The prasino Group

Final Report

For Determining Bleed Rates for Pneumatic Devices in British Columbia

December 18, 2013

Executive Summary

Regulations in BC stipulate that all greenhouse gas (GHG) emissions from pneumatic instruments and pumps must be tracked for reporting and compliance purposes. In order to help industry quantify these emissions more efficiently and cost effectively, the BC Climate Action Secretariat (CAS), Ministry of Natural Gas Development and Canadian Association of Petroleum Producers (CAPP) engaged The Prasino Group (Prasino) to determine bleed rates for a suite of common pneumatic controllers and pumps. This survey is the first of its kind and was funded by the Science and Community Knowledge (SCEK) Fund.

Pneumatic controllers and pumps use pressurized fuel gas to perform operations such as pressure control, temperature control, liquid level controller and chemical injection. This fuel gas is subsequently released to the atmosphere after the operation is performed. The bleed rate of a pneumatic device is defined as the amount of fuel gas released to the atmosphere per hour. Figure 1 shows the breakdown of GHG emissions from the oil and gas sector in BC with a detailed breakdown of the sources of vented methane. The high bleed pneumatic controllers and pumps, which are the subject of this study, contribute 436,000 tCO2e of the 1,723,000 tCO2e from vented methane. The amount of contribution from pneumatic devices and pumps is expected to change as a result of this study.

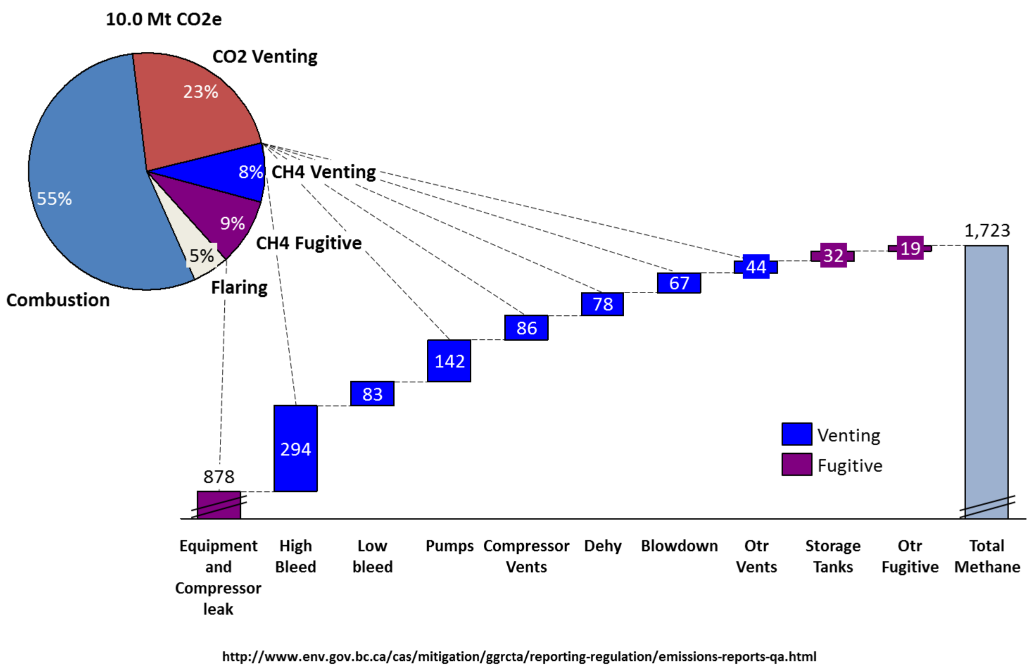

Figure 1: Detailed Breakdown of vented and fugitive methane sources in the BC oil and gas sector (source BC CAS 2013).

The purpose of the survey was to determine the average bleed rate of pneumatic controllers and pumps when operating under field conditions in BC. Bleed rates were sampled from pneumatic devices using a positive displacement bellows meter at upstream oil and gas facilities across a variety of producing fields in the Fort St. John, BC and surrounding, areas. Descriptive statistics, general linear models and regression analysis was performed on the data to investigate the bleed rates and draw robust, relevant conclusions.

All outcomes were achieved. The results of the analysis led to the development of three generic bleed rates and twenty specific bleed rates for common pneumatic controllers and pumps for BC's oil and gas industry. These bleed rates can be used in the development of emission factors for GHG reporting and potentially offset purposes.

Table 1: Summary of Findings

Pneumatic Device	Average Bleed Rate (m^3/hr)	Coefficients[1] (supply pressure, injection pressure, strokes per min)	Equivalent Device
Generic High Bleed Controller	0.2605	0.0012	-
Generic High Bleed Intermittent Controller	0.2476	0.0012	-
Pressure Controllers			
Fisher 4150	0.4209	0.0019	4150K, 4150R, 4160, CVS 4150
Fisher C1	0.0649	0.0003	-
Fisher 4660	0.0151	-	4660A
Level Controllers			
Fisher 2500	0.3967	0.0011	2500S, 2503, L3
Fisher 2680	0.2679	0.0014	2680A
Fisher 2900	0.1447	-	2900A, 2901, 2901A
Fisher L2	0.2641	0.0012	-
Murphy L1200	0.2619	0.0012	L1100, L1200N, L1200DVO
Norriseal 1001	0.1868	-	1001A, 1001XL
SOR 1530	0.0531	-	-
Positioners			
Fisher Fieldvue DVC6000	0.2649	0.0011	6030, 6020, 6010
Temperature Controllers			
Kimray HT-12	0.0351	-	-
Transducers			
Fairchild TXI7800	0.1543	0.0009	TXI7850
Fisher 546	0.3547	0.0017	546S
Fisher i2P-100	0.2157	0.0009	-
Pumps			
Generic Piston Pump	0.5917	0.00202, 0.000059, 0.0167	-
Generic Diaphragm Pump	1.0542	0.0005, 0.000027, 0.0091	-
Morgan HD312	1.1292	0.00418, 0.000034, 0.0073	HD312-3K, HD312-5K
Texsteam 5100	0.9670	0.0003,0.000034, 0.0207	5100LP, 5100H
Williams P125	0.4098	0.00019, 0.000024, 0.0076	-
Williams P250	0.8022	0.00096, 0.000042, 0.0079	-
Williams P500	0.6969	0.00224, -0.000031, 0.0046	-

[1] Controllers that do not have a coefficient should use the mean bleed rate instead of the bleed rate equation.

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1. Introduction

This report outlines the methodology and analytical methods used to develop bleed rates for reporting GHG emissions from pneumatic controllers and pumps (collectively referred to as 'devices') in British Columbia (BC). The development of emissions factors may allow for an alternative method of monitoring and reporting GHGs from pneumatic devices, as per an agreement between the Canadian Association of Petroleum Producers (CAPP) and the B.C. Ministry of Environment's Climate Action Secretariat (CAS). The Prasino Group (Prasino) has been engaged by the Science and Community Environmental Knowledge Fund (SCEK) in order to develop these bleed rates based on quantitative sampling of pneumatic devices in BC. This document is the final project report and builds off the subsequent three reports (Sampling Methodology, First Round Sampling Report and Final Sampling Report) that were submitted to SCEK. This document is meant to be a standalone report and describes:

- The sampling methodology used to obtain the field bleed rate samples;
- The characteristics of the samples;
- The statistical analysis performed on the field bleed rate samples as well as a discussion of the results; and
- The recommended bleed rates for each pneumatic device included in the survey.

2. Sampling Methodology

Pneumatic devices used in B.C.'s oil and gas sector fall into two categories:

1. Pneumatic chemical injection pumps (typically injecting methanol into a pipeline); and,
2. Pneumatic controllers, which regulate pressure, temperature, fluid level, or some other process variable.

There are dozens of manufacturers of the types of pneumatic devices listed above. Even though the device types perform similar functions, they have inherently different bleed rates. Due to constraints, it was necessary to narrow sampling to the most common or representative devices. A "Device Selection Approach" was used to narrow the sample and determine the most common devices in the field.

Figure **2** below outlines the steps that were followed to develop the initial list of devices for sampling. Further detail will be provided in the next section. The following section describes the process that was used for selecting which devices to include in the sampling regime.

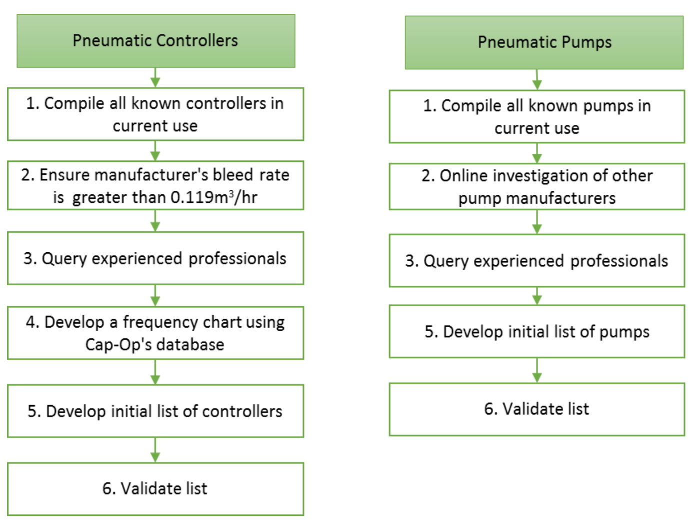

Figure 2: Device Selection Approach[2]

2.1 Pneumatic Controllers

In order to determine which pneumatic controllers to include in our sample, multiple steps were undertaken as illustrated in

Figure **2**. Through this process, 15 controllers were identified as common. For the rare devices that are not within the scope of this project, a generic high-bleed rate has been developed for all high-bleed controllers. This ensures that any pneumatic controller can apply a bleed rate that is representative of field conditions.

Step 1: Compile All Known Controllers

Prasino initially developed a complete list of all known pneumatic low and high-bleed controllers that were anticipated to be used in the upstream oil and gas industry in BC. Using one or more of the sources listed below, the make, model, and manufacturers' stated bleed rate of each controller was determined:

- *Canadian Environmental Technology Advancement Corporation-West (CETAC): Efficient Use of Fuel Gas in Chemical Injection Pumps. Fuel Gas Best Management Practices.* The BMP lists manufacturer bleed rates of controllers in m^3/hr of natural gas.
- *Pacific Carbon Trust (PCT): High-Bleed to Low-Bleed Conversion for Pneumatic Controllers. Meta-Protocol for Oil and Gas Emission Reductions Projects.* In the protocol, the bleed rates were stated in standard cubic feet per hour (scfh) of air, based on manufacturer stated specifications. The volume of air bled was converted to natural gas by multiplying by 1.3[3]. When a range of bleed rates was listed, the highest value was taken to be conservative.
- *Environmental Protection Agency: Gas STAR – Options for Reducing Methane Emissions from Pneumatic Devices in the Natural Gas Industry*. This document stated the bleed rates of high- and low-bleed controllers in scfh of air. These values were converted to m^3/hr of natural gas.
- *Western Climate Initiative (WCI): Final Essential Requirements of Mandatory Reporting.* This report references the BMP, PCT Protocol and EPA Gas STAR for the pneumatic controller list and bleed rates. The manufacturer bleed rates in this document are in m^3/hr.
- *Manufacturer websites* were referenced to determine the steady state air consumption for pneumatic controllers. The highest steady state air consumption was recorded. The bleed rates were stated in m^3/hr and scfh.
- *Cap-Op Energy samples from the DEEPP database* were used to look at controllers and pumps that are already in the field and have been sampled previously by GreenPath Energy Ltd[4].

