Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project Internal Reference:

Project: NOvA Ash River Cooling System

Title: NOvA Far Detector Cooling System Hydraulic Calculations

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Key Words: Ash River, Cooling, Far Detector

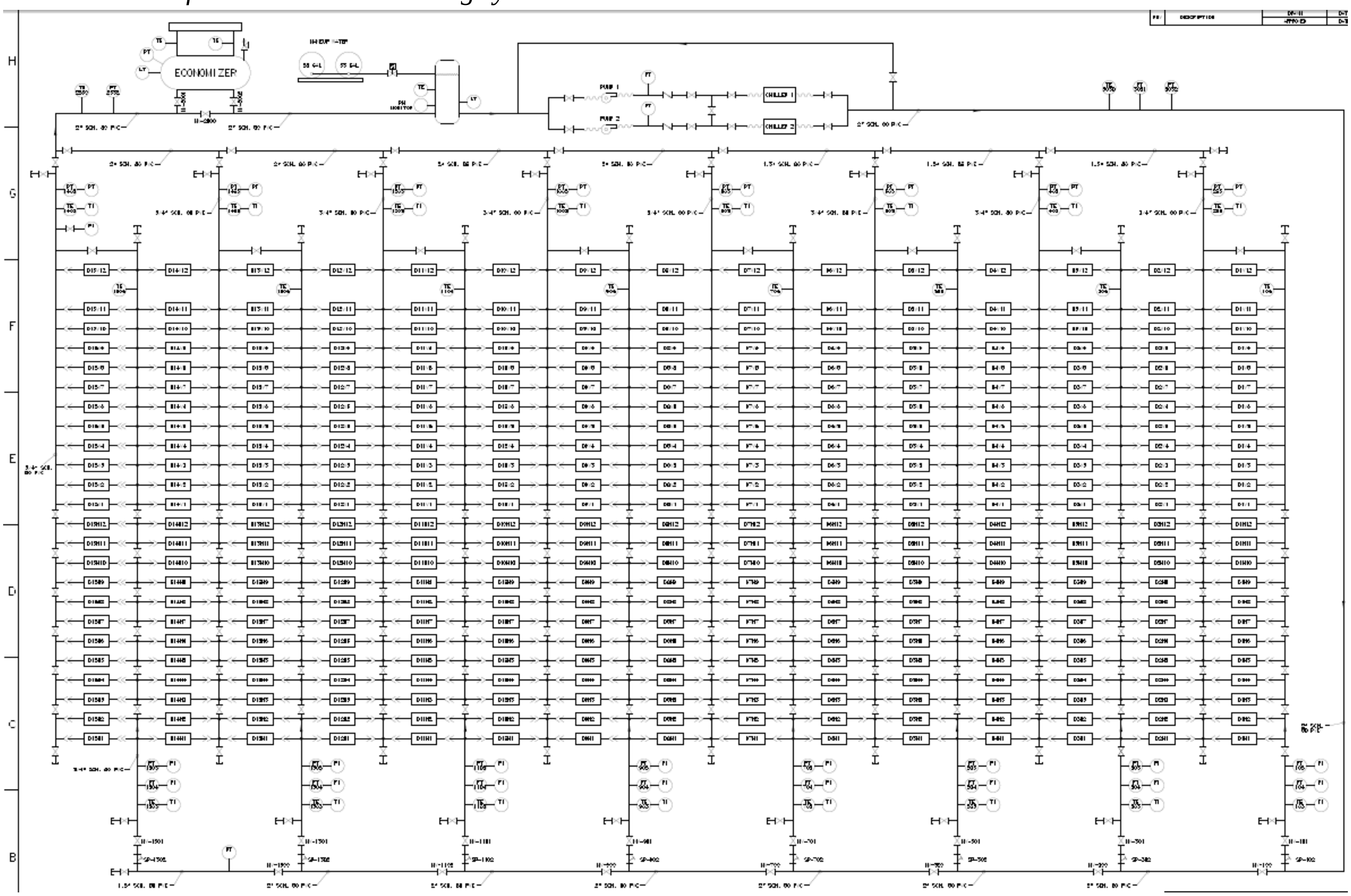
Applicable Codes:

Abstract Summary: The following note details hydraulic flow calculations performed for the NOvA Far Detector Cooling System in Ash River done to obtain the system curve. Total pressure drops were calculated for all system routing and used to determine the largest percent difference in TEC row flow in the system. Ratios of the pressure drops to the average were then used to compute true flow rates in TEC rows.

Discussion/Summary

The following pages contain a Mathcad script used to calculate pressure drops based on routing in the NOvA Far Detector at Ash River. Arrays and matricies of equations have been suppressed, and the equations used for calculation will be listed in the following section in general form. All variables in the Mathcad script have been declared independently and equations are all in generic form to provide a template for calculating pressure drops and branch flows in any system with as many as 24 parallel branches.

P&ID for the Ash River cooling system:



A word about the P&ID: The bottom main line is the supply to be located underneath the lowest catwalk, and the top main line is the return to be located either parallel to the supply or mounted to the wall near the top far corner of the detector, depending on geometric constraints. The chiller and pump piping is to be located underneath the top catwalk. The di-block supply lines seen vertically connecting to the main supply at the bottom are ¾'' nominal diameter and will penetrate all but the top level catwalk at a frequency of every other di-block. The main return is seen at the top below the chillers in similar fashion with the di-block returns connecting vertically at every other di-block.

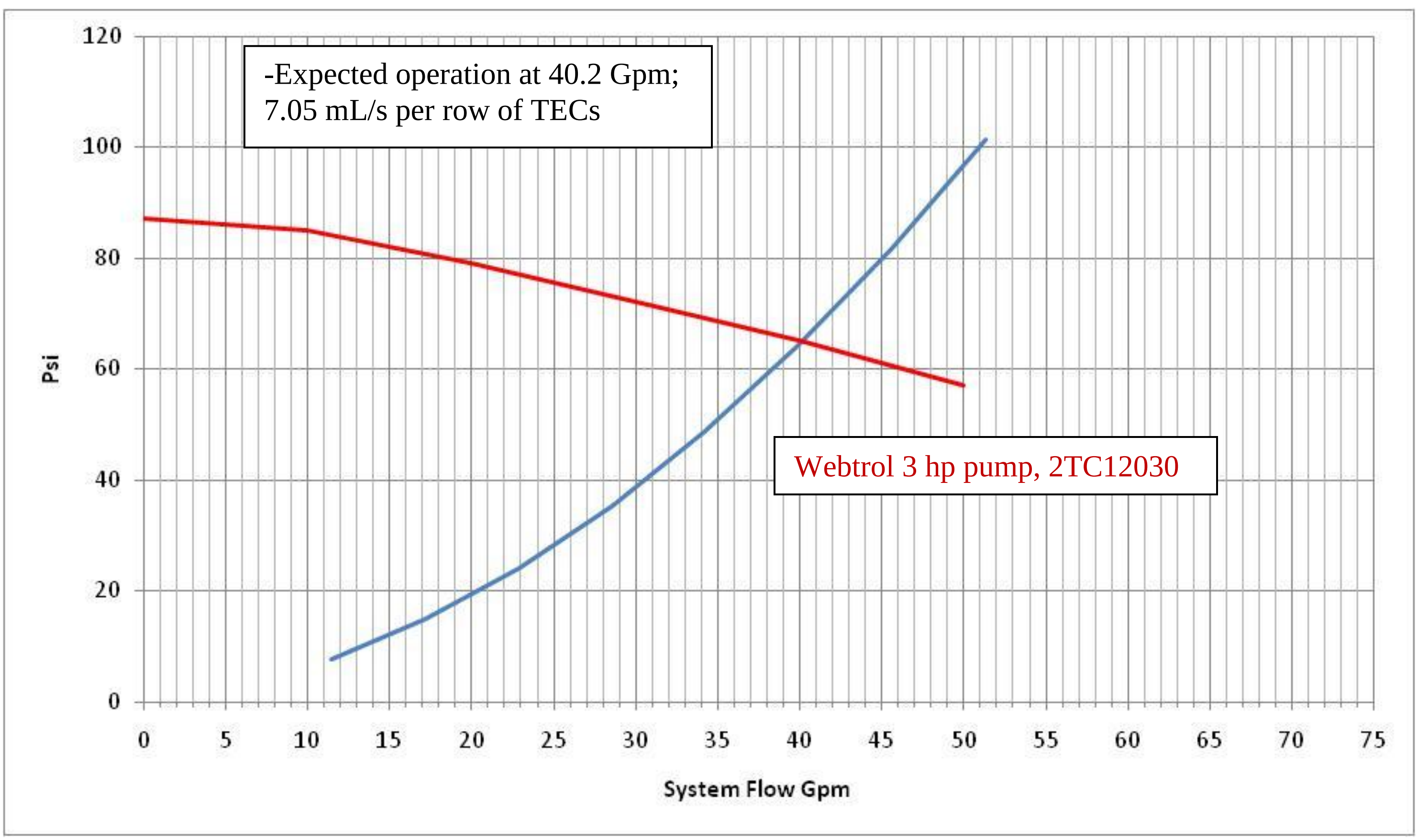
- **Important changes relative to the Near Detector cooling system:**
  - ✓ TEC orifices have been replaced with full port openings.
    - Pressure drop (psi) through 32 TECs as a function of flow (mL/s), as determined by testing:

      $$\Delta P_{TEC}\left(Q_{TEC}\right) := 0.694505219 \cdot Q_{TEC}^{2} + 1.787741560 \cdot Q_{TEC} - 1.338893157$$
  - ✓ TECs are now cooled in series, all 32 per row.
  - ✓ Rather than a supply and return line between each di-block, supply and return lines will alternate with di-blocks. See P&ID below for clarification.
  - ✓ A 10 ton chiller with a turndown ration to 20% has been selected (with backup):
    - Pressure drop (psi) through the chiller as a function of flow (Gpm), as provided by the manufacturer:

      $$\Delta P_{Chiller}\left(Q_{pump}\right) := 0.005009296 \cdot Q_{pump}^{2} - 0.037285672 \cdot Q_{pump} + 1.221136192$$
  - ✓ A Webtrol size 501, 3 hp, high head, 2 stage centrifugal pump has been selected (with backup). See the system curve graph for detail on the pump capabilities.
  - ✓ Rather than a main filter, each di-block supply will be equipped with a wye strainer. The strainer was assumed at a standard mesh for analysis; however a smaller mesh will likely be used causing a negligible rise in total pressure drop.

$$\Delta P_{1wye}\left(Q_{1}\right) := 0.0189 \cdot Q_{1}^{2} + 0.0091 \cdot Q_{1}$$ (Colton Industries)

System and pump curves:



- **Equations used for analysis (Crane):**
  - *Friction factors* are computed by Mathcad by the following relationships which have been extracted from the Moody chart curves for very smooth pipe which merge at relatively low Reynolds #'s (RE).
    - 64/Reynolds # (if Reynolds # < 3,000)
    - 0.3541*$(\text{Reynolds }\#)^{-0.266}$ (if 3,000 < Reynolds # < 35,000)
    - 0.1676*$(\text{Reynolds }\#)^{-0.194}$ (if Reynolds # > 35,000)
  - *Reynolds #*: $50.6 * \frac{\rho * Q}{d * v}$
  - *Pressure drop (pipe):* 0.000216*$\frac{f * L * \rho * Q^2}{d^5}$
  - *Pressure drop (fittings):* 0.00001799*$\frac{K * \rho * Q^2}{d^4}$
  - *Pressure drop (Colder quick disconnects; $c_v = 0.14$):* $\left(\frac{Q}{0.14}\right)^2$
  - *β factor for enlargement or contraction:* $\frac{d_{smaller}}{d_{larger}}$
  - *K factors for fittings:*
    - Tee runs: 20f
    - Tee branches: 60f
    - Elbows: 15f
    - Sudden contraction (θ = 180°): 0.5*$(1-\beta)^2$
    - Sudden enlargement (θ = 180°): $(1-\beta^2)^2$
      - *Note: Reducing tee branch K values are the sum of the tee branch K value and the sudden enlargement or contraction K value.*

Where:

Q = Flow rate, Gpm unless otherwise noted

ρ = density, $\frac{lb}{ft^3}$

d = inner diameter, inches

ν = absolute dynamic viscosity, cp

f = friction factor

L = length, feet

θ = angle of contraction or enlargement, degrees

- **Results of Analysis**
  - *Analysis was done on the system with only the first di-block active, and again with all 15 active.*
  - Running the first di-block only:

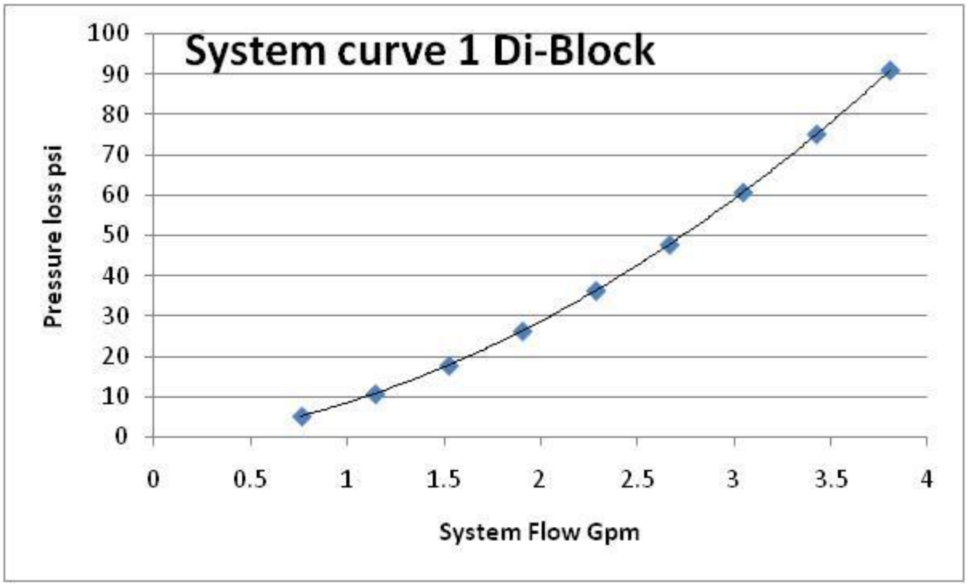


Figure: System curve running only the first di-block. No pump curve is shown due to the excessively low flow rates needed for one di-block; however the 3 hp pump will be present with a main bypass line in order to lower the di-block flow in this situation.

- Max percent difference (within range) in TEC row flow rates: 3.5%

- <u>Running all 15 di-blocks</u>:

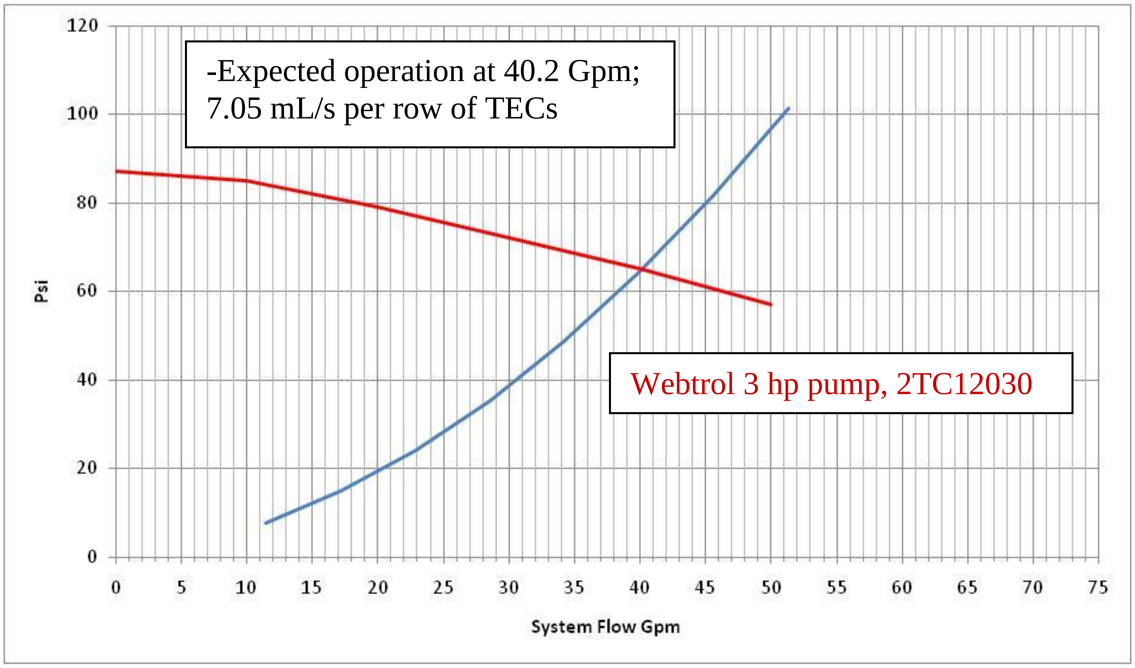


Figure: System and pump curves for the full system as shown previously

- System pressure drop: **65.1 psi**
- Max percent difference (within range) between TEC row flow rates: **3.8%**, with the highest flow reaching the first and last supply (*which I'll refer to as single flow lines since they only have half the typical flow*), and the smallest repeating toward the geometric center of the system.
- System flow: **40.2 Gpm, or 7.05 mL/s per TEC row**. (on average)

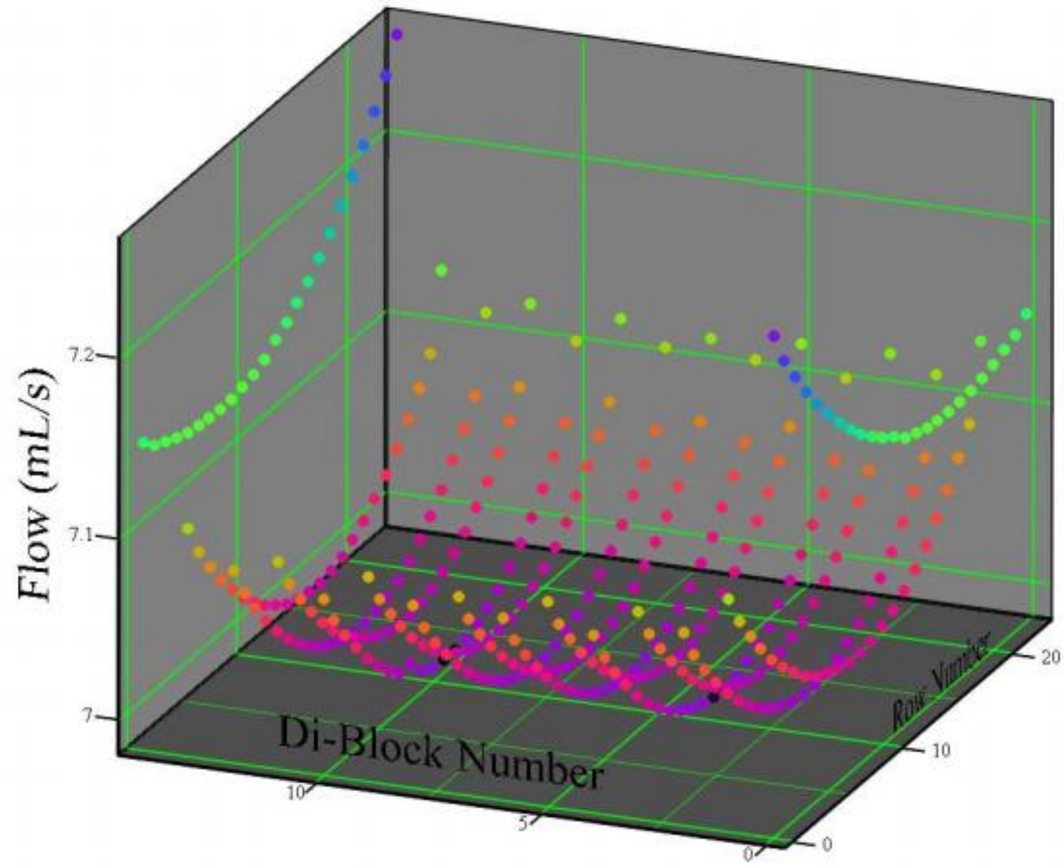
-
- TEC row flow rates 15x24 matrix (di-block number by column, row number by row with matrix row 1 equivalent to the lowest TEC row and vice versa to the top back corner of the detector).

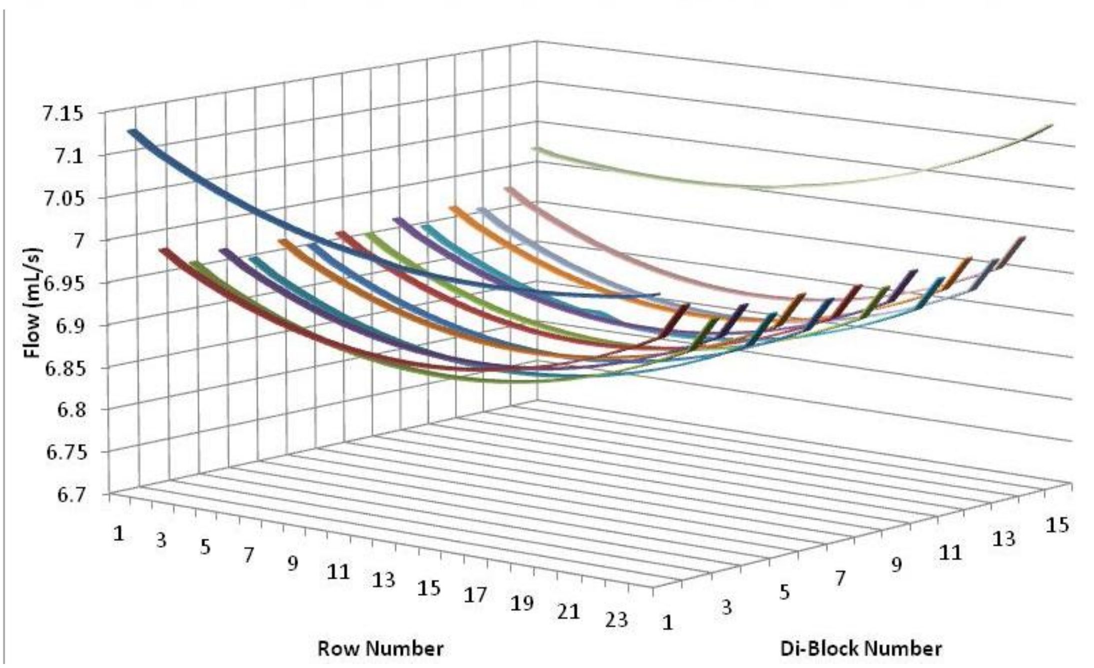
Di-block number 1-15

TEC row number 1-24 (bottom of the detector = top row of matrix)

