Determining Emissions Factors for Pneumatic Devices in British Columbia

Final Field Sampling Report

November 5th, 2013

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1. Introduction

The Prasino Group (Prasino) has been engaged by the Science and Community Environmental Knowledge Fund (SCEK) in order to develop field tested emission factors for reporting greenhouse gas (GHG) emissions from pneumatic controllers and pumps (collectively referred to as 'devices') in British Columbia. The project is based on quantitative sampling of pneumatic devices in order to develop emissions factors as method of calculating and reporting of 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) and the Ministry of Natural Gas Development.

This report outlines the findings of the completed field sampling program after two rounds of collecting pneumatic bleed rates in the field from August 2nd until September October 23rdth 2013. This document describes:

- Preliminary analysis and results of the measured bleed rate samples;
- Outlines what further statistical analysis will be completed

2. Characteristics of the Sample Population

The objective of the project is to develop statistically significant bleed rates for a collection of common pneumatic devices. In order to calculate a statistically significant bleed rate, with 95% confidence, a minimum of 30 samples is required per device. A total of 765 samples were taken across 30 producing fields in BC from fifteen common pneumatic controllers and five common pneumatic pumps as identified in the field. The sample selection process is outlined in the Project Methodology document (dated August 8, 2013).

2.1 Device Type

Table 1 outlines the number of samples per pneumatic device type.

Table 1. 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
Total		**765**

2.1.1 Pneumatic Controllers

Prior to sampling, an indicative list of 15 common pneumatic controllers was identified. 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 (three devices found in the field); and
- Dyna-Flo 4000 (four devices found in the field).

Table 2 (below) summarises the number of samples by controller device. Devices in the “other” category may be used to test for significance in creating a generic emissions factor for pneumatic devices. Fisher 2500 was initially included in the analysis but 30 samples were never achieved. Initial analysis was included for this controller type based on CAS’ request.

Table 2. Pneumatic Controllers from 1st and 2nd Round Sampling.

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

[1] Other refers to devices that were not on the list of 15 common devices; however, these bleed rate samples may be used to develop generic emission factors.

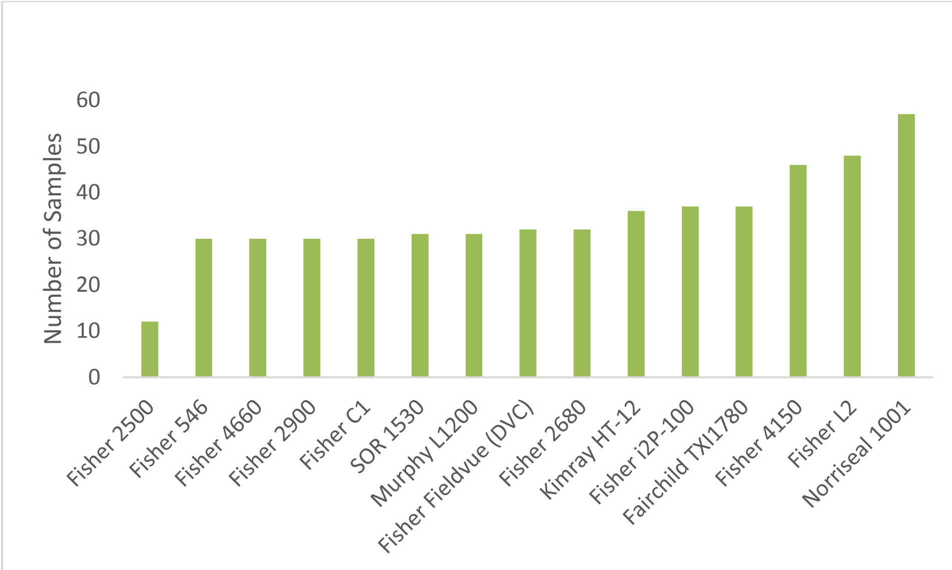

Figure 1: Frequency Graph of Pneumatic Controllers

2.1.2 Pneumatic Pumps

The sampling results for pump devices are summarised in Table 3 (below). The pumps with the low counts were initially sampled because it was unknown what pump types would have 30 samples. However, in the analysis phase these samples will be used to attempt to develop generic pump emissions factors.

Table 3. Pneumatic Pumps from 1st and 2nd Sampling.

Pneumatic Pumps	Number of Samples	Second Round Samples	Total
Williams P125	50	0	50
Williams P250	28	0	28
Williams P500	12	0	12
Texsteam 5100	47	0	47
Morgan HD312	3	32	35
Morgan HD187	0	3	3
Ingersoll Rand	2	0	2
Linc 84T	4	0	4
Checkpoint 1250	3	0	3
Total	**149**	**35**	**184**

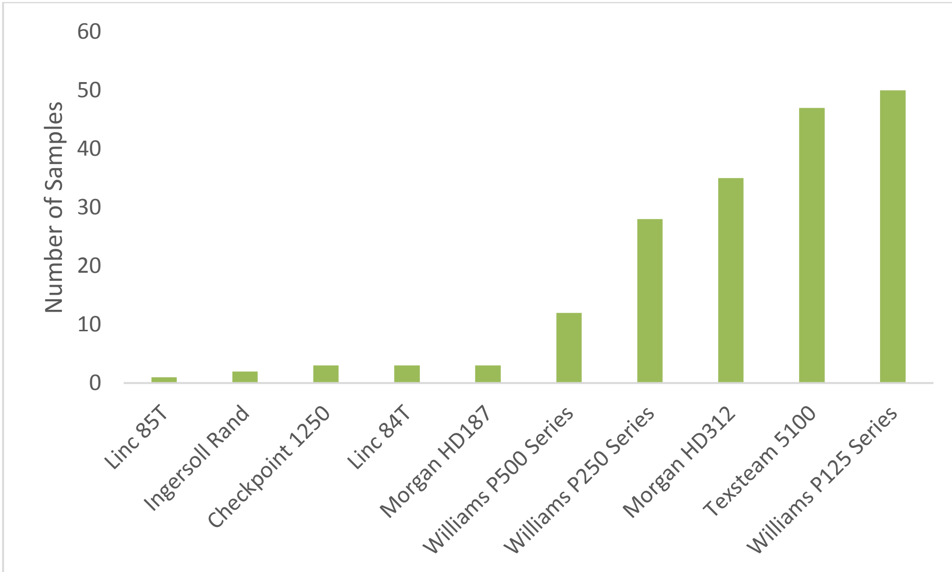

Figure 2**: Frequency Graph of Pneumatic Pumps**

2.2 Producers

To reduce sampling bias, a cross-section of oil and gas producing companies that use high bleed pneumatic devices were included in the survey to ensure sampling was representative and spread across producers as well as producing fields. As this is a study focussing on high bleed pneumatics, companies that do not use these instruments in their inventory have not been included. Figure 2 (below) shows the breakdown of sampling across the eight producers.

The second round of sampling focused on attaining more samples from CNRL because they were under represented after the first round of sampling. More samples were also taken from Devon because analysis indicated that they had a sufficient inventory of pneumatic pumps to achieve statistical significance for those that were lacking from the first round of sampling.

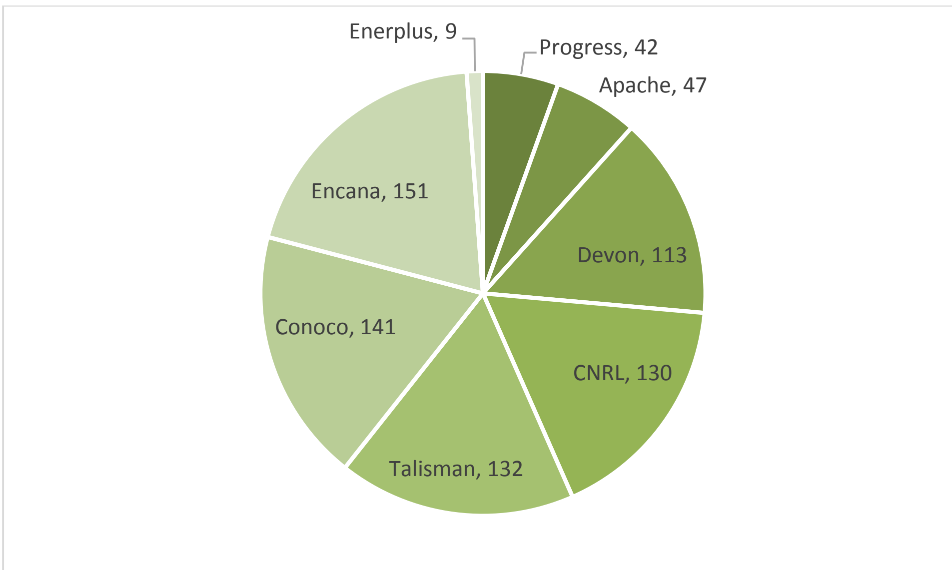

Figure 2: Breakdown of Samples by Producer

2.3 District and Sub-District

Table 4 outlines the number of samples per district as well as a breakdown of samples by producing field. As per the project methodology, the locations were chosen based on:

1. The proximity to Fort St. John in order to determine device bleed rates in an efficient and cost-effective manner;
2. The accessibility due to seasonality. Field locations with winter access only were excluded from the survey due to logistics and cost; and
3. Producer identified areas with a concentration of devices included in the survey.

Samples were collected from areas in northeastern BC and Alberta; Brooks, Dawson Creek, Fort St. John, Grand Prairie and Hanna districts.. Comparing the number of samples from the two provinces, 9 samples were taken from Alberta and 756 from BC. In total samples were taken from 30 different producing fields as shown in Table 4.

Table 4. Number of Samples by District and Sub-District.

Producing Field	Number of Samples
Dawson Creek	**254**
Bissette	111
Brassey	7

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

3. Findings

Preliminary data are presented in Appendix A. The data has been normalized for pressure and temperature differences in operating conditions and show the distribution and normality tests for each pneumatic controller or pump type

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

included in the survey. Each controller or pump also has the initial calculated emissions factor at stated operating conditions. Graphs are presented below showing the linear calculation of the bleed rates with 95% confidence interval bands and the manufacturer specifications for the pneumatic device type. The emissions factors are subject to change during the analysis phase of the project after investigation into outliers and operating conditions.

4. Next Steps

4.1 Further Analysis & Final Report

The final report will contain the following elements:

- Final emission factor equations for each pneumatic controller and pump;
- Generic emission factors for each pneumatic device type;
- Discussion of results for each pneumatic controller and pump; and
- Analysis to compare bleed rates across fields, producers, and device types examining potential causation of trends identified

Appendix A: Normalized Pneumatic Controller Data

Below is the preliminary analysis for each pneumatic device with a statistically significant population from the survey. A histogram and normality plot were created in Minitab 16. Some of the data was transformed to determine if the data would need parametric or non-parametric statistical test during the analysis and report writing phase of the project. A table with standardized operating conditions was used to compare the mean field bleed rate and 95% confidence interval bands with manufacturer specifications. Fisher 2500 was included even though only 12 samples were attained. Some controller types had outliers removed and the number of samples included in statistical analysis was less than thirty. Conditions associated with operations and maintenance contributed to the removal of outliers. Some outliers has extremely high bleed rate which may be associated with the normalization of data because of changes to the supply pressure. Manufacturer specification are provided in different forms. Some manufacturer specification provide high and low ranges, the maximum gas bled or single points given the supply pressure. Other manufacturer brochures do not list the supply pressure. These controllers were included based on WCI bleed rates or subject matter expert inquiry.

A.1 Level Controller

A.1.1 Fisher 2500

Twelve samples were collected for Fisher 2500 during sampling. Thirty samples were targeted but due to variability in controller locations and poor inventories, thirty samples were unable to be attained. Figure A.1.1 below shows the distribution of samples normalized for supply pressure.

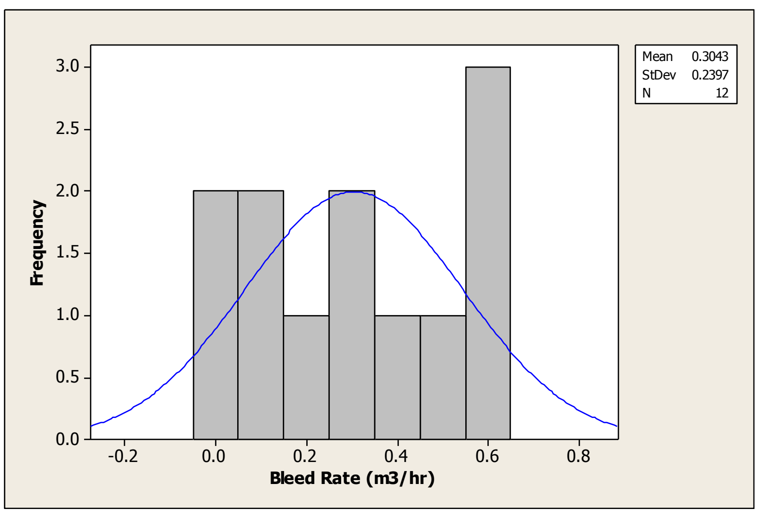

Figure A.1.1. Distribution of field samples with normalized bleed rates.

When the 12 samples are plotted on a graph (see Figure A.1.2) to test for normality, the Kolmogorov-Smirnov (KS) test indicates that the data is normally distributed ($p>0.05$).

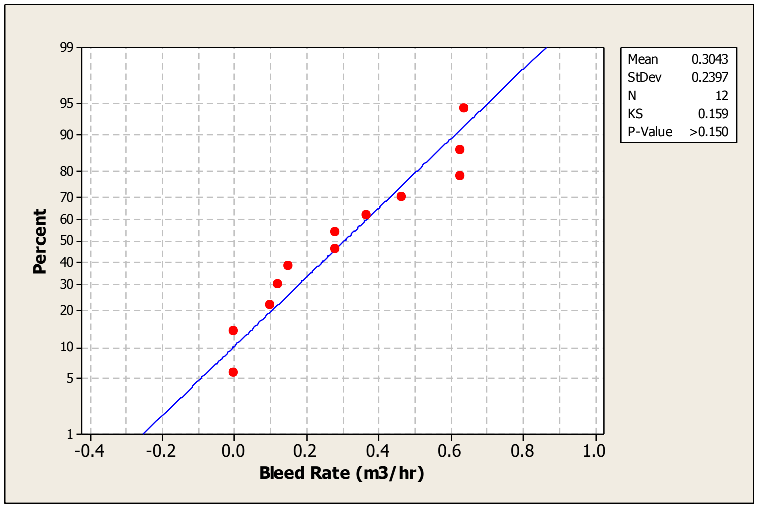

Figure A.1.2. Distribution of samples showing that the normalized bleed rates are normally distributed.

The original descriptive statistics from the normalized data can be used to determine the mean and 95% confidence interval. Table A.1.1 compares the mean, and upper and lower bounds of the 95% confidence interval. The bleed rates ranges from the manufacturer specification are also provided at 200 and 345 kPa

Table A.1.1. Shows the mean, lower and upper bounds of the 95% confidence interval with the manufacturer ranges for Fisher 2500.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)	Lower Manufacturer Specification (m^3/hr)	Upper Manufacturer Specification (m^3/hr)
200	0.3043	0.1520	0.4567	0.1616	1.0182
345	0.5250	0.2623	0.7877	0.2776	1.6127

The values from the table were plotted (Figure A.1.3) to produce an emissions equation and illustrate the field sample mean compared to the 95% Confidence Interval and manufacturer ranges.

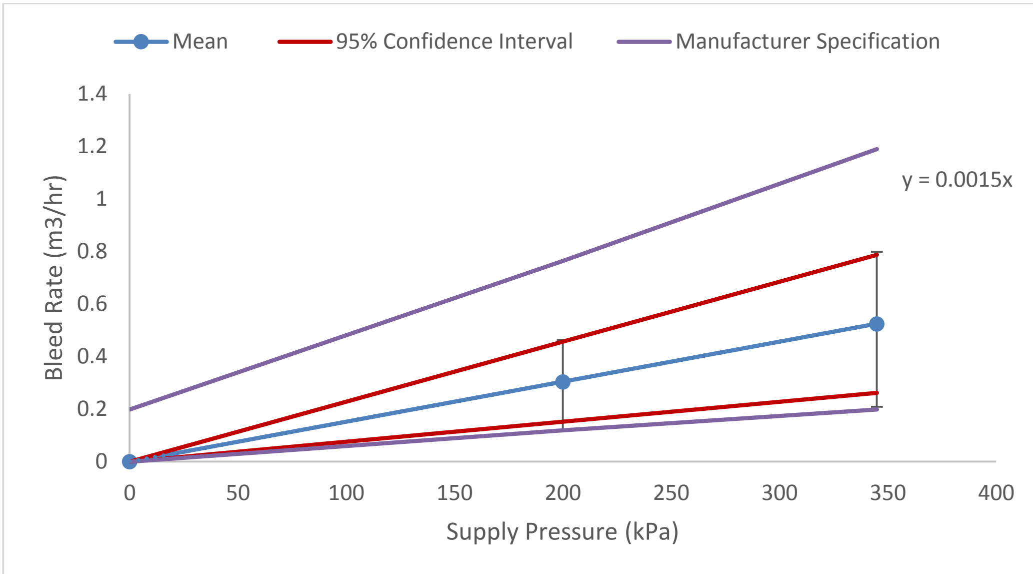

Figure A.1.3. The graph shows the mean, 95% confidence interval and manufacturer ranges for gases bled. The bars represent 50% of the field sample points.

Supply Pressure = 200 kPa Emissions Factor = 0.3043 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.5250 m^3/hr

Emissions equation:

Bleed Rate (m^3/hr) = 0.0015(Supply Pressure)

A.1.2 Fisher 2680

Thirty two samples were collected for Fisher 2680 during sampling. Figure A.1.4 below shows the distribution of samples normalized for supply pressure using a square root transformation.

