Fermilab

Particle Physics Division
Mechanical Department Engineering Note

Number: MD-ENG-316 Date: 2 March 2011

Project Internal Reference:

Project: NOvA

Title: NOvA IPND TEC Flow Rate Variance

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Key Words: NOvA, IPND, cooling, TEC flow

Applicable Codes:

Abstract Summary: This note details TEC flow data taken from the first two di-blocks of the near detector (IPND). First a flow rate was taken for each port while bypassing the TEC to be used as a baseline, and then a flow rate was taken in series with each TEC to determine actual TEC flow. Pressure loss across the TEC's was also measured on each hose manifold, and an approximate pressure loss v. flow rate chart was also constructed.

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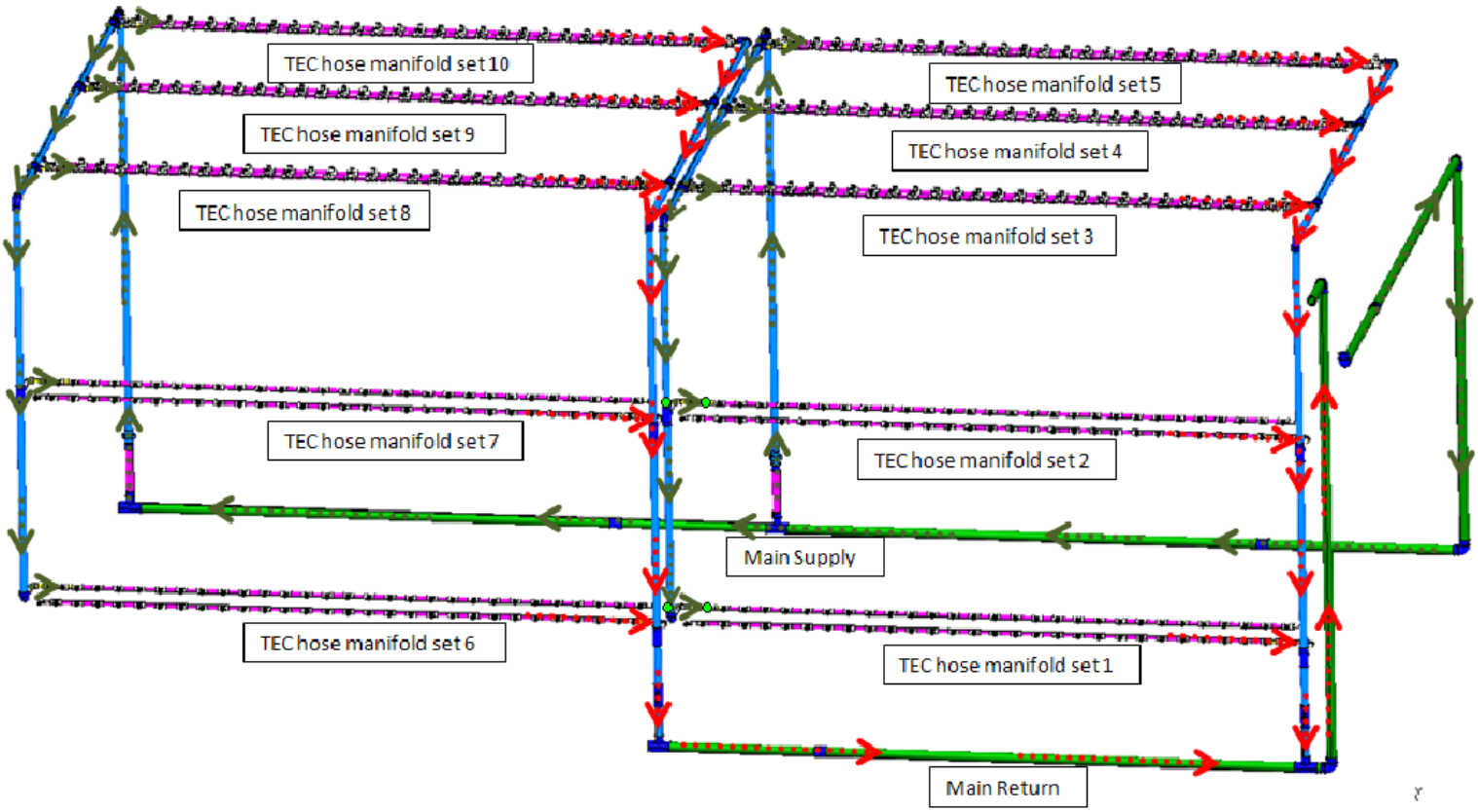
I. Discussion of Methodologies and Nomenclature



The figure above contains the labeling scheme used while collecting data, and illustrates the direction of flow with the green arrows representing supply lines and the red indicating return lines.

Equipment: All flow measurements were taken with a Key Instruments variable area series FR2000 acrylic flow meter. The meter reads in gallons per hour and has a range of 0-10 with a major unit of 1 and a minor unit of 0.2. Flows were then later converted to milliliters per second for convenience. The flow meter supports a dial type valve on the front which allows control of the orifice the water passes through. This valve was determined to most consistently mock the pressure drop of the TEC while opened to 1.25 rotations. I will explain the significance of this in the next section. A pressure measurement was also taken from each supply and return manifold in three positions using an Ashcroft pressure gauge with a range of 0-60 psi.

Methodology: When taking flow measurements, two values were obtained for each of the TEC's in the first two di-blocks of the IPND. The first was taken without the TEC with the flow meter jumped directly from the supply to the return header, with the dial valve opened to 1.25 rotations as discussed in the previous section. The flow measurement taken while bypassing the TEC with the flow meter's valve in such a position that it mocks the pressure drop of the TEC is a way of establishing a baseline reading for the ports. If the flow rate recorded while bypassing the TEC in this fashion is near the average expected, it eliminates erroneous

data caused by partial blockages or other abnormalities in the plumbing itself. The second measurement recorded was simply the flow rate taken through the TEC with the flow meter in series. The baseline data could also provide insight into suspiciously high or low TEC flow rates recorded by looking into the correlation between the two values.

**Note: When measurements were taken, the measurement was preformed two or more times until a consistent value was found.*

When connecting the flow meter in series to the TEC, it is apparent that this extra component will in fact increase the pressure loss across the particular branch, causing the observed flow rates to be lower than actual ones. However, with the small orifices' within the TEC's and the high pressure drop across them, the pressure drop across the flow meter was determined to be insignificant and was neglected. The amount of head the TEC's currently require is approximately 55 feet, compared to the approximate 3 feet that the flow meter requires for the same flow rate. With the flow meter increasing the pressure drop by only about 6%, this factor was neglected.

Another factor worth discussing is the orientation of the flow meter while taking measurements. The meter must be held vertically to produce an accurate reading, which is difficult in certain cases do to obstructions on the detector. For example, on the detectors side it is possible to connect the meter and read values at pipe level and with a minimum length of connecting tubes. However when taking measurements on the detectors top, in order to read the meter vertically much more tube must be used to make the connection while holding the meter about 1 foot above pipe level on the moving platform. This amount of extra tube and added height will also increase the pressure drop through the flow meter system; however when values taken at the pipe level were compared to values taken higher and with extra tubing the difference was seen to be negligible.

II. Initial Data, Calculations, and Conversion Factors

For convenience I will list all initial known data, conversion factors used, and initial calculations.