FlowRates1 =

7.26	7.11	7.09	7.1	7.08	7.09	7.08	7.09	7.08	7.09	7.08	7.1	7.09	7.11	7.15
7.24	7.09	7.07	7.08	7.06	7.08	7.06	7.07	7.06	7.08	7.06	7.08	7.07	7.09	7.14
7.23	7.08	7.06	7.07	7.05	7.06	7.05	7.06	7.05	7.06	7.05	7.06	7.06	7.08	7.14
7.21	7.07	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.06	7.14
7.2	7.06	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.05	7.14
7.19	7.05	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.04	7.13
7.18	7.04	7.02	7.02	7.01	7.02	7.01	7.02	7.01	7.02	7.01	7.02	7.02	7.04	7.13
7.17	7.03	7.01	7.02	7	7.02	7	7.01	7	7.02	7	7.02	7.01	7.03	7.13
7.16	7.03	7	7.01	7	7.01	7	7.01	7	7.01	7	7.01	7	7.02	7.13
7.16	7.02	7	7.01	6.99	7.01	7	7	7	7.01	6.99	7.01	7	7.02	7.14
7.15	7.02	7	7.01	6.99	7	6.99	7	6.99	7	6.99	7.01	7	7.02	7.14
7.15	7.02	7	7	6.99	7	6.99	7	6.99	7	6.99	7	7	7.02	7.14
7.14	7.02	7	7	6.99	7	6.99	7	6.99	7	6.99	7	7	7.02	7.15
7.14	7.02	7	7.01	6.99	7	6.99	7	6.99	7	6.99	7.01	7	7.02	7.15
7.14	7.02	7	7.01	6.99	7.01	7	7	7	7.01	6.99	7.01	7	7.02	7.16
7.13	7.03	7	7.01	7	7.01	7	7.01	7	7.01	7	7.01	7	7.02	7.16
7.13	7.03	7.01	7.02	7	7.02	7	7.01	7	7.02	7	7.02	7.01	7.03	7.17
7.13	7.04	7.02	7.02	7.01	7.02	7.01	7.02	7.01	7.02	7.01	7.02	7.02	7.04	7.18
7.14	7.05	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.04	7.19
7.14	7.06	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.05	7.2
7.14	7.07	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.06	7.21
7.14	7.08	7.06	7.07	7.05	7.06	7.05	7.06	7.05	7.06	7.05	7.06	7.06	7.08	7.23
7.15	7.09	7.07	7.08	7.06	7.08	7.06	7.07	7.06	7.08	7.06	7.08	7.07	7.09	7.24
7.15	7.13	7.11	7.12	7.1	7.12	7.11	7.11	7.11	7.12	7.1	7.12	7.11	7.13	7.26





Figures: The two figures above show the TEC row flow rates within the 24 rows of each of the fifteen di-blocks. They contain the same information but were created with different applications to provide a better visual interpretation; their data sets are perpendicular to each other. Row number one is the bottom of the detector and row 24 is the uppermost corner row. It is easily seen the first and last di-blocks will have a slightly greater TEC flow rate in every row.

Beginning of Mathcad Script

Known Data

-Temperature assumed at 50 degrees F, or 10 degrees C
-density ρ @ 50F is 62.41 lb/ft^3
-Dynamic viscosity @ 50F is 1.3 centipoise

$\rho := 62.41 \ \frac{lb}{ft^3}$ $\upsilon := 1.3$ centipoise $mLsTOgpm := \frac{1}{63.0902}$

Pipe Data (id)

2inch	$d_2 := 1.939$	inches
1.5 inch	$d_{1.5} := 1.5$	inches
1 inch	$d_1 := 0.957$	inches
3/4 inch	$d_{.75} := 0.742$	inches
1/2 inch	$d_{.5} := 0.546$	inches
hose i.d.	$d_{hose} := 0.155$	inches

TEC vs. Flow Q relationship (32 TECs) see NOvA Docdb doc #5772

$$\Delta P_{TEC}(Q_{TEC}) := 0.694505219 Q_{TEC}^{2} + 1.787741561 Q_{TEC} - 1.338893157$$

Friction Factor vs. Reynolds # relationship for PVC pipe

$$f(RE) := \begin{cases} \left(\left(\frac{64}{RE}\right)\right) & \text{if } (RE < 3000) \\ 0.3541 \cdot RE^{-0.266} & \text{if } 2999 < RE < 35000 \\ 0.1676 \cdot RE^{-0.194} & \text{otherwise} \end{cases}$$

Main flow within the 15 di-blocks

$Q_{main} := (7.05)\cdot 24\cdot 15 = 2538 \quad \frac{mL}{s} \quad Q_{main} := Q_{main}\cdot mLsTOgpm = 40.23$ Gpm

$AdjFac_{1main} := 1$

Di-Block single Main line flow $Q_{1main} := \left(\frac{Q_{main}}{15}\right) AdjFac_{1main}$ $Q_{1main} = 2.6819$ Gpm

Di-Block double Main line flow $Q_{1mainS} := \left(\frac{Q_{main}}{7.5}\right) AdjFac_{1main}$ $Q_{1mainS} = 5.3637$ Gpm

TEC row

TEC row flow (Gpm) $Q_{1row_{1,1}} = 0.1117$

TEC row Reynolds # $RE_{1TEC_{1,1}} = 1751.2851$

TEC row ΔP (psi) $\Delta P_{1TEC_{1,1}} = 45.7833$

di-block supply section flow rates

Di-Block supply section flow rates, double/single flow (Gpm)

$Q_{1M\_DBS2} =$

0	0
1	5.3637
2	5.1403
3	4.9168
4	4.6933
5	4.4698
6	4.2463
7	4.0228
8	3.7993
9	3.5758
10	3.3523
11	3.1289
12	2.9054
13	2.6819
14	2.4584
15	2.2349
16	2.0114
17	1.7879
18	1.5644
19	1.3409
20	1.1174
21	0.894
22	0.6705
23	0.447
24	0.2235
0	0

$Q_{1M\_DBS} =$

0	0
1	2.6819
2	2.5701
3	2.4584
4	2.3466
5	2.2349
6	2.1232
7	2.0114
8	1.8997
9	1.7879
10	1.6762
11	1.5644
12	1.4527
13	1.3409
14	1.2292
15	1.1174
16	1.0057
17	0.894
18	0.7822
19	0.6705
20	0.5587
21	0.447
22	0.3352
23	0.2235
24	0.1117
0	0

di-block return section flow rates

Di-Block return section flow rates, double/single flow (Gpm)

$Q_{1M\_DBR2} =$

0	0
1	0.2235
2	0.447
3	0.6705
4	0.894
5	1.1174
6	1.3409
7	1.5644
8	1.7879
9	2.0114
10	2.2349
11	2.4584
12	2.6819
13	2.9054
14	3.1289
15	3.3523
16	3.5758
17	3.7993
18	4.0228
19	4.2463
20	4.4698
21	4.6933
22	4.9168
23	5.1403
24	5.3637
25	0

$Q_{1M\_DBR} =$

0	0
1	0.1117
2	0.2235
3	0.3352
4	0.447
5	0.5587
6	0.6705
7	0.7822
8	0.894
9	1.0057
10	1.1174
11	1.2292
12	1.3409
13	1.4527
14	1.5644
15	1.6762
16	1.7879
17	1.8997
18	2.0114
19	2.1232
20	2.2349
21	2.3466
22	2.4584
23	2.5701
24	2.6819
25	0

di-block supply/return section diameters

Di-block supply/return section diamter's (inch) All 3/4" nom. dia.

Matrix is compressed with all elements set to the i.d. of .75 sch. 80 pipe di-block supply/return reynolds #

Di-block supply/return reynolds #'s, double/single flow

ɔuble flow supply/return

$RE_{1M\_DBS2} =$

0	0
1	17560.0558
2	16828.3868
3	16096.7178
4	15365.0488
5	14633.3798
6	13901.7109
7	13170.0419
8	12438.3729
9	11706.7039
10	10975.0349
11	10243.3659
12	9511.6969
13	8780.0279
14	8048.3589
15	7316.6899
16	6585.0209
17	5853.3519
18	5121.6829
19	4390.014
20	3658.345
21	2926.676
22	2195.007
23	1463.338
24	731.669