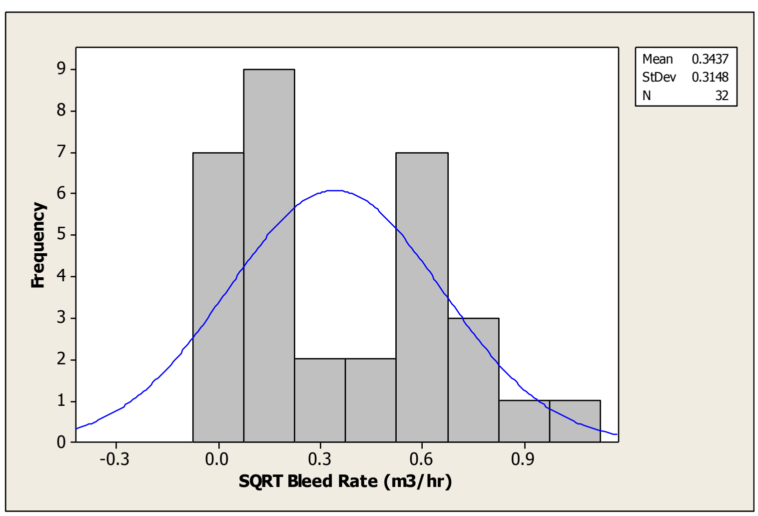

Figure A.1.4. Distribution of normalized samples with a square root transformation.

When the 32 samples are plotted on a graph (see Figure A.1.5) to test for normality, the KS test indicates that the data is not normally distributed (p<0.05). Multiple transformations were used on the data but it is not normally distributed. This sample set appears to have a bimodal distribution. This sample set can be compared to other level controllers using non-parametric test like the Mann-Whitney test or general linear model.

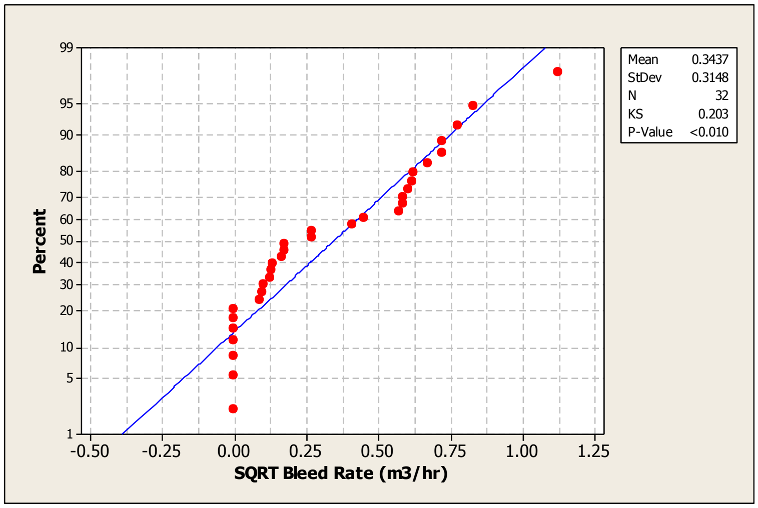

Figure A.1.5. Distribution of samples showing that the normalized samples are not normally distributed.

The original descriptive statistics from the normalized data can be used to determine the mean and 95% confidence interval. Table A.1.2 compares the mean, and upper and lower bounds of the 95% confidence interval. The manufacturer ranges are also provided at 137 and 241 kPa. The linear line for manufacturer specification are extrapolated.

Table A.1.2. Shows the mean, lower and upper bounds of the 95% confidence interval with the manufacturer ranges for Fisher 2680.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bound (m^3/hr)	Upper Bounds (m^3/hr)	Manufacturer Specification (m3/hr)
200	0.1805	0.1008	0.2602	0.03
345	0.3114	0.1739	0.4489	0.04

The values from the table were plotted (Figure A.1.6) to produce an emissions equation and illustrate the field sample mean compared to the 95% Confidence Interval and manufacturer ranges.

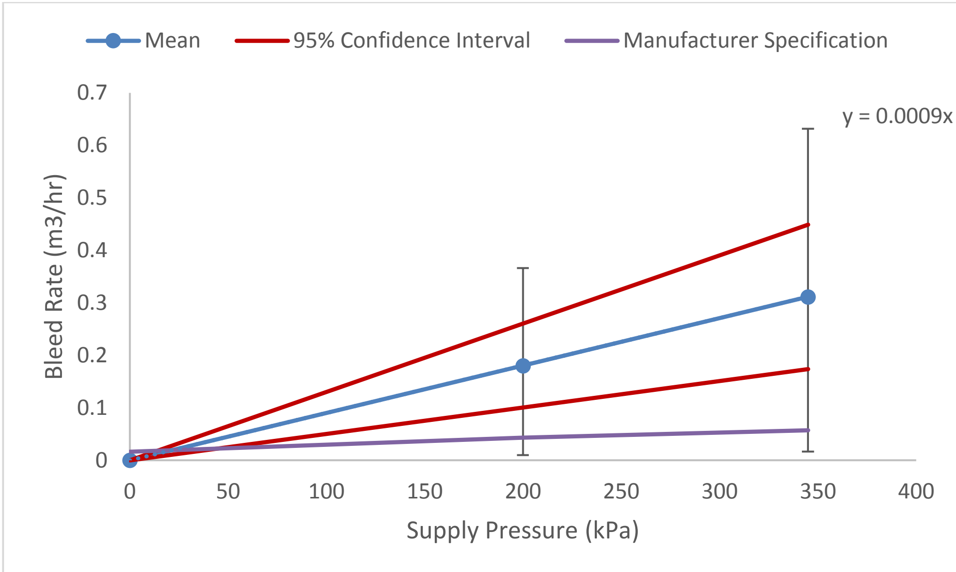

Figure A.1.6. The graph shows the mean, 95% confidence interval and manufacturer ranges of gases bled. The bars around the mean represent 50% of the sample points.

Supply Pressure = 200 kPa   Emissions Factor = 0.1805 m^3/hr

Supply Pressure = 345 kPa   Emissions Factor = 0.3114 m^-/hr

Emissions Equation:

Bleed Rate (m3/hr) = 0.0009(Supply Pressure)

A.1.3 Fisher 2900

Thirty samples were collected for Fisher 2900 during sampling. Figure A.1.7 below shows the distribution of samples normalized for supply pressure using a square root transformation.

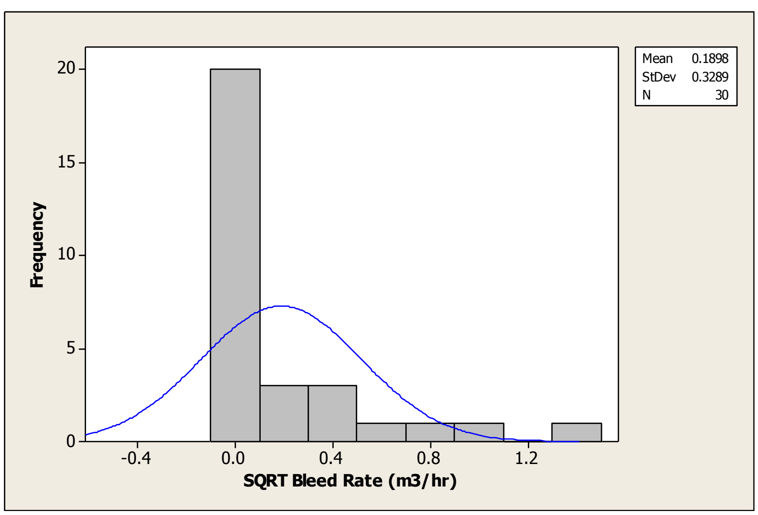

Figure A.1.7. Distribution of normalized bleed rate samples using a Square Root Transformation.

When 30 samples are plotted on a graph (see Figure A.1.8) to test for normality, KS test indicates that the data is not normally distributed ($p<0.05$). The data appears to have a positive skewed distribution. This sample set can be compared to other level controllers using non-parametric test like the Mann-Whitney test or general linear model.

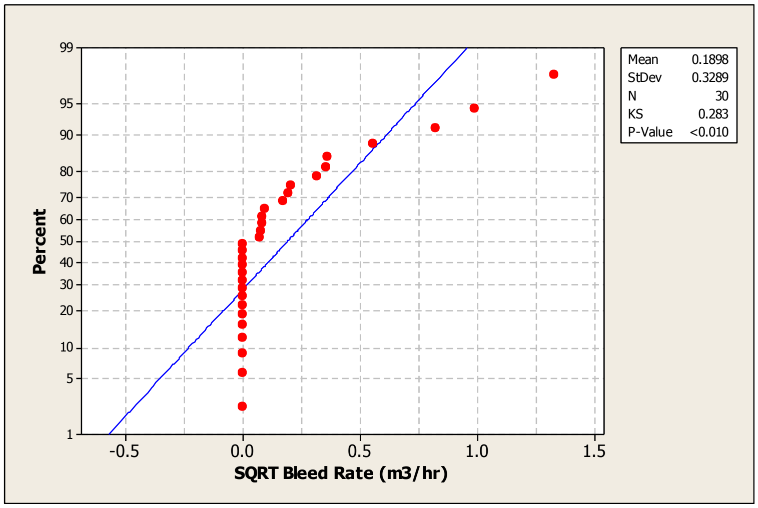

Figure A.1.8. Distribution of samples showing that the normalized samples are not normally distributed.

The original descriptive statistics from the normalized data can be used to determine the mean and 95% confidence interval. Table A.1.3 compares the mean, and upper and lower bounds of the 95% confidence interval.

Table A.1.3. Shows the mean, lower and upper bounds of the 95% confidence interval for Fisher 2900.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
200	0.1406	0.0009	0.2804
345	0.2426	0.0016	0.4836

The values from the table were plotted (Figure A.1.9) to produce an emissions equation and illustrate the field sample mean compared to the 95% Confidence Interval.

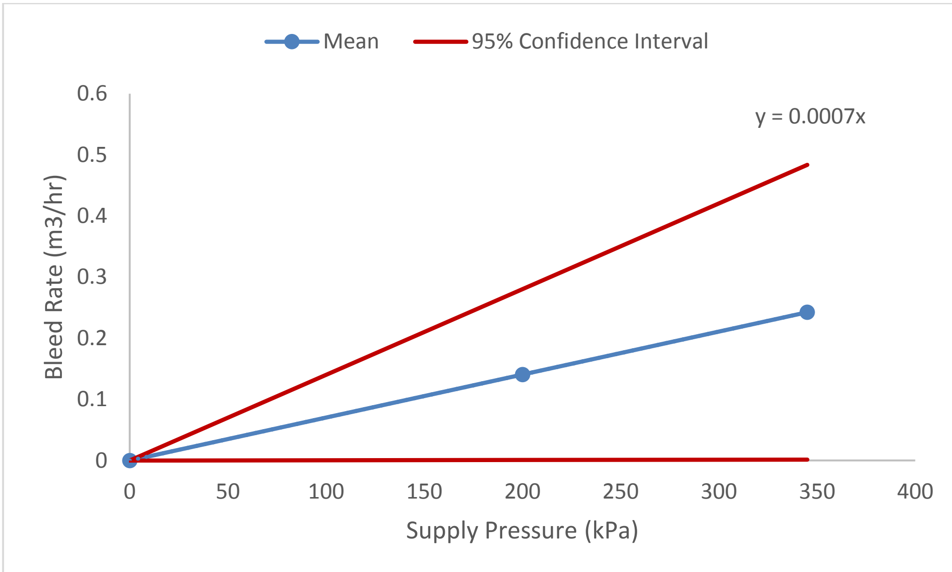

Figure A.1.9. The graph shows the mean and 95% confidence interval of gases bled. No error bars are presented because of the positive skew in the distribution.

Supply Pressure = 200 kPa Emissions Factor = 0.1406 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.2426 m^3/hr

Emissions Equation

Bleed Rate (m^3/hr) = 0.007 (Supply Pressure (kPa))

A.1.4 Fisher L2

Forty eight samples were collected for Fisher L2 during sampling. Figure A.1.10 below shows the distribution of samples normalized for supply pressure.

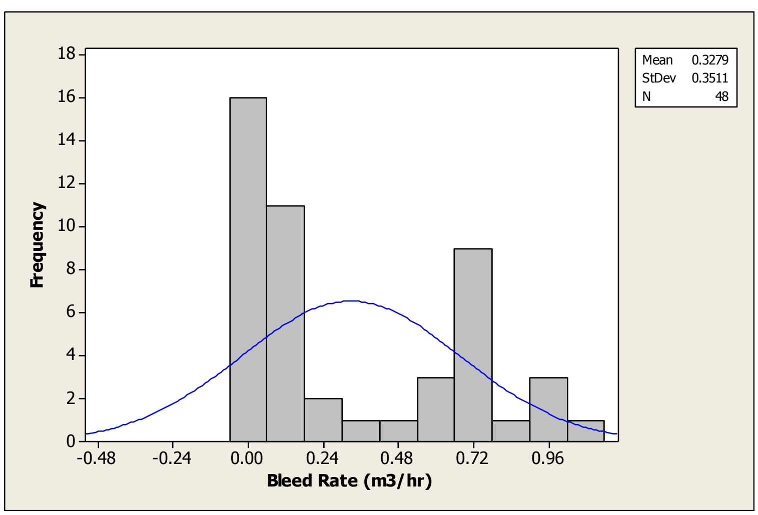

Figure A.1.10. Distribution of normalized bleed rate samples.

When 48 samples are plotted on a graph (see Figure A.1.11) to test for normality, KS test indicates that the data is not normally distributed ($p<0.05$). The data appears to have a bimodal distribution. This sample set can be compared to other level controllers using non-parametric test like the Mann-Whitney test or generally linear model.

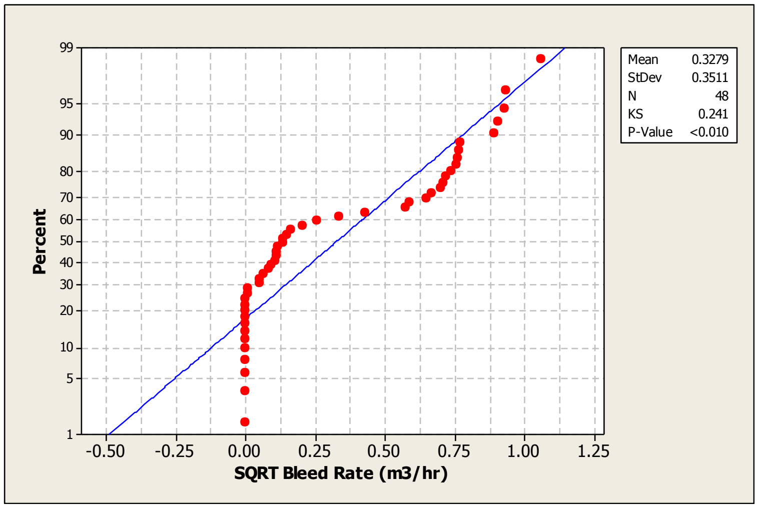

Figure A.1.11. Distribution of samples showing that the normalized samples are not normally distributed.

The original descriptive statistics from the normalized data can be used to determine the mean and 95% confidence interval. Table A.1.4 compares the mean, and upper and lower bounds of the 95% confidence interval and the manufacturer specifications at given supply pressures.

Table A.1.4. Shows the mean, lower and upper bounds of the 95% confidence interval with the manufacturer ranges for Fisher L2.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m3/hr)	Upper Bounds (m3/hr)	Manufacturer Specification (m^3/hr)
200	0.2283	0.1372	0.3193	0.0435
345	0.3937	0.2366	0.5509	0.0751

The values from the table were plotted (Figure A.1.12) to produce an emissions equation and illustrate the field sample mean compared to the 95% Confidence Interval and manufacturer specification.

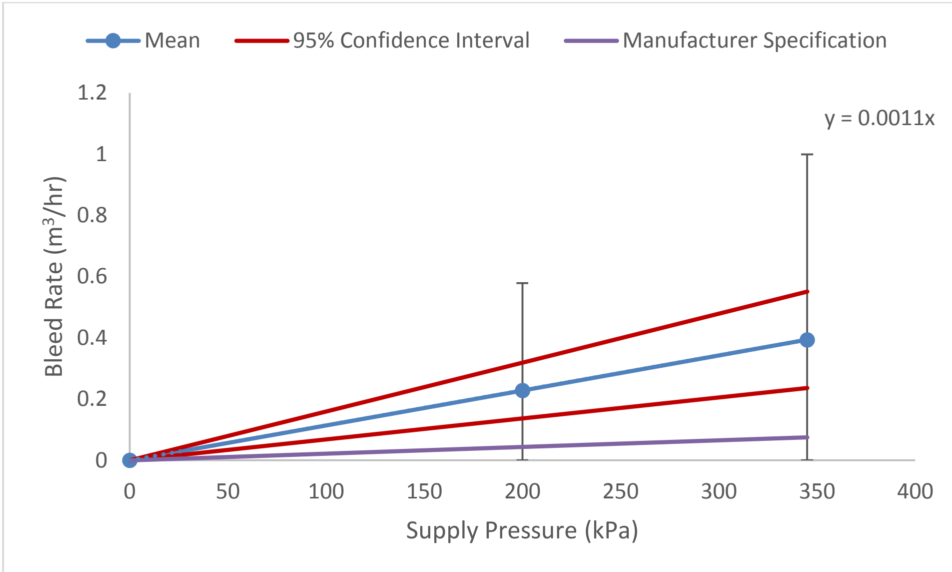

Figure A.1.12. The graph shows the mean and 95% confidence interval of gases bled. The bars around the mean represent 50% of the sample points.

Supply Pressure = 200 kPa Emissions Factor = 0.2283 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.3937 m3/hr

Emissions Equation

Bleed Rate (m^3/hr) = 0.0011(Supply Pressure (kPa))

A.1.5 Murphy L1200

Thirty one samples were collected for Murphy L1200 Series during sampling. Figure A.1.13 below shows the distribution of samples normalized for supply pressure.

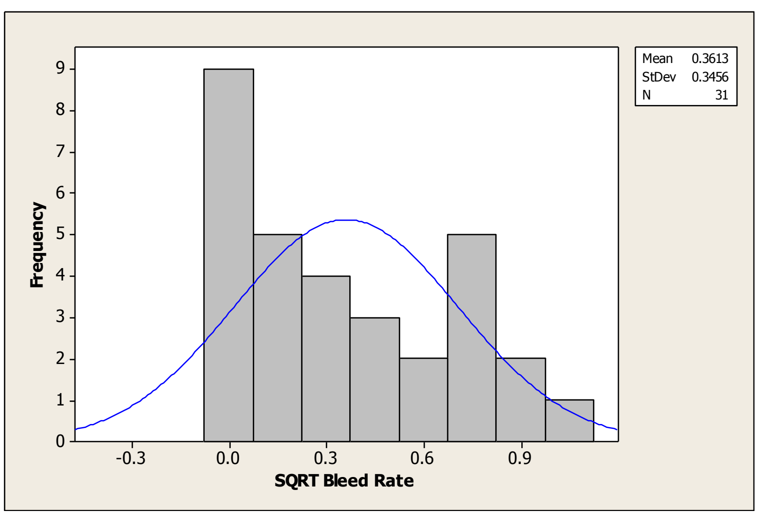

Figure A.1.13. Distribution of field samples with normalized bleed rates and a square root transformation.