Step 2: Equivalent Devices

Controllers may have different makes and models but serve the same function. Controllers are considered equivalent devices if they have interchangeable parts. A list of equivalent devices was compiled using information from device vendors and subject matter experts, and is presented in Appendix A (J. Anhalt, personal communication, July 2013; B. Van Vliet, personal communication, July 2013).

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[2] "Cap-Op's Database" refers to Cap-Op Energy's Distributed Energy Efficiency Project Platform (DEEPP), which was queried for historical pneumatic controller information. Cap-Op Energy is a sub-contractor to Prasino.

[3] The value 1.3 is based on the density and molar mass of air and natural gas in ideal gas conditions. This manner of conversion is an industry standard.

[4] GreenPath Energy Ltd. is the contractor who was responsible for completing the field sampling protocol.

Step 3: Ensure Manufacturer Bleed Rates are Greater than 0.119 m^3/hr

Manufacturer bleed rates were used to determine which controllers are considered high bleed and therefore relevant for sampling. However, these manufacturer bleed rates are based on manufacturer lab testing and may not reflect actual field conditions. The steady state bleed rates reported are static bleed rates of controllers that are not actuating and thus dynamic bleeding is not captured. Therefore, the manufacturer bleed rates may not accurately express the actual vented natural gas through these controllers because the steady state does not include dynamic bleeding. The relationship between the bleed rates of controllers that are running on dirty/wet natural gas compared to air is unknown. It is likely that controllers operating in the field bleed more than controllers tested in a laboratory using air.

The current definition whether a controller is a high or low bleed controller is based on the WCI Reporting Regulation definition: “high-bleed devices are defined as all natural gas powered devices which continuously bleed at a rate greater than 0.17 m^3/hr.”

Many controllers have manufacturer bleed rates just below 0.17 m^3/hr, and thus appear to be a low-bleed controller. Since manufacturers do not consider the dynamic bleed rate in their stated bleed rate, many low-bleed controllers in fact bleed more than 0.17 m^3/hr on a regular basis. To ensure all relevant controllers that bleed more than 0.17 m^3/hr (including static and dynamic bleeding) are included within the sample, the manufacturer bleed rates were compared to a limit of 0.119 m^3/hr (CAS, 2013). In many cases, the manufacturer states a range of bleed rates that are dependent on other operating parameters of the controller (i.e. 1.4 scfh at 20 psi vs. 3 scfh at 30 psi). In this case, the highest bleed rate was recorded to ensure that all controllers with the potential to bleed higher than 0.17 m^3/hr were included. Refer to Appendix A for highest manufacturer bleed rates. Controllers that have been excluded from sampling as a result of this step are represented at the bottom of the table in Appendix A.

Step 4: Query Subject Matter Experts

Subject matter experts were queried as per the request of CAS to determine if the list of pneumatic devices was inclusive and representative. Several low-bleed controllers below the limit of 0.119 m^3/hr have been included based on these discussions to investigate if controllers that are labelled according to manufacturer specification actually perform as a low bleed device in the field. Four low-bleed controllers were included in the survey: Fisher C1, Fisher 4660, SOR 1530 and Kimray HT-12. The results of the query are represented in Appendix A.

Step 5: Determine the Frequency of Occurrence of Controllers

Using Cap-Op’s DEEPP database, the eligible list of all pneumatic controllers was filtered down to focus sampling on devices that are considered common. Cap-Op Energy has an extensive +2000 sample database from previous work on pneumatic devices from the upstream oil and gas industry in Alberta and BC. This database was used as a proxy for determining which controllers are common among producers in the Canadian oil and gas industry. The samples could not however be included in the survey because they were taken using the Bacharach High-Flow Sampler and this survey is using the Calscan vent gas bellows meter for reasons presented in Section 2.4.3. These eligible controllers were compared with the extensive field samples database from Cap-Op Energy’s DEEPP to examine the frequency of eligible controllers previously surveyed in the field. The results are depicted in Figure 3 below.

Step 6: Develop Initial List

The common list of pneumatic controllers used to guide first round sampling can be found in Appendix B. The results include:

- The top 10 controllers represent 89% of the surveyed controllers in the Cap-Op database.
- The top 15 controllers represent 97% of the surveyed controllers in the Cap-Op database.
- Rare devices are those that comprise the remaining 3% of the surveyed controllers in the Cap-Op database.

This initial list was used to guide first round of sampling because the selected devices were anticipated to be frequent enough to produce statistically valid emissions factors.

Step 7: Validate list

Upon completion of the first round of sampling the original list was compared with what was observed in the field to determine if the anticipated list of 15 devices was the most common. Based on survey data collected in the field, two devices were found to be common and added to the sample: Fairchild TXI7800; and Murphy L1200. Two devices were found to be rarer than initially thought and thus have been removed from the sample population: Fisher 2660 (no devices found in the field); and Dyna-Flo 4000 (two devices found in the field).

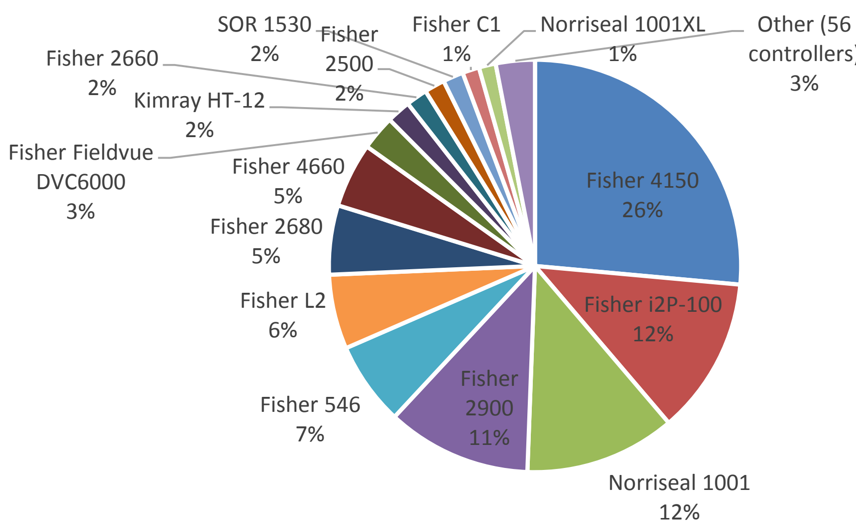

Figure 3: Frequency of pneumatic controllers found in the Cap-Op database

2.2 Pneumatic Pumps

The methodology used for determining the list of pneumatic pumps does not mirror the methodology used for pneumatic controllers because the Cap-Op database does not contain sufficient pump field samples to draw similar conclusions. The list of pneumatic pumps was compiled from the CAPP (2008), PCT (2011) and the Cap-Op DEEPP database. These sources were cross-referenced with manufacturer websites and subject matter experts to make a comprehensive initial list, presented in Appendix B. This initial list was used to guide first round of sampling; however, all pumps were sampled in the first round to determine which types were common among the producers sampled. Five common pumps were identified after the first round of sampling and were targeted during the second round of sampling: Texsteam 5100; Morgan HD 312; Williams P125; Williams P250; Williams P500.

2.3 Sampling Approach

The following section provides detail on how the field samples were collected as well as justification for which companies and geographic areas were selected for sampling.

The analysis and discussions in this report distinguish the 'sample set' or 'sample' from the 'population'. In general, this analysis operates under the assumptions that the true number and state of the population (i.e. all pneumatic devices in BC) is unknown. Determining whether the sample is representative of the population, and to what extent is a major component of this report and helps to characterize the validity of the results. Statistical analyses and conclusions are contingent on the assumption of an unknown population.

2.3.1 Bleed Rate Metering

The metering requirements for this project are unique and as such there are few options for determining gas vent rates from devices in a cost effective manner.

The desired meter must have the following characteristics:

- Mobility – the meter will have to be mobile such that the sampling teams can apply the meter to pneumatic devices in-service at various facilities throughout BC. This requires a relatively simple installation and removal procedure, with a low weight and portability such that it can be moved by one or two people to within a few feet of an existing pneumatic device as it is installed on-site. Breaking, cutting or dissembling process pipes, flanges or joints is not acceptable, however vent tubing may be intercepted for measurement.
- Range – the meter must be designed to accommodate the measurement of flow rates between zero and approximately $1m^3/h$ of gas at pressures ranging from atmospheric to a few feet of water column with minimal back pressure.
- Explosive Environment – All electronic devices intended for use within CSA classified zones require intrinsically safe electronic enclosures such that potentially arcing /sparking ignition sources are completely isolated from potentially explosive atmospheres that occur in oil and gas facilities. This is a minimum safety requirement for all sampling team and on-site personnel.

The desired meter should have the following characteristics:

- Time series data to distinguish static and dynamic operation on pneumatic devices.
- Minimal to no back pressure
- High precision, 2% or less uncertainty on reported values
- High accuracy, with correction for variable parameters such as gas composition, temperature, barometric pressure, humidity, etc.

Based on an extensive review of meters available in the industry, two options which were found to be best candidates included the Bacharach High Flow Sampler and the Calscan Hawk 9000 Vent Gas Meter. The Bacharach High Flow Sampler is designed to measure the rate of gas leakage around various processes in natural gas transmission, storage and compressor facilities. This is accomplished by sampling at a very large flow rate (8 to 10 scfh) to completely capture any gas leaking from the component. By accurately measuring the flow rate of the sampling stream and the natural gas concentration, it is possible to calculate the rate of gas leak.

Figure 4: Calscan Hawk 9000 Meter

Prasino elected to use the Hawk 9000 vent gas meter (supplied by Calscan Energy) to measure and digitally log flow vent gas over time (which will vary based on the device sampled). This allowed for both the static and dynamic bleed rates for pneumatic controllers, as well as the dump cycles for pneumatic pumps and level controllers, to be captured. A drawback of the Bacharach High Flow Sampler is that it captures a snapshot in time; rather than a time series measurement. The Bacharach High Flow Sampler can fail to capture the dynamic bleeding events. The Hawk 9000 meter uses a positive displacement diaphragm meter that detects flow rates down to zero, and can also effectively measure any type of vent gas (methane, air, or propane). In addition, the Hawk uses a precision pressure sensor, an external temperature probe and industry standard gas flow measurement algorithms to accurately measure the gas rates and correct for pressure and temperature differences. As a result, flow measurement accuracies within ±2%[5]. A picture of the Calscan Hawk 9000 is presented in Figure 3 and an example output chart is provided in Figure 5 below.

[5] The meter is calibrated from -40°C to +60°C and uses "Gas Rate Algorithm AGA7" and "Equation of State AGA8".