$RE_{1M\_DBR2} =$

0	0
1	731.669
2	1463.338
3	2195.007
4	2926.676
5	3658.345
6	4390.014
7	5121.6829
8	5853.3519
9	6585.0209
10	7316.6899
11	8048.3589
12	8780.0279
13	9511.6969
14	10243.3659
15	10975.0349
16	11706.7039
17	12438.3729
18	13170.0419
19	13901.7109
20	14633.3798
21	15365.0488
22	16096.7178
23	16828.3868
24	17560.0558

single flow supply/return

$$RE_{1M\_DBS} = \begin{pmatrix} 0 & 0 \\ 1 & 8780.0279 \\ 2 & 8414.1934 \\ 3 & 8048.3589 \\ 4 & 7682.5244 \\ 5 & 7316.6899 \\ 6 & 6950.8554 \\ 7 & 6585.0209 \\ 8 & 6219.1864 \\ 9 & 5853.3519 \\ 10 & 5487.5174 \\ 11 & 5121.6829 \\ 12 & 4755.8485 \\ 13 & 4390.014 \\ 14 & 4024.1795 \\ 15 & 3658.345 \\ 16 & 3292.5105 \\ 17 & 2926.676 \\ 18 & 2560.8415 \\ 19 & 2195.007 \\ 20 & 1829.1725 \\ 21 & 1463.338 \\ 22 & 1097.5035 \\ 23 & 731.669 \\ 24 & 365.8345 \end{pmatrix} \qquad RE_{1M\_DBR} = \begin{pmatrix} 0 & 0 \\ 1 & 365.8345 \\ 2 & 731.669 \\ 3 & 1097.5035 \\ 4 & 1463.338 \\ 5 & 1829.1725 \\ 6 & 2195.007 \\ 7 & 2560.8415 \\ 8 & 2926.676 \\ 9 & 3292.5105 \\ 10 & 3658.345 \\ 11 & 4024.1795 \\ 12 & 4390.014 \\ 13 & 4755.8485 \\ 14 & 5121.6829 \\ 15 & 5487.5174 \\ 16 & 5853.3519 \\ 17 & 6219.1864 \\ 18 & 6585.0209 \\ 19 & 6950.8554 \\ 20 & 7316.6899 \\ 21 & 7682.5244 \\ 22 & 8048.3589 \\ 23 & 8414.1934 \\ 24 & 8780.0279 \end{pmatrix}$$

▶ di-block supply/return section lengths

Di-block supply/return section lengths (feet): Di-block supply/return section lengths (feet): all about 50 inches with the exeption of first and last sections which will be partially neglected

▶ di-block supply/return section pressure drops

Di-Block supply/return ΔP's, double/single flow (psi)

double flow

$\Delta P_{1M\_DBS2} =$

0	0
1	0.2268
2	0.165
3	0.1528
4	0.141
5	0.1295
6	0.1185
7	0.1079
8	0.0977
9	0.088
10	0.0786
11	0.0698
12	0.0614
13	0.1068
14	0.0459
15	0.0389
16	0.0324
17	0.0264
18	0.021
19	0.0161
20	0.0117
21	0.0041
22	0.0031
23	0.0021
24	0.0021

$\Delta P_{1M\_DBR2} =$

0	0
1	0.001
2	0.0021
3	0.0031
4	0.0041
5	0.0117
6	0.0161
7	0.021
8	0.0264
9	0.0324
10	0.0389
11	0.0459
12	0.1068
13	0.0614
14	0.0698
15	0.0786
16	0.088
17	0.0977
18	0.1079
19	0.1185
20	0.1295
21	0.141
22	0.1528
23	0.165
24	0.1777

single flow

$$\Delta P_{1M\_DBS} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0682 \\ 2 & 0.0496 \\ 3 & 0.0459 \\ 4 & 0.0424 \\ 5 & 0.0389 \\ 6 & 0.0356 \\ 7 & 0.0324 \\ 8 & 0.0294 \\ 9 & 0.0264 \\ 10 & 0.0236 \\ 11 & 0.021 \\ 12 & 0.0184 \\ 13 & 0.0321 \\ 14 & 0.0138 \\ 15 & 0.0117 \\ 16 & 0.0098 \\ 17 & 0.0041 \\ 18 & 0.0036 \\ 19 & 0.0031 \\ 20 & 0.0026 \\ 21 & 0.0021 \\ 22 & 0.0015 \\ 23 & 0.001 \\ 24 & 0.001 \end{pmatrix} \qquad \Delta P_{1M\_DBR} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0005 \\ 2 & 0.001 \\ 3 & 0.0015 \\ 4 & 0.0021 \\ 5 & 0.0026 \\ 6 & 0.0031 \\ 7 & 0.0036 \\ 8 & 0.0041 \\ 9 & 0.0098 \\ 10 & 0.0117 \\ 11 & 0.0138 \\ 12 & 0.0321 \\ 13 & 0.0184 \\ 14 & 0.021 \\ 15 & 0.0236 \\ 16 & 0.0264 \\ 17 & 0.0294 \\ 18 & 0.0324 \\ 19 & 0.0356 \\ 20 & 0.0389 \\ 21 & 0.0424 \\ 22 & 0.0459 \\ 23 & 0.0496 \\ 24 & 0.0534 \end{pmatrix}$$

▶ β's for di-block supply/return

β's di-block supply/return tee's

assume Θ = 180 degrees for contraction/expansion $\Theta := 180$

$\beta_{1DBS\_T_{1,1}} = 0.2089$ for all tee's supply and return

▶ K factors di-block supply/return

K factor's di-block supply/return tee runs, double and single flow

double flow | single flow

	$K_{1DBSrun2}$	$K_{1DBRrun2}$	$K_{1DBSrun}$	$K_{1DBRrun}$
0	0	0	0	0
1	0.529	1.3121	0.636	2.6241
2	0.535	1.1663	0.643	2.3326
3	0.541	0.6998	0.651	1.3995
4	0.548	0.4998	0.659	0.9997
5	0.556	0.8213	0.668	0.7775
6	0.563	0.7786	0.678	0.6362
7	0.572	0.7448	0.688	0.5383
8	0.581	0.7169	0.699	0.4665
9	0.591	0.6935	0.710	0.8339
10	0.601	0.6732	0.723	0.8096
11	0.613	0.6556	0.737	0.7883
12	0.625	0.6399	0.752	0.7694
13	0.639	0.6258	0.769	0.7526
14	0.655	0.6132	0.788	0.7373
15	0.673	0.6016	0.809	0.7234
16	0.693	0.591	0.833	0.7107
17	0.716	0.5813	0.466	0.699
18	0.744	0.5723	0.538	0.6881
19	0.778	0.5639	0.636	0.678
20	0.821	0.556	0.777	0.6686
21	0.499	0.5487	0.999	0.6598
22	0.699	0.5418	1.399	0.6515
23	1.166	0.5353	2.332	0.6436
24	1.312	0.3946	2.624	0.4745

▶ Pressure drops di-blockl supply/return tee runs

ΔP's di-block supply/return tee runs, double and single flow (psi)

double flow

$$\Delta P_{1DBSrun2} = \begin{pmatrix} 0 & 0 \\ 1 & 0.1081 \\ 2 & 0.1003 \\ 3 & 0.0927 \\ 4 & 0.0853 \\ 5 & 0.0782 \\ 6 & 0.0714 \\ 7 & 0.0648 \\ 8 & 0.0586 \\ 9 & 0.0525 \\ 10 & 0.0468 \\ 11 & 0.0413 \\ 12 & 0.0362 \\ 13 & 0.0313 \\ 14 & 0.0267 \\ 15 & 0.0225 \\ 16 & 0.0185 \\ 17 & 0.0149 \\ 18 & 0.0116 \\ 19 & 0.0087 \\ 20 & 0.0062 \\ 21 & 0.0023 \\ 22 & 0.0016 \\ 23 & 0.001 \\ 24 & 0.0005 \end{pmatrix}$$

$$\Delta P_{1DBRrun2} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0005 \\ 2 & 0.001 \\ 3 & 0.0016 \\ 4 & 0.0023 \\ 5 & 0.0062 \\ 6 & 0.0087 \\ 7 & 0.0116 \\ 8 & 0.0149 \\ 9 & 0.0185 \\ 10 & 0.0225 \\ 11 & 0.0267 \\ 12 & 0.0313 \\ 13 & 0.0362 \\ 14 & 0.0413 \\ 15 & 0.0468 \\ 16 & 0.0525 \\ 17 & 0.0586 \\ 18 & 0.0648 \\ 19 & 0.0714 \\ 20 & 0.0782 \\ 21 & 0.0853 \\ 22 & 0.0927 \\ 23 & 0.1003 \\ 24 & 0.0806 \end{pmatrix}$$

single flow

$$\Delta P_{1DBSrun} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0163 \\ 2 & 0.0151 \\ 3 & 0.0139 \\ 4 & 0.0128 \\ 5 & 0.0118 \\ 6 & 0.0107 \\ 7 & 0.0097 \\ 8 & 0.0088 \\ 9 & 0.0079 \\ 10 & 0.007 \\ 11 & 0.0062 \\ 12 & 0.0054 \\ 13 & 0.0047 \\ 14 & 0.004 \\ 15 & 0.0034 \\ 16 & 0.0028 \\ 17 & 0.0012 \\ 18 & 0.0011 \\ 19 & 0.0009 \\ 20 & 0.0007 \\ 21 & 0.0006 \\ 22 & 0.0004 \\ 23 & 0.0002 \\ 24 & 0.0001 \end{pmatrix} \qquad \Delta P_{1DBRrun} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0001 \\ 2 & 0.0002 \\ 3 & 0.0004 \\ 4 & 0.0006 \\ 5 & 0.0007 \\ 6 & 0.0009 \\ 7 & 0.0011 \\ 8 & 0.0012 \\ 9 & 0.0028 \\ 10 & 0.0034 \\ 11 & 0.004 \\ 12 & 0.0047 \\ 13 & 0.0054 \\ 14 & 0.0062 \\ 15 & 0.007 \\ 16 & 0.0079 \\ 17 & 0.0088 \\ 18 & 0.0097 \\ 19 & 0.0107 \\ 20 & 0.0118 \\ 21 & 0.0128 \\ 22 & 0.0139 \\ 23 & 0.0151 \\ 24 & 0.0121 \end{pmatrix}$$

