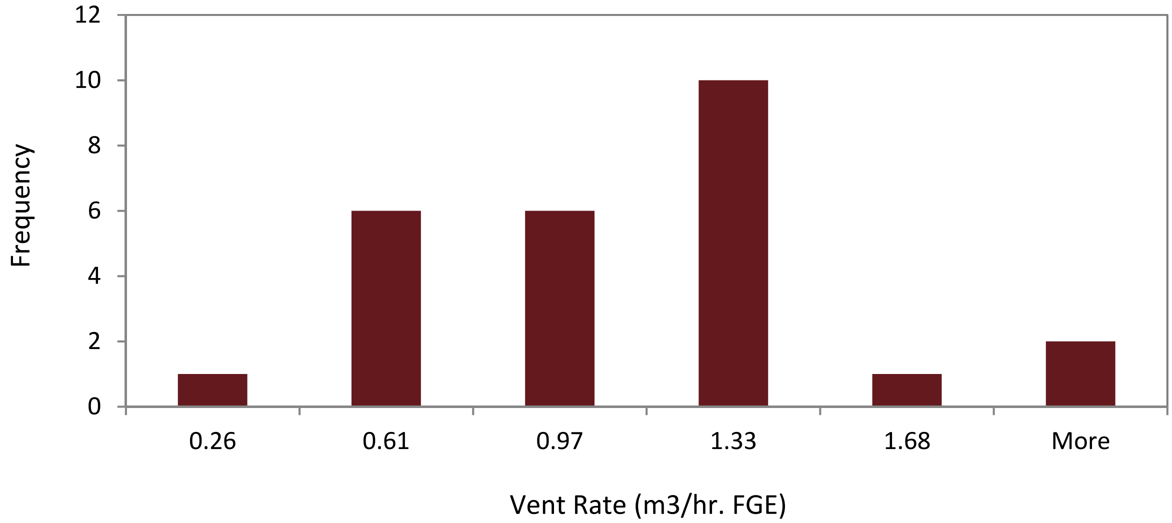

Fig. 28: Bruin / Texsteam 5100 Vent Rate Histogram

Temperature Effects on Vent Rates

The impact of ambient pressure and temperature changes was also investigated. It is understood that the ambient temperature and fuel gas temperature are not equal. Instrumentation is kept at a more even temperature with the Cata-Dyne™ heater in the building. Temperature variation will occur due to the 6m pipe away vent line outside the building to the Hawk 9000 and/or with a 6m supply line from the e-MEAS™ to the pneumatic device of interest. Further understanding was needed to quantify the impact of both ambient pressure and temperature changes on the measured vent rates captured in the datalogger of the e-MEAS™. Detailed calculations are included in Appendix A.

The temperature and pressure variance for Rocky Mountain House, AB in 2016 (Government of Canada, 2017) was reviewed to determine a reasonable measure of maximum and minimum for both variables. With all other variables held constant, the impact of atmospheric pressure changes between 87.13kPa and 91.97kPa, was calculated for both the maximum and minimum inter-stage volume bottle pressures. For max pressure, it was found to be 59.78g +/- 0.16g/0.28g. For min pressure, it was found to be 40.51g +/- 0.17/0.28g. Taking the difference in mass between maximum and minimum pressure states cancelled the offset effect almost equally. Similarly, with all other variables including pressure held constant, the impact of an atmospheric temperature changes between -32.7C and 29.7C, was calculated for both the maximum and minimum inter-stage volume bottle pressures. For max ambient temperature, it was found to be 59.78g +/- 8.64g/5.46g. For minimum ambient temperature, it was found to be 40.51g +/-

3.97/13.47g. Taking the difference in mass between full and empty states in this case did not cancel the offset equally.

On the hottest days of the year, the mass difference between 345.16kPag (50.06psig) and 556.08kPag (80.65psig) would be 17.73g, where on the coldest days of the year, the mass difference between 345.16kPag (50.06psig) and 556.08kPag (80.65psig) would be 22.33g. The difference of 4.6g means that the volume bottle would need to be refilled more frequently in the summer than the winter if the rate of consumption was equal.

To determine if the pneumatic device vent rate would be the same, back calculations were done using Fisher™ Specification Manager valve sizing software. For a valve coefficient (Cv) of 0.003 (fixed orifice), supply pressure of 241kPag (35psig) and atmospheric pressure of 90.2kPa, the temperatures were changed from -32.2 degrees Celsius (C) to 15C and then again to 29.7C. The calculated flow rate, or vent rate in this case, was 5.563scfh, 5.081scfh and 4.955scfh respectively as shown in Fig. 29.