System Data (Two Active Di-Blocks)

Total system flow rate	Gpm	23
Number of active TEC's	#	300
Expected manifold set flow rate total	Gpm	2.3
Expected TEC flow rate	Gpm	0.0767
Expected TEC flow rate	Gph	4.6
Expected TEC flow rate	mL/s	4.8
Conversion Factors		
Gpm to mL/s	mL/s	63.09
Gph to mL/s	mL/s	1.0515

III. Raw Data – TEC manifolds

The following is the raw data gathered from each of the ten TEC hose manifolds, along with some statistical data derived from it. Data is always listed with the supply side of the manifold set first. Bypass and TEC flow refer to the two values obtained as discussed in the first section; flow without the TEC and the meter's dial valve opened to 1.25 rotations is referred to as bypass flow, and flow with the TEC in series is referred to as TEC flow.

TEC Hose Manifold Set 1

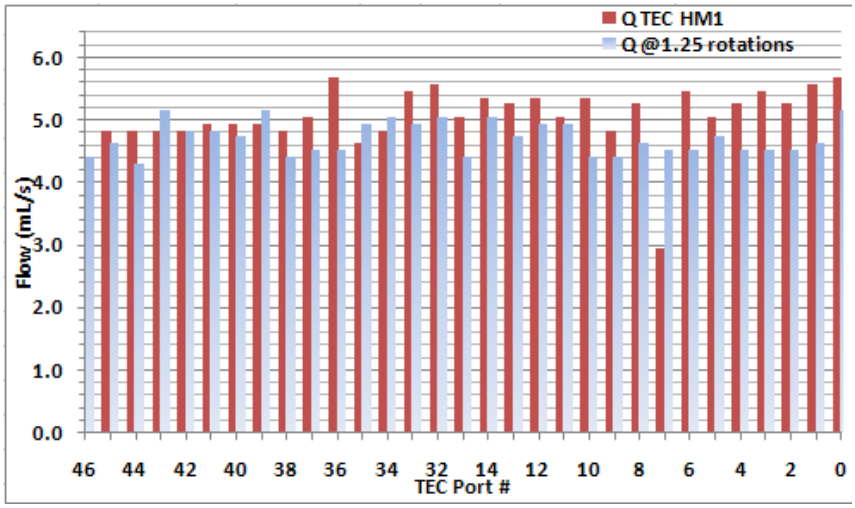
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
46	4.4	4.8
45	4.6	4.8
44	4.3	4.8
43	5.2	4.8
42	4.8	4.8
41	4.8	4.9
40	4.7	4.9
39	5.2	4.9
38	4.4	4.8
37	4.5	5.0
36	4.5	5.7
35	4.9	4.6
34	5.0	4.8
33	4.9	5.5
32	5.0	5.6
15	4.4	5.0
14	5.0	5.4
13	4.7	5.3
12	4.9	5.4
11	4.9	5.0
10	4.4	5.4
9	4.4	4.8
8	4.6	5.3
7	4.5	2.9
6	4.5	5.5
5	4.7	5.0
4	4.5	5.3
3	4.5	5.5
2	4.5	5.3
1	4.6	5.6
0	5.2	5.7

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	39	15
-Middle port	38.5	14.5
-Last port	38	14

B. Raw Data Properties

Average TEC Pressure Loss	psi	24
Total Manifold Flow	Gpm	2.6
Average TEC Flow	mL/s	5.1
Bypass Flow Standard Deviation	mL/s	0.248
TEC Flow Standard Deviation	mL/s	0.47
Outliers	#	1
Average TEC Flow Excluding Outliers	mL/s	5.1
TEC Flow Standard Deviation Excluding Outliers	mL/s	0.286



TEC Hose Manifold Set 2

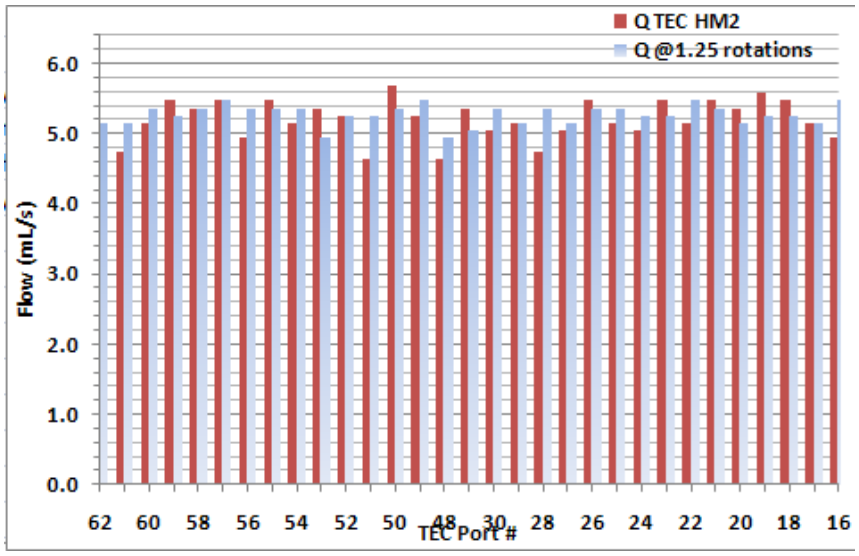
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
62	5.2	5.3
61	5.2	4.7
60	5.4	5.2
59	5.3	5.5
58	5.4	5.4
57	5.5	5.5
56	5.4	4.9
55	5.4	5.5
54	5.4	5.2
53	4.9	5.4
52	5.3	5.3
51	5.3	4.6
50	5.4	5.7
49	5.5	5.3
48	4.9	4.6
31	5.0	5.4
30	5.4	5.0
29	5.2	5.2
28	5.4	4.7
27	5.2	5.0
26	5.4	5.5
25	5.4	5.2
24	5.3	5.0
23	5.3	5.5
22	5.5	5.2
21	5.4	5.5
20	5.2	5.4
19	5.3	5.6
18	5.3	5.5
17	5.2	5.2
16	5.5	4.9

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	36.5	12
-Middle port	36	12
-Last port	37	13

B. Raw Data Properties

Average TEC Pressure Loss	psi	24.17
Total Manifold Flow	Gpm	2.7
Average TEC Flow	mL/s	5.2
Bypass Flow Standard Deviation	mL/s	0.134
TEC Flow Standard Deviation	mL/s	0.263
Outliers	#	**0**
Average TEC Flow Excluding Outliers	mL/s	N/A
TEC Flow Standard Deviation Excluding Outliers	mL/s	N/A