▶ K factors, di-block supply/return tee banches

K factor's di-block supply/return tee branches

Di-Block supply/return tee branch
assume a sudden contraction/exp
(with Θ = 180)

$K_{1DBSbranch}$ =

0	0
1	2.6709
2	2.6709
3	2.6709
4	2.6709
5	2.6709
6	2.6709
7	2.6709
8	2.6709
9	2.6709
10	2.6709
11	2.6709
12	2.6709
13	2.6709
14	2.6709
15	2.6709
16	2.6709
17	2.6709
18	2.6709
19	2.6709
20	2.6709
21	2.6709
22	2.6709
23	2.6709
24	0.4782

$K_{1DBRbranch}$ =

0	0
1	0.9146
2	3.1073
3	3.1073
4	3.1073
5	3.1073
6	3.1073
7	3.1073
8	3.1073
9	3.1073
10	3.1073
11	3.1073
12	3.1073
13	3.1073
14	3.1073
15	3.1073
16	3.1073
17	3.1073
18	3.1073
19	3.1073
20	3.1073
21	3.1073
22	3.1073
23	3.1073
24	3.1073

▸ Pressure drop di-block supply/return branches

ΔP's di-block supply/return tee branches (psi)

$$\Delta P_{1DBSbranch} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0649 \\ 2 & 0.0649 \\ 3 & 0.0649 \\ 4 & 0.0649 \\ 5 & 0.0649 \\ 6 & 0.0649 \\ 7 & 0.0649 \\ 8 & 0.0649 \\ 9 & 0.0649 \\ 10 & 0.0649 \\ 11 & 0.0649 \\ 12 & 0.0649 \\ 13 & 0.0649 \\ 14 & 0.0649 \\ 15 & 0.0649 \\ 16 & 0.0649 \\ 17 & 0.0649 \\ 18 & 0.0649 \\ 19 & 0.0649 \\ 20 & 0.0649 \\ 21 & 0.0649 \\ 22 & 0.0649 \\ 23 & 0.0649 \\ 24 & 0.0116 \end{pmatrix} \qquad \Delta P_{1DBRbranch} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0222 \\ 2 & 0.0755 \\ 3 & 0.0755 \\ 4 & 0.0755 \\ 5 & 0.0755 \\ 6 & 0.0755 \\ 7 & 0.0755 \\ 8 & 0.0755 \\ 9 & 0.0755 \\ 10 & 0.0755 \\ 11 & 0.0755 \\ 12 & 0.0755 \\ 13 & 0.0755 \\ 14 & 0.0755 \\ 15 & 0.0755 \\ 16 & 0.0755 \\ 17 & 0.0755 \\ 18 & 0.0755 \\ 19 & 0.0755 \\ 20 & 0.0755 \\ 21 & 0.0755 \\ 22 & 0.0755 \\ 23 & 0.0755 \\ 24 & 0.0755 \end{pmatrix}$$

▸ Pressure loss across row connections

ΔP of the 12" connection hoses and valved disconnects (psi)

disconnects: [Cv = 0.14] (2 per row)

$$\Delta P_{1rowCNC} = \begin{pmatrix} 0 & 0 \\ 1 & 1.4117 \\ 2 & 1.4117 \\ 3 & 1.4117 \\ 4 & 1.4117 \\ 5 & 1.4117 \\ 6 & 1.4117 \\ 7 & 1.4117 \\ 8 & 1.4117 \\ 9 & 1.4117 \\ 10 & 1.4117 \\ 11 & 1.4117 \\ 12 & 1.4117 \\ 13 & 1.4117 \\ 14 & 1.4117 \\ 15 & 1.4117 \\ 16 & 1.4117 \\ 17 & 1.4117 \\ 18 & 1.4117 \\ 19 & 1.4117 \\ 20 & 1.4117 \\ 21 & 1.4117 \\ 22 & 1.4117 \\ 23 & 1.4117 \\ 24 & 1.4117 \end{pmatrix}$$

Wye strainer flow v. ΔP relationship, di-block supply, double/single flow (psi)

$$\Delta P_{1wye}(Q_1) := 0.0189 \cdot Q_1^{\,2} + 0.0091 Q_1$$

Double flow

$$\Delta P_{1wye}\left(Q_{1mainS}\right) = 0.5926$$

Single flow

$$\Delta P_{1wye}\left(Q_{1main}\right) = 0.1603$$

Di-Block valves ΔP (psi)

$$K_{DBvalve} := 3 \cdot f\left(RE_{1M\_DBS2_{1,1}}\right)$$

$$\Delta P_{1DBvalve} := 0.00001799 \cdot \left[\frac{\left[K_{DBvalve} \cdot \rho \cdot \left[\left(Q_{1main}\right)^2\right]\right]}{\left(d_{1M\_DBS_{1,1}}\right)^4}\right] = 0.0021$$

$$\Delta P_{1DBvalve} = 0.0021$$

*Single and double flow conditions will be neglected here

▶ Total pressure losses within a di-block

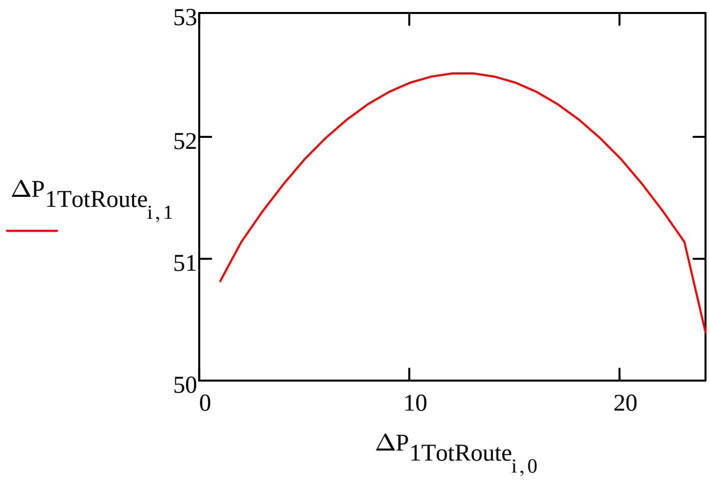
Total Pressure loss within a di-block (psi)

Double flow route (di-blocks 2 - 15Right)

$i := 1, 2 .. 24$

$\Delta P_{1TotRoute} =$

0	0
1	50.8118
2	51.1323
3	51.3782
4	51.6031
5	51.8061
6	51.9802
7	52.13
8	52.2552
9	52.3555
10	52.4309
11	52.4812
12	52.5064
13	52.5064
14	52.4812
15	52.4309
16	52.3555
17	52.2552
18	52.13
19	51.9802
20	51.8061
21	51.6031
22	51.3782
23	51.1323
24	50.3943