When the 31 samples are plotted on a graph (see Figure A.1.14) to test for normality, the KS test indicates that the data is not normally distributed (p<0.05). Multiple transformations were used on the data but it is not normally distributed. This sample set appears to have a bimodal distribution. This sample set can be compared to other level controllers using non-parametric test like the Mann-Whitney test or general linear model.

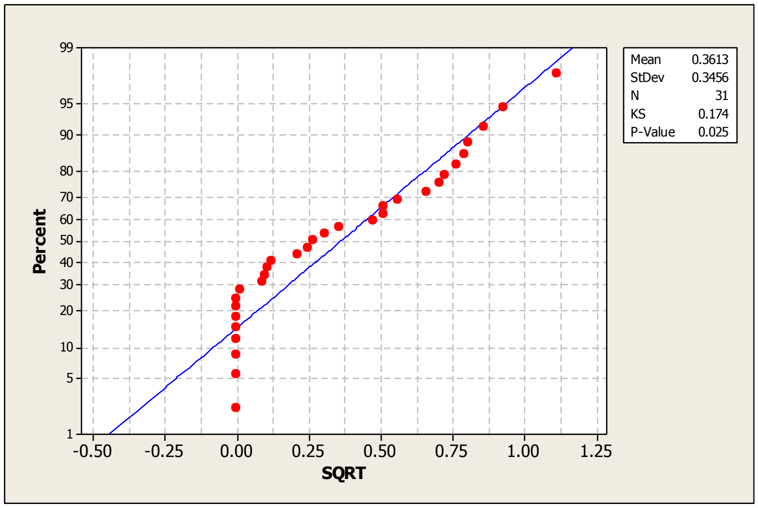

Figure A.1.14. Distribution of samples showing that the normalized bleed rates are not normally distributed.

The original descriptive statistics from the normalized data can be used to determine the mean and 95% confidence interval. Table A.1.5 compares the mean, and upper and lower bounds of the 95% confidence interval. No manufacturer bleed rate is specified in their brochure.

Table A.1.5. Shows the mean, lower and upper bounds of the 95% confidence interval for Murphy L1200.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
200	0.2461	0.1283	0.3640
345	0.4246	0.2213	0.6279

The values from the table were plotted (Figure A.1.15) to produce an emissions equation and illustrate the field sample mean compared to the 95% Confidence Interval.

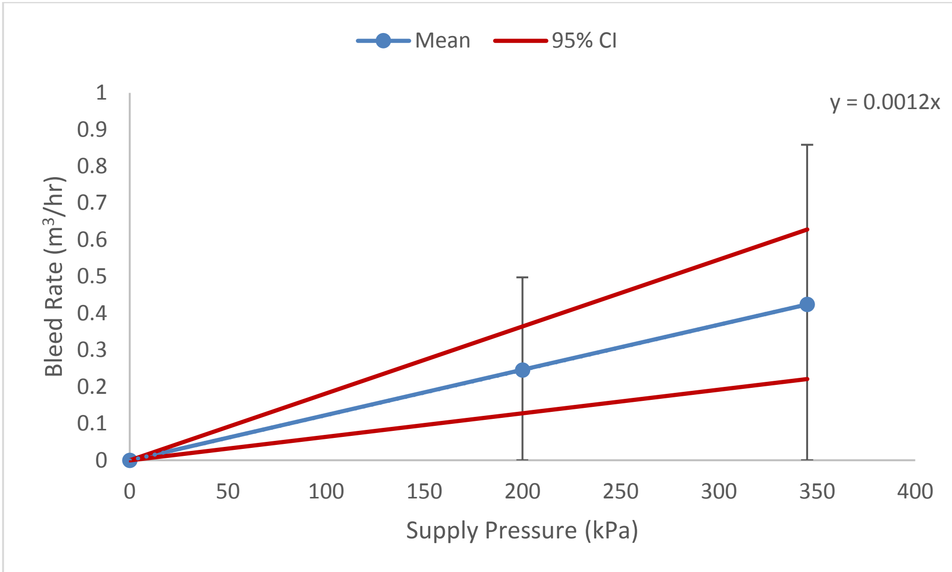

Figure A.1.15. The graph shows the mean and the 95% confidence interval ranges of gas bled. The bars around the mean represent 50% of the sample points.

Supply Pressure = 200 kPa Emissions Factor = 0.2461 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.4246 m^3/hr

Emissions Equation:

Bleed Rate (m^3/hr) = 0.0012(Supply Pressure (kPa))

A.1.6 Norriseal 1001

Fifty two samples were collected for Norriseal 1001 during sampling. Figure A.1.16 below shows the distribution of samples normalized for supply pressure.

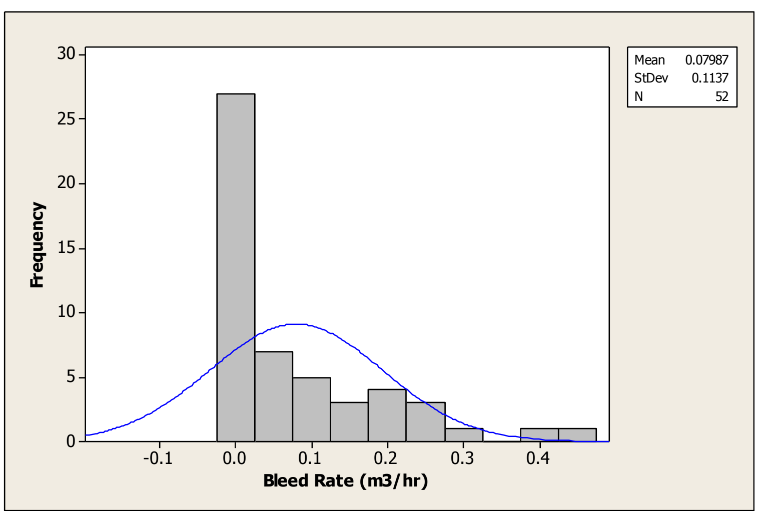

Figure A.1.16. Distribution of normalized samples.

When the 52 samples are plotted on a graph (see Figure A.1.17) to test for normality, the KS test indicates that the data is not normally distributed ($p<0.05$). Multiple transformations were used on the data but it is not normally distributed. This sample set appears to have a positive skewed distribution. This sample set can be compared to other level controllers using non-parametric test like the Mann-Whitney test or general linear model.

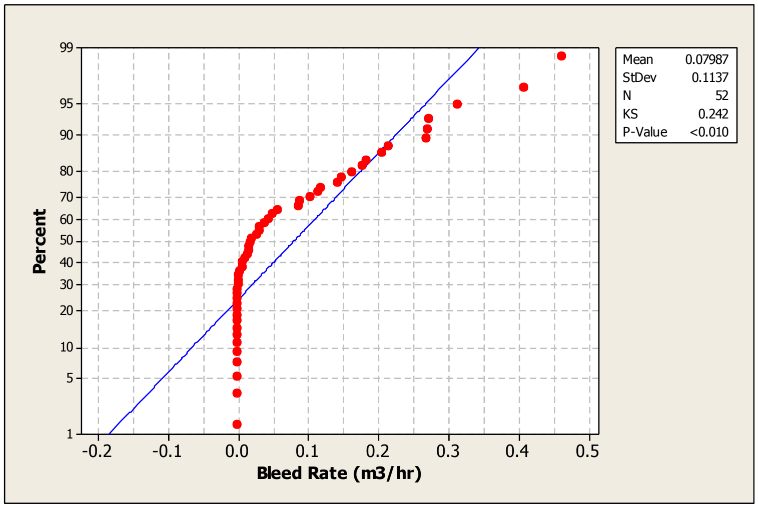

Figure A.1.17. Distribution of samples showing that the normalized samples are not normally distributed.

The original descriptive statistics from the normalized data can be used to determine the mean and 95% confidence interval. Table A.1.6 compares the mean, and upper and lower bounds of the 95% confidence interval and the manufacturer specification.

Table A.1.6. Shows the mean, lower and upper bounds of the 95% confidence interval with the manufacturer specification for Norriseal 1001.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)	Manufacturer Specification (m^3/hr)
200	0.0799	0.0482	0.1115	0.0057
345	0.1378	0.0832	0.1924	0.0098

The values from the table were plotted (Figure A.1.18) to produce an emissions equation and illustrate the field sample mean compared to the 95% Confidence Interval and manufacturer ranges.

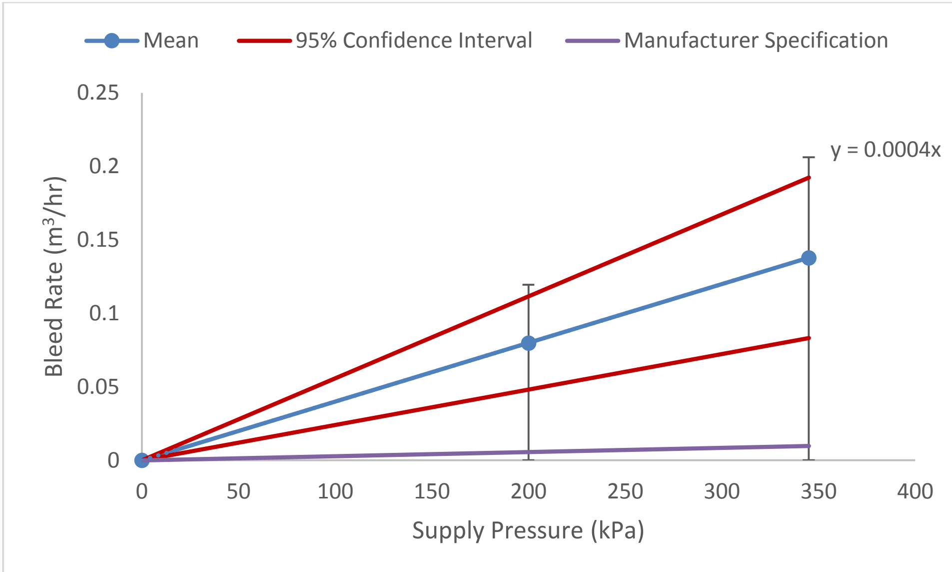

Figure A.1.18. The graph shows the mean and 95% confidence interval and manufacturer specification of gas bled. The bars around the mean represent 50% of the data.

Supply Pressure = 200 kPa Emissions Factor = 0.0799 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.1378 m^3/hr

Emissions Equation:

Bleed Rate (m3/hr) = 0.0004(Supply Pressure (kPa))

A.1.7 SOR 1530

Thirty one samples were collected for SOR 1530 during sampling. Figure A.1.19 below shows the distribution of samples normalized for supply pressure.

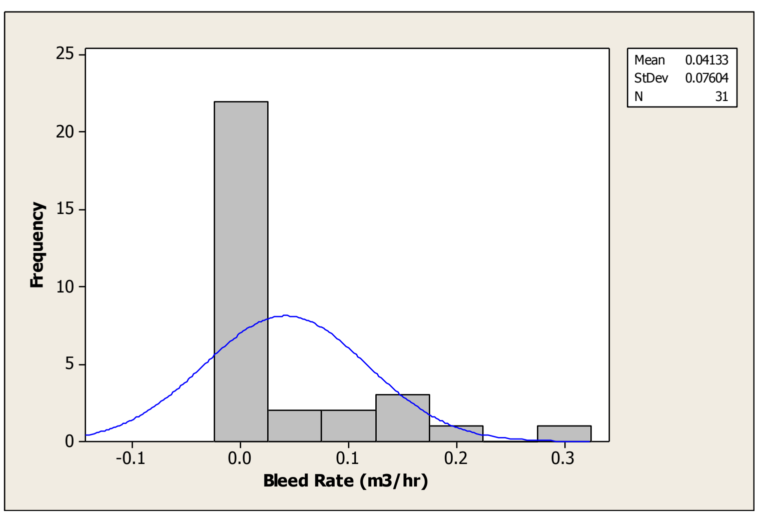

Figure A.1.19. Distribution of normalized samples.

When the 32 samples are plotted on a graph (see Figure A.1.20) to test for normality, the KS test indicates that the data is not normally distributed (p<0.05). Multiple transformations were used on the data but it is not normally distributed. This sample set appears to have a positive skewed distribution. This sample set can be compared to other level controllers using non-parametric test like the Mann-Whitney test or general linear model.

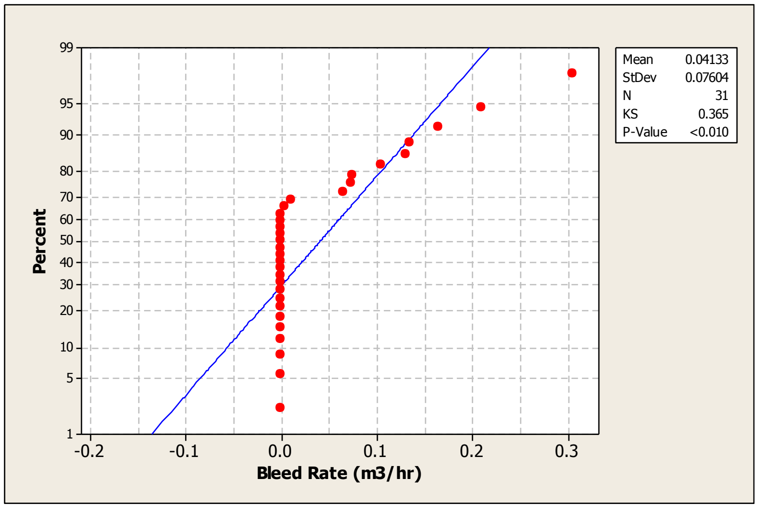

Figure A.1.20. Distribution showing that the normalized samples are not normally distributed.

The original descriptive statistics from the normalized data can be used to determine the mean and 95% confidence interval. Table A.1.7 compares the mean, and upper and lower bounds of the 95% confidence interval. Manufacturer maximum steady state air consumption was 0.14 m^3/hr at 345 kPa.

Table A.1.7. Shows the mean, lower and upper bounds of the 95% confidence interval for SOR 1530.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
200	0.0413	0.0134	0.0692
345	0.0713	0.0232	0.1194

The values from the table were plotted (Figure A.1.21) to produce an emissions equation and illustrate the field sample mean compared to the 95% Confidence Interval.

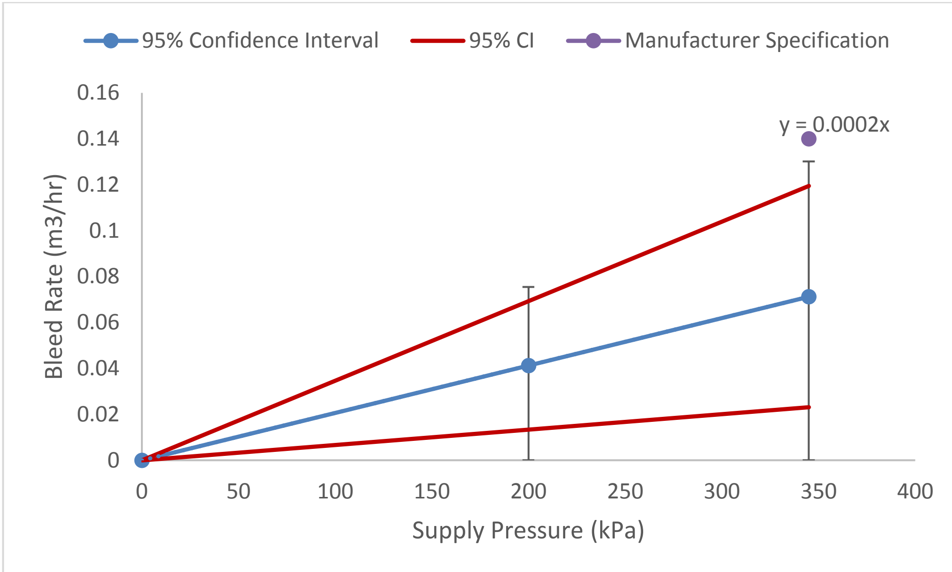

Figure A.1.21. The graph shows the mean, 95% confidence intervals and manufacturer ranges of gases bled. The bars around the mean represent 50% of the sample points

Supply Pressure = 200 kPa Emissions Factor = 0.0413 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.0713 m^3/hr

Emissions Equation:

Bleed Rate (m^3/hr) = 0.0002(Supply Pressure (kPa))

A.2 Positioner

A.2.1 Fisher Fieldvue 6000

Thirty two samples were collected for Fisher Fieldvue 6000 during sampling. Figure A.2.1 below shows the distribution of samples normalized for supply pressure using a square root transformation.

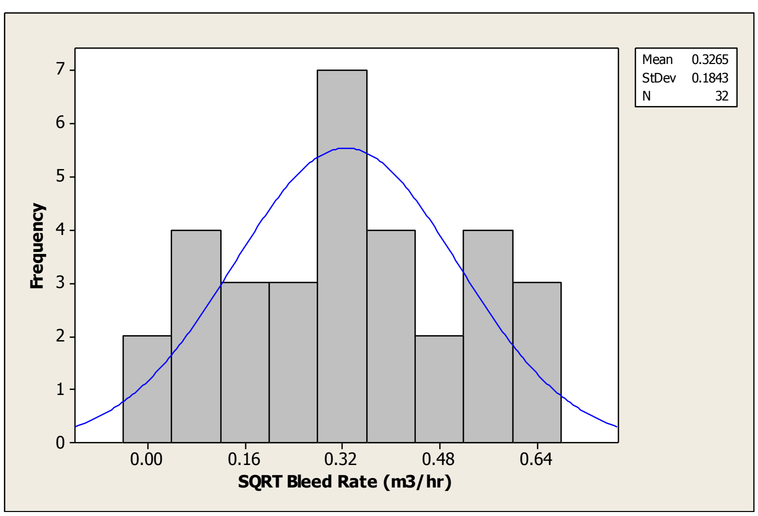

Figure A.2.1. Distribution of normalized samples with a square root transformation.