Variable Name	Units	Minimum	Normal	Maximum
SERVICE & SIZING				
Gas		~NITROGEN	~NITROGEN	~NITROGEN
Inlet Pressure (P1)	psig	35.000	35.000	35.000
Pressure Change (dP)	psi	35.000	35.000	35.000
Inlet Temperature (T1)	deg C	-32.2000	15.0000	29.7000
Volumetric Flow Rate Gas (Qg)	scfh	5.563	5.081	4.955
Pressure drop ratio factor (Xt)		0.760	0.760	0.760
Pressure Recovery Factor (Fl)		0.950	0.950	0.950
Valve style modifier (Fd)		0.050	0.050	0.050
Critical Pressure (Pc)	psia	492.420	492.420	492.420
Critical Temperature (Tc)	deg C	-146.9000	-146.9000	-146.9000
Atmospheric Pressure	kPa	90.2	90.2	90.2
Dynamic Viscosity (Mu)	cP	0.010	0.010	0.010
Specific heats ratio (gamma)		1.400	1.400	1.400
Molecular Weight/Specific Gravity	M	28.130	28.130	28.130
Inlet Compressibility Factor (Z1)		0.996	0.998	0.999
Pipe Size Up	in	0.5	0.5	0.5
Pipe Schedule Up		STD	STD	STD
Pipe Size Down	in	0.5	0.5	0.5
Pipe Schedule Down		STD	STD	STD
Nominal Valve Diameter (dv)	in	0.500	0.500	0.500
Sizing Coefficient (Cv)		0.003	0.003	0.003
dP Choked	psi	36.543	36.543	36.543
dP/P1 Valve		0.728	0.728	0.728
Fp		1.00	1.00	1.00
Item Notes:				

Fig. 29: Fisher™ Specification Manger Valve/Regulator Sizing Calculation

With lower atmospheric pressure acting on the instrument or pump, there is less backpressure effect on the vent rate. When ambient temperatures are lower, vent rates may be higher. As shown in Fig. 30, the vent rate in Alberta with typical seasonal variation could be as much as 12 percent. Consequently, it is important to be mindful of when the sample vent rate was measured and what the ambient temperature and pressure were. Most pumps and instruments are operated in western Canada in buildings heated with Cata-Dyne™ heaters, which helps mitigate the impact of ambient temperatures on pneumatic device vent rates.