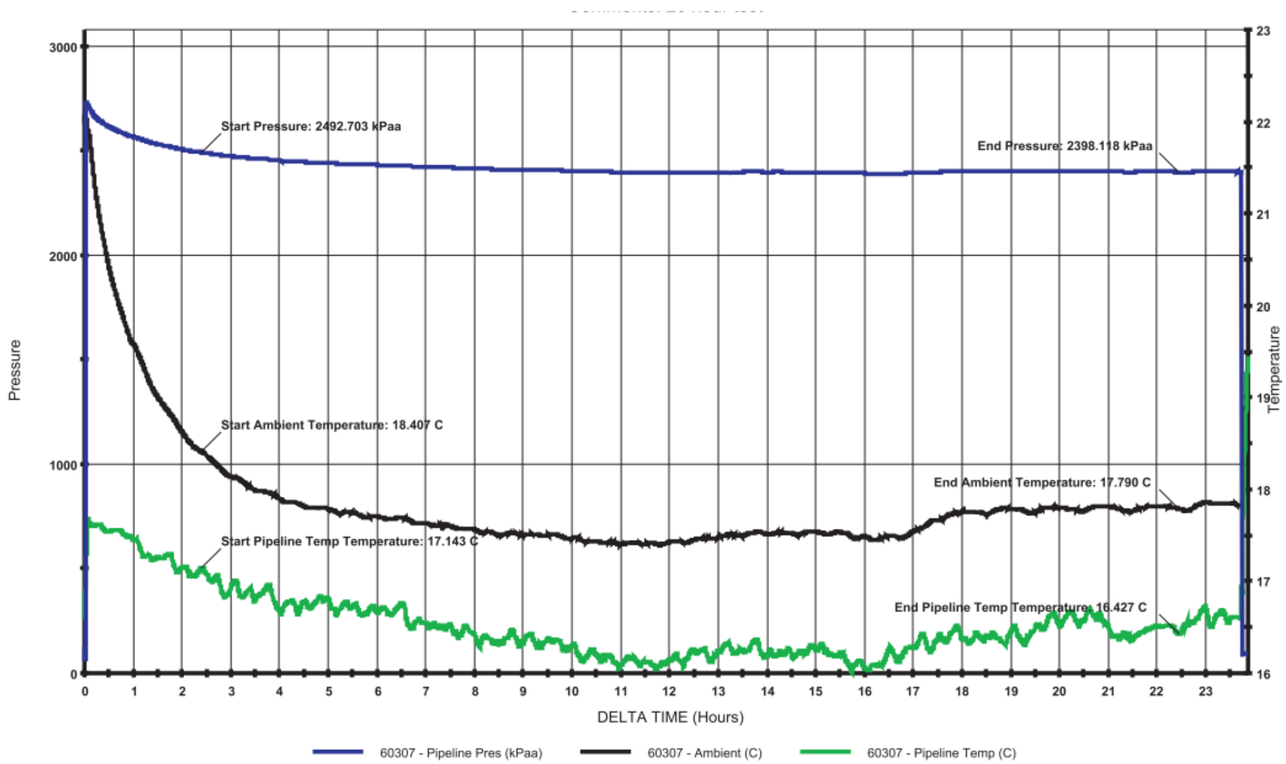

Figure 5: Example of Calscan Output Graph

2.3.2 Sample Size

The sampling program aimed to collect thirty samples of each device type identified as common according to Section 2.0 Sampling Methodology. Thirty was chosen as a minimum sample size in order to allow for statistical inferences to be drawn. When the sample size is sufficiently large (conventionally, 30 or larger), the standard error can be used to calculate a one-tail 95% confidence interval. As the sample population increases, the confidence interval should get smaller due to a decreased standard error (McClave and Sincich, 2003). In general, when calculating confidence interval, larger sample sizes and narrow confidence intervals must be balanced against the cost of additional sampling and the diminishing returns of incrementally smaller improvements to confidence intervals with each additional sample. Thirty samples for each common device type allows for the quantification of bleed rates with confidence intervals within a realistic budget and time frame.

2.3.3 Data Collection and Transfer

To manage the large amount of data that was collected during this sampling program, Cap-Op designed a software application (app) to be used in the field in order to increase data quality and tracking, and eliminate manual data recording. A field sampling guide was followed by the Greenpath sampling team and is provided in Appendix C.

All parameters were inputted into the app at the sampling location. Where appropriate, the app has dropdown menus to increase efficiency in compiling data. Numeric input fields have expected ranges of values and options for the units, so that if a value is entered outside of the range a message appears for the user to ensure the input is correct.

When the user has access to internet, the app will sync with Cap-Op Energy's DEEPP. The DEEPP will provide various functionalities for managing the data collected in the field including data storage and organizing the data into the desired output format of a download-able Excel files.

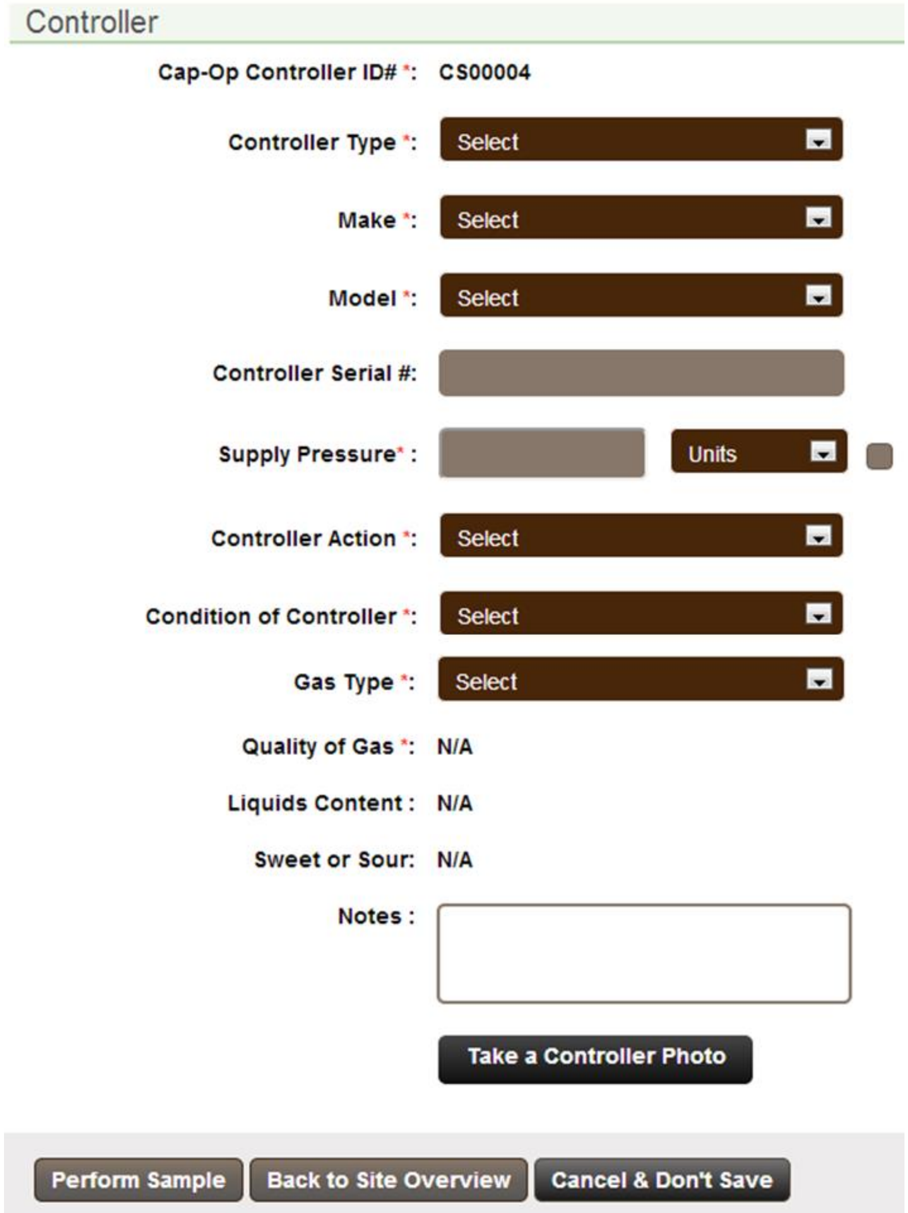

Figure 6: Screen Shot of Cap-Op Energy's Data Collection App

2.3.4 Errors, Uncertainty and Biases

Errors, uncertainty and biases are part of every analysis and are discussed here for transparency and clarity. Overall, through critical review of the potential errors, uncertainties and biases inherent to this study, robust and reliable results can be attained.

An error is an unsupported result or conclusion that arose through improper application of methods, calculations, or data management. Every effort has been made to eliminate errors from the analysis and a system of checks has been employed to eliminate error from the analysis. Error can be eliminated from analysis, while bias and uncertainty cannot be.

Uncertainty, as it pertains to measurement of physical states or processes, describes the precision (or lack thereof) at which a characteristic or parameter can be defined. The precision associated with the measurement of bleed rates from a pneumatic device can be characterized through review of the techniques used to measure the parameters in question.

The meter chosen for this project (see Section 2.3.1) uses self-actuating, reciprocating bellows to discretely count fixed volumes of gas being vented from the device in five second intervals. The limitations associated with this type of measurement, and the uncertainties imposed, include:

- Volumes of gas vented lower than the fixed volume of one inflated bellow in a five second interval cannot be resolved. The uncertainty of any values of bleed rate reported by the meter under this value is large. This effect is typically characterized as the 'turn-down ratio' of a meter and every meter will have limits, turn-down or some range beyond which its reported values are unreliable. The Hawk 9000 meter has the range of flows that is appropriate for the intent of this study and thus mitigates this form of uncertainty to the extent possible.
- Pressures of vented gas lower than the back pressure imposed by the meter will significantly alter the value of gas being vented by the device. Back-pressure is a significant concern when measuring pneumatic control devices since the performance and bleed rate of the device may be inherently dependent on the back pressure of vented gas. This uncertainty impacts all ranges of gas flow, but in general will impose large uncertainty on high flows of gas since back pressure increases with flow. Devices which reported a zero bleed rate may actually have simply been 'plugged' by the internal actuating mechanisms of the meter. In general, it is impossible to measure the state of a system without disturbing the system, and this effect is unavoidable regardless of the type or extent of metering equipment chosen. It is anticipated that while the metering system chosen does impose a back pressure which may be more significant than other metering systems, the benefits of this metering system (time series bleed rate values and temperature pressure compensation) outweigh the detrimental effects of back pressure on the validity of results.
- Gas compositions vary from location to location and from moment to moment and the estimation of gas composition at each measurement point is a source of uncertainty. It is prohibitively expensive to have real-time gas composition parameters available to the measurement devices such that the uncertainty associated with gas composition could be further reduced. The estimations and assumptions made on gas composition for temperature and pressure correction of measured volumes is considered appropriate for the scope of this project.
- Digitization of data imposes uncertainty to values recorded during measurement through the limitation of significant digits (decimal places). The uncertainty imposed through the significant digits carried by data management systems in this project is considered to have contributed a negligible degree of uncertainty to the overall result.

In general, a statistic is biased if it is determined by an approach or method which systematically gives rise to differences between sample data and population data. Every effort was made in this sampling approach to avoid or minimize the effects of biases, nevertheless biases exist and are discussed below:

- Opportunistic Sampling Approach - The sampling approach used is a non-probability technique called opportunistic sampling, where sampling locations were chosen purposefully. The locations were chosen based on the following criteria:
  - The proximity to Fort St. John. Fort St. John is arguably a hub of oil and gas production within BC, with a majority of activity found within 500 km. In order to determine device bleed rates in an efficient and cost-effective manner, sampling was focused in this area. Sampling did not occur in the Fort Nelson region because many sites in Northern BC are winter access only or only accessible by helicopter.
  - The accessibility due to seasonality. Field locations with winter access only were excluded from the survey due to logistics and cost.
  - Producer identified device "hot spots". Areas with a high concentration of devices were identified by cross-referencing producer's inventories with the list of common devices.

- Sweet natural gas well-sites were preferred, followed by compressor stations and batteries, then sour gas well sites. Sweet sites were preferred over sour sites because they are typically run off compressed natural gas, whereas sour sites are typically run off propane or air. Well-sites were preferred over larger facilities because they typically house the common pneumatic controllers and pumps.