When the 32 samples are plotted on a graph (see Figure A.2.2) to test for normality, the KS test indicates that the data is normally distributed (p>0.05).

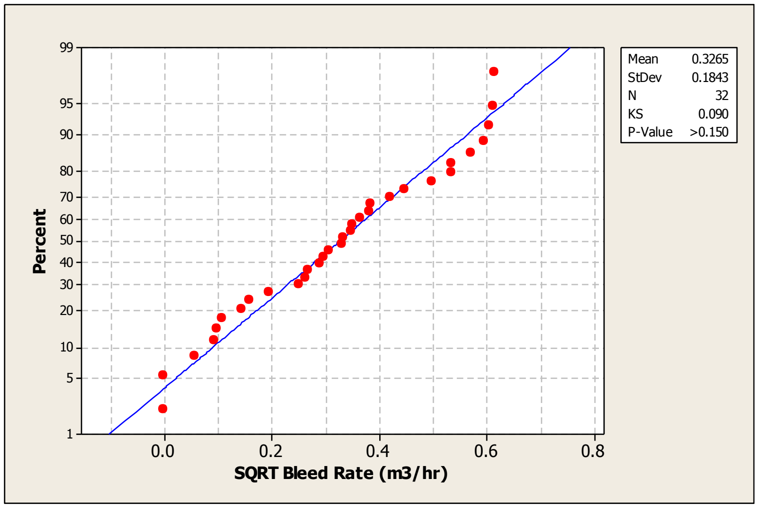

Figure A.2.2. Distribution of samples showing that the normalized samples are normally distributed.

The original descriptive statistics can be used from the normalized data to determine the mean and 95% confidence interval. Table A.2.1 compares the mean, upper and lower 95% confidence interval and the steady state manufacturer ranges.

Table A.2.1. Shows the mean, lower and upper bounds of the 95% confidence interval with the manufacturer ranges for Fisher Fieldvue 6000 series.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)	Lower Manufacturer Range (m^3/hr)	Upper Manufacturer Range (m^3/hr)
200	0.1395	0.0950	0.1840	0.0812	0.5801
345	0.2406	0.1639	0.3174	0.1151	0.8757

The values from the table were plotted (Figure A.2.3) to produce an emissions equation and illustrate the field sample mean compared to the 95% confidence interval and manufacturer ranges.

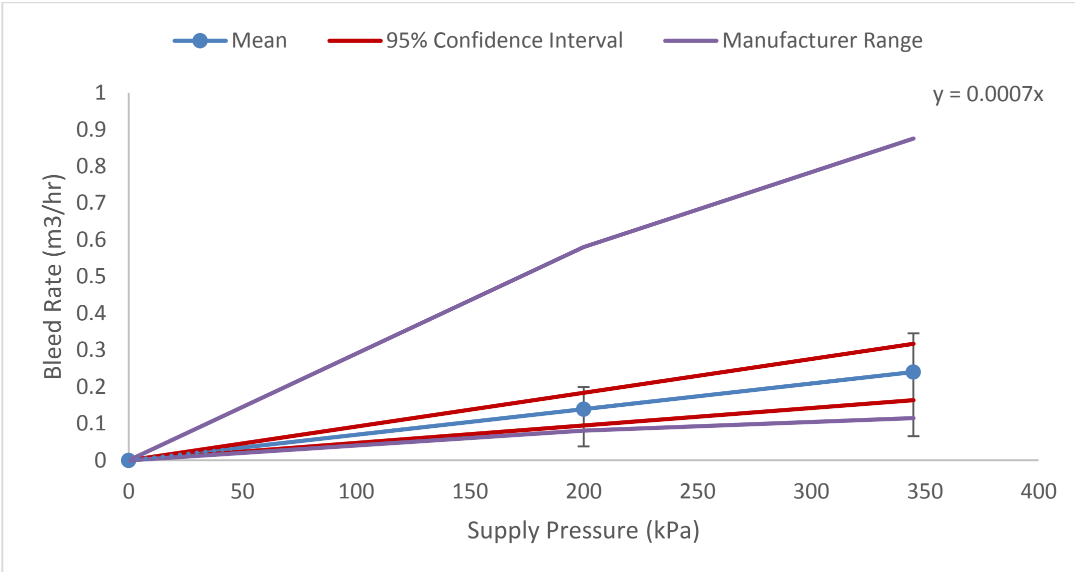

Figure A.2.3. The graph shows the mean, 95% confidence intervals and manufacturer ranges of gases bled. The bars around the mean represent 50% of the sample points.

Supply Pressure = 200 kPa Emissions Factor = 0.1395 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.2406 m^3/hr

Emissions Equation:

Bleed Rate (m^3/hr) = 0.0007(Supply Pressure (kPa))

A.3 Pressure Controller

A.3.2 Fisher 4150

Forty five samples were collected for Fisher 4150 during sampling. Figure A.3.4 below shows the distribution of samples normalized for supply pressure using a square root transformation.

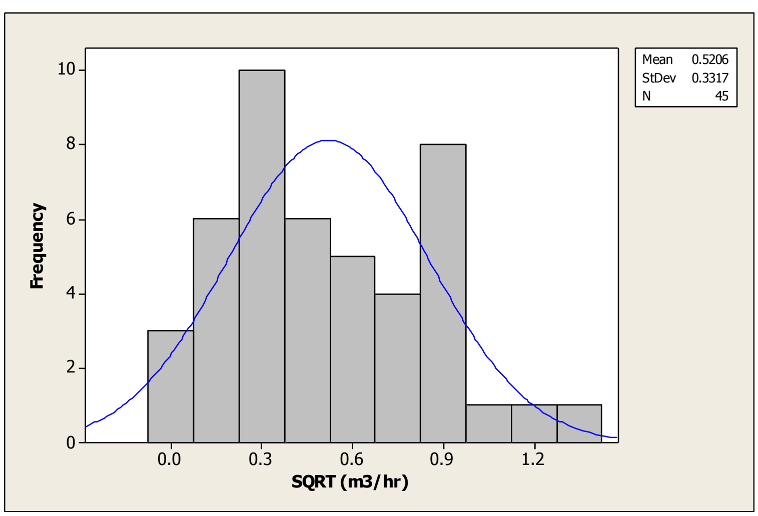

Figure A.3.4. Distribution of normalized samples with a square root transformation

When 45 samples are plotted on graph (see Figure A.3.5) to test for normality, the KS test indicates that the data is normally distributed ($p>0.05$). Statistical tests can be used to determine if the Fisher 4150 sample population is significantly different that other pressure controllers.

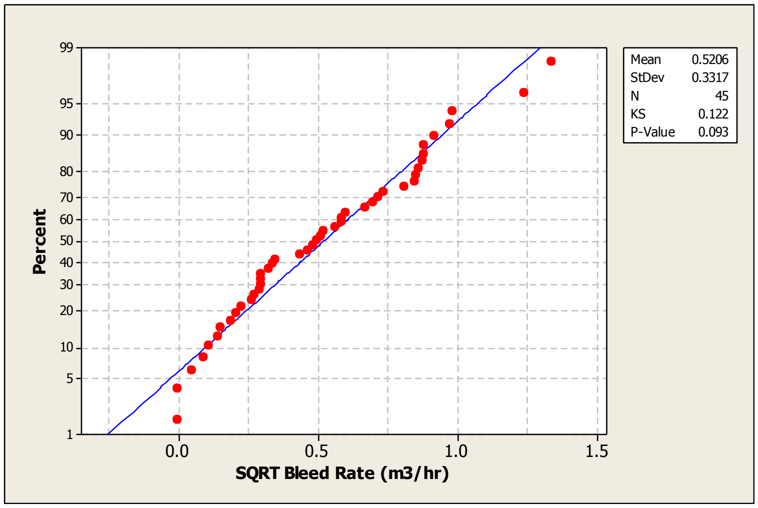

Figure A.3.5. Distribution of samples showing that the normalized samples are normally distributed.

The original descriptive statistics can be used from the normalized data to determine the mean and 95% confidence interval. Table A.3.2 compares the mean, upper and lower 95% confidence interval and the steady state manufacturer ranges.

Table A.3.2. Shows the mean, lower and upper bounds of the 95% confidence interval with the manufacturer ranges for Fisher 4150.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)	Lower Manufacturer Range (m^3/hr)	Upper Manufacturer Range (m^3/hr)
200	0.3340	0.2349	0.4445	0.12	0.76
345	0.5864	0.4052	0.7676	0.2	1.2

The values from the table were plotted (Figure A.3.6) to produce an emissions equation and illustrate the field sample mean compared to the 95% confidence interval and manufacturer ranges.

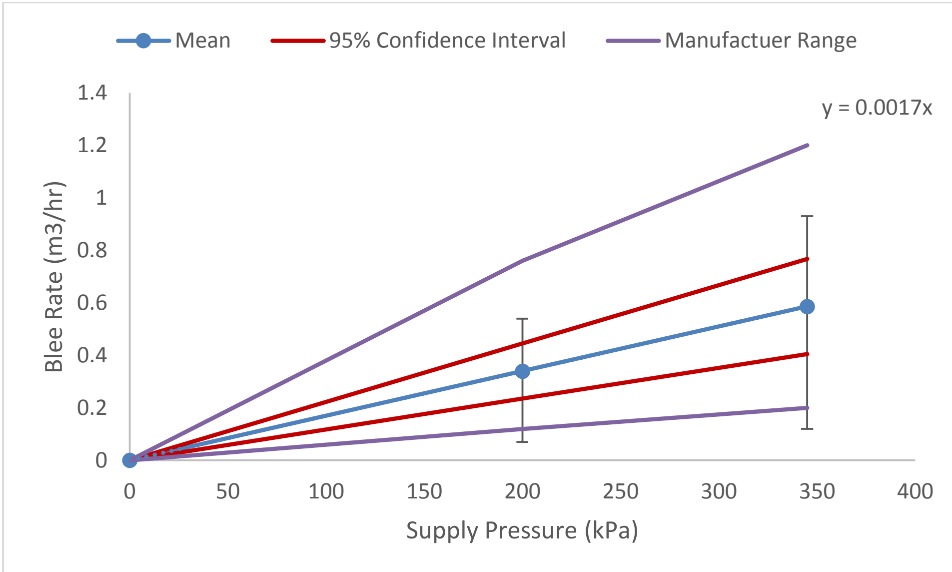

Figure A.3.6. The graph shows the mean, 95% confidence intervals and manufacturer ranges of gases bled. The bars around the mean represent 50% of the sample points.

Supply Pressure = 200 kPa Emissions Factor = 0.3340 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.5864 m^3/hr

Emissions Equation:

Bleed Rate (m^3/hr) = 0.0017(Supply Pressure (kPa))

A.3.3 Fisher 4660

Thirty samples were collected for Fisher 4660 during sampling. Figure A.3.7 below shows the distribution of sample normalized for supply pressure.

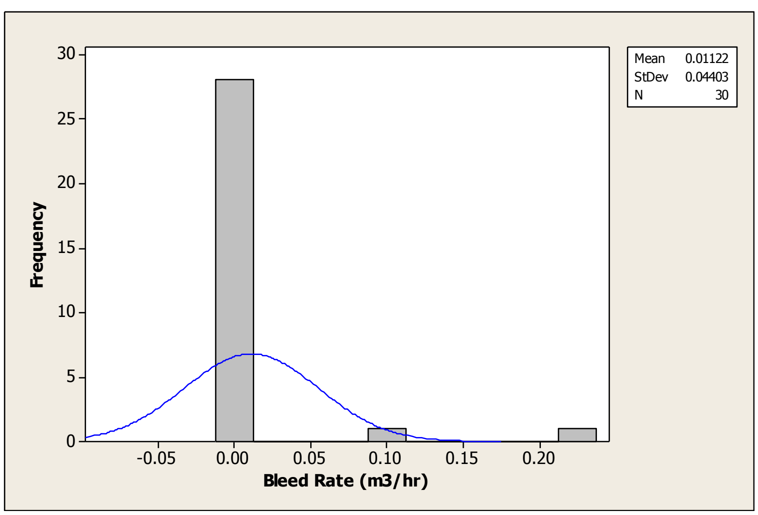

Figure A.3.7. Distribution of normalized samples.

When 30 samples are plotted on a graph (see Figure A.3.8), the KS test indicates that the samples are not normally distributed (p<0.05). This sample population had a positive skewed distribution.

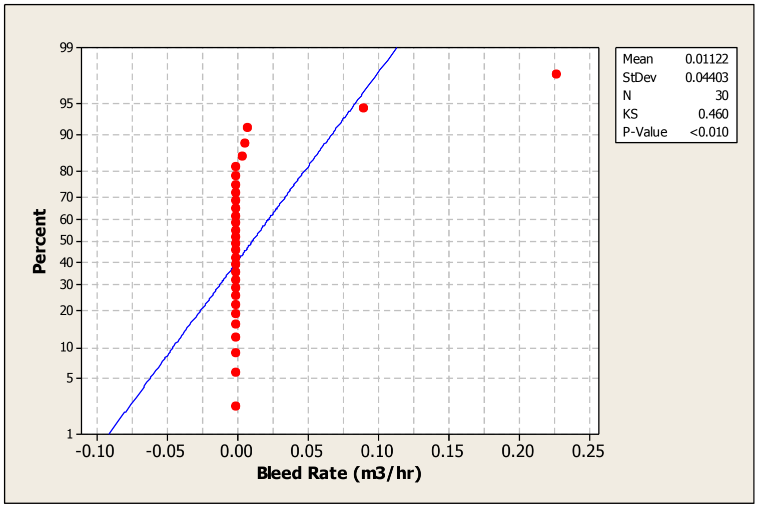

Figure A.3.8. Distribution of samples showing that the normalized samples are normally distributed.

The original descriptive can be used from the normalized data to determine the mean and 95% confidence interval. Table A.3.3 compares the mean, lower and upper 95% confidence interval. The manufacturer specification states the steady state air consumption at 0.00134 m3/hr at full supply pressure. The lower bounds did not go below 0 because a controller does not have a negative bleed rate.

Table A.3.3. Shows the mean, lower and upper bounds of the 95% confidence interval for Fisher 4660.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
200	0.0112	0	0.0277
345	0.0194	0	0.0477

The values from the table were plotted (Figure A.3.9) to produce an emissions equation and illustrate the field sample mean compared to the 95% confidence interval. No bars for the data are presented due to the skewed distribution.

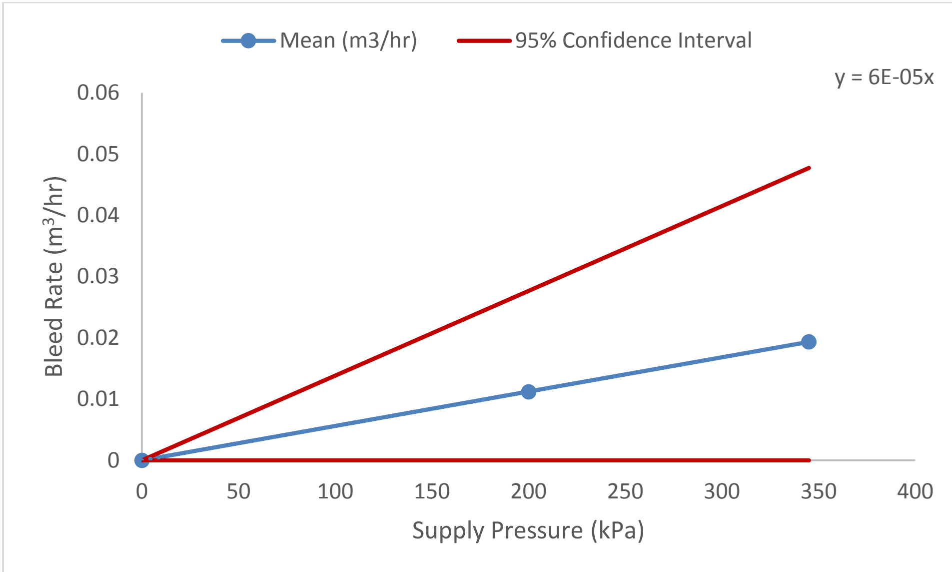

Figure A.3.9. Shows the mean and 95% confidence intervals. Manufacturer specifications are stated above.

Supply Pressure = 200 kPa	Emissions Factor = 0.0112 m3/hr
Supply Pressure = 345 kPa	Emissions Factor = 0.019351 m3/hr

Emissions Equation:

Bleed Rate (m^3/hr) = 0.00006(Supply Pressure (kPa))

A.3.4 Fisher C1

Twenty eight samples were collected for Fisher C1 during sampling. Figure A.3.10 shows the distribution of normalized samples.

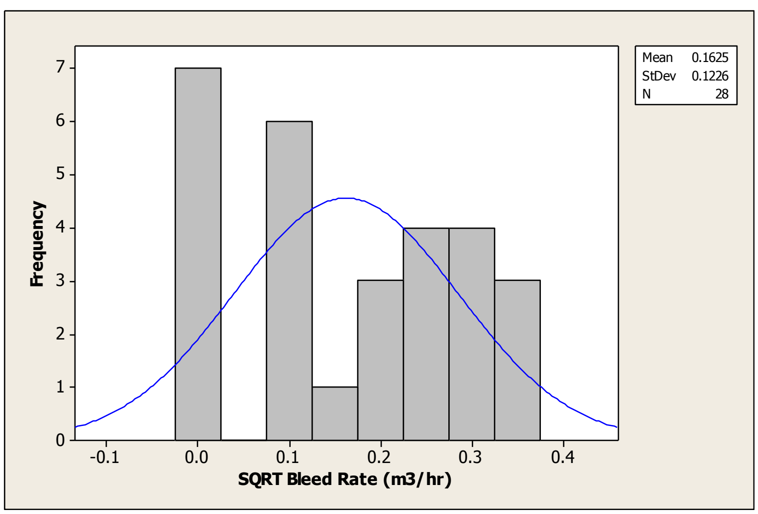

Figure A.3.10. Distribution of normalized samples.

When 28 samples are plotted on a graph (see Figure A.3.11), the KS test indicates that the samples are normally distributed using a square root transformation.