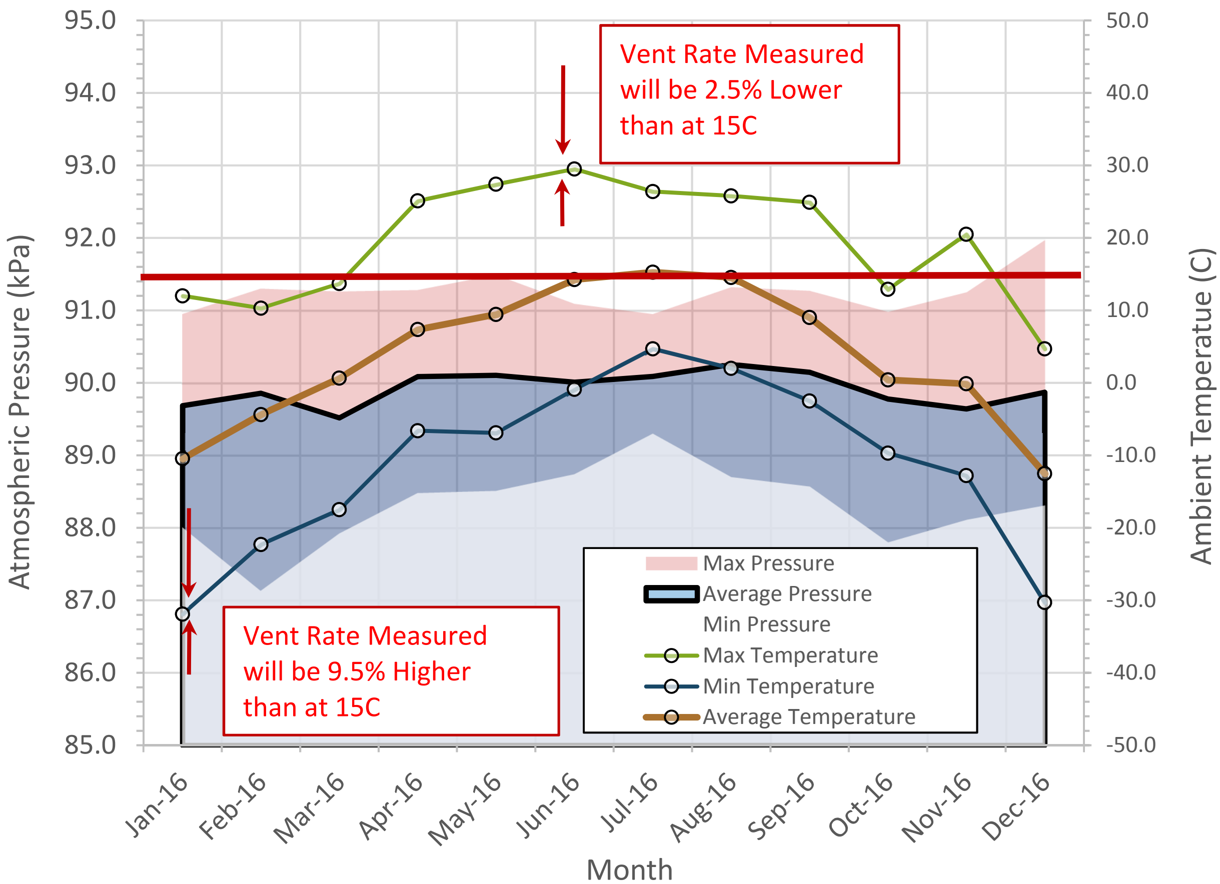

Fig. 30. Atmospheric Monthly Pressure and Temperature Impact on Vent Rate
- Rocky Mountain House, 2016 *(Government of Canada, 2017)*

Conclusions

Steady state vent rates are only one component of emissions from pneumatic devices. In the case of level controllers, pumps or other devices used in active control loops, dynamic consumption is often a more significant element of total emissions from the device. The results of the level controller tests indicated:

- There is a large difference between steady state consumption and the volume of gas consumed in a dump event.
- Steady state aligned with manufacturer published data (<1scfh) however the volume associated with a dump event was two orders of magnitude larger (50-150scfh)
- The average vent rate of Fisher™ L2(snap) acting level controllers dumping more frequently than one every 15min was three times larger than the vent rate of Fisher™ L2(snap) controllers that didn't dump in the duration measured (typically 30min.).
- The flat profile of steady state consumption of level controllers could lead to misinterpretation that this is an intermittent type of vent device, not continuous.
- Dump cycle period is shorter with lower pneumatic supply pressures.
- While the volume of gas needed to stroke a pneumatically actuated dump valve cannot be eliminated, unless switched to an electric or electrohydraulic actuator, the transient consumption can be with relays designed to do so.
- Modern, implementation ready, level controllers are designed with relays that eliminate consumption associated with transient "simmer" states and convert them to be more discrete, open or closed, with no increase in vent rate between operating states.

Measured volumes supplied to pneumatic devices are higher than measured volumes vented from them.

- Measurements made with the e-MEAS™, without the Hawk 9000 flow meter measuring the flow of gas vented from the pneumatic device, were higher than those measured with.
- Measuring the volume through a pipe away vent with the Hawk 9000 was on average within one percent of that measured by the e-MEAS™, but three percent less than measured by the e-MEAS™ without the Hawk 9000 connected downstream of the pneumatic device.
- Vent rates measured from pneumatic devices were very similar at vent rates below 6scfh to those measuring the volume supplied to them.
- Insufficient data was gathered at vent rates above 0.27m3/hr. FGE with both measurement devices to analyze if the measured vent rates have greater differences at high vent rates than low vent rates. More work is necessary to determine differences.

Sensitivity/proportional band (PB) adjustments and set point changes on pressure controller emission rates may impact vent rates:

- The steady state vent rate of Fisher™ C1 pressure controllers, was not impacted by proportional band adjustments when changed between 0, 5 and 10.
- The changes in set pressure on either end of the 207kPag (30psig) bourdon tube range only resulted in less than 0.03m3/hr. FGE variance in vent rates.
- The measured vent rates with and without the downstream Hawk 9000 PD meter downstream were within 0.004m3/hr. FGE.
- All measured nitrogen values for the Fisher™ C1 pressure controller were lower than the manufacturer published steady state vent rate of 0.13m3/hr. air.

The vent rates from transducers vary with model changes, output pressure and backpressure effects:

- Unlike newer 1st Gen Fisher™ i2P-100 and 2nd Gen Fisher™ i2P-100 transducers, Fisher™ 546 transducers vent less with increasing output pressure
- Backpressure impacted transducer vent rates and performance
  - Increasing backpressure on transducers shifted the output pressure from the transducers by the amount of pressure applied.
  - The proportional offset through the full output range of the transducer resulted in a reduced vent rate.

Sampled chemical injection pumps used for wellhead and pipeline chemical injection vented at similar rates proportional to stroke frequency:

- Chemical injection pumps at the wellhead vented 0.94m3/hr. FGE.
- Chemical injection pumps used at the pipeline vented 1.09m3/hr. FGE.
- Chemical injection pumps considered as one population vented 0.97m3/hr. FGE.

These values are similar given that pump vent rates are influenced by injection pressure, injection volume, stroke rate, stoke length. Further vent gas measurement testing would not be expected to yield such similar numbers. More field measurements would provide additional insight on how representative this sample is of the installed population.