Opportunistic sampling has known limitations, including the sampling error[6] which cannot be estimated, and that exclusion bias may arise from the non-random choice of sampling locations. However, random sampling was logistically impractical in this scenario and all efforts to minimize exclusion bias were made, by choosing sampling locations that were representative of a multitude of producers operating in BC, and production fields and sub-districts.

The effect of this exclusion bias is that the statistics describing the sample, may not accurately reflect the population statistics, and the extent to which this occurs cannot be determined. The likelihood and impact of this bias has been minimized by ensuring a sufficiently large sample size (the greater the sample size, the less selection biases will impact a result).

- Producer Influence – The sampling approach described above inherently allows for a set of biases which are the possibility for intentional and unintentional skewed sampling. Since permission was required from producers to access sites, and moreover, recommendations on which sites to visit were solicited from producers, it must be acknowledged that the producers may have unintentionally directed sampling to areas with more or less bleeding devices.
- Location – Pneumatic devices in the province of BC are limited to operation in the northern boreal shield or boreal plains climates at altitudes approximately centered around 690m above sea level. Oil and gas reserves are limited to those found in the western Canadian sedimentary basin and are not representative of global conditions. Biases arise from these geographic limitations and apply should the results of this study be implicated in jurisdictions outside of BC, however are irrelevant within the context of BC pneumatic device emissions.

[6] *Sampling error* is an estimation of the difference between the true population mean and the sample mean, usually expressed in terms of standard error. Standard error cannot be reliably calculated using non-probability sampling techniques, although a mean, standard deviation, and confidence interval can be calculated with large (>30) sample numbers.

3. Sample Characteristics

In order to calculate a statistically significant bleed rate, with 95% confidence, a minimum of 30 samples was required per device. A total of 765 samples were taken across 28 producing fields in BC and 2 producing fields in Alberta.

Table 2. Number of Samples by Device Type

Device Type		Number of Samples
Pneumatic Controllers	Level Controller	254
	Positioner	43
	Pressure Controller	142
	Temperature Controller	41
	Transducer	101
Pneumatic Pumps	Chemical Injection	184

3.1 Pneumatic Controllers

Table 3 (below) summarises the number of samples by controller device. Devices in the "other" category were used to develop a generic emissions factor for pneumatic devices not specifically listed here.

Table 3. Pneumatic Controllers Sampled

Pneumatic Controllers	First Round Samples	Second Round Samples	Total
Pressure Controllers			
Fisher 4150	35	11	46
Fisher C1	27	3	30
Fisher 4660	29	1	30
Level Controllers			
Fisher L2	37	11	48
Murphy L1200	27	4	31
Norriseal 1001	47	10	57
SOR 1530	28	3	31
Fisher 2900	22	8	30
Fisher 2680	22	10	32
Fisher 2500	8	4	12
Positioner			
Fisher Fieldvue (DVC)	20	12	32
Temperature Controller			
Kimray HT-12	36	0	36
Transducer			
Fisher i2P-100	37	0	37
Fisher 546	27	3	30
Fairchild TXI7800	36	1	37
Other	53	7	64
Total	**491**	**90**	**581**

3.2 Pneumatic Pumps

The sampling results for pump devices are summarised in Table 4 (below).

Table 4. Pneumatic Pumps Sampled

Pneumatic Pumps	First Round Samples	Second Round Samples	Total
Morgan HD312	3	32	35
Texsteam 5100	47	0	47
Williams P125	50	0	50
Williams P250	28	0	28
Williams P500	12	0	12
Other	9	3	12
Total	**149**	**35**	**184**

3.3 Producers

To reduce sampling bias, a cross-section of oil and gas producing companies were included in the survey to ensure sampling was representative and spread across producers as well as producing fields. Figure 3 (below) shows the breakdown of sampling across the eight producers.

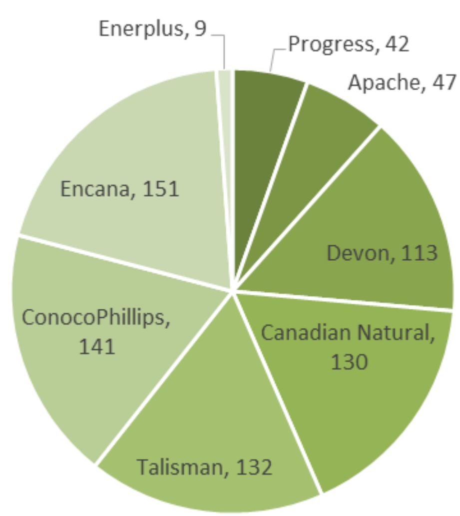

Figure 7: Breakdown of Samples by Producer

3.4 District and Sub-District

Table 5 outlines the number of samples per district as well as a breakdown of samples by producing field. Samples were collected from areas in northeastern BC; in the Fort St John, Brooks, Dawson Creek, Grand Prairie and Hanna districts (Figure 8). In total samples were taken from 30 different producing fields, with 756 samples coming from BC and 9 from Alberta.

Figure 8: Sampling Location

Table 5. Number of Samples by District and Sub-District

Producing Field	Number of Samples
Dawson Creek	**254**
Bissette	111
Brassey	7
Half Moon	7
Redwillow River	41
Sundown	25
Swan Lake	63
Fort St. John	**394**
Beaverdam	5
Blueberry	42
Buick Creek	29
Bullmoose	4
Bulrush	11
Burnt River	42
Cecil Lake	27
Eagle	36
Farrell	9
Farrell Creek West	43
Ladyfern	14
Monais	4
Muskrat	33
Nancy	26
North Cache	7

Producing Field	Number of Samples
North Pine	5
Owl	1
Septimus	16
Stoddart	29
Sukunka	11
Grand Prairie[7]	**108**
Hiding Creek	45
Noel	63
Hanna (AB)	**7**
Leo	7
Brooks (AB)	**2**
Verger	2
Total	**765**

4. Analysis

The analytical approach began by determining the mean sample bleed rate for each pneumatic controller and pump included in the survey. Table 6 below show the mean bleed rates, the 95% confidence interval (CI) and the standard deviation for the 20 common devices included in the survey. These bleeds rates are corrected for temperature, pressure and gas type.

Table 6: Results of Analysis by Device Model

Pneumatic Device	Number of Samples	Average Bleed Rate (m^3/hr)	95% Confidence Interval (m^3/hr)	Standard Deviation (m^3/hr)
Pressure Controllers				
Fisher 4150	46	0.4209	0.5322	0.4593
Fisher C1	30	0.0649	0.0981	0.1106
Fisher 4660	30	0.0151	0.0329	0.0592
Level Controllers				
Fisher 2500	12	0.3967	0.5559	0.3353
Fisher 2680	32	0.2679	0.3782	0.3793
Fisher 2900	30	0.1447	0.2496	0.3490
Fisher L2	48	0.2641	0.3538	0.3779
Murphy L1200	31	0.2619	0.3618	0.3383
Norriseal 1001	57	0.1868	0.2670	0.3679
SOR 1530	31	0.0531	0.0841	0.1049
Positioners				
Fisher Fieldvue DVC6000	32	0.2649	0.3633	0.3386
Temperature Controllers				

[7] Samples labelled Grand Prairie were taken from producing fields in BC.

Pneumatic Device	Number of Samples	Average Bleed Rate (m^3/hr)	95% Confidence Interval (m^3/hr)	Standard Deviation (m^3/hr)
Kimray HT-12	36	0.0351	0.0621	0.0987
Transducers				
Fairchild TXI7800	37	0.1543	0.1877	0.1234
Fisher 546	30	0.3547	0.4279	0.2436
Fisher i2P-100	37	0.2157	0.2602	0.1646
Pumps				
Morgan HD312	35	1.1292	1.3592	0.8271
Texsteam 5100	47	0.9670	1.1467	0.7490
Williams P125	50	0.4098	0.5092	0.4272
Williams P250	28	0.8022	1.0156	0.6863
Williams P500	12	0.6969	0.9741	0.5836

4.1 Analysis for Determining a Generic Bleed Rate

The next step of the analysis was to determine if a generic bleed rate could be generated for high-bleed controllers and pumps. Devices that were determined to be high bleeding (i.e. bleed rate>0.17m^3/hr) were grouped together in the analysis. If the calculated mean bleed rate was larger than the threshold, the device was included in the analysis, and if the calculated mean bleed rate was smaller than the threshold, the device was excluded from the analysis for determining a generic bleed rate. Certain controllers that are considered low-bleeding according to WCI or manufacturer specifications actually bled above the low bleed threshold and were therefore included in the analysis. Using Minitab, a statistical analysis software, a general linear model (GLM) was performed on the data to determine if there was a significant difference between the mean bleed rates of controllers and pumps. The results are presented in Table 7.

Table 7: Results of the Overview Analysis

Pneumatic Device	Number of Samples	Average Bleed Rate (m^3/hr)	95% Confidence Interval (m^3/hr)	Standard Deviation (m^3/hr)	P-Value
High Bleed Controllers	406	0.2605	0.2880	0.3371	0.129
High Bleed Intermittent	195	0.2476	.2893	0.3537	0.738
Piston Pumps	96	0.5917	0.6926	0.6007	0.060
Diaphragm Pumps	85	1.0542	1.1948	0.7878	0.362

For high bleed controllers, a p-value>0.05 was calculated, meaning that there was no significant differences between the mean bleed rates. The mean bleed rate is representative of the population and can therefore be applied to any high bleed controller model. For intermittent high bleed controller, a p-value>0.05 was calculated, meaning that there was no significant differences between the mean bleed rates. The mean bleed rate is representative of the population and can therefore be applied to any intermittent high bleed controller model. For all pumps, a p-value<0.05 was calculated, meaning that there is a significant difference between all pump models and a generic bleed rate may not be representative of the entire population. Due to the large variance in bleed rates across all pumps, the pumps were grouped into two categories: diaphragm pumps and piston pumps. A p-value>0.05 was calculated for both types of pumps, meaning that the mean bleed rate is representative of the entire population.

Box plot distributions of all field samples are presented in Appendix D.

4.2 Bleed Rate Equations

The most accurate bleed rate would take into account quantitative variables. A regression analysis was performed to investigate which quantitative variables affected the bleed rate. A regression analysis showed that there was a positive correlation between certain pneumatic controller bleed rates and supply pressure. A regression analysis showed that there was a positive correlation between pneumatic pump bleed rates, supply pressure, injection pressure and strokes per minute.

Controller Bleed Rate Equation $Bleed\ Rate_j = m * SP_j$

Where:

m = the supply pressure coefficient (see Appendix E)

SP_j = the supply pressure of controller j

Pump Bleed Rate Equation[8] $Bleed\ Rate_j = (g * SP_j) + (n * DP_j) + (p * SPM_j)$

Where:

g = the supply pressure coefficient (see Appendix E)

SP_j = the supply pressure of pump j, (kPa)

n = the discharge pressure coefficient, (see Appendix E)

DP_j = the discharge pressure of pump j, (kPa)

p = the strokes per minute coefficient (see Appendix E)

SPM_j = the strokes per minute of pump j

For producers who know the operating conditions of their devices, they should use the following bleed rate equations. It should be noted that this method will only provide a more accurate bleed rate compared to the average bleed rate shown in Table 7 and Table 8 if the producer is certain of the operating conditions. Adding complexity may increase the overall error in bleed rates if operating conditions are estimated. Figure 9 provides an overview of the approach used to analyze the data.

[8] It should be noted that if the pump is operating at less than five strokes per minute, the emissions equation is not applicable and the mean bleed rate should be used.