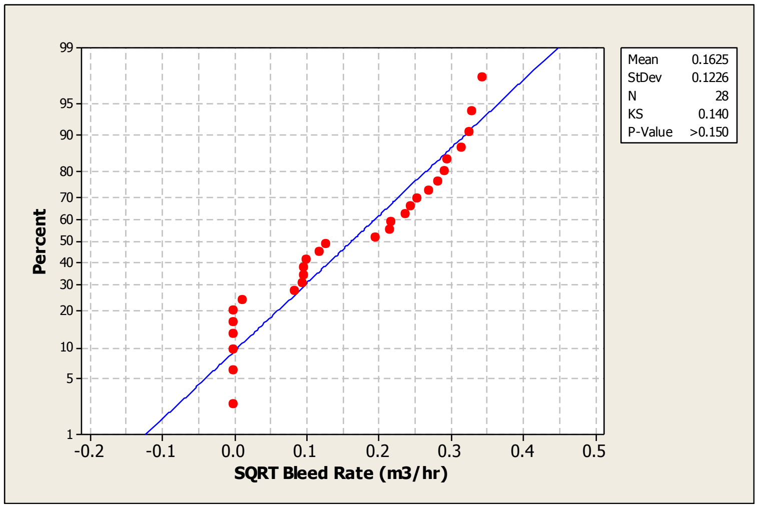

Figure A.3.11. Distribution of samples showing the normalized samples are normally distributed.

The original descriptive can be used from the normalized data to determine the mean and 95% confidence interval. Table A.3.4 compare the mean, lower and upper 95% confidence interval.

Table A.3.4. Shows the mean, lower and upper bounds of the 95% confidence interval for Fisher C1. The manufacturer specification are 0.012 at 241 kPa.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
200	0.0409	0.0252	0.0566
345	0.0705	0.0435	0.0976

The values from the table were plotted (Figure A.3.12) to produce and emissions equation and illustrate the field sample mean compared to the 95% confidence interval.

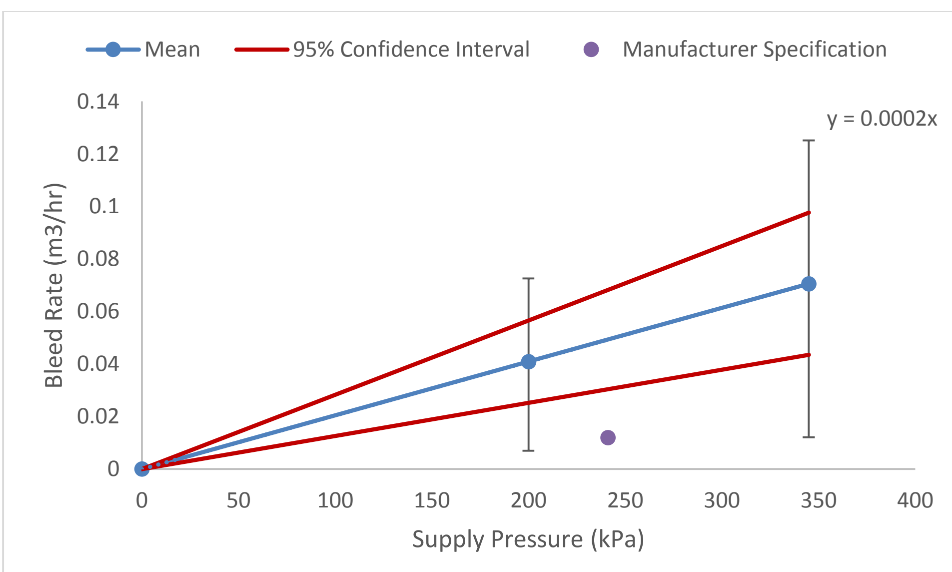

Figure A.3.12. The graph shows the men and 95% confidence intervals.

Supply Pressure = 200 kPa   Emissions Factor = 0.0409 m^3/hr

Supply Pressure = 345 kPa   Emissions Factor = 0.0706 m^3/hr

Emissions Equation:

Bleed Rate (m^3/hr) = 0.0002(Supply Pressure (kPa))

A.4 Temperature Controller

A.4.1 Kimray HT-12

Thirty five samples were collected for Kimray HT12 during field sampling. Figure A.4.1 below shows the distribution of normalized samples.

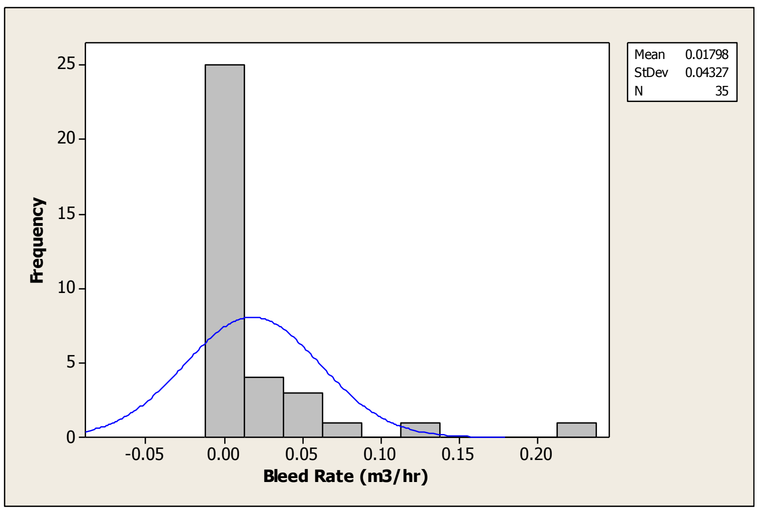

Figure A.4.1. Distribution of normalized samples.

When 35 samples are plotted on a graph (see Figure A.4.2), the KS test indicates that the samples are not normally distributed. This data shows a positive skewed distribution of samples.

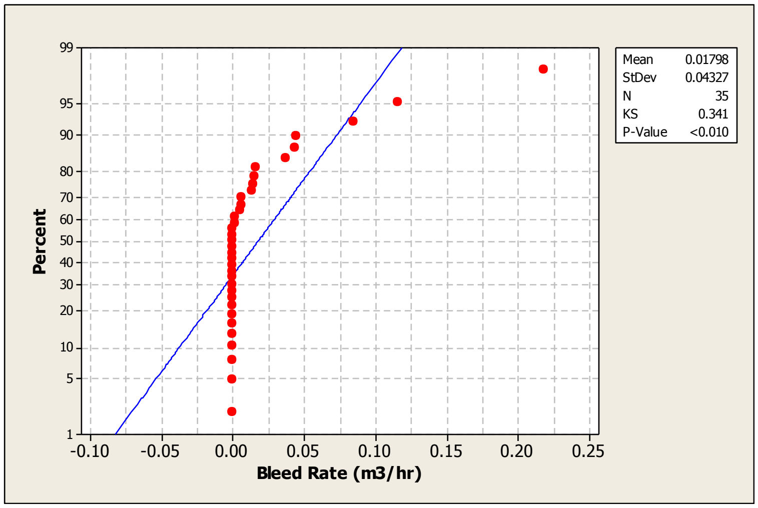

Figure A.4.2. Distribution of samples showing that the normalized samples are normally distributed.

The original descriptive can be used from the normalized data to determine the mean and 95% confidence interval. Table A.4.1 compares the mean, lower and upper 95% confidence interval.

Table A.4.1. Shows the mean, lower and upper bounds of the 95% confidence interval.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
200	0.018	0.0031	0.0328
345	0.031	0.0054	0.0567

The values from the table were plotted (Figure A.4.3) to produce and emissions equation and illustrate the field sample mean compared to the 95% confidence interval. The manufacturer specification is stated as a no bleed device. No bars are presented for the range of data due to the skewed distribution.

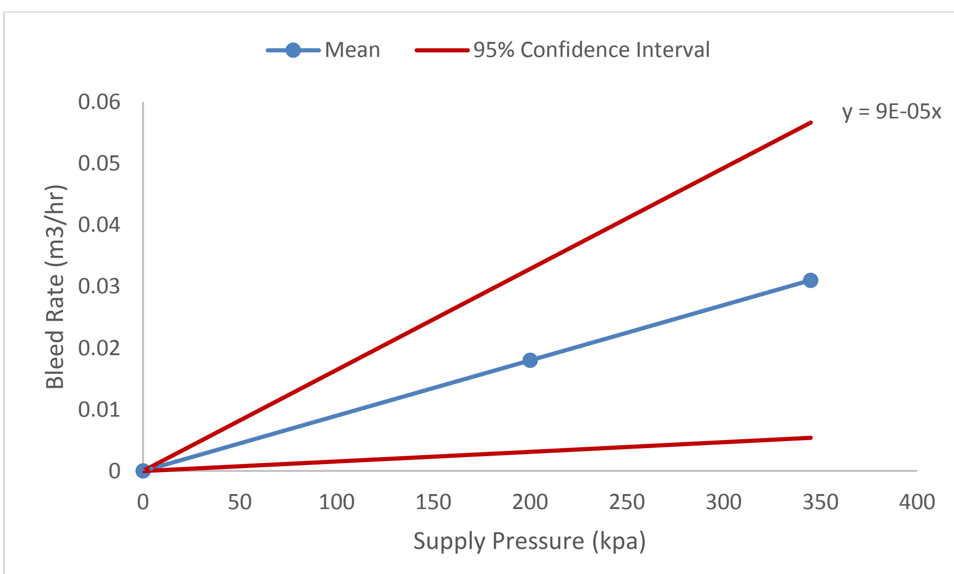

Figure A.4.3. The graph shows the mean and 95% confidence interval. No manufacturer specifications are shown because the Kimray HT12 is a no bleed device with only dynamic bleeding.

Supply Pressure = 200 kPa Emissions Factor = 0.018 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.031 m^3/hr

Emissions Equations:

Bleed Rate (m^3/hr) = 0.00009(Supply Pressure (kPa))

A.5 Transducer

A.5.1 Fairchild TXI 7800 Series

Thirty four samples were collected for Fairchild TXI 7800 series during sampling. Figure A.5.1 below shows the distribution of normalized samples.

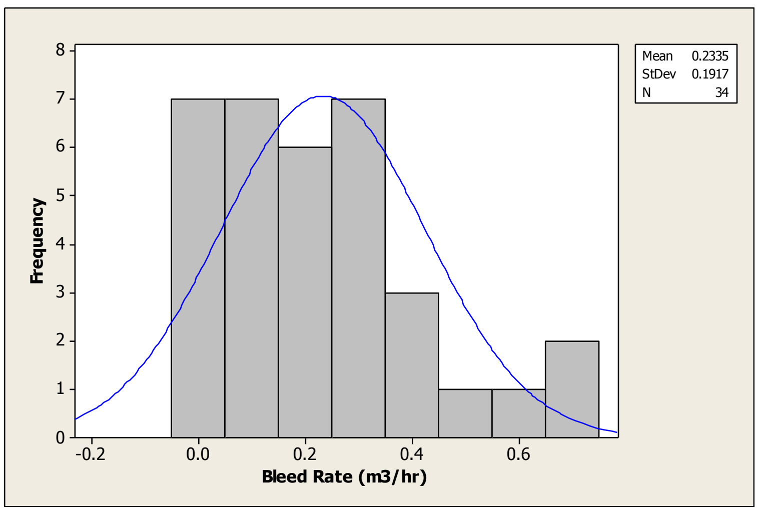

Figure A.5.1. Distribution of normalized samples.

When 34 samples are plotted on a graph (see Figure A.5.2) to test for normality, the KS test indicates that the data is normally distributed ($p>0.05$).

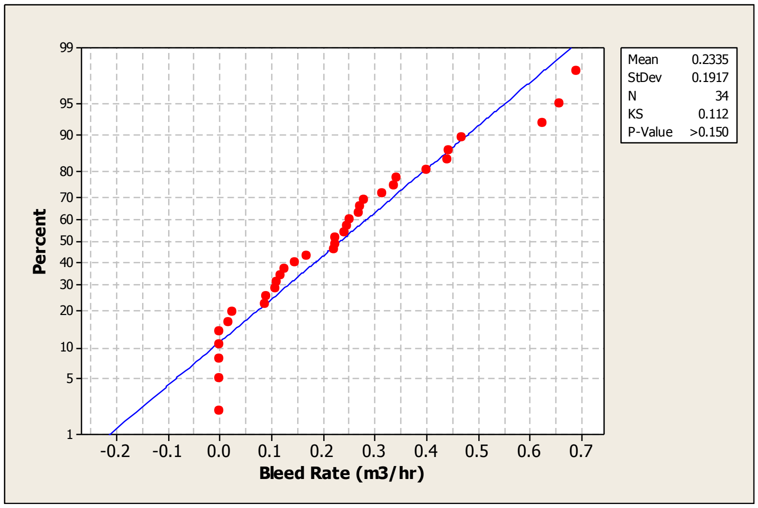

Figure A.5.2. Distribution of samples showing that normalized samples are normally distributed.

The descriptive statistics can be used from the normalized data to determine the mean and 95% confidence interval. Table A.5.1 below compares the mean and 95% confidence interval with the manufacturer specifications.

Table A.5.1. Shows the mean, lower and upper bounds of the 95% confidence interval with the manufacturer ranges for the Fairchild TXI 7800 series.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)	Max. Manufacturer Specification (m^3/hr)
200	0.2335	0.1667	0.3004	0.38
345	0.4029	0.2875	0.5183	0.66

The values from the table were plotted (Figure A.5.3) to produce an emissions equation and illustrate the field sample mean compared to the 95% confidence interval and manufacturer specification.

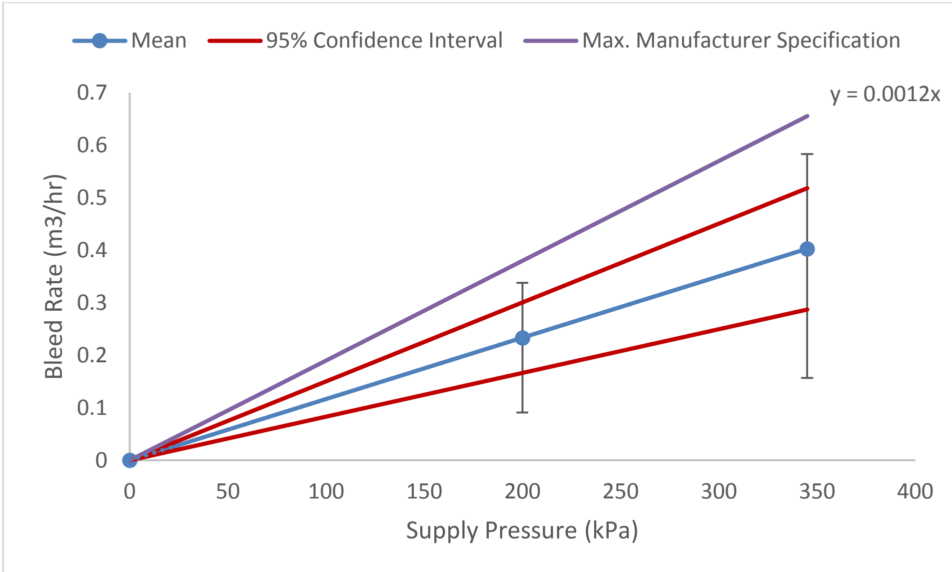

Figure A.5.3. The graph shows the mean, 95% confidence intervals and max manufacturer specification of gases bled. The bars around the mean represent 50% of the sample points.

Supply Pressure = 200 kPa Emissions Factor = 0.2335 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.4029 m^3/hr

Emissions Factor:

Bleed Rate (m^3/hr) = 0.0012(Supply Pressure (kPa))

A.5.2 Fisher 546

Thirty samples were collected for Fisher 546 during sampling. Figure A.5.4 below shows the distribution of samples normalized for supply pressure.

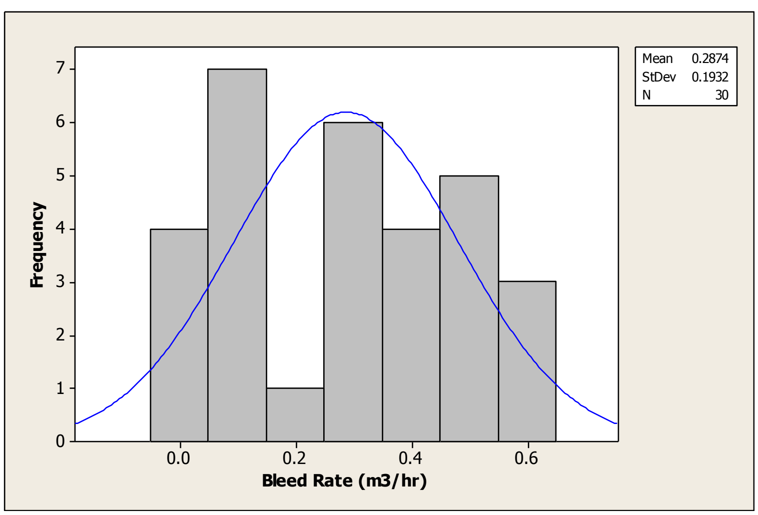

Figure A.5.4. Distribution of normalized samples.

When the 30 samples are plotted on a graph (see Figure A.5.4) to test for normality, the KS test indicates that the data is normally distributed (p>0.05).

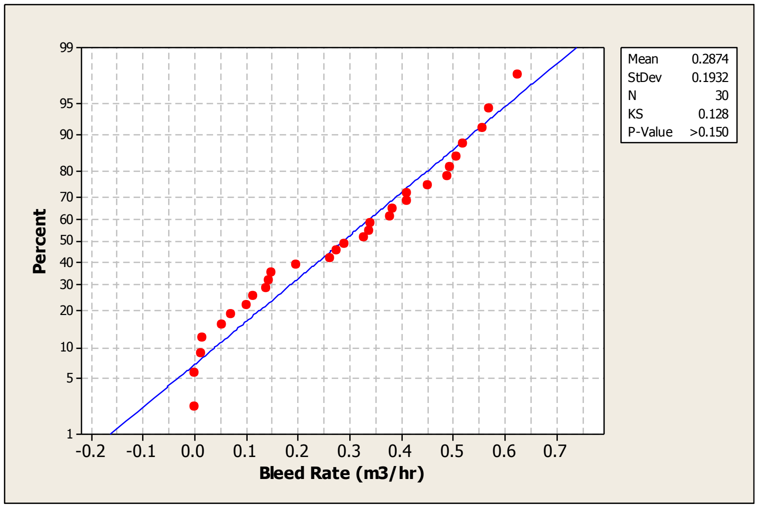

Figure A.5.4. Distribution of samples showing that the normalized samples are normally distributed.