$\Delta P_{1max} := \Delta P_{1TotRoute_{12,1}}$

$\Delta P_{1min} := \Delta P_{1TotRoute_{2,4\ ,\ \ 1}}$

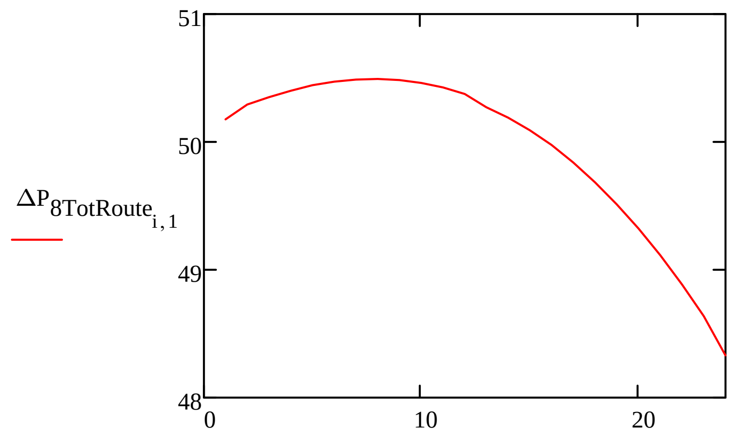
$$PercentDiff_{\Delta P} := \frac{(\Delta P_{1max} - \Delta P_{1min})}{\left[\frac{(\Delta P_{1max} + \Delta P_{1min})}{2}\right]} = 3.2803 \cdot \%$$

Percentage flow difference within a double flow Di-Block

$$\sqrt{1 + PercentDiff_{\Delta P}} - 1 = 1.6269 \cdot \%$$

Single flow only (di-block 1)

$$\Delta P_{8TotRoute} = \begin{pmatrix} 0 & 0 \\ 1 & 50.175 \\ 2 & 50.2915 \\ 3 & 50.3486 \\ 4 & 50.3993 \\ 5 & 50.4423 \\ 6 & 50.47 \\ 7 & 50.4864 \\ 8 & 50.4908 \\ 9 & 50.4824 \\ 10 & 50.4606 \\ 11 & 50.4246 \\ 12 & 50.374 \\ 13 & 50.2706 \\ 14 & 50.1886 \\ 15 & 50.0902 \\ 16 & 49.9747 \\ 17 & 49.8373 \\ 18 & 49.6826 \\ 19 & 49.5106 \\ 20 & 49.3207 \\ 21 & 49.1121 \\ 22 & 48.8842 \\ 23 & 48.6363 \\ 24 & 48.3288 \end{pmatrix}$$



$$\Delta P_{8max} := \Delta P_{8TotRoute_{8,1}}$$

$$\Delta P_{8min} := \Delta P_{8TotRoute_{24,1}}$$

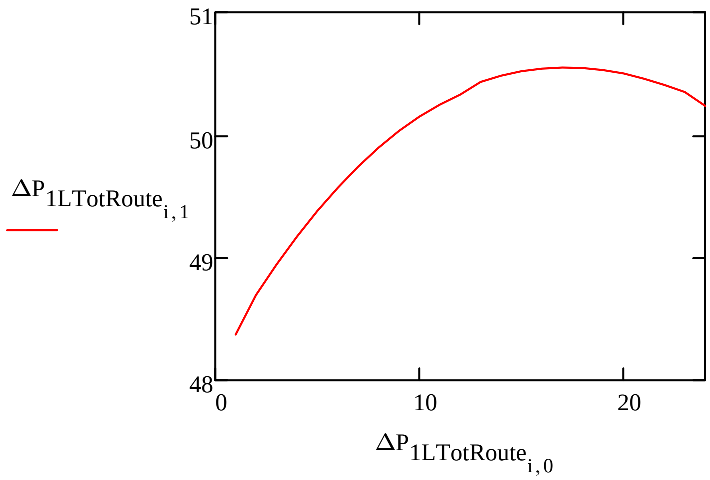
$$PercentDiff_{\Delta P8} := \frac{\left(\Delta P_{8max} - \Delta P_{8min}\right)}{\left[\frac{\left(\Delta P_{8max} + \Delta P_{8min}\right)}{2}\right]} = 4.3757 \cdot \%$$

Percentage flow difference within di-block 1 (single flow supply)

$$\sqrt{1 + PercentDiff_{\Delta P8}} - 1 = 2.1644 \cdot \%$$

Single flow (di-block 15 left route)

$$\Delta P_{1LTotRoute} = \begin{pmatrix} 0 & 0 \\ 1 & 48.3722 \\ 2 & 48.694 \\ 3 & 48.9419 \\ 4 & 49.1698 \\ 5 & 49.3784 \\ 6 & 49.5683 \\ 7 & 49.7403 \\ 8 & 49.895 \\ 9 & 50.0324 \\ 10 & 50.1479 \\ 11 & 50.2463 \\ 12 & 50.3283 \\ 13 & 50.4317 \\ 14 & 50.4824 \\ 15 & 50.5183 \\ 16 & 50.5401 \\ 17 & 50.5485 \\ 18 & 50.5441 \\ 19 & 50.5277 \\ 20 & 50.5 \\ 21 & 50.4571 \\ 22 & 50.4063 \\ 23 & 50.3492 \\ 24 & 50.2358 \end{pmatrix}$$



$$\Delta P_{1Lmax} := \Delta P_{1LTotRoute_{18,1}}$$

$$\Delta P_{1Lmin} := \Delta P_{1LTotRoute_{1,1}}$$

$$PercentDiff_{\Delta P1L} := \frac{\left(\Delta P_{1Lmax} - \Delta P_{1Lmin}\right)}{\left[\frac{\left(\Delta P_{1Lmax} + \Delta P_{1Lmin}\right)}{2}\right]} = 4.3914 \cdot \%$$

Percentage flow difference within di-block 15Left (single flow on left route only)

$$\sqrt{1 + PercentDiff_{\Delta P1L}} - 1 = 2.1721 \cdot \%$$

Main supply and return (outside the di-blocks)

Main supply/return flow

Main supply/return section flow (Gpm)

$$Q_{MSpipe} = \begin{pmatrix} 0 & 0 \\ 1 & 40.2281 \\ 2 & 37.5462 \\ 3 & 32.1825 \\ 4 & 26.8187 \\ 5 & 21.455 \\ 6 & 16.0912 \\ 7 & 10.7275 \\ 8 & 5.3637 \end{pmatrix} \qquad Q_{MRpipe} = \begin{pmatrix} 0 & 0 \\ 1 & 5.3637 \\ 2 & 10.7275 \\ 3 & 16.0912 \\ 4 & 21.455 \\ 5 & 26.8187 \\ 6 & 32.1825 \\ 7 & 34.8644 \\ 8 & 40.2281 \end{pmatrix}$$

Main supply/return section Reynolds #'s

Main supply/return section Reynolds #'s

$$RE_{1MSpipe} = \begin{pmatrix} 0 & 0 \\ 1 & 50397.9941 \\ 2 & 47038.1279 \\ 3 & 40318.3953 \\ 4 & 33598.6628 \\ 5 & 26878.9302 \\ 6 & 26059.1228 \\ 7 & 17372.7486 \\ 8 & 8686.3743 \end{pmatrix} \qquad RE_{1MRpipe} = \begin{pmatrix} 0 & 0 \\ 1 & 8686.3743 \\ 2 & 17372.7486 \\ 3 & 26059.1228 \\ 4 & 26878.9302 \\ 5 & 33598.6628 \\ 6 & 40318.3953 \\ 7 & 43678.2616 \\ 8 & 50397.9941 \end{pmatrix}$$

Main supply/return section Length's (feet)

$$L_{1MSpipe} := \begin{pmatrix} 0 & 0 \\ 1 & 100 \\ 2 & 24 \\ 3 & 24 \\ 4 & 24 \\ 5 & 24 \\ 6 & 24 \\ 7 & 24 \\ 8 & 24 \end{pmatrix} \qquad L_{1MRpipe} := \begin{pmatrix} 0 & 0 \\ 1 & 24 \\ 2 & 24 \\ 3 & 24 \\ 4 & 24 \\ 5 & 24 \\ 6 & 24 \\ 7 & 24 \\ 8 & 60 \end{pmatrix}$$