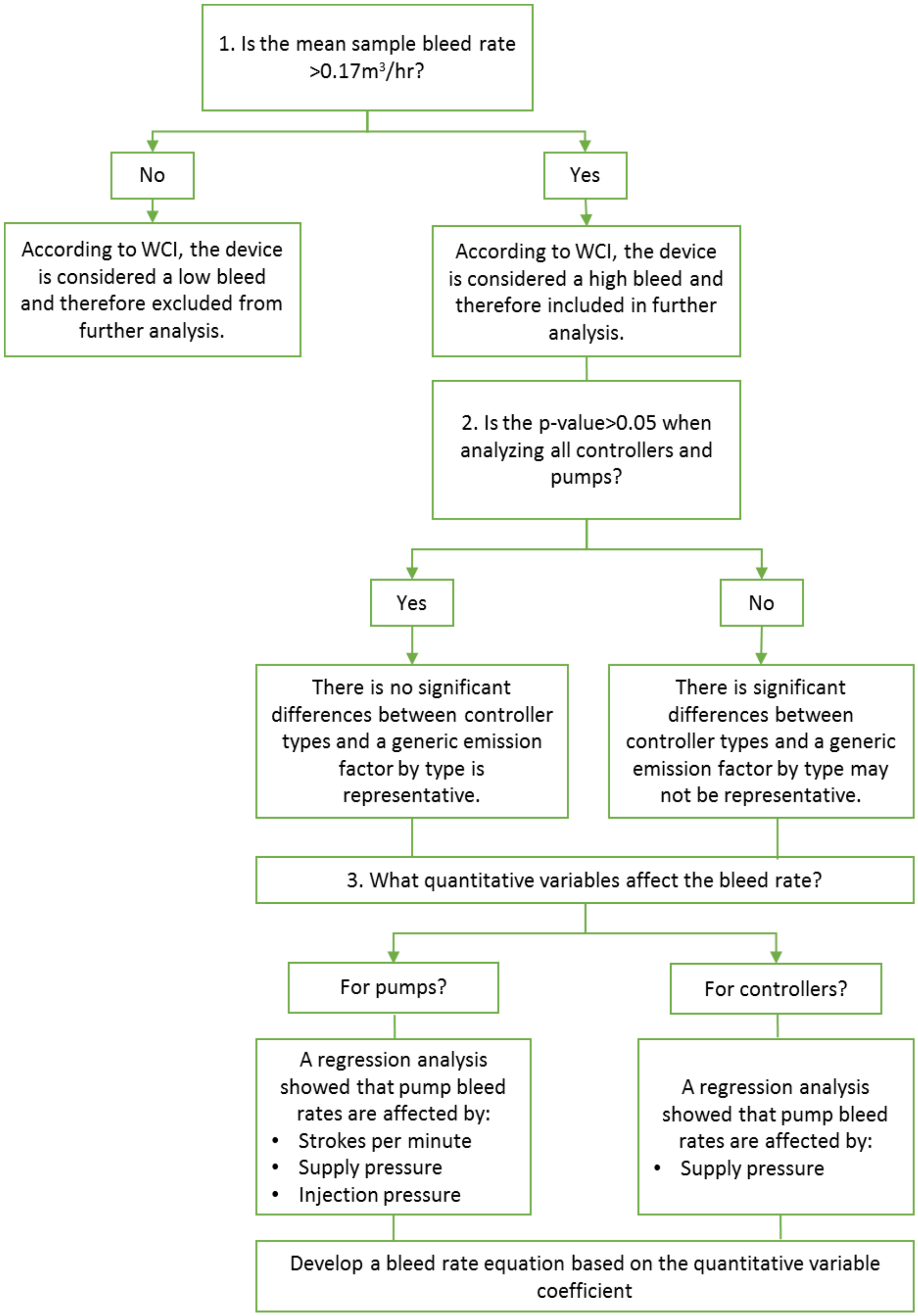

Figure 9: Diagram Illustrating the Quantitative Analysis

5. Comparison of Bleed Rates

Table 8 and Table 9 compare the average bleed rate to the manufacturer's specification as well as previously published bleed rates. A discussion on variability between the mean bleed rate and the manufacturer specification is provided in Section 6 below. A discussion on variability between the mean bleed rate and the EPA default is provided below. Overall, the average bleed rate for high bleed and intermittent controllers were lower than the EPA default; however, the average bleed rate for low bleed controllers and pumps were both higher than the EPA default. These findings align with a similar study that was performed in the United States by the University of Texas (Allen *et al.* 2013).

Table 8: Comparison of Pneumatic Controller Bleed Rates

Pneumatic Controllers	Average Bleed Rate (m^3/hr)	Manufacturer Specification (m^3/hr)	WCI (m^3/hr)	CAPP (m^3/hr)	EPA (m^3/hr)
Pressure Controllers					
Fisher 4150	0.421	0.691	0.736	0.680-1.841	0.071-0.821
Fisher C1[9]	0.065	0.097	0.147	-	-
Fisher 4660	0.015	0.174	0.142	-	0.142
Level Controllers					
Fisher L2[9]	0.264	0.032	0.043	-	-
Fisher 2500	0.397	1.100	1.189	1.189	0.283-2.03
Fisher 2680[9]	0.268	0.040	0.028	<0.028	<0.028
Fisher 2900	0.145	0.453	0.651	0.510-3.60	-
Murphy L1200[10]	0.262	-	-	-	-
Norriseal 1001[9]	0.187	0.057	0.057	0.006	0.006
SOR 1530[7]	0.053	0.142	-	-	-
Positioners					
Fisher DVC6000	0.265	0.38	0.396	0.400-1.39	0.396
Temperature Controller					
Kimray HT-12[9]	0.035	0.000	-	-	-
Transducer					
Fairchild TXI7800	0.154	0.380	0.241	-	-
Fisher 546	0.355	0.648	0.850	0.423-1.700	0.595
Fisher i2P-100	0.216	0.180	0.283	-	-

[9] Considered a low bleed controller according to manufacturer specification and WCI's definition <0.17m^3/hr.

[10] This pneumatic device was not on the initial list for pneumatics but was included due to prominence in the field.

Table 9. Comparison of pneumatic pump bleed rates.

Pneumatic Pumps	Mean Bleed Rate (m^3/hr)	Max Air Consumption (Man Specification[11] (m^3/hr)	CAPP (m^3/hr)[12]	WCI (m^3/hr)[13]	EPA (m^3/hr)
Morgan HD312	1.1292	1.35	0.236	0.3945	0.3767
Texsteam 5100	0.9670	2.31	0.236	0.3945	0.3767
Williams P125	0.4098	0.21	0.236	0.3945	0.3767
Williams P250	0.8022	1.33	0.236	0.3945	0.3767
Williams P500	0.6969	2.46	0.236	0.3945	0.3767

6. Discussion

6.1 Outliers

Outliers were not excluded from the sample population because the purpose of the survey was to capture real field conditions and generate a bleed rate that is representative of all field conditions. Certain controllers can have abnormally high bleed rates due to operations and maintenance; however, these bleed rates are representative of real world conditions and therefore were included in the analysis.

6.2 Throttling vs. Snap-Acting Controllers

Two types of controllers were sampled in the field, throttling and snap-acting controllers. Throttling controllers bleed continuously as they constantly throttle between static and dynamic states. Actuating or intermittent bleed devices perform snap-acting control and release gas only when they stroke a valve open or closed. The static bleed rate is steady-state gas consumption. When a controller performs an action, the pressurized gas is subsequently vented through the controller to the atmosphere, also known as the dynamic bleed rate.

The dynamic bleed rate can be much greater than the static bleed rate based on the operating conditions of the controller. The total bleed rate (static + dynamic) depends on the frequency the controller is performing an action. Snap-acting controllers typically have greater variability in dynamic and static action due to the intermittency of the actions. Snap-acting controllers are predominantly in their static, inactive state until an action is required, which results in a short burst of dynamic bleeding.

Figure 10 shows an example of how the bleed rate varies over time for a snap-acting controller. The difference between the static rate and the amplitude of the dynamic event is the dynamic bleed rate. The most important variable that dictates the bleed rate however is the frequency of the dynamic events, which is dependent on a number of variables (dry/wet gas, tank size, etc.) Level controllers are a prime example of a snap-acting controller because they only dynamically bleed when they are prompted by an event, typically to empty a liquids tank.

[11] The stated manufacturer max air consumption value assumes a supply pressure of 690 kPa (100 psi), which is a max supply pressure.

[12] http://www.capp.ca/getdoc.aspx?DocId=86223&DT=NTV

[13] http://www.theclimateregistry.org/downloads/2010/04/Final-OGP-Protocol.pdf

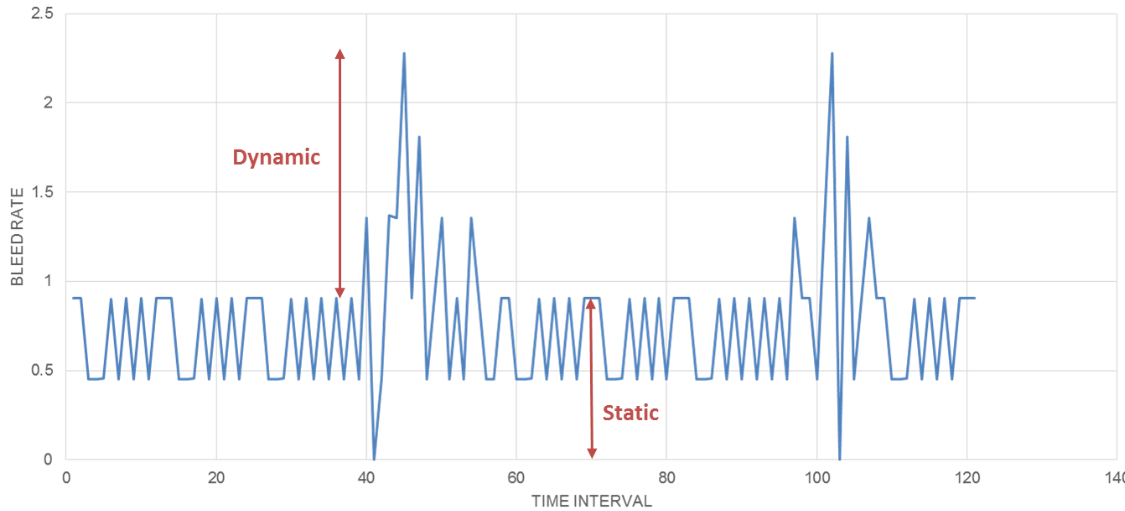

Figure 10: Graph Showing the Dynamic and Static Action

Since the sampling methodology limited the sample time to 30 minutes, there was variability in the amount of static and dynamic action that was captured from a given controller. This variability was due to the frequency of dynamic events. Depending on operating conditions, certain controllers did not perform an action within the 30 minute timeframe, so only the static bleed rate was captured. For example, if a level controller dumps on average every four hours, the sampling team may or may not have caught the dynamic bleed rate of the controller. This created variability in the amount of dynamic versus static bleeds that were capture by an individual sample; however, due to our large sample sets, this variability is representative of how controllers are performing under real operating condition.

This variance was mostly seen in level controllers because they are snap-acting and operate in an on or off type condition. The level controller samples showed a range of values depending on how many dynamic events occurred over a sampling period. This was an expected outcome because level controllers have primarily static bleed rates with variable dynamic events. Our analysis captured both static and dynamic events over the sampling time frame and are both accounted for when using the average as a representative bleed rate for the samples with skewed and bimodal distribution.