The descriptive statistics can be used from the normalized data to determine the mean and 95% confidence interval and manufacturer ranges. Table A.5.2 compares the mean, and the upper and lower bounds of the 95% confidence interval.

Table A.5.2. Shows the mean, lower and upper bounds of the 95% confidence interval and manufacturer specification for Fisher 546.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)	Manufacturer specification (m^3/hr)
200	0.2874	0.2153	0.3596	0.6423
345	0.4958	0.3714	0.6203	1.1080

The values from the table were plotted (Figure A.5.5) to produce an emissions equation and illustrate the field sample mean compared to the 95% confidence interval and manufacturer specification.

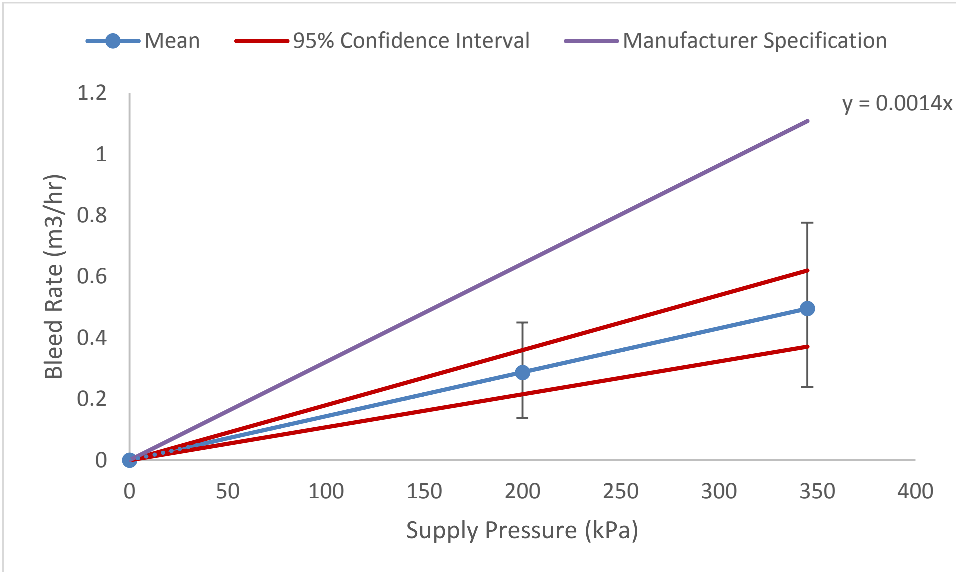

Figure A.5.5. The graph shows the mean, 95% confidence intervals and manufacturer specification of gases bled. The bars around the mean represent 50% of the sample points

Supply Pressure = 200 kPa	Emissions Factor = 0.2874 m3/hr
Supply Pressure = 345 kPa	Emissions Factor = 0.4029 m3/hr

Emissions Equation:

Bleed Rate (m^3/hr) = 0.0014 (Supply Pressure (kPa))

A.5.3 Fisher i2P-100

Thirty six Fisher i2P-100 bleed rate samples were gathered during the field sampling. Figure A.5.6 below shows the distribution of the corrected field samples.

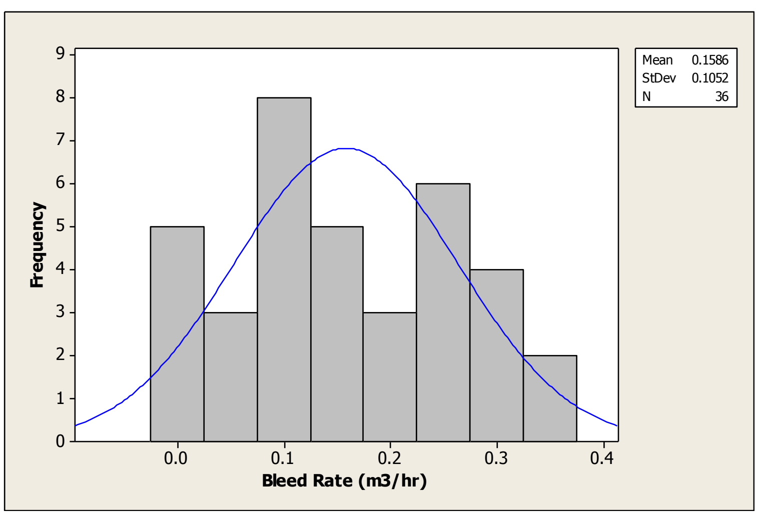

Figure A.5.6. Distribution of normalized samples.

Figure A.5.7 plots the normalized data on a graph and the KS P-value indicates that the samples are normally distributed (p>0.05). On this basis, the average bleed rate can now be compared to other transducers to determine if a generic bleed rate can be produced or if the populations are significantly different.

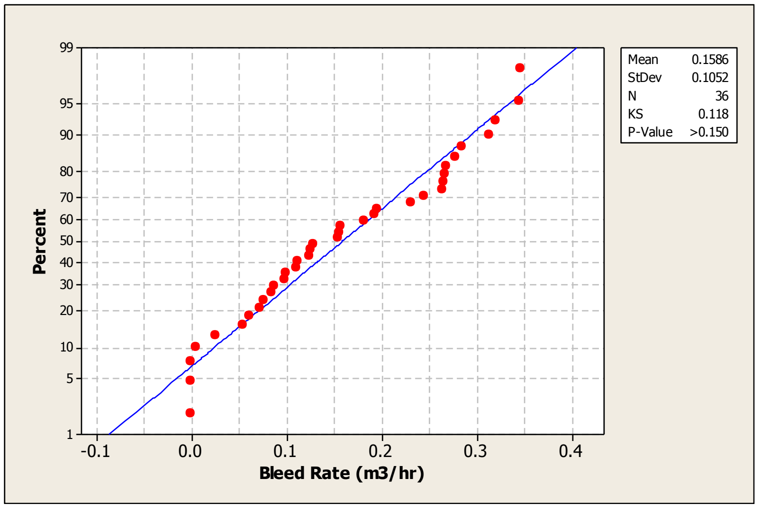

Figure A.5.7. A distribution test on the normalized data.

The original descriptive statistics from the normalized data can be used to determine the mean and the 95% confidence interval. Table compares the mean, and the upper and lower bounds of the 95% confidence interval. The bleed rate ranges from the manufacturer specification are also provided at both 200 and 345 kPa.

Table A.5.3. Shows the mean and 95% confidence interval compared to the manufacturer specification.

Supply Pressure (kPa)	Mean (m^3/hr)	Lower Bound (m^3/hr)	Upper Bound (m^3/hr)	Manufacturer Specification (m3/hr)
200	0.1586	0.1230	0.1942	0.1714
345	0.2736	0.2122	0.3350	0.2957

The values from the table were plotted on (Figure A.5.8) an emissions equation and illustrate the field samples mean with the 95% confidence interval compared to the manufacturer specifications.

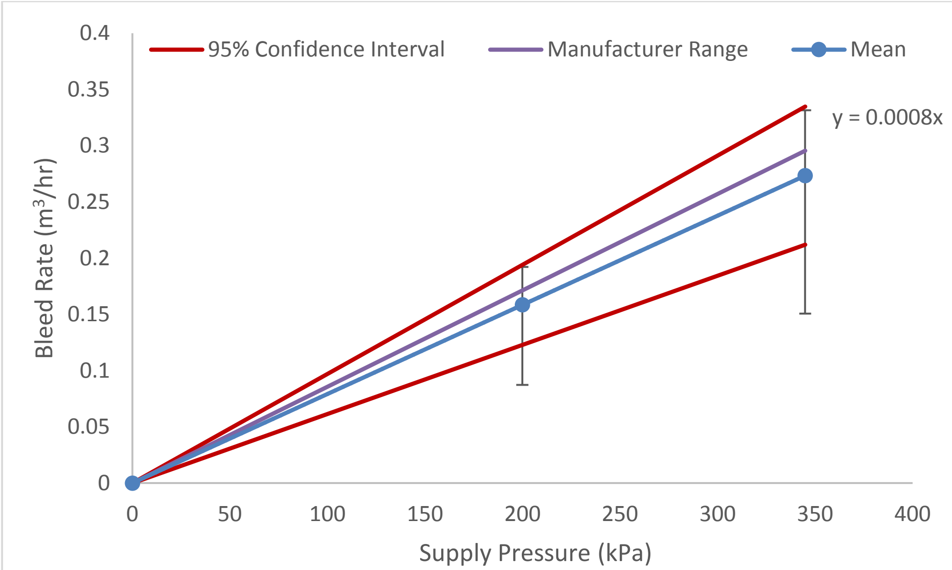

Figure A.5.8. The graph shows the mean, 95% Confidence Interval and manufacturer ranges of gases bled. The bars around the mean represent 50% of the field samples.

Supply Pressure = 200 kPa Emissions Factor = 0.1586 m^3/hr

Supply Pressure = 345 kPa Emissions Factor = 0.2736 m^3/hr

Emissions Equation:

Bleed Rate (m^3/hr) = 0.0008(Supply Pressure (kPa))

Appendix B: Normalized Chemical Pump Controller Data

Below is the analysis after a completed sampling program where statistical significant populations were attained for each pneumatic device included in the survey. A histogram and normality plot were created in Minitab 16. Some of the data was transformed to determine if the data would need parametric or non-parametric statistical test during the analysis and report writing phase of the project. A table with standardized operating conditions was used to compare the mean field bleed rate and 95% confidence interval bands with manufacturer specifications.

B.1 Chemical Injection Pumps

The five chemical injection pumps were normalized for operating conditions including supply pressure and injection rate. The bleed rate and chemical injection rates were normalized against stokes per minute to develop an emissions factor based with the independent variable the chemical injection rate and the dependent variable the bleed rate. All pumps were standardized to 20L/day for initial analysis. However, this will change for the final emissions factor to reflect the volume of chemical the pump may use.

B.1.1 Morgan HD312

Twenty nine samples were collected for Morgan HD312 Series during sampling. Figure B.1.1 shows the distribution of the normalized data.

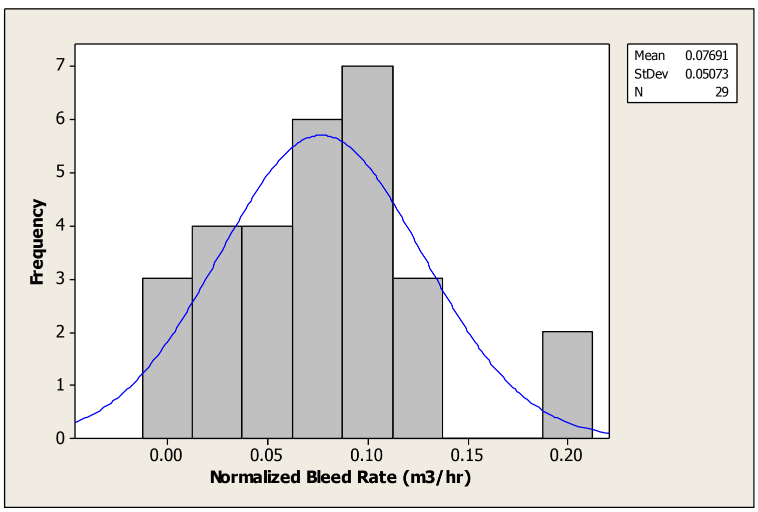

Figure B.1.1. Distribution of normalized samples.

When the 29 samples are plotted on a graph (see Figure B.1.2), the KS test indicates that field sample bleed rates are normally distributed.

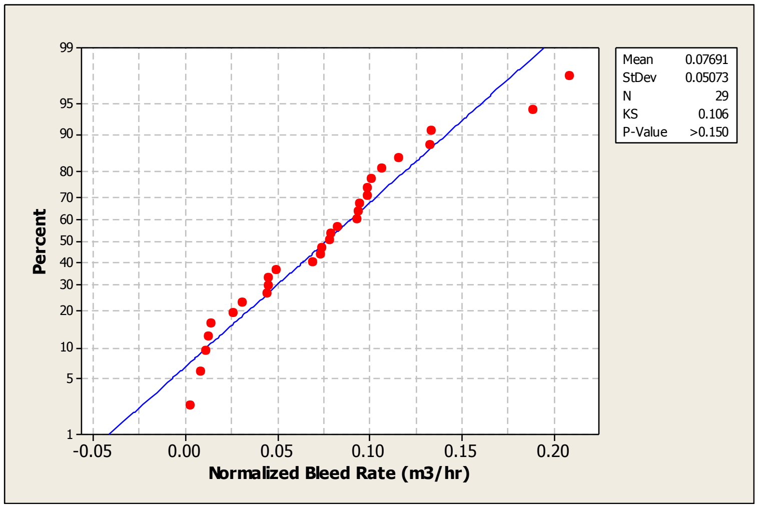

Figure B.1.2. A normality test for normalized field samples.

Figure B.1.3 shows the distribution of chemical injection rates with a log transformation.

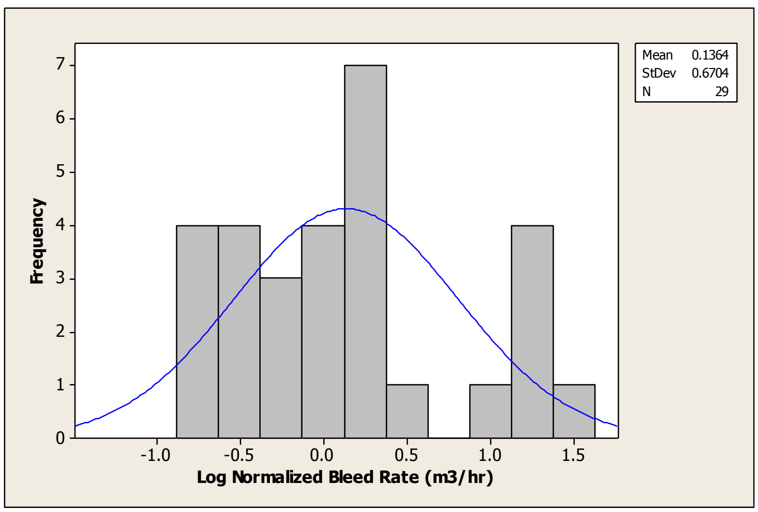

Figure B.1.3. Distribution for normalized chemical injection rates with a Log transformation.

When the 29 samples are plotted on a graph (see Figure B.1.4) to test for normality, the KS test indicates that the chemical injection rates are normally distributed ($p>0.05$).

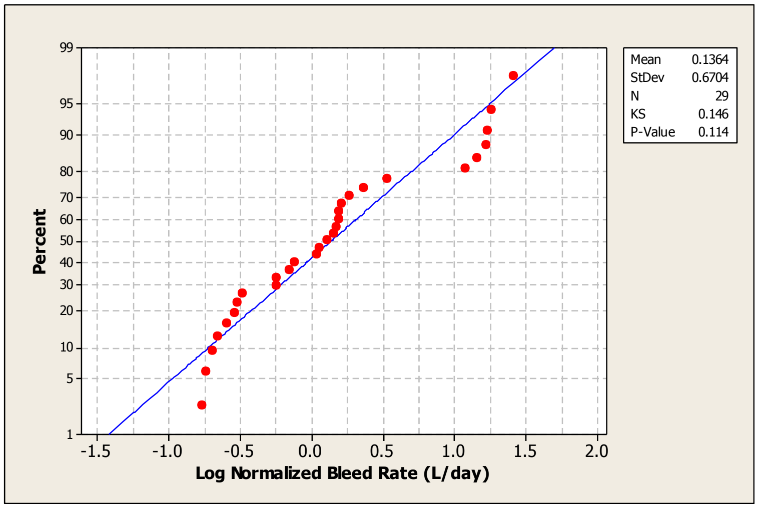

Figure B.1.4. A normality test for chemical injection rates.

Using two standard strokes per minute conditions (10 and 30), the normalized mean bleed rate and volume of chemical injected were calculated (see Table B.1.1).

Table B.1.1. Shows the normalized values of mean bleed rate and the 95% confidence intervals along with the volume of chemical injected.

Strokes per Minute	Mean (m3/hr)	Chemical Injected (L/day)	95% Confidence Interval	Upper Bounds (m3/hr)
10	0.0927	4.4141	0.0695	0.1159
30	0.2780	13.2423	0.2083	0..3478

The mean bleed rate and volume of chemical injected were calculated under standard stroke per minute conditions and plotted of a graph to develop a linear emissions equation (Figure B.1.5). The manufacturer specification for bleed rate is not provided in the product brochures.

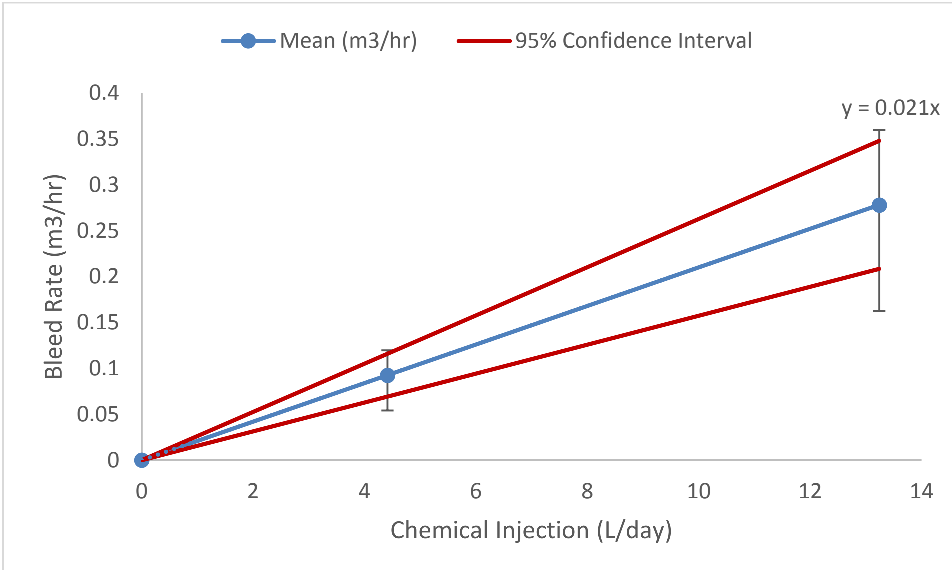

Figure B.1.5. Emissions Equation for Morgan HD312 pumps with the 95% confidence interval. Bars represent 50% of the sample points.