TEC Hose Manifold Set 3

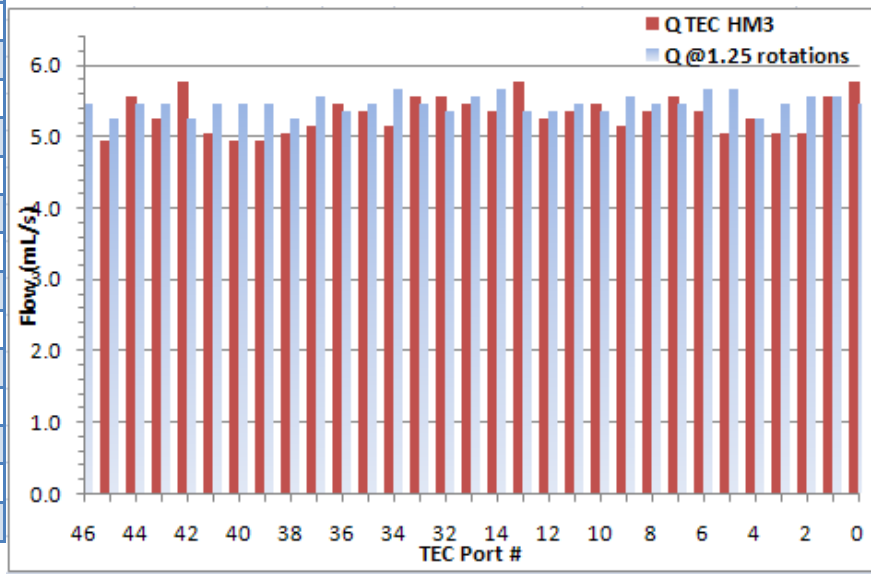
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
46	5.5	4.9
45	5.3	4.9
44	5.5	5.6
43	5.5	5.3
42	5.3	5.8
41	5.5	5.0
40	5.5	4.9
39	5.5	4.9
38	5.3	5.0
37	5.6	5.2
36	5.4	5.5
35	5.5	5.4
34	5.7	5.2
33	5.5	5.6
32	5.4	5.6
15	5.6	5.5
14	5.7	5.4
13	5.4	5.8
12	5.4	5.3
11	5.5	5.4
10	5.4	5.5
9	5.6	5.2
8	5.5	5.4
7	5.5	5.6
6	5.7	5.4
5	5.7	5.0
4	5.3	5.3
3	5.5	5.0
2	5.6	5.0
1	5.6	5.6
0	5.5	5.8

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	34	9
-Middle port	34	9
-Last port	34	9

B. Raw Data Properties

Average TEC Pressure Loss	psi	25
Total Manifold Flow	Gpm	2.7
Average TEC Flow	mL/s	5.3
Bypass Flow Standard Deviation	mL/s	0.118
TEC Flow Standard Deviation	mL/s	0.25
Outliers	#	**0**
Average TEC Flow Excluding Outliers	mL/s	N/A
TEC Flow Standard Deviation Excluding Outliers	mL/s	N/A



TEC Hose Manifold Set 4

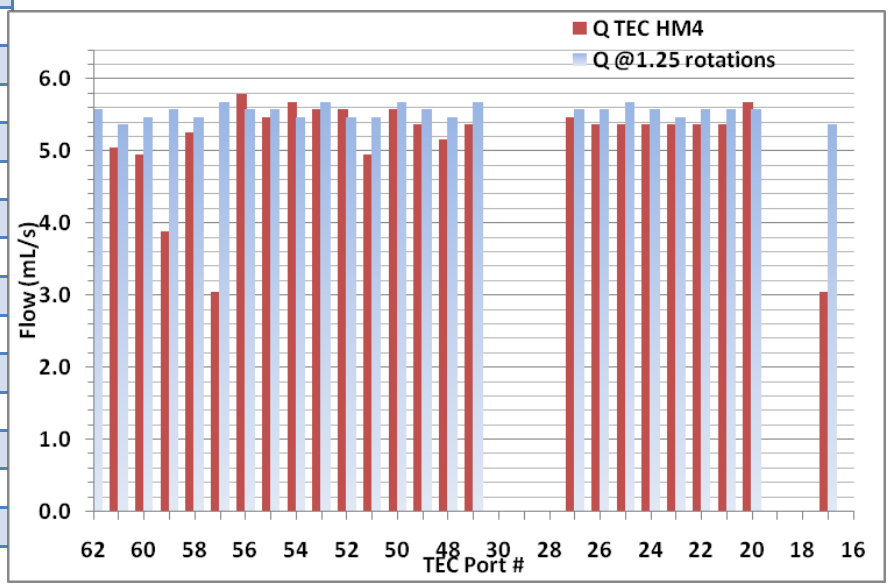
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
62	5.6	5.4
61	5.4	5.0
60	5.5	4.9
59	5.6	3.9
58	5.5	5.3
57	5.7	3.0
56	5.6	5.8
55	5.6	5.5
54	5.5	5.7
53	5.7	5.6
52	5.5	5.6
51	5.5	4.9
50	5.7	5.6
49	5.6	5.4
48	5.5	5.2
31	5.7	5.4
30	*No TEC*	*No TEC*
29	*No TEC*	*No TEC*
28	*No TEC*	*No TEC*
27	5.6	5.5
26	5.6	5.4
25	5.7	5.4
24	5.6	5.4
23	5.5	5.4
22	5.6	5.4
21	5.6	5.4
20	5.6	5.7
19	*No TEC*	*No TEC*
18	*No TEC*	*No TEC*
17	5.4	3.0
16	*No TEC*	*No TEC*

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	34	8
-Middle port	34	8.5
-Last port	34	8

B. Raw Data Properties

Average TEC Pressure Loss	psi	25.83
Total Manifold Flow	Gpm	2.1
Average TEC Flow	mL/s	5.1
Bypass Flow Standard Deviation	mL/s	0.0879
TEC Flow Standard Deviation	mL/s	0.689
Outliers	#	3
Average TEC Flow Excluding Outliers	mL/s	5.4
TEC Flow Standard Deviation Excluding Outliers	mL/s	0.21



TEC Hose Manifold Set 5

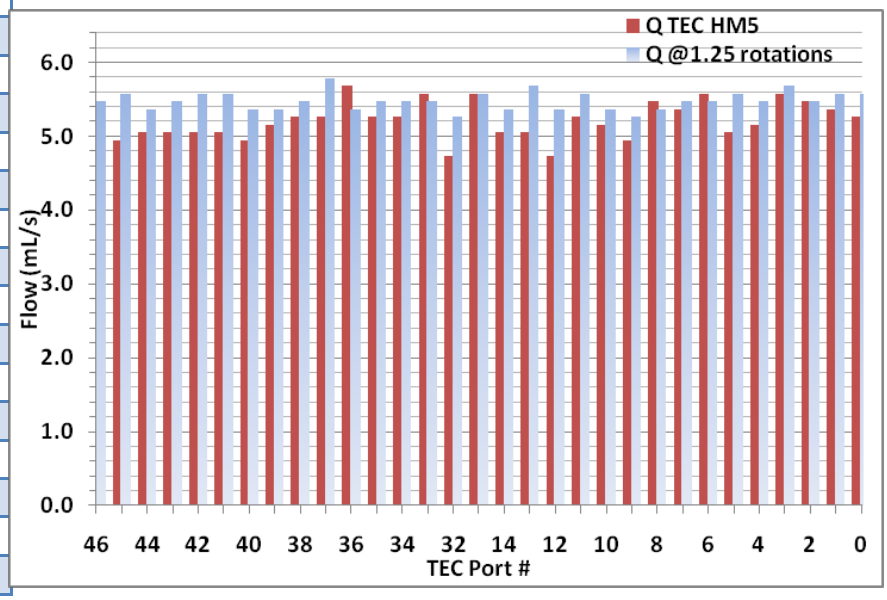
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
46	5.5	4.9
45	5.6	4.9
44	5.4	5.0
43	5.5	5.0
42	5.6	5.0
41	5.6	5.0
40	5.4	4.9
39	5.4	5.2
38	5.5	5.3
37	5.8	5.3
36	5.4	5.7
35	5.5	5.3
34	5.5	5.3
33	5.5	5.6
32	5.3	4.7
15	5.6	5.6
14	5.4	5.0
13	5.7	5.0
12	5.4	4.7
11	5.6	5.3
10	5.4	5.2
9	5.3	4.9
8	5.4	5.5
7	5.5	5.4
6	5.5	5.6
5	5.6	5.0
4	5.5	5.2
3	5.7	5.6
2	5.5	5.5
1	5.6	5.4
0	5.6	5.3