6.3 Manufacturer Specification

Differences are observed between the average bleed rate and the manufacturer specification. It should be noted that this variability was expected. The manufacturer specification measures the steady-state air consumption in a lab setting. The purpose of the survey is to determine the average bleed rate of pneumatic controllers and pumps when operating under real field conditions. The field bleed rates differed from manufacturer rates because they are operating under real world conditions with variability in dynamic and static action. For pumps, the field bleed rates are different than manufacturer rates because they are provided with a maximum air consumption using a maximum supply pressure.

6.4 Gas vs. Air vs. Propane

The majority of the field samples were taken at sweet well sites; however, as devices became harder to find, the sampling team targeted compressor stations and batteries as well as sour sites in order to reach the 30 sample threshold. A handful of air samples were obtained from larger facilities because typically, bigger facilities run compressed air instead of pressurized natural gas. A handful of propane samples were obtained from sour well sites because an alternative to process natural gas is required at sour sites, so pressurized propane is typically used. Air and propane samples were corrected using a density ratio in order to compare equivalent volumes of natural gas bled.

6.5 Calscan Vent Gas Meter

When determining which metering device to use during sampling, the Calscan bellows meter was chosen over the Bacharach High-Flow Sampler because it has greater accuracy and has the ability to capture the static and dynamic bleed rates (see Section 2.3.1 for a complete discussion on the differences). A drawback exists; however, that should be discussed and may explain some of the variability in the data. It is well-known that metering a device can affect the operation of the device when hooked up due to back pressure. It is possible that certain controllers didn't produce enough pressure when hooked up to overcome the back pressure, resulting in a zero reading.

6.6 Producer and Sub-District

A multitude of producers and sub districts within British Columbia were sampled; however, the purpose was not to determine differences between producers and sub-districts but determine generic BC wide bleed rates that reflect values from a variety of locations and producers. Since we have taken our samples from a variety of fields, the average bleed rate captures the variability between producers and sub-districts. The intent of the survey was not to determine whether producers and sub-districts were influencing variables; however, the methodology was designed to ensure that these variables were accounted.

6.7 Adding a Device Model to the Survey

If a producer wishes to develop an average bleed rate for a controller or pump that was outside the scope of this survey, they can follow the sampling methodology outlined in Section 2. A minimum of 30 bleed rates per device model must be achieved using a mass flow meter from a variety of producing fields and producers. Please reference the Project Methodology (July 29th 2013) report for the full protocol.

6.8 Mean vs. Median

Many of the snap acting level controllers had skewed or bi-modal distribution. Typically the median is used to represent the value for central tendency in non-normal distributions; however, the goal for this project was to develop an average where all the samples are weighted equally. The mean is recommended because it weights all samples equally; whereas the median would neglect samples on the tail of the distribution. The median would not accurately reflect the combined static and dynamic bleed rate; whereas the mean places equal weight on each sample. Using the median as a measure of central tendency would ignore the data that represents the dynamic action over the course of sampling. Thus, when calculating the most accurate bleed rate, the mean is more representative than the median because of static and dynamic actions.

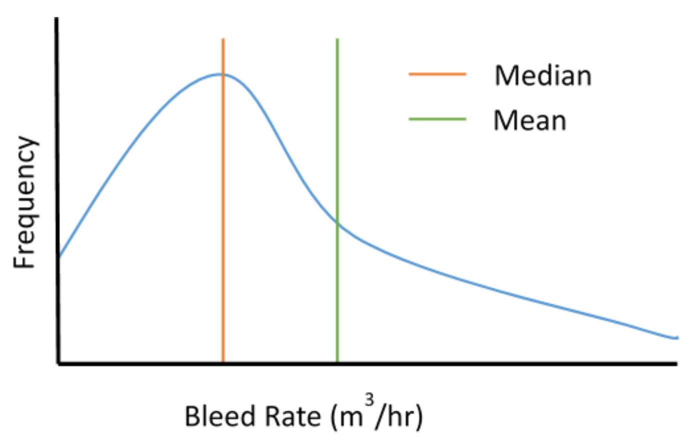

Figure 11: Non-Normal Distribution

6.9 General Linear Model

A general linear model is a statistical test that analyzes variance between sample populations. It was chosen to compare the samples because some populations showed a non-normal distribution and because the samples sizes differed. This statistical test incorporates different ANOVA tests and non-parametric tests to produce and accurate p-value. A general linear model is more robust when dealing with different normalities and variance in sample populations compared to a standard ANOVA and was therefore selected (Bolker *et al.* 2009).

6.10 Summer vs. Winter Sampling

The sampling was performed over the summer months of August and early September. The Calscan Hawk 9000 meter normalized all the samples for temperature and pressure differences in order to eliminate the different operating variables. A known constraint of our sampling methodology was that not all chemical injection pumps operate in the summer months. To eliminate this issue, the sampling team would turn the pump on and perform samples at three normal operating speeds (high, medium and low strokes per minute).

7. Applications of the Analysis

The mean bleed rates calculated in this survey are applicable for GHG reporting. A decision tree is provided in **Figure 12** and Figure 13 below to aid producers in determining which bleed rate to apply.

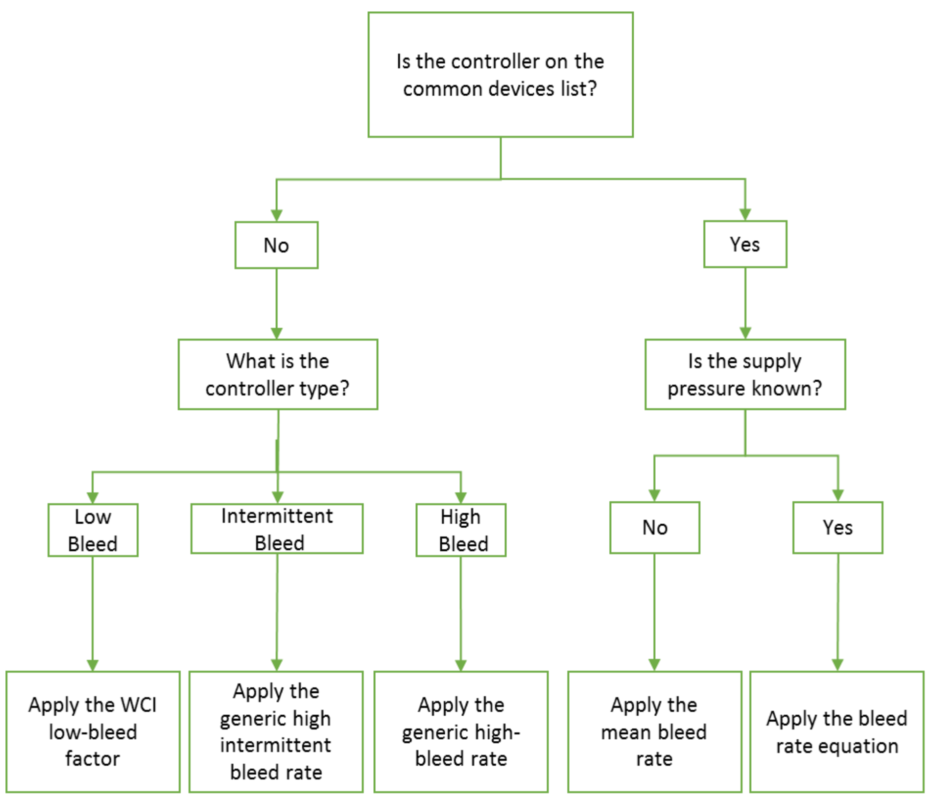

Figure 12: Controller Decision Tree

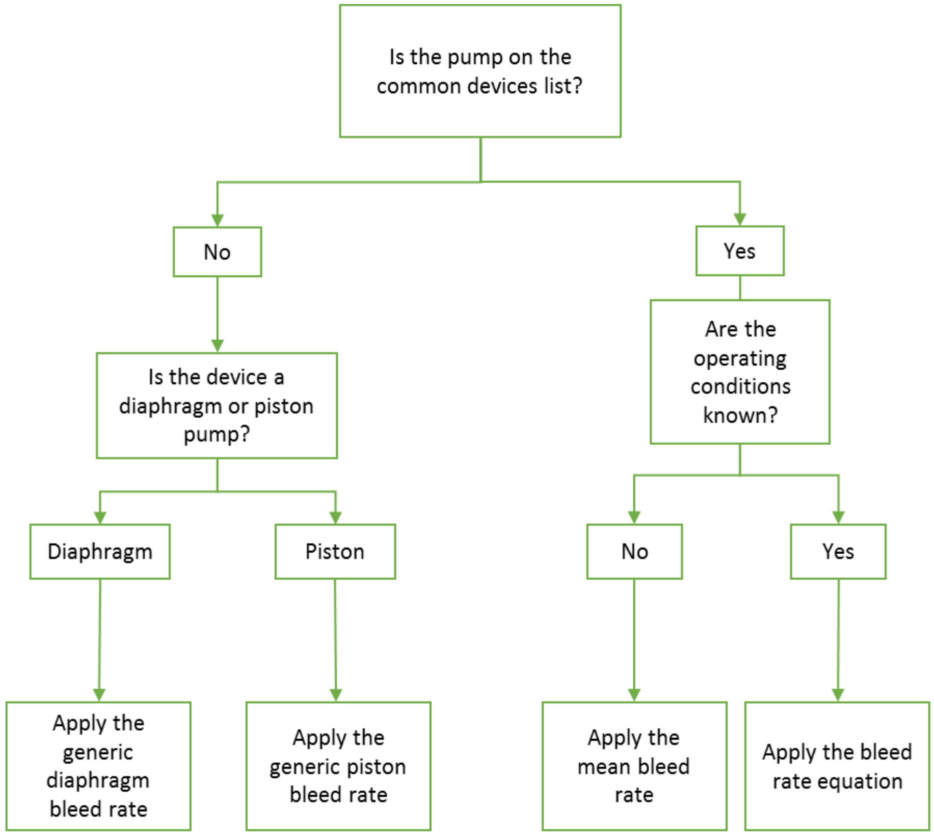

Figure 13: Pump Decision Tree

8. Observations

This study involved comprehensive analysis of pneumatic devices and a significant fieldwork program. This, combined with the fact that this study was one of the first of its kind, resulted in the research team observing several instances where the general body of scientific knowledge in this area could be advanced. These are outlined below:

1. Dynamic vs. static bleed rates: By nature, controller devices have a baseline bleed rate with dynamic events where more gas may be vented. In this study, the maximum sampling time was set at 30 minutes for each device, which added variability to the amount static and dynamic action captured in the sampling of snap-acting controllers (see section 6.2 for further discussion). The time interval between dynamic events may be longer than a 30 minute cycle. Future surveys investigating intermittent bleeding controllers, if undertaken, may consider capturing two complete dynamic cycles if reasonably practicable.

2. Categorisation of 'high', 'intermittent', and 'low bleed': The survey was focused around high-bleed pneumatic controllers. It was observed that for some high bleed devices the calculated mean bleed rate fell below the 0.17m3/hr WCI high bleed threshold and some tested low bleed controllers were higher. As an analysis of the observed differences were not within the scope of the project no further work to assess possible cause was undertaken, at this time. It is observed that future studies may consider all types of pneumatic controllers so that categorisation can be more fully tested and to ensure that field tested emission factors are available for all emitting pneumatic devices.