The linear emissions equation determines the emissions based on the volume of chemical injected daily. For example, if a producer is injected 20 liters of chemical per day the emissions equation can determine the bleed rate.

Bleed Rate (m^3/hr) = 0.021(Chemical Injected (L/day))

Bleed Rate (m^3/hr) = 0.021(20(L/day))

Emission Rate at 20 L = 0.42 (m^3/hr/L/day)

Emissions Rate at 20 L = 0.504 m^3/L

B.1.2 Texsteam 5100

Forty one samples were collected for Texsteam 5100 Series during sampling. Figure B.1.6 shows the distribution of the normalized samples.

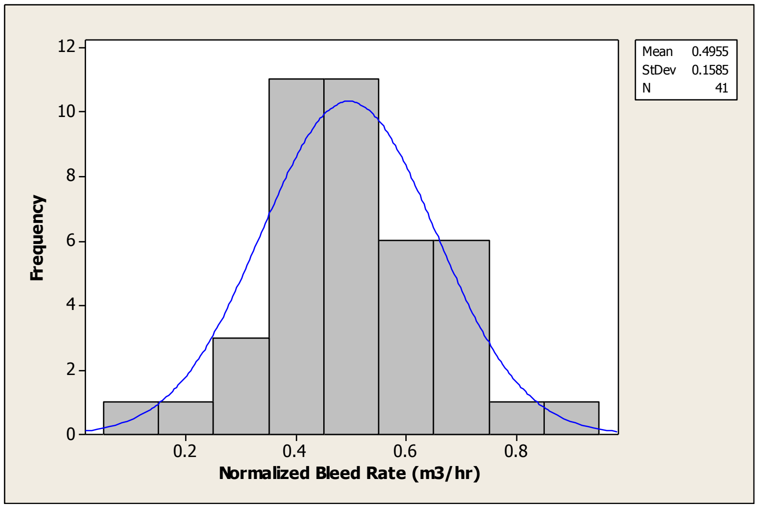

Figure B.1.6. Distribution of the normalized samples.

When the 44 samples are plotted on a graph (see Figure B.1.7) to test for normality, the KS test indicates that the data is normally distributed (p> 0.05).

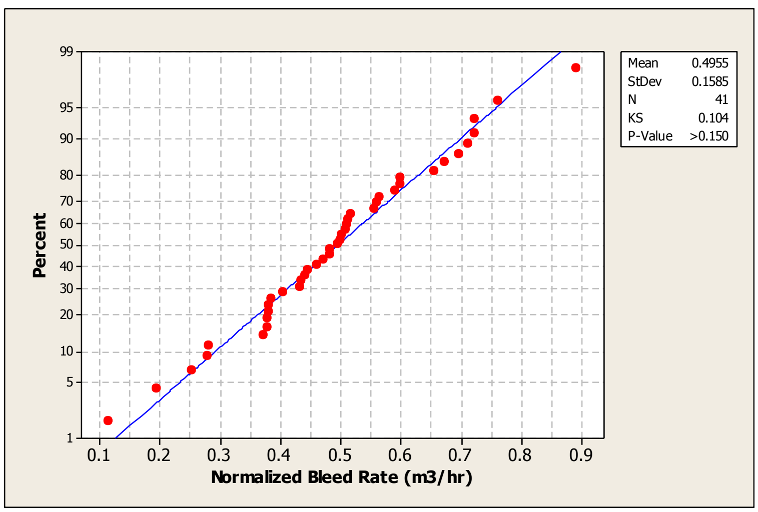

Figure B.1.7. A normality test for field samples.

Figure B.1.8 shows the distribution of the normalized chemical injection rates with a square root transformation.

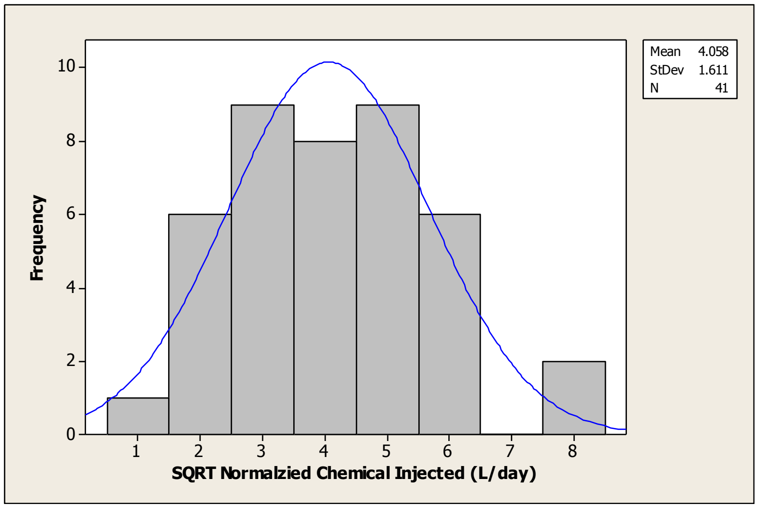

Figure B.1.8. Distribution of Chemical Injected (L/day) with a square root transformation.

When the 41 samples are plotted on a graph (see Figure B.1.9) to test for normality, the KS test indicates that the data is normally distributed (p> 0.05).

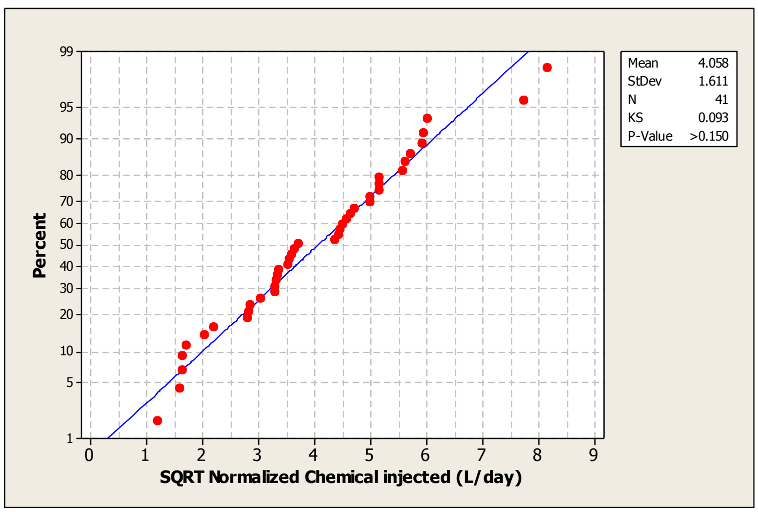

Figure B.1.9. A normality test for the distribution of chemical injected (L/day).

Using two standard strokes per minute conditions (10 and 30), the normalized mean bleed rate and volume of chemical injected were calculated (see Table B.1.2).

Table B.1.2. Shows the normalized values of mean bleed rate and the 95% confidence intervals along with the volume of chemical injected.

Strokes Per Minute	Mean (m^3/hr)	Chemical Injected (L/day)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
10	0.4955	18.9985	0.4455	0.5455
30	1.4865	56.9955	1.3364	1.6366

The mean bleed rate and volume of chemical injected were calculated under standard stroke per minute conditions and plotted of a graph to develop a linear emissions equation (Figure B.1.10).

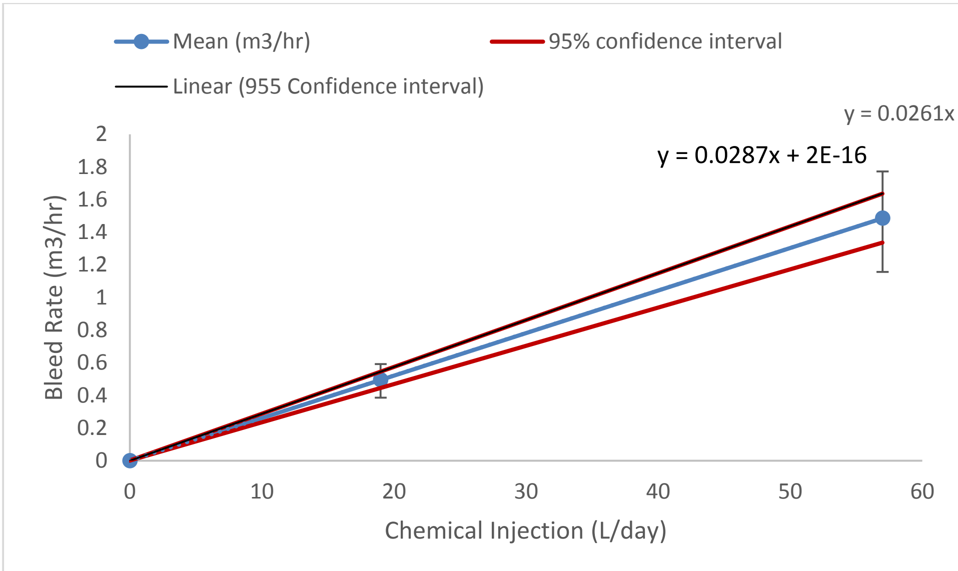

Figure B.1.10. The emissions equation for Texsteam 5100 with the 95% confidence interval. The bars represent 50% of the data.

The linear emissions equation determines the emissions based on the volume of chemical injected daily. For example, if a producer is injected 20 liters of chemical per day the emissions equation can determine the bleed rate.

Bleed Rate (m^3/hr) = 0.0261(Chemical Injected (L/day))

Bleed Rate (m^3/hr) = 0.0261(20(L/day))

Emissions Rate at 20 L = 0.522(m^3/hr/L/day)

Emissions Rate at 20 L = m^3/L

B.1.3 Williams P125 Series

Forty one samples were collected for Williams P125 Series during sampling. Figure B.1.11 shows the distribution of normalized bleed rate samples using a square root transformation.

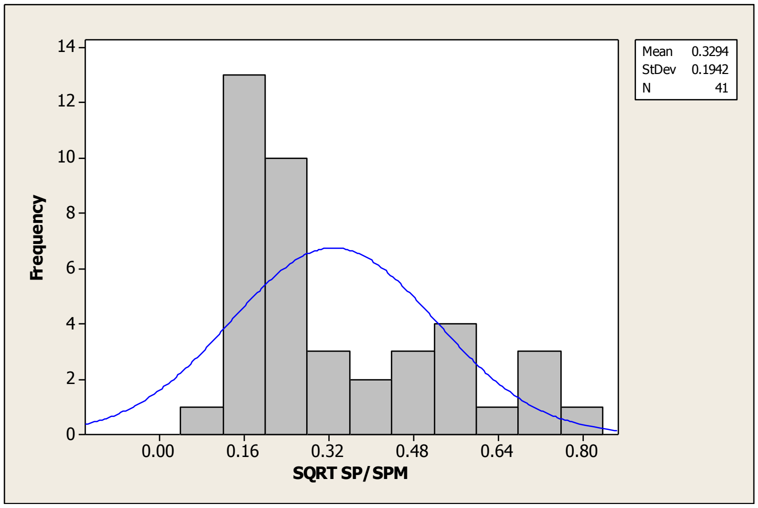

Figure B.1.11. Distribution of normalized bleed rate samples showing a positive skewed distribution.

When the 41 samples are plotted on the graph (see Figure B.1.12) to test for normality, the KS test indicates the data is not normally distributed ($p<0.05$). Statistical test can still be used to compare Williams pumps, due to the robustness of data and the use of different statistical tests.

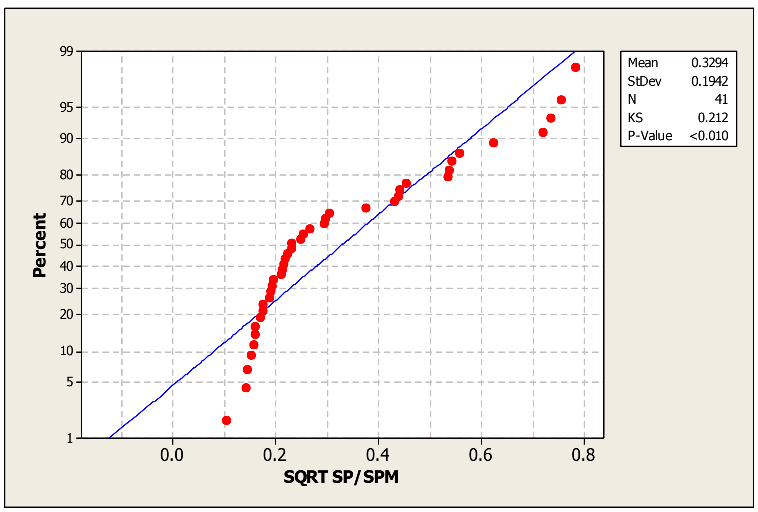

Figure B.1.12. A normality test for the distribution of normalized samples using a square root transformation.

Figure B.1.13 shows the distribution of normalized chemical injection rates using a square root transformation.

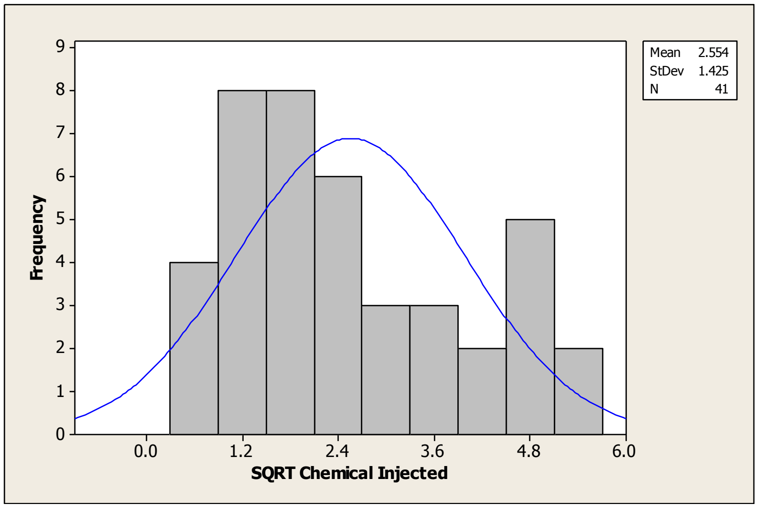

Figure B.1.13. Distribution of normalized chemical injection rates using a square root transformation.

When the 41 samples were plotted on graph (see Figure B.1.14) to test for normality, the KS test indicates that the data is normally distributed ($p>0.05$).

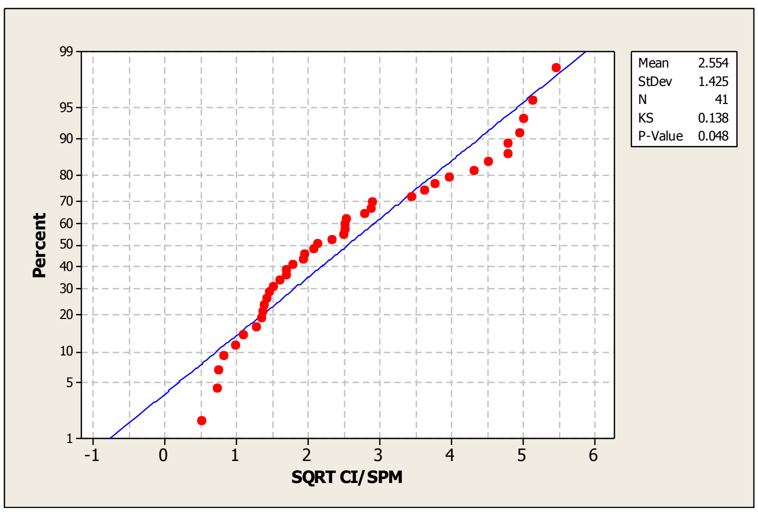

Figure B.1.14. A normality test for the distribution of normalized chemical injected rates.

Using two standard strokes per minutes conditions (10 and 30), the normalized bleed rate and chemical injection rate were calculated (see Table B.1.).

Table B.1.3. Shows the normalized values of mean bleed rate and 95% confidence interval along with volume of chemical injected.

Strokes Per Minute	Mean (m^3/hr)	Chemical Injected (L/day)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
10	0.1751	8.5005	0.1108	0.2394
30	0.5253	25.5016	0.3324	0.7181

The mean bleed rate and volume of chemical injected were calculated under standard stroke per minute conditions and plotted of a graph to develop a linear emissions equation (Figure B.1.15).

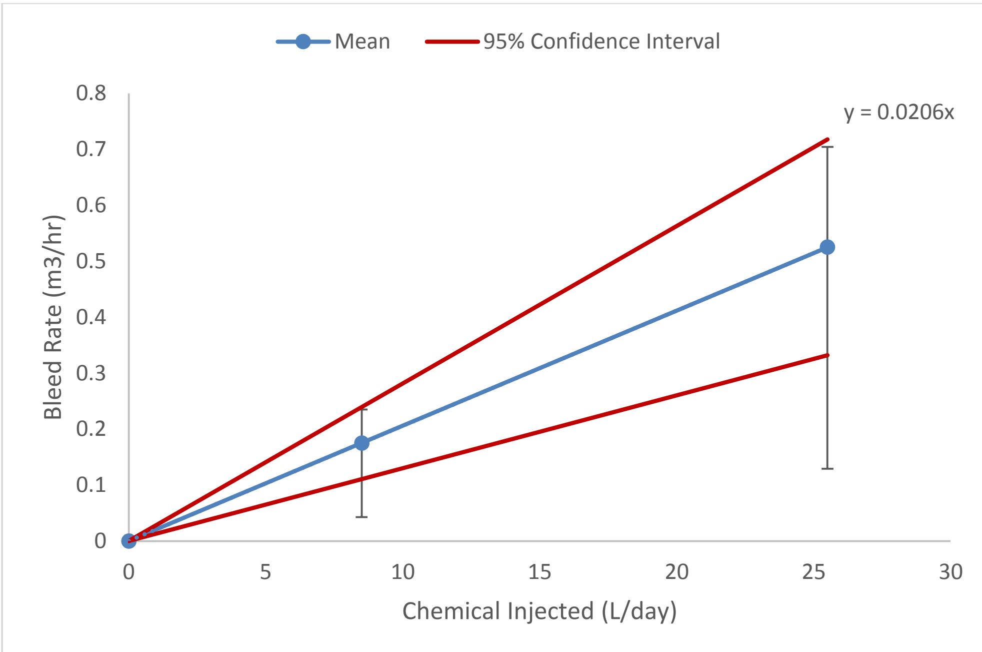

Figure B.1.15. The emissions equation for Williams P125 Series with the 95% confidence interval. The bars represent 50% of the data.