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	34.5	9
-Middle port	33.5	8
-Last port	33.5	8

B. Raw Data Properties

Average TEC Pressure Loss	psi	25.5
Total Manifold Flow	Gpm	2.7
Average TEC Flow	mL/s	5.2
Bypass Flow Standard Deviation	mL/s	0.116
TEC Flow Standard Deviation	mL/s	0.238
Outliers	#	**0**
Average TEC Flow Excluding Outliers	mL/s	N/A
TEC Flow Standard Deviation Excluding Outliers	mL/s	N/A



TEC Hose Manifold Set 6

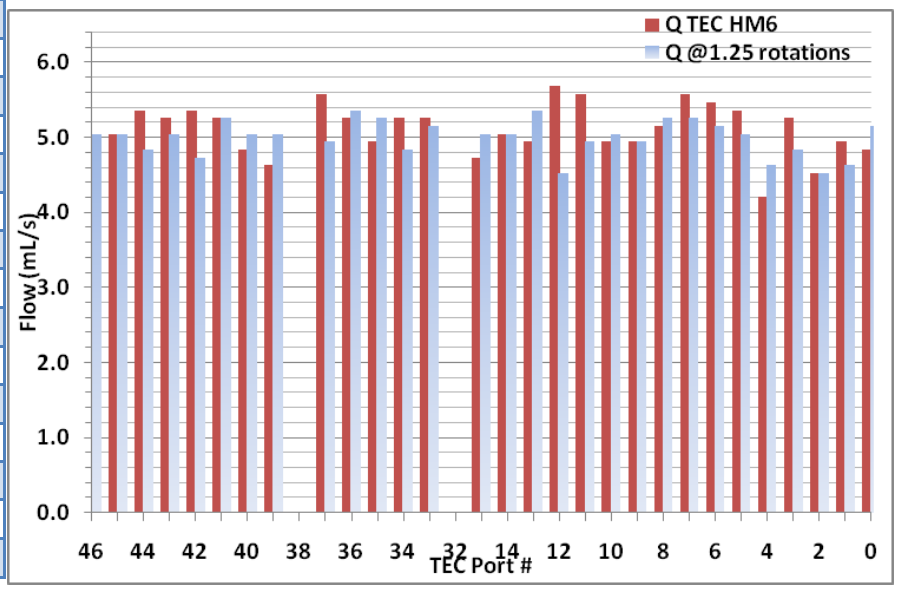
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
46	5.0	4.6
45	5.0	5.0
44	4.8	5.4
43	5.0	5.3
42	4.7	5.4
41	5.3	5.3
40	5.0	4.8
39	5.0	4.6
38	*No TEC*	*No TEC*
37	4.9	5.6
36	5.4	5.3
35	5.3	4.9
34	4.8	5.3
33	5.2	5.3
32	*No TEC*	*No TEC*
15	5.0	4.7
14	5.0	5.0
13	5.4	4.9
12	4.5	5.7
11	4.9	5.6
10	5.0	4.9
9	4.9	4.9
8	5.3	5.2
7	5.3	5.6
6	5.2	5.5
5	5.0	5.4
4	4.6	**4.2**
3	4.8	5.3
2	4.5	4.5
1	4.6	4.9
0	5.2	4.8

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	38	14.5
-Middle port	38.5	14
-Last port	38.5	14.5

B. Raw Data Properties

Average TEC Pressure Loss	psi	24
Total Manifold Flow	Gpm	2.5
Average TEC Flow	mL/s	5.1
Bypass Flow Standard Deviation	mL/s	0.221
TEC Flow Standard Deviation	mL/s	0.336
Outliers	#	**1**
Average TEC Flow Excluding Outliers	mL/s	5.1
TEC Flow Standard Deviation Excluding Outliers	mL/s	0.299



TEC Hose Manifold Set 7

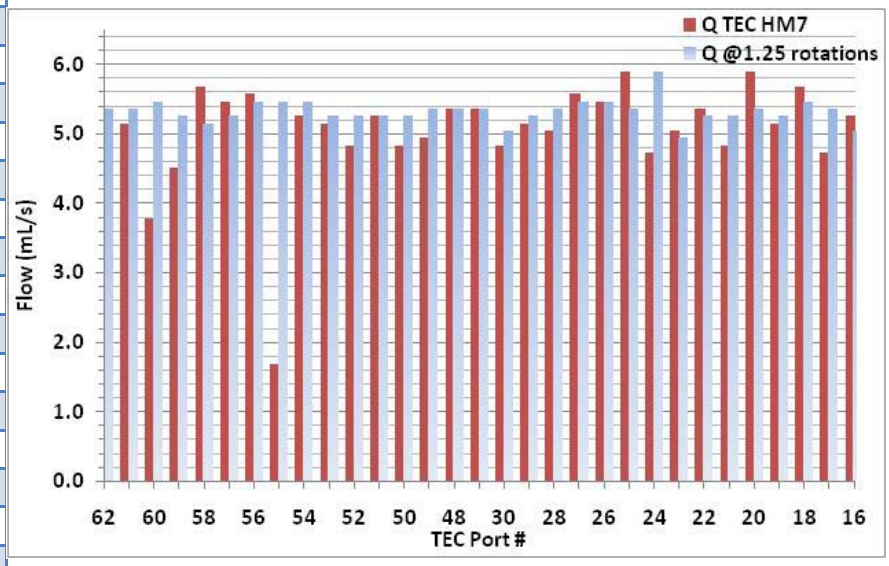
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
62	5.4	5.4
61	5.4	5.2
60	5.5	3.8
59	5.3	4.5
58	5.2	5.7
57	5.3	5.5
56	5.5	5.6
55	5.5	1.7
54	5.5	5.3
53	5.3	5.2
52	5.3	4.8
51	5.3	5.3
50	5.3	4.8
49	5.4	4.9
48	5.4	5.4
31	5.4	5.4
30	5.0	4.8
29	5.3	5.2
28	5.4	5.0
27	5.5	5.6
26	5.5	5.5
25	5.4	5.9
24	5.9	4.7
23	4.9	5.0
22	5.3	5.4
21	5.3	4.8
20	5.4	5.9
19	5.3	5.2
18	5.5	5.7
17	5.4	4.7
16	5.0	5.3

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	36.5	13
-Middle port	36.5	12.5
-Last port	36.5	12

B. Raw Data Properties

Average TEC Pressure Loss	psi	24
Total Manifold Flow	Gpm	2.6
Average TEC Flow	mL/s	5.1
Bypass Flow Standard Deviation	mL/s	0.159
TEC Flow Standard Deviation	mL/s	0.721
Outliers	#	2
Average TEC Flow Excluding Outliers	mL/s	5.2
TEC Flow Standard Deviation Excluding Outliers	mL/s	0.335