9. Conclusion

The purpose of the survey was to determine a representative average bleed rate for high bleed pneumatic controllers and pneumatic pumps when operating under field conditions. All outcomes were achieved. The results of the analysis led to the development of three generic bleed rates and twenty specific bleed rates for common pneumatic controllers and pumps for BC's oil and gas industry. These bleed rates can be used in the development of emission factors for GHG reporting and potentially offset purposes.

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Appendix A: Compilation of All Known Pneumatic Controllers

Description	Manufacturer	Model	Manufacturer Rate (m^3/h NG)	Source	Equivalent Devices	Sample?	Justification
Pressure Controller	Ametek	Series 40	0.22	WCI/CAPP BMP/GAS Star		Yes	High-bleed
Positioner	Becker	HPP-5	0.18	WCI		Yes	High-bleed
Pressure Controller	Bristol Babcock	Series 502 A/D	0.22	WCI/CAPP BMP/GAS Star		Yes	High-bleed
Pressure Controller	Dyna-Flo	4000	0.89	WCI	Dyna-Flo 5000	Yes	High-bleed
Pressure Controller	Dyna-Flo	4000LB	0.13	Dyna-Flo		Yes	High-bleed
Transducer	Fairchild	TXI 7800	0.31	WCI		Yes	High-bleed
Transducer	Fisher	546	1.10	WCI	Fisher 546S Fisher 546	Yes	High-bleed
Transducer	Fisher	646	0.29	WCI		Yes	High-bleed
Transducer	Fisher	846	0.44	WCI/CAPP BMP/GAS Star	Fisher 846S	Yes	High-bleed
Level Controller	Fisher	2500	1.55	WCI		Yes	High-bleed
Level Controller	Fisher	2900	0.85	WCI/CAPP BMP/GAS Star	Fisher 2901 Fisher 2900A	Yes	High-bleed
Positioner	Fisher	3582	0.59	WCI		Yes	High-bleed
Positioner	Fisher	3590	1.10	WCI		Yes	High-bleed
Positioner	Fisher	3660	0.26	WCI		Yes	High-bleed
Positioner	Fisher	3661	0.38	WCI		Yes	High-bleed
Pressure Controller	Fisher	4100	1.83	WCI	Fisher 4101	Yes	High-bleed
Pressure Controller	Fisher	4150	0.96	WCI	Fisher 4150K Fisher 4160R CVS 4150	Yes	High-bleed

Description	Manufacturer	Model	Manufacturer Rate (m^3/h NG)	Source	Equivalent Devices	Sample?	Justification
					Fisher 4150K Fisher 4160		
Temperature Controller	Fisher	4156			Fisher 4156 Fisher 4166	Yes	High-bleed
Pressure Controller	Fisher	4194	0.16	WCI		Yes	High-bleed
Pressure Controller	Fisher	4195	0.16	WCI		Yes	High-bleed
High-Low Pressure Pilot	Fisher	4660	0.18	Gas STAR	Fisher 4660A	Yes	High-bleed
Positioner	Fisher	Fieldvue DVC5000	0.37	WCI/CAPP BMP/GAS Star	FisherDVC5040 FisherDVC5030 FisherDVC5020 FisherDVC5010	Yes	High-bleed
Level Controller	Fisher	2900A			Fisher 2901A	Yes	High-bleed
Positioner	Fisher	3582i	0.76	WCI		Yes	High-bleed
Positioner	Fisher	3620J	0.98	WCI		Yes	High-bleed
Pressure Transmitter	Fisher	C1	0.19	WCI		Yes	High-bleed
Positioner	Fisher	Fieldvue DVC6000	0.52	WCI/CAPP BMP/GAS Star	FisherDVC6030 FisherDVC6020 FisherDVC6010	Yes	High-bleed
Transducer	Fisher	i2P-100	0.37	WCI	Fisher i2P-100, 4-20mA	Yes	High-bleed
Pressure Controller	Foxboro	43AP	0.66	WCI/CAPP BMP/GAS Star		Yes	High-bleed
Level Controller	Invalco	AE-155	1.95	WCI		Yes	High-bleed

Description	Manufacturer	Model	Manufacturer Rate (m^3/h NG)	Source	Equivalent Devices	Sample?	Justification
Level Controller	Invalco	CT Series	1.47	WCI/CAPP BMP/GAS Star	NATCO Flextube (CT Series)	Yes	High-bleed
Positioner	Invalco	Flextube (CT Series)	1.47	WCI	NATCO Flextube (CT Series)	Yes	High-bleed
Pressure Controller	ITT Barton	338	0.22	WCI/CAPP BMP/GAS Star		Yes	High-bleed
Pressure Controller	ITT Barton	4195	0.13	Gas Star		Yes	High-bleed
Pressure Controller	ITT Barton	335P	0.22	WCI/CAPP BMP/GAS Star		Yes	High-bleed
Level Controller	Kimray	Gen2	0.54	Manufacturer's website[14]		Yes	High-bleed
Temperature Controller	Kimray	HT-12				Yes	High-bleed
Level Controller	Mallard	3201				Yes	High-bleed
Positioner	Masoneilan	4600B Series	0.88	WCI		Yes	High-bleed
Positioner	Masoneilan	4700B Series	0.88	WCI		Yes	High-bleed
Positioner	Masoneilan	7400 Series	1.36	WCI		Yes	High-bleed
Positioner	Moore Products	73N-B PtoP	1.33	WCI/CAPP BMP/GAS Star		Yes	High-bleed
Positioner	Moore Products	750P	1.55	WCI/CAPP BMP/GAS Star		Yes	High-bleed
Transducer	Moore Products	IPX2				Yes	High-bleed

[14] http://mobile.kimray.com/downloads/instruction/GENIIBACKmount.pdf

Description	Manufacturer	Model	Manufacturer Rate (m^3/h NG)	Source	Equivalent Devices	Sample?	Justification
Pressure Controller	Natco	CT	1.55	WCI		Yes	High-bleed
Pressure Controller	Norriseal	4900				Yes	High-bleed
Level Controller	Norriseal	1005PI				Yes	High-bleed
Pressure Controller	Time Mate	2000				Yes	High-bleed
Level Controller	Wellmark	2001A	0.13	CAPP		Yes	High-bleed
Positioner	YTC	YT-2400				Yes	High-bleed
Level Controller	Fisher	2660	0.04	CAPP BMP	Fisher 2660A	Yes	PCT
Level Controller	Fisher	2680	0.04	CAPP BMP	Fisher 2680A	Yes	PCT
Level Controller	Fisher	L2	0.06	WCI		Yes	PCT
Level Controller	Norriseal	1001	0.07	WCI	1001A	No	PCT
Level Controller	Norriseal	1001XL	0.07	WCI		No	PCT
Positioner	Becker	ERP-2.0	0.00	WCI/CAPP BMP/GAS Star		No	Low-bleed
Controller	Becker	VRP-SB	0.00	Gas Star		No	Low-bleed
Pressure Controller	Bristol Babcock	358	0.07	Gas Star		No	Low-bleed
Pressure Controller	Bristol Babcock	359	0.07	Gas Star		No	Low-bleed
Pressure Controller	Bristol Babcock	5455 Model 624-III	0.09	WCI		No	Low-bleed

Description	Manufacturer	Model	Manufacturer Rate (m^3/h NG)	Source	Equivalent Devices	Sample?	Justification
Pressure Controller	Bristol Babcock	Series 5453-Model 624 - II	0.11	Gas STAR		No	Low-bleed
Pressure Controller	Bristol Babcock	Series 5455 Model-624 10F	0.11	WCI/CAPP BMP/GAS Star		No	Low-bleed
Pressure Transmitter	Bristol Babcock	Series 5457-70F	0.11	Gas STAR		No	Low-bleed
Transducer	Bristol Babcock	Series 9110-00A	0.02	WCI/CAPP BMP/GAS Star		No	Low-bleed
Level Controller	Fisher	2100	0.04	WCI/CAPP BMP/GAS Star		No	Low-bleed
Positioner	Masoneilan	SVI Digital	0.04	CAPP		No	Low-bleed
Positioner	VRC	VP700G	0.04	WCI/CAPP BMP/GAS Star		No	Low-bleed

Appendix B: Initial List of Pneumatic Devices Included in the Sample

Pneumatic Controller List

This list was developed by analyzing the frequency each controller make/model appeared in Cap-Op's field sample database. These 15 controllers make up 97% of the database.

Description	Manufacturer	Model	Equivalents	Name	Count	Percentage
Pressure Controller	Fisher	4150	Fisher 4150K Fisher 4160R CVS 4150 Fisher 4150K Fisher 4160	Fisher 4150	380	26.44%
Transducer	Fisher	i2P-100	Fisher i2P-100, 4-20mA	Fisher i2P-100	177	12.32%
Level Controller	Norriseal	1001	1001A	Norriseal 1001	170	11.83%
Level Controller	Fisher	2900	Fisher 2901 Fisher 2900A Fisher 2901A	Fisher 2900	163	11.34%
Transducer	Fisher	546	Fisher 546S Fisher 546	Fisher 546	94	6.54%
Level Controller	Fisher	L2		Fisher L2	84	5.85%
Level Controller	Fisher	2680	Fisher 2680A	Fisher 2680	78	5.43%
High-Low Pressure Pilot	Fisher	4660	Fisher 4660A	Fisher 4660	73	5.08%
Positioner	Fisher	Fieldvue DVC6000	FisherDVC6030 FisherDVC6020 FisherDVC6010	Fisher Fieldvue DVC6000	39	2.71%
Temperature Controller	Kimray	HT-12		Kimray HT-12	27	1.88%
Level Controller	Fisher	2660	Fisher 2660A	Fisher 2660	24	1.67%
Level Controller	Fisher	2500	Fisher 2506	Fisher 2500	23	1.60%
Level Switch	SOR	1530		SOR 1530	23	1.60%
Pressure Transmitter	Fisher	C1		Fisher C1	19	1.32%
Level Controller	Norriseal	1001XL		Norriseal 1001XL	19	1.32%
Total						97%

Pneumatic Pump List

This is a comprehensive list of known pump models that exist in the field. The list was developed by surveying multiple sources (industry, manufacturers, etc.). First round sampling uncovered which pumps were common (see bolded below) in order to target were sampling.

Manufacturer	Model
Arrow	548
Arrow	5100
Bruin	5000
Bruin	BR113LP
Checkpoint	1250
COE	5100
CVS	5100
CVS	C-252
Flowmore	5100
Graco	716
Ingersoll Rand	-
Linc	84-T Series
Linc	282
Morgan	4500
Morgan	**HD312**
Plainsman	-
Texsteam	**5100**
Timberline	2500, 5000, 1560 Series
Western Chemical Pump	ACE Series
Wilden	5000
Williams	**P125**
Williams	**P250**
Williams	**P500**

Appendix C: Field Sampling Guide

The subsequent guidelines were taken from the full Sampling Methodology report and were followed by the GreenPath field sample team:

What to Sample On-Site

- Sample all pneumatic controllers (including their equivalents) from the list provided (found in Appendix B).
- Sample all pumps. If pumps are turned off and you have permission from the operator to turn it on, take separate samples of the pump at different operating speeds (high, medium and low strokes per minute). Limit different operating speeds to speeds that the pump would function under normal operating conditions.

Duration of Sampling

All samples need to:

- be taken for at least 30 min, or
- until 2 ft^3 of gas has been collected

Sampling Device

- Attach the Calscan Hawk 9000 positive displacement bellows meter to the pneumatic device according to manufacturer specification.