Bleed Rate (m^3/hr) = 0.0206(Chemical Injected (L/day))

Bleed Rate (m^3/hr) = 0.0.206(20(5) L/day)

Emissions Rate at 20L/day = 0.412 (m^3/hr/L/day)

Emissions Rate at 20L/day = 0.4944 m^3/L

B.1.4 Williams P250 Series

Forty one samples were collected for Williams P125 Series during sampling. Figure B.1.16 shows the distribution of normalized bleed rate samples using a square root transformation.

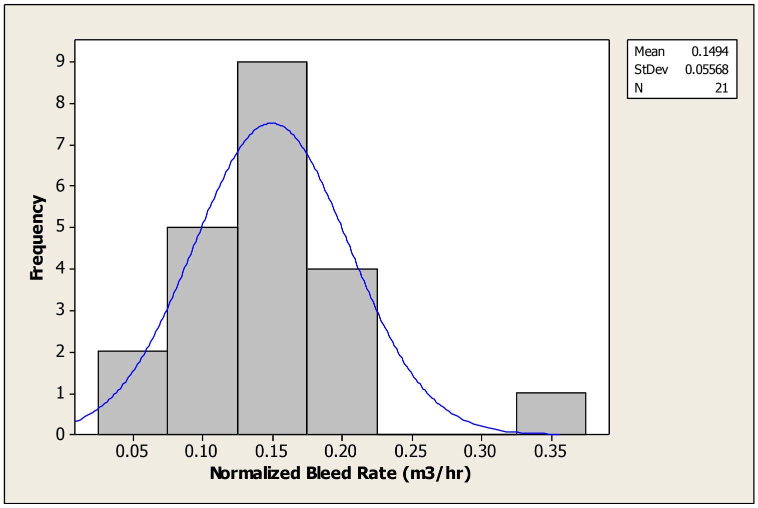

Figure B.1.16. The distribution of normalized samples.

When 21 samples are plotted on the graph (see Figure B.1.17) to test for normality, the KS test indicates that the data is normally distributed (p>0.05). Statistical test can be used to compare different sized Williams pumps.

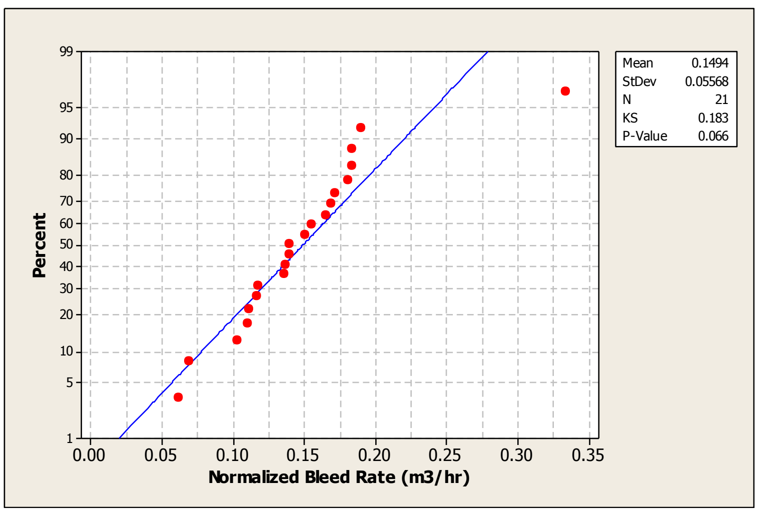

Figure B.1.17. A normality test for the distribution of normalized samples.

Figure B.1.18 shows the normalized distribution of chemical injection rates.

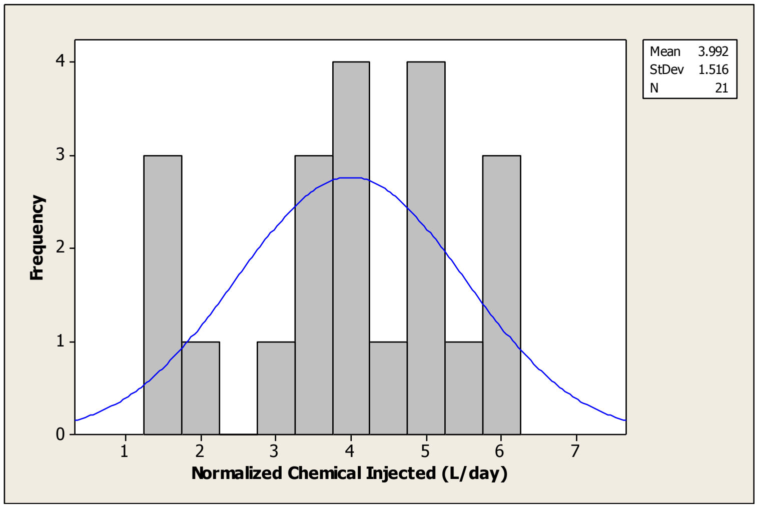

Figure B.1.18. Distribution of normalized chemical injection samples.

When the 21 samples are plotted on the graph (see Figure B.1.19) to test for normality, the KS test indicates that the data is normally distributed ($p>0.05$).

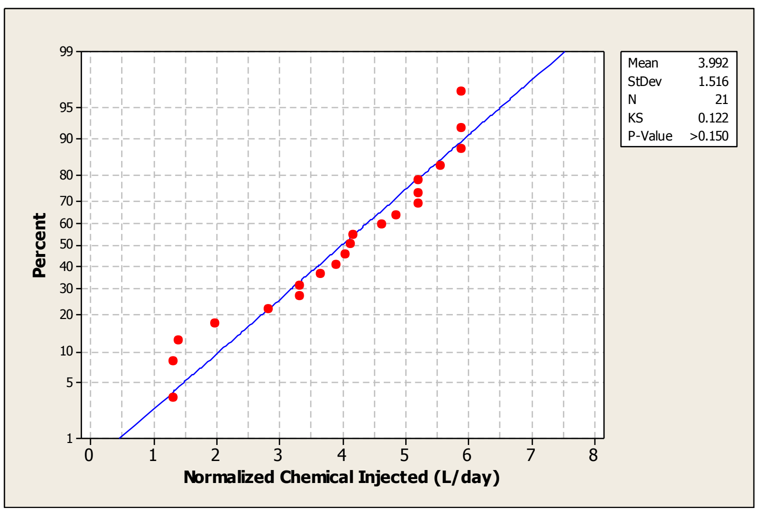

Figure B.1.19. A normality test for the distribution of normalized chemical injection rates.

Using two standard stroke conditions, the normalized bleed rate and chemical injection rates were calculated.

Table B.1.4. Shows the normalized values of mean bleed rate and 95% confidence interval along with volume of chemical injected.

Strokes per Minute	Mean (m^3/hr)	Chemical Injected (L/day)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
10	0.1427	4.0566	0.1147	0.1706
30	0.4285	12.1698	0.3446	0.5125

The mean bleed rate and volume of chemical injected were calculated under standard stroke per minute conditions and plotted of a graph to develop a linear emissions equation (Figure B.1.20).

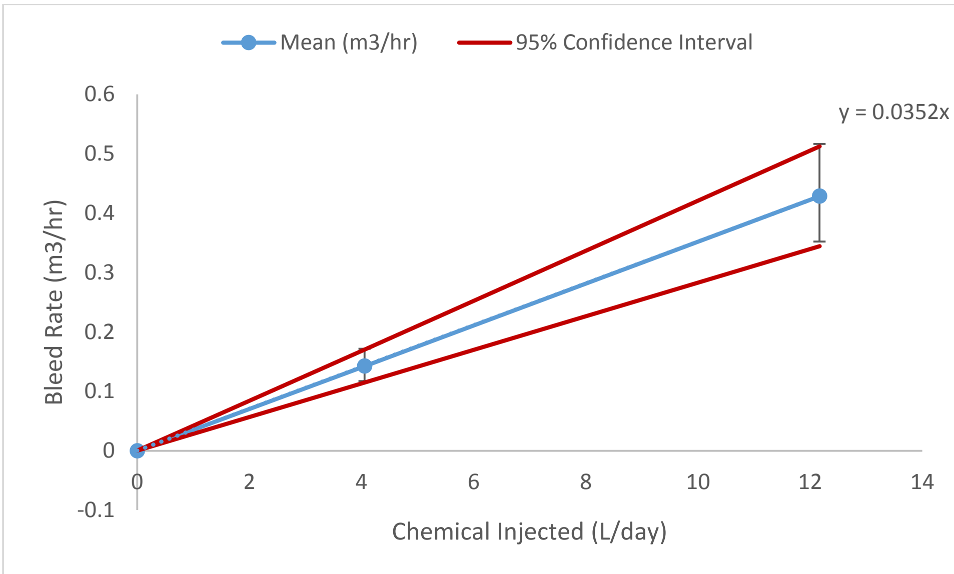

Figure B.1.20. The emissions equation for Williams P250 Series with the 95% confidence interval. The bars represent 50% of the data.

Bleed Rate (m^3/hr) = 0.0352(Chemical Injection (L/day)

Bleed Rate (m^3/hr) = 0.0352 (20 L/day)

Emissions Rate at 20L = 0.704 (m^3/hr/L/day)

Emissions Rate at 20L = 0.8448 m^3/L

B.1.5 Williams P500 Series

Twelve samples were collected for Williams P500 Series during sampling. Figure B.1.21 shows the distribution of samples.

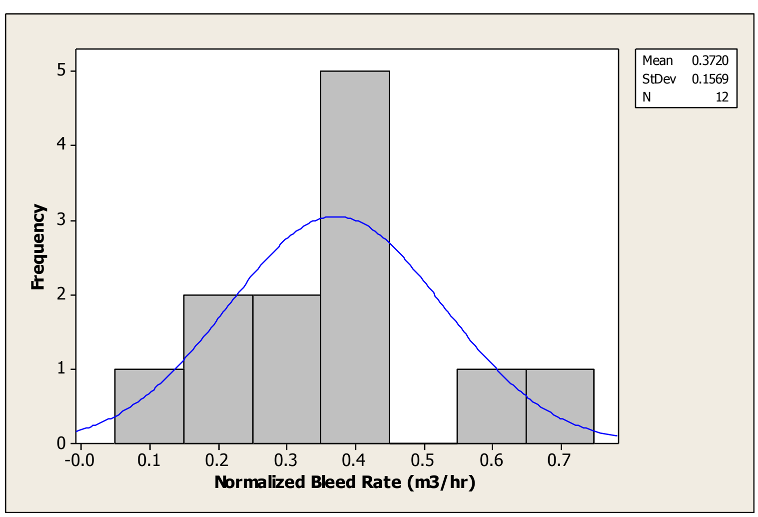

Figure B.1.21. Distribution of normalized sample bleed rates.

When the 12 samples are plotted on the graph (see Figure B.1.22) to test for normality, the KS test indicates that the data is normally distributed (p>0.05).

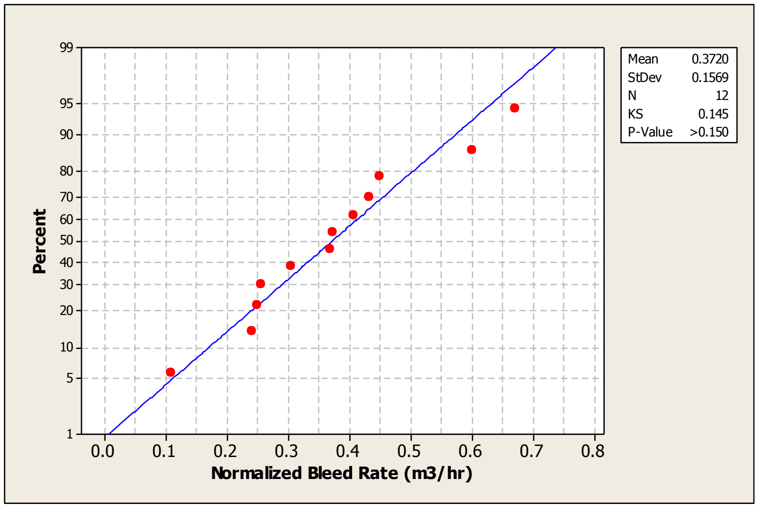

Figure B.1.22. A normality test for the distribution of normalized bleed rates.

Figure B.1.23 shows the distribution of normalized chemical injection rates.

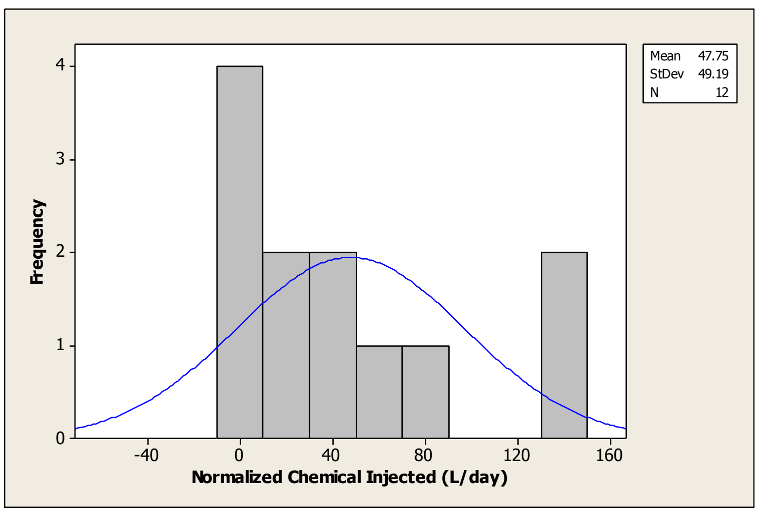

Figure B.1.23. A normality test for the distribution of normalized samples.

When the 12 samples are plotted on the graph (see Figure B.1.24) to test for normality, the KS test indicates that the data is normally distributed.

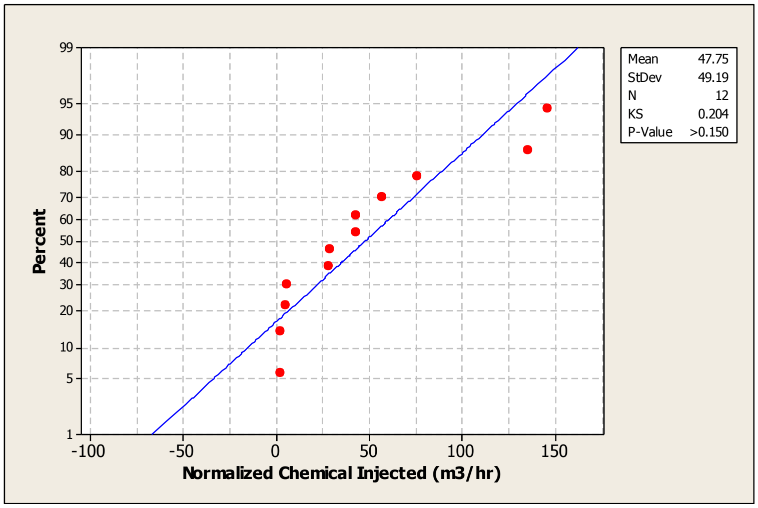

Figure B.1.24. A normality test for the distribution of normalized chemical injection rates

Using two standard stroke rates conditions, the normalized bleed rate and chemical injection rates were calculated.

Table B.1.5. Shows the normalized values of mean bleed rate and 95% confidence interval along with volume of chemical injected.

Strokes per Minute	Mean (m^3/hr)	Chemical Injected (L/day)	Lower Bounds (m^3/hr)	Upper Bounds (m^3/hr)
10	0.3720	47.7478	0.2723	0.4717
30	1.1160	143.2433	0.8168	1.4150

The mean bleed rate and volume of chemical injected were calculated under standard stroke per minute conditions and plotted of a graph to develop a linear emissions equation (Figure B.1.25).

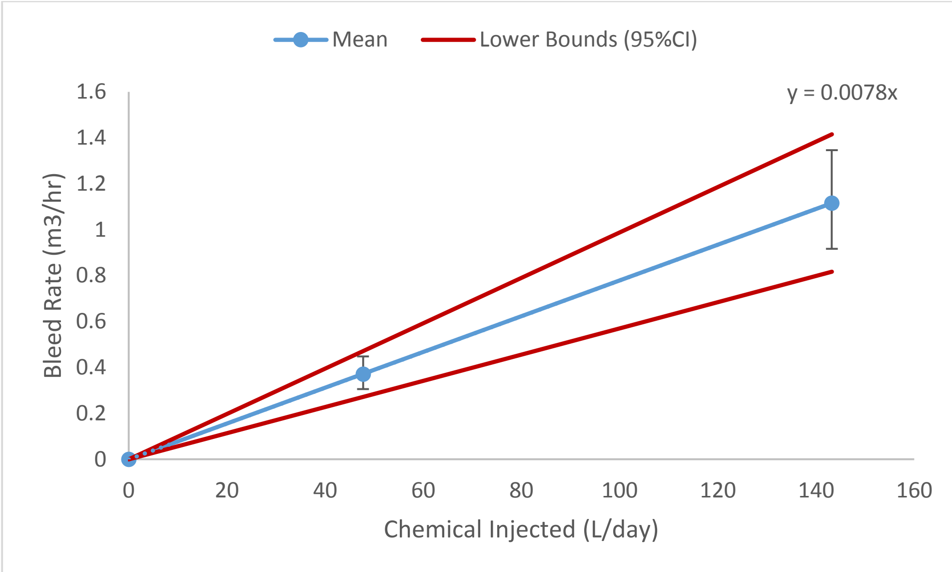

Figure B.1.25. The emissions equation for Williams P500 Series with the 95% confidence interval. The bars represent 50% of the data.

Bleed Rate (m^3/hr) = 0.0078(Chemical Injection (L/day))

Bleed Rate (m^3/hr) = 0.0078 (20 L/day)

Bleed Rate at 20L = 0.156 (m^3/hr)

Emissions Rate at 20L = 0.1872 (m^3/L)