TEC Hose Manifold Set 8

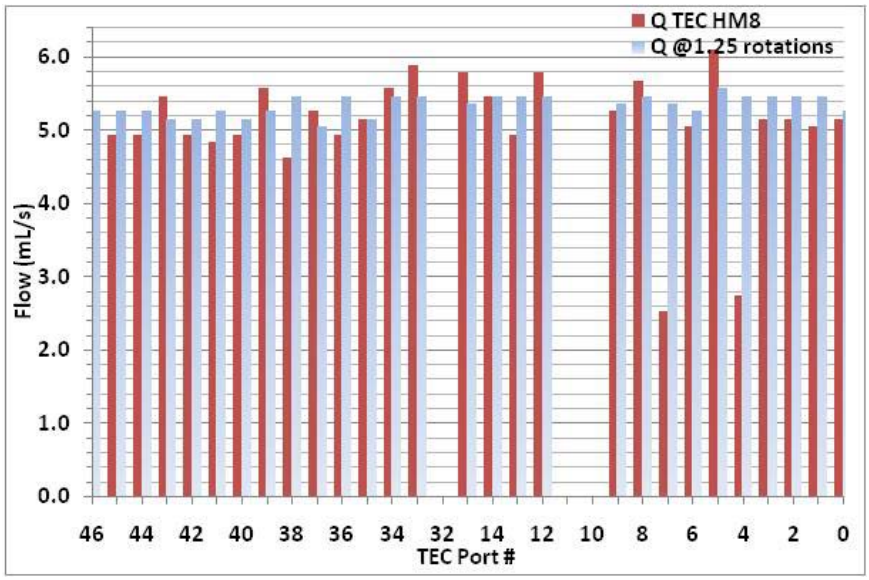
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
46	5.3	5.5
45	5.3	4.9
44	5.3	4.9
43	5.2	5.5
42	5.2	4.9
41	5.3	4.8
40	5.2	4.9
39	5.3	5.6
38	5.5	4.6
37	5.0	5.3
36	5.5	4.9
35	5.2	5.2
34	5.5	5.6
33	5.5	5.9
32	*No TEC*	*No TEC*
15	5.4	5.8
14	5.5	5.5
13	5.5	4.9
12	5.5	5.8
11	*No TEC*	*No TEC*
10	*No TEC*	*No TEC*
9	5.4	5.3
8	5.5	5.7
7	5.4	**2.5**
6	5.3	5.0
5	5.6	6.1
4	5.5	**2.7**
3	5.5	5.2
2	5.5	5.2
1	5.5	5.0
0	5.3	5.2

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	34	10
-Middle port	34	9
-Last port	34	9

B. Raw Data Properties

Average TEC Pressure Loss	psi	24.67
Total Manifold Flow	Gpm	2.4
Average TEC Flow	mL/s	5.1
Bypass Flow Standard Deviation	mL/s	0.133
TEC Flow Standard Deviation	mL/s	0.743
Outliers	#	**2**
Average TEC Flow Excluding Outliers	mL/s	5.3
TEC Flow Standard Deviation Excluding Outliers	mL/s	0.354



TEC Hose Manifold Set 9

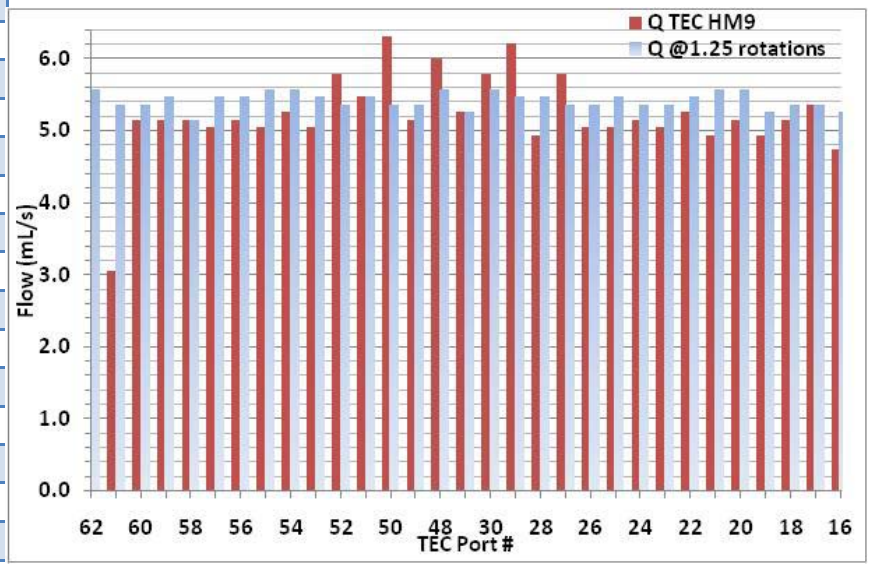
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
62	5.6	5.7
61	5.4	3.0
60	5.4	5.2
59	5.5	5.2
58	5.2	5.2
57	5.5	5.0
56	5.5	5.2
55	5.6	5.0
54	5.6	5.3
53	5.5	5.0
52	5.4	5.8
51	5.5	5.5
50	5.4	6.3
49	5.4	5.2
48	5.6	6.0
31	5.3	5.3
30	5.6	5.8
29	5.5	6.2
28	5.5	4.9
27	5.4	5.8
26	5.4	5.0
25	5.5	5.0
24	5.4	5.2
23	5.4	5.0
22	5.5	5.3
21	5.6	4.9
20	5.6	5.2
19	5.3	4.9
18	5.4	5.2
17	5.4	5.4
16	5.3	4.7

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	33.5	9
-Middle port	34	9
-Last port	34.5	9.5

B. Raw Data Properties

Average TEC Pressure Loss	psi	24.83
Total Manifold Flow	Gpm	2.7
Average TEC Flow	mL/s	5.2
Bypass Flow Standard Deviation	mL/s	0.106
TEC Flow Standard Deviation	mL/s	0.532
Outliers	#	1
Average TEC Flow Excluding Outliers	mL/s	5.3
TEC Flow Standard Deviation Excluding Outliers	mL/s	0.373



TEC Hose Manifold Set 10

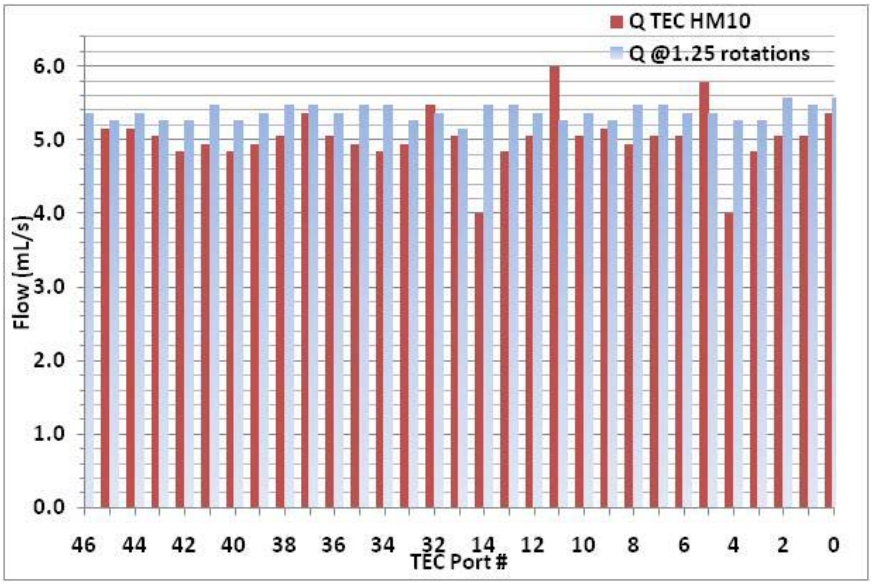
A. Data Taken

TEC Port #	Bypass Flow (mL/s)	TEC Flow (mL/s)
46	5.4	5.0
45	5.3	5.2
44	5.4	5.2
43	5.3	5.0
42	5.3	4.8
41	5.5	4.9
40	5.3	4.8
39	5.4	4.9
38	5.5	5.0
37	5.5	5.4
36	5.4	5.0
35	5.5	4.9
34	5.5	4.8
33	5.3	4.9
32	5.4	5.5
15	5.2	5.0
14	5.5	4.0
13	5.5	4.8
12	5.4	5.0
11	5.3	6.0
10	5.4	5.0
9	5.3	5.2
8	5.5	4.9
7	5.5	5.0
6	5.4	5.0
5	5.4	5.8
4	5.3	4.0
3	5.3	4.8
2	5.6	5.0
1	5.5	5.0
0	5.6	5.4