Appendix D: Box Plot Distributions

A box plot distribution graph is a way to show the distribution of categorical samples. The black line represents the median value for a sample population. The grey box represents the first and third quartile or 50% of the data. The black lines show the range of observations. The median is represented by the horizontal line and the mean is the circle in the grey box.

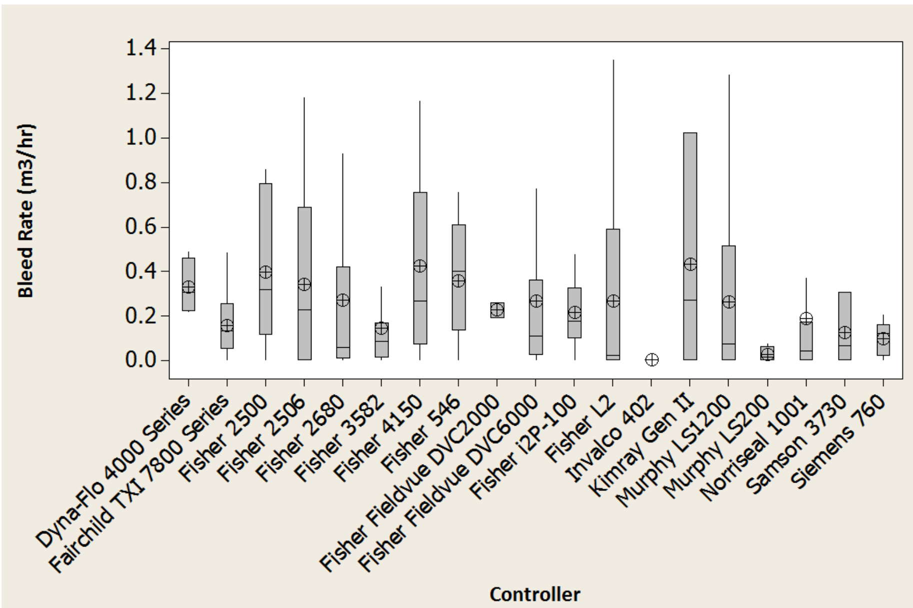

Figure 14: Box Plot Distribution for High-Bleed Controllers

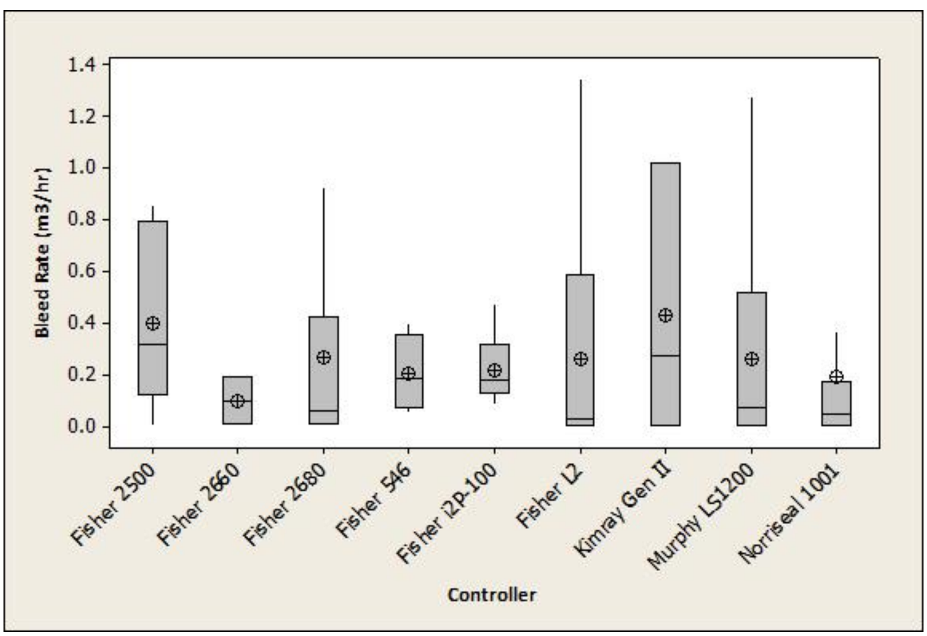

Figure 15: Box Plot Distribution for High Bleed Intermittent Controllers

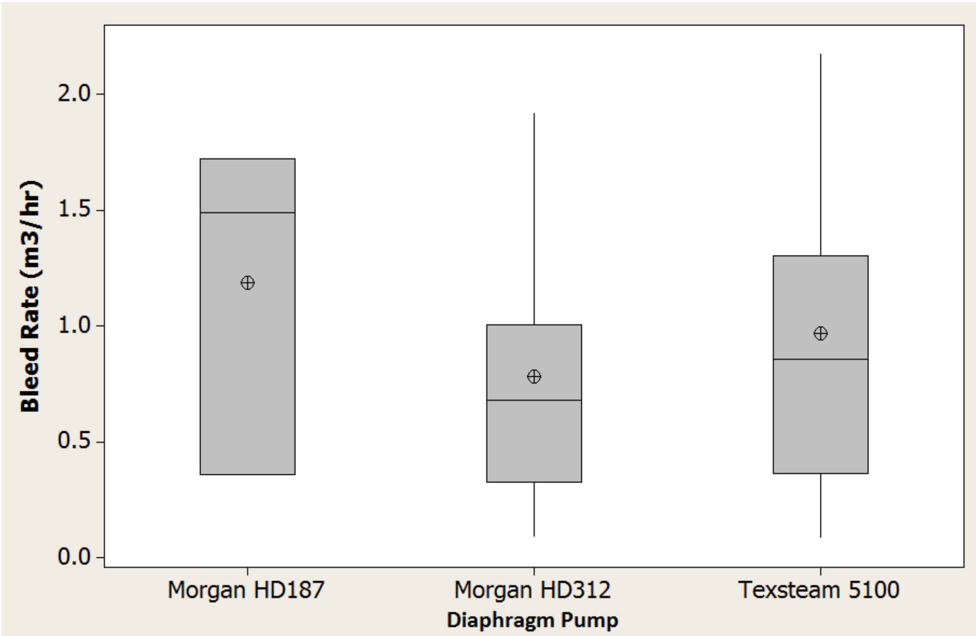

Figure 16: Box Plot Distribution for Diaphragm Pumps

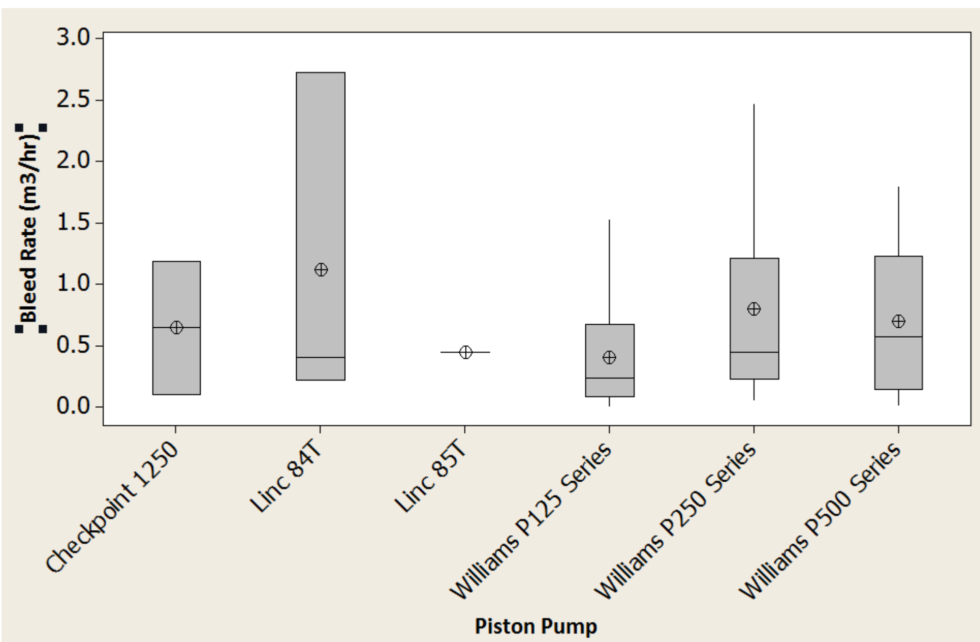

Figure 17: Box Plot Distribution for Piston Pumps

Appendix E: Bleed Rate Equation Coefficients

Pneumatic Controllers

A regression analysis showed that there was a positive correlation between certain pneumatic controller bleed rates and supply pressure.

Table 10: Controller Bleed Rate Equation Coefficients

Controller	Mean Bleed Rate (m^3/hr)	Coefficient[15]	R^2	Correlation[16]
High Bleed Pneumatic Controllers	0.2605	0.0012	0.41	Positive
High Bleed Intermittent Controllers	0.2476	0.0012	0.35	Positive
Pressure Controller				
Fisher 4150	0.4209	0.0019	0.46	Positive
Fisher C1	0.0649	0.0003	0.25	Positive
Fisher 4660	0.0151	-	0.05	Weak
Level Controller				
Fisher 2500	0.3967	0.0011	0.73	Strong
Fisher 2680	0.2679	0.0014	0.39	Positive
Fisher 2900	0.1447	-	0.13	Weak
Fisher L2	0.2641	0.0012	0.33	Positive
Murphy L1200	0.2619	0.0012	0.38	Positive
Norriseal 1001	0.1868	-	0.23	Weak
SOR 1530	0.0531	-	0.21	Weak
Positioners				
Fisher DVC 6000	0.2649	0.0011	0.75	Strong
Temperature Controller				
Kimray HT-12	0.0351	-	0.06	Weak
Transducer				
Fairchild TXI7800	0.1543	0.0009	0.60	Positive
Fisher 546	0.3547	0.0017	0.77	Strong
Fisher i2P-100	0.2157	0.0009	0.65	Strong

15 Controllers showing a weak correlation to supply pressure do not have a representative bleed rate equation and should therefore use the mean bleed rate instead of the emission equation.

16 Strong correlation indicates $R^2>0.64$
Positive correlation indicates $0.25<R^2<0.64$
Weak correlation indicates $R^2<0.25$

Pneumatic Pumps

A regression analysis showed that there was a positive correlation between pneumatic pump bleed rates, supply pressure, injection pressure and strokes per minute. The most accurate bleed rate would take into account these 3 operating variables when calculating the bleed rate for a pneumatic pump.

Table 11: Pump Bleed Rate Equation Coefficients

Pneumatic Pump	Mean Bleed Rate (m^3/hr)	Supply Pressure Coefficient (g)[17]	Injection Pressure Coefficient (n)[17]	Strokes Per Minute Coefficient (p)[17]	R^2	Correlation[18]
Diaphragm	1.0542	0.00202	0.000059	0.0167	0.68	Strong
Piston	0.5917	0.00050	0.000027	0.0091	0.49	Positive
Morgan HD312	1.1292	0.00418	0.000034	0.0073	0.66	Strong
Texsteam 5100	0.9670	0.00030	0.000034	0.0207	0.74	Strong
Williams P125	0.4098	0.00019	0.000024	0.0076	0.53	Positive
Williams P250	0.8022	0.00096	0.000042	0.0079	0.53	Positive
Williams P500	0.6969	0.00224	-0.000031	0.0046	0.74	Strong

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17 The coefficients are to be used in the pump bleed rate equation:
Bleed Rate = m * (Supply Pressure in kPa) + n * (Injection Pressure in kPa) + p * (Strokes per Min)

18 Strong correlation indicates $R^2>0.64$
Positive correlation indicates $0.25<R^2<0.64$
Weak correlation indicates $R^2<0.25$