Instrument and pump vent rates are impacted by ambient temperature and pressure:

- With lower atmospheric pressure acting on the instrument or pump, there is less pressure acting on the pneumatic device, which may result in higher vent rates.
- When ambient temperatures are lower, vent rates may be higher.
- The vent rate in Alberta with typical seasonal pressure and temperature variation could vary as much as 12 percent.

- Many pumps and instruments are operated in buildings heated with a Cata-Dyne™ heater, which helps mitigate the impact of low ambient temperatures on pneumatic device vent rates.

Recommendations

Improved pneumatic efficiency of control loops can be achieved by installing low/no-vent instruments and pumps and by optimizing their performance. Properly tuned pneumatic devices, including pressure controllers, pressure switches, transducers and positioners, can achieve the response needed to effectively control the process. As process conditions change, pneumatic devices should be re-tuned. Optimizing the performance requires understanding how sensitive the measurement element needs to be and the amount of action and speed of response the final control element needs to take in response to those changes in process.

In the context of pneumatic level controllers, dumping more volume less frequently is recommended to conserve fuel gas. This is important for both Greenfield design and Brownfield retrofits. To dump more volume, the geometry of the vessel, and more specifically the height difference between the level controller and the dump valve line needs to wide enough to allow full use of the sensing length of the displacer and wide enough ensure the dump valve can close before gas passes through it. To ensure the valve can close fast enough, the level controller output needs to reset to 0kPag quickly when insufficient buoyant force acts on it. Also, to prevent draining the fluid too quickly, the trim of the dump valve and or the travel of the plug off the seat cannot be too large. Optimizing the performance of a level control loop requires review of not just the controller, but the dump valve too.

The Alberta Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices (Alberta Environment and Parks, 2017) includes table values for specific types of retrofits that can be used to quantify fuel gas savings and methane venting reductions. Using published values or emission factors makes the GHG quantification much simpler and easier, but may reduce accuracy. Understanding the error associated with field measurements and how close field values are to published steady state vent rates provides the means of quantifying the amount of GHG vent reductions achieved. Improved accuracy of emission factors using field results would improve accuracy of regulator report and offset calculations.

Using table reference vent rates and reduction factors that have been field verified is almost essential to undertaking this activity effectively. Referencing table values representative of field performance, inclusive of dynamic vent rates for more active control loops such as level controllers, ensures instruments with low steady state vent rates are not overlooked as opportunity for GHG reductions in upstream oil and gas operations. For that reason, it is recommended that the measured vent rate of 0.75m3/hr. FGE (0.58m3/hr. air) for Fisher™ L2 snap acting level controllers dumping at least as frequently as once every 15 minutes be added to the table in the protocol. Having that value accepted as being representative of similar frequency dump installed Fisher™ L2s, will be an enabler to achieve a further 0.5MT CO2e reduction in Alberta not currently realized when referencing only steady state vent rates. The implications are also bigger for methane regulations by both the Alberta Energy Regulator (AER) and Environment Canada Climate Change (ECCC). To hit a 45 percent reduction target in upstream oil and gas, focus should also include consideration for dynamically active instruments and pumps.

Application

Pneumatic efficiency is a key focus area for achieving methane emission reductions. Reducing vented methane by focusing on retrofit of existing pneumatic devices with low or no vent instrumentation and pumps at upstream oil and gas sites will provide measurable reductions (Prasino Group, 2013). More specifically, along with chemical injection pumps, optimizing the pneumatic performance of transducers, pressure controllers and level controllers are where most of the pneumatic fuel gas efficiency improvements will be made.

Knowing the focus is important, but taking on the task of achieving large scale reductions by doing retrofits at thousands of small scale sites requires coordination of effort. The make and model of the device in service along with process details such as supply pressure, output pressure, control range, action, stroke frequency and materials of construction are key to being able to successfully install (in-kind) low/no-vent replacements. Gathering field vent rate measurements before and after completion of a retrofit helps deliver confidence in the methane reductions being achieved, but adds a layer of cost and complexity to the project scope that makes the task more complicated.

Field instruments, including level controllers were retrofit without shutting in the well and specific to level controllers, retrofit without de-pressurizing the separator or changing the displacer. Not shutting in production or limiting the duration while performing pneumatic device retrofits helps mitigate the impact on well production while achieving meaningful reductions of steady state, transient and dynamic vent rates.

Measurement matters. The measurements gathered in this study, showed that there are backpressure effects when vent gas rates are measured from the instrument vent tubing. This study confirmed that backpressure, transient and dynamic vent rates impact measured flow rates. This study also found that pneumatic control loops operating in a predominantly steady state vent gas at a rate similar to manufacture published vent rates. For dynamically active instruments and pumps, vent measurements deliver additional certainty beyond manufacture published steady state vent rates to achieve the reductions needed.