Pressure's Measured		
Location	**P in (psi)**	**P out (psi)**
-First port	34	9
-Middle port	34	9
-Last port	34	9

B. Raw Data Properties

Average TEC Pressure Loss	psi	25
Total Manifold Flow	Gpm	2.6
Average TEC Flow	mL/s	5.0
Bypass Flow Standard Deviation	mL/s	0.101
TEC Flow Standard Deviation	mL/s	0.361
Outliers	#	2
Average TEC Flow Excluding Outliers	mL/s	5.1
TEC Flow Standard Deviation Excluding Outliers	mL/s	0.257

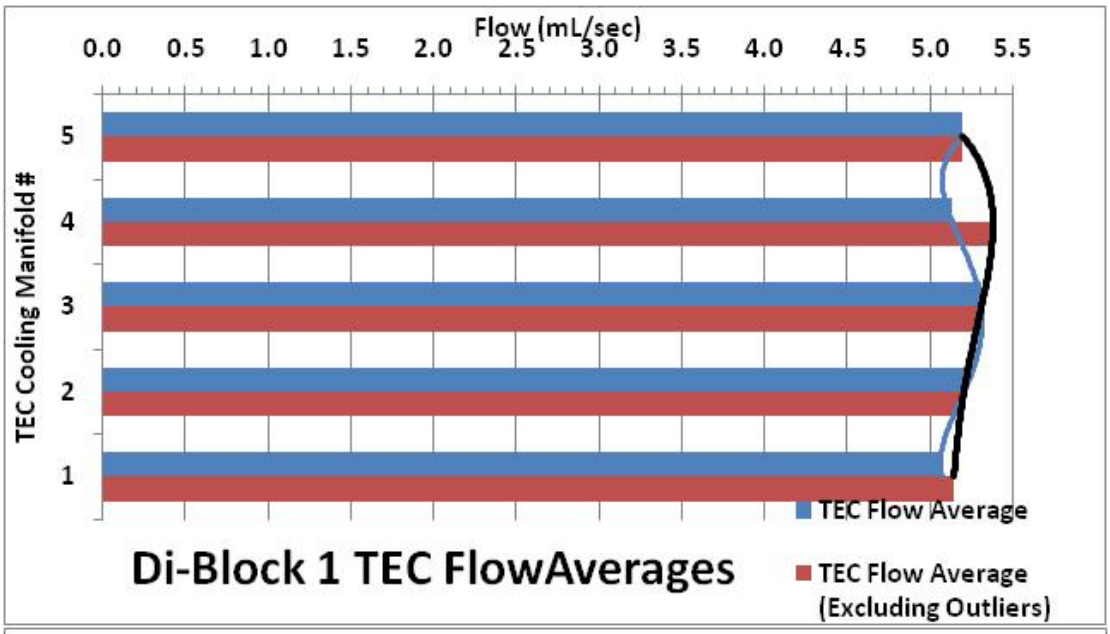


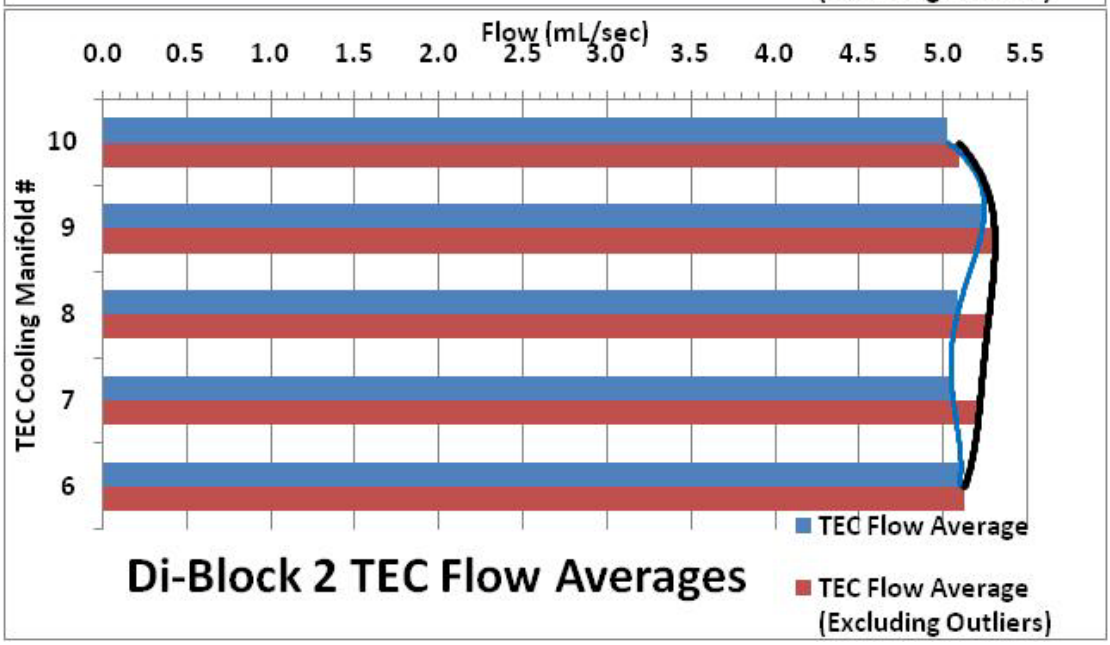
IV. Cumulative Data

In this section I will list the cumulative data obtained from analysis of the entire data sample. The chart lists useful statistical information, and is followed by graphs and figures for easy flow data analysis.

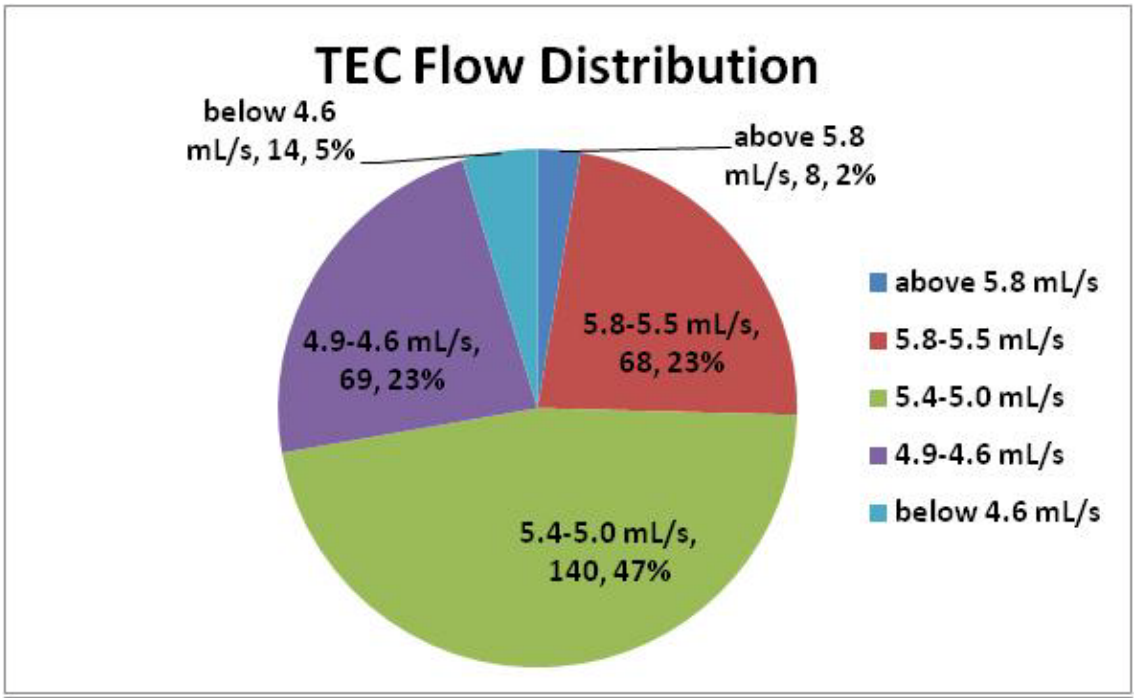
Cumulative Data	unit	value										
TEC Pressure Loss Average	psi	24.7										
***Total System Flow**	Gpm	Cumulative total	24.4									
		Actual	23									
TEC Flow Averages	mL/s	TEC Man.	1	2	3	4	5	6	7	8	9	10
		Avg. Flow	5.1	5.2	5.3	5.1	5.2	5.1	5.1	5.1	5.2	5.0
Cumulative TEC Flow Avg.	mL/s	Measured Cumulative Average:							5.1			
		Expected Average:							4.8			
		Cumulative Average (with 5.7% *reduction factor):							4.8			
TEC Flow Standard Deviation	mL/s	0.49										
Number of Flow Outliers	#	Di-Block 1:	4									
		Di-Block 2:	8									
		Total:	12									
TEC Flow Averages (Excluding Outliers)	mL/s	TEC Man.	1	2	3	4	5	6	7	8	9	10
		Avg. Flow	5.1	5.2	5.3	5.4	5.2	5.1	5.2	5.3	5.3	5.1
TEC Flow Standard Deviation (Excluding Outliers)	mL/s	0.297										
Cumulative TEC Flow Avg. (Excluding Outliers)	mL/s	Cumulative Average (Di-Block 1 = Di-Block 2):							5.2			
Standard TEC Flow Range	mL/s	4.6-5.8	-High to low range is about a 23% difference in flow									

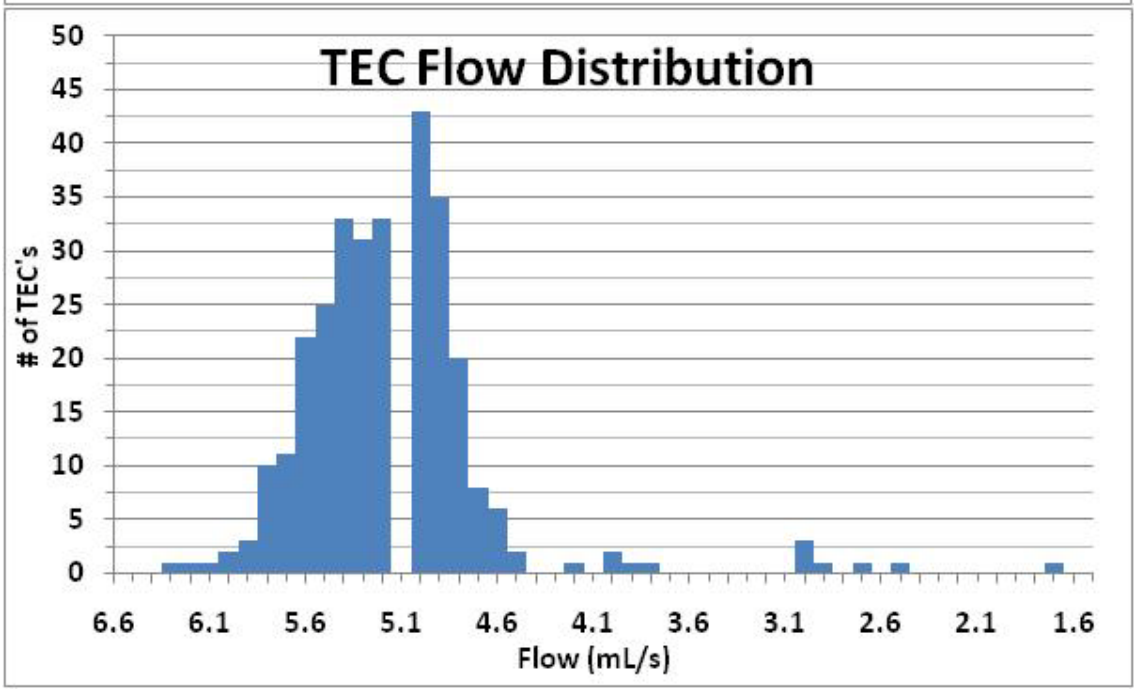
*Total System Flow: It is seen that the cumulative system flow is 24.4 Gpm when adding all the measured values, where the actual total system flow rate is 23 Gpm. This indicates to obtain true flows a correction factor must be incorporated to account for error in the flow meter. This factor comes to a **5.7% reduction for true flow rates**.





The two figures above are a breakdown of the average TEC flow by manifold number. Values illustrated in blue are the average TEC flow averages by incorporating all data; the red values are the average TEC flow rates when excluding the outlier data points (partially clogged orifices?). When looking at the blue values, the distribution of averages appears to be scattered with no definable pattern, as illustrated by the differing blue curve fits. However when the outlying data points are removed from the averages a normalized trend is produced and repeats in the first and second di-block, as illustrated by the two nearly perfectly matching thick black curve fits. Averages computed without outlier data will be considered closer to the true averages when trying to look at trends in the data. By looking at the nomenclature diagram it is seen that manifold numbers 5 and 10 are nearest the main supply, and manifolds 1 and 6 are nearest the main return. The peak flows in the normalized averages occur in the manifold second nearest the main supply, and the minimums occur in the manifolds nearest the main supply and return. This trend matches the analytically calculated predictions extremely well.





The two figures above illustrate the distribution of TEC flows rates. They show the same data; however the pie chart is broken into flow ranges, and the bar graph is broken down into 0.1 mL/s increments. When looking at the bar graph, it can be seen the flow rates follow a very normalized, Belle curve like, pattern with very short or scattered outlier tails. The gap in the 5.1 mL/s data on the horizontal axis is unrealistic and due to significant digit loss when converting from Gph to mL/s; it should be ignored. The pie chart indicates that almost half of the TEC's flow in a range from 5.0-5.4 mL/s, and 93% of the TEC's are in the range of 4.6-5.8 mL/s, about a 23% difference between the high and low. The handful shown to have flows faster than 5.8 mL/s are likely caused by manufacturing defects such as slightly larger orifices, and the 5% that flow lower than 4.6 mL/s are likely caused by partially clogged orifices.

V. A Word about the Outlier Data Points

There was a total of 12 outlier data points. When a TEC was demonstrating a low flow rate as in the outliers, the 6 inch #10 threaded hose assemblies were removed. Once removed, the orifices were brushed out and the pair of hoses was flow rate tested against an identical set which was known to flow properly. Once an average flow rate was consistently obtained, the hoses were reinstalled into their respective TEC's on the detector and the flow was tested again. The data below was gathered on the outliers.

TEC Hose Set Location	Flow Rate @ about 5 Feet of Static Head (mL/s)	Flow Rate once Reinstalled (mL/s)	Notes
Baseline for comparison ***Manifold 6, Port 39***	*1.2*	*4.8*	*Flow rate before removing and testing: 4.6 mL/s*
Manifold 8, Port 4	1.5	5.8	
Manifold 8, Port 7	1.4	5.2	Replaced one hose
Manifold 7, Port 55	1.2	5.2	
Manifold 1, Port 7	1.4	5.2	
Manifold 4, Port 57	1.2	5.4	Slightly smaller orifices
Manifold 4, Port 17	1.4	5.2	
Manifold 9, Port 61	1.2	5.4	Slightly smaller orifices
Manifold 7, Port 60	1.4	5.5	
Manifold 4, Port 59	1.2	5.5	Slightly smaller orifices
Manifold 10, Port 4	1.2	5.4	Slightly smaller orifices
Manifold 10, Port 14	1.4	6.6	
Manifold 6, Port 4	1.5	5.9	

It can be seen the flow rate of the baseline pair of hoses used for comparison (TEC Manifold 6, Port 39) had a measured flow rate on the detector of 4.6 mL/sec, which is at the bottom of the standard flow range seen. Therefore, with none of the outlier pairs tested at about 5 feet of static head presenting a flow rate below this, all of the removed pairs are within normal range. Once the pairs of hoses were reinstalled on the detector, they were flow tested and all were within normal range. 4 pairs were discovered to have slightly different orifices which may be common throughout the detector; however they had no measurable effect.

VI. TEC Pressure Loss v. Flow Rate Extrapolation

By calculating a flow resistance coefficient (K) based on the data taken, an approximate relationship between pressure loss and flow rate can be plotted.

Total system flow rate (: **23 Gpm**

Total # of active TEC's in the IPND: **300**

Average pressure loss measured across the TEC's: **24.7 psi**

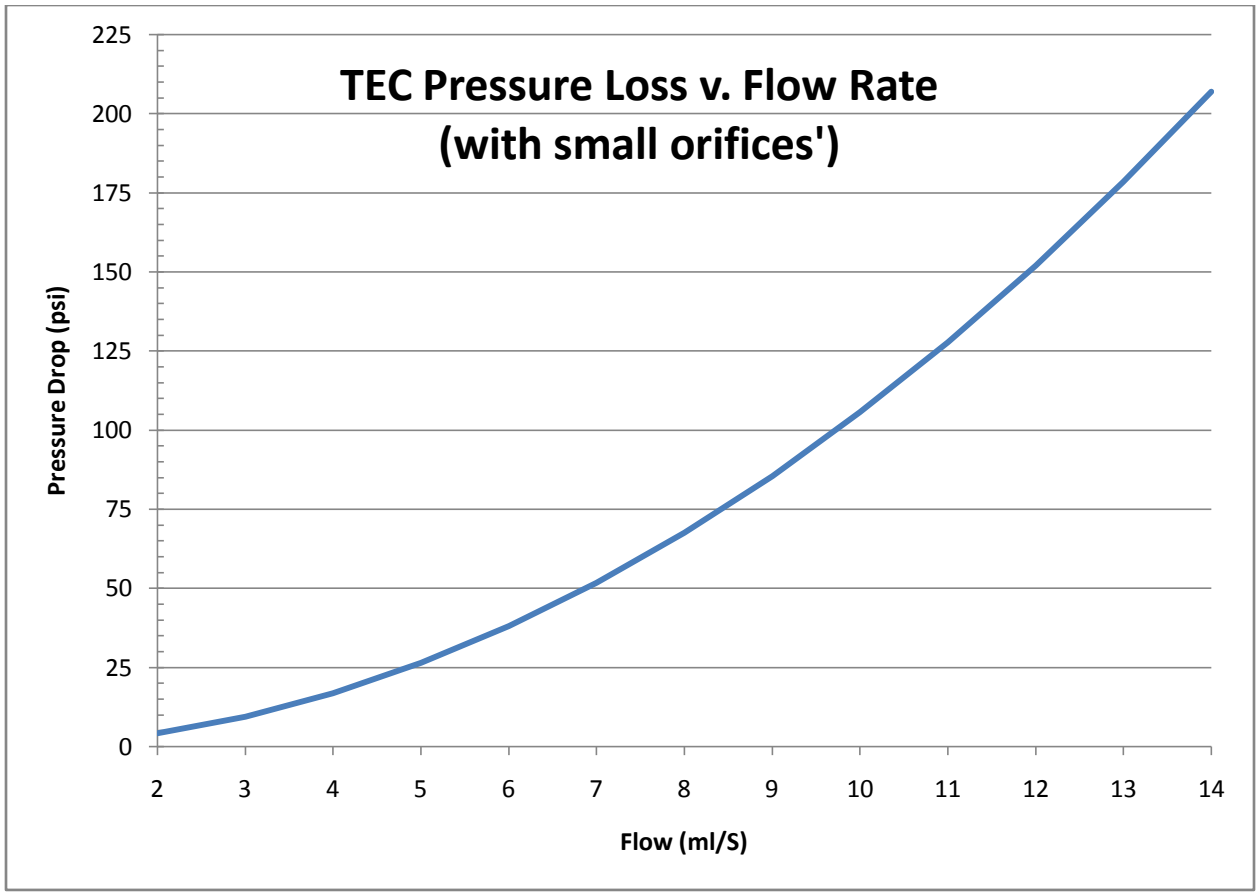
Average flow rate per TEC: ——— — ***= 4.84 ml/s***

Typical pressure loss through fittings: ———

Modified TEC pressure loss equation:

— ———

TEC Flow (ml/s)	Pressure Loss (psi)	Total System Flow (Gpm)
2	4.2	9.8
3	9.5	14.7
4	16.9	19.7
5	26.4	24.6
6	38.0	29.5
7	51.7	34.4
8	67.6	39.3
9	85.5	44.2
10	105.6	49.1
11	127.7	54.0
12	152.0	59.0


TEC Pressure Loss v. Flow Rate
(with small orifices')
Pressure Drop (psi)
225
200
175
150
125
100
75
50
25
0
2
3
4
5
6
7
8
9
10
11
12
13
14
Flow (ml/S)

VII. Conclusions and Summary

At the conclusion of this note all TEC's installed on the detector can be considered clear of blockages and to have a normal flow rate. A normal flow rate on the detector as measured by the Key Instruments variable area series FR2000 flow meter will be in the range of 4.4 – 5.5 Gph (or 4.6 – 5.8 mL/sec after converting). This is about a 23% difference from the high to the low range, with almost 100% within this range (some display higher flow rates, and some drop with partial clogs). When clogs are made apparent by low flow rates or little heat transfer, they can simply be removed, cleaned, and reinstalled, or simply replaced. No problems were found with the heatsinks. It should be kept in mind that different flow meters can display different values due to the calibration of the meter and its relative correction factors; therefore the same meter should be used for accurate comparisons. If the true flow rate is desired; a 5.7% reduction factor should be used, bringing the true normal flow range to 4.1 – 5.2 Gph (4.3 – 5.5 mL/sec).