ΔP's main supply/return sections

Main supply/return section pressure drops (psi)

$$\Delta P_{1MRpipe} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0389 \\ 2 & 0.1294 \\ 3 & 0.2613 \\ 4 & 0.1276 \\ 5 & 0.1879 \\ 6 & 0.2619 \\ 7 & 0.3026 \\ 8 & 0.9796 \end{pmatrix} \qquad \Delta P_{1MSpipe} = \begin{pmatrix} 0 & 0 \\ 1 & 1.6326 \\ 2 & 0.3459 \\ 3 & 0.2619 \\ 4 & 0.1879 \\ 5 & 0.1276 \\ 6 & 0.2613 \\ 7 & 0.1294 \\ 8 & 0.0389 \end{pmatrix}$$

▶ Main supply/return valve K factors

Main supply/return valve K factors

$$K_{MSvalve} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0624 \\ 2 & 0.0643 \\ 3 & 0.0664 \\ 4 & 0.0705 \\ 5 & 0.0711 \\ 6 & 0.0791 \\ 7 & 0.0952 \end{pmatrix} \qquad K_{MRvalve} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0791 \\ 2 & 0.0711 \\ 3 & 0.0705 \\ 4 & 0.0664 \\ 5 & 0.0643 \\ 6 & 0.0633 \\ 7 & 0.0615 \end{pmatrix}$$

▶ Main supply/return valve pressure drops

Main supply/return valve pressure drops (psi)

$$\Delta P_{1MRvalve} = \begin{pmatrix} 0 & 0 \\ 1 & 0.002 \\ 2 & 0.0041 \\ 3 & 0.0072 \\ 4 & 0.0038 \\ 5 & 0.0053 \\ 6 & 0.0061 \\ 7 & 0.0079 \end{pmatrix} \qquad \Delta P_{1MSvalve} = \begin{pmatrix} 0 & 0 \\ 1 & 0.007 \\ 2 & 0.0053 \\ 3 & 0.0038 \\ 4 & 0.0026 \\ 5 & 0.0041 \\ 6 & 0.002 \\ 7 & 0.0006 \end{pmatrix}$$

▶ Main supply/return tee run reynolds #'s

Main supply/return tee run Reynolds #'s

$$RE_{MStrun} = \begin{pmatrix} 0 & 0 \\ 1 & 50397.9941 \\ 2 & 47038.1279 \\ 3 & 40318.3953 \\ 4 & 33598.6628 \\ 5 & 26878.9302 \\ 6 & 26059.1228 \\ 7 & 17372.7486 \\ 8 & 8686.3743 \end{pmatrix} \qquad RE_{MRtrun} = \begin{pmatrix} 0 & 0 \\ 1 & 8686.3743 \\ 2 & 17372.7486 \\ 3 & 26059.1228 \\ 4 & 26878.9302 \\ 5 & 33598.6628 \\ 6 & 40318.3953 \\ 7 & 43678.2616 \\ 8 & 50397.9941 \end{pmatrix}$$

▶ Main supply/return tee run K factors

Main supply/return tee run K factor's

$$K_{MStrun} = \begin{pmatrix} 0 & 0 \\ 1 & 0.4102 \\ 2 & 0.4158 \\ 3 & 0.4284 \\ 4 & 0.4427 \\ 5 & 0.4698 \\ 6 & 0.4737 \\ 7 & 0.5277 \\ 8 & 0.9517 \end{pmatrix} \qquad K_{MRtrun} = \begin{pmatrix} 0 & 0 \\ 1 & 0.9517 \\ 2 & 0.5277 \\ 3 & 0.4737 \\ 4 & 0.4698 \\ 5 & 0.4427 \\ 6 & 0.4284 \\ 7 & 0.4218 \\ 8 & 0.4102 \end{pmatrix}$$

▶ Main supply/return tee run ΔP's

Main supply/return tee run pressure drops (psi)

$$\Delta P_{MStrun} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0527 \\ 2 & 0.0466 \\ 3 & 0.0352 \\ 4 & 0.0253 \\ 5 & 0.0172 \\ 6 & 0.0272 \\ 7 & 0.0135 \\ 8 & 0.0061 \end{pmatrix} \qquad \Delta P_{MRtrun} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0061 \\ 2 & 0.0135 \\ 3 & 0.0272 \\ 4 & 0.0172 \\ 5 & 0.0253 \\ 6 & 0.0352 \\ 7 & 0.0407 \\ 8 & 0.0527 \end{pmatrix}$$

▶ β's main supply/return tee branches

Main supply/return tee branch β's

$$\beta_{MStbranch} = \begin{pmatrix} 0 & 0 \\ 1 & 0.3827 \\ 2 & 0.3827 \\ 3 & 0.3827 \\ 4 & 0.3827 \\ 5 & 0.3827 \\ 6 & 0.4947 \\ 7 & 0.4947 \\ 8 & 0.4947 \end{pmatrix} \qquad \beta_{MRtbranch} = \begin{pmatrix} 0 & 0 \\ 1 & 0.4947 \\ 2 & 0.4947 \\ 3 & 0.4947 \\ 4 & 0.3827 \\ 5 & 0.3827 \\ 6 & 0.3827 \\ 7 & 0.3827 \\ 8 & 0.3827 \end{pmatrix}$$

Main supply/return tee branch K's

Main supply/return tee branch K's

$$K_{MStbranch} = \begin{pmatrix} 0 & 0 \\ 1 & 2.0052 \\ 2 & 2.0052 \\ 3 & 2.0052 \\ 4 & 2.0052 \\ 5 & 2.0052 \\ 6 & 1.9561 \\ 7 & 1.9561 \\ 8 & 0.3777 \end{pmatrix} \qquad K_{MRtbranch} = \begin{pmatrix} 0 & 0 \\ 1 & 0.5705 \\ 2 & 2.1489 \\ 3 & 2.1489 \\ 4 & 2.307 \\ 5 & 2.307 \\ 6 & 2.307 \\ 7 & 2.307 \\ 8 & 2.307 \end{pmatrix}$$

Main supply/return tee branch pressure drops

Main supply/return tee branch pressure drops (psi)

$$\Delta P_{MStbranch} = \begin{pmatrix} 0 & 0 \\ 1 & 0.2137 \\ 2 & 0.2137 \\ 3 & 0.2137 \\ 4 & 0.2137 \\ 5 & 0.2137 \\ 6 & 0.2084 \\ 7 & 0.2084 \\ 8 & 0.0101 \end{pmatrix} \qquad \Delta P_{MRtbranch} = \begin{pmatrix} 0 & 0 \\ 1 & 0.0152 \\ 2 & 0.229 \\ 3 & 0.229 \\ 4 & 0.2458 \\ 5 & 0.2458 \\ 6 & 0.2458 \\ 7 & 0.2458 \\ 8 & 0.2458 \end{pmatrix}$$

Main supply/return elbows pressure drop (psi)

$$\Delta P_{MSRelbows} := 0.00001799 \cdot \left[\frac{\left[30 \cdot f\left(RE1_{MSpipe_{1,1}}\right) \cdot \rho \cdot \left[\left(Q_{MSpipe_{1,1}}\right)^2\right]\right]}{\left(d_2\right)^4} \right]$$

$$\Delta P_{MSRelbows} = 0.0791$$

Chiller: Flow v. ΔP relationship (Gpm v. psi)

$$\Delta P_{Pump}\left(Q_{pump}\right) := 0.005009296 Q_{pump}^{\ 2} - 0.037285672 Q_{pump} + 1.221136192$$

$$\Delta P_{Pump}\left(Q_{MSpipe_{1,1}}\right) = 7.8278 \quad \text{psi}$$

Main supply/return route pressure losses

Main supply/return route pressure losses based on right/left and di-block supply # (psi)

$\Delta P_{M1L} = 13.047$ $\Delta P_{M1R} = 13.2101$

$\Delta P_{M2L} = 13.6127$ $\Delta P_{M2R} = 13.4589$

$\Delta P_{M3L} = 13.7669$ $\Delta P_{M3R} = 13.4931$

$\Delta P_{M4L} = 13.7151$ $\Delta P_{M4R} = 13.5625$

$\Delta P_{M5L} = 13.7139$ $\Delta P_{M5R} = 13.4904$

$\Delta P_{M6L} = 13.7727$ $\Delta P_{M6R} = 13.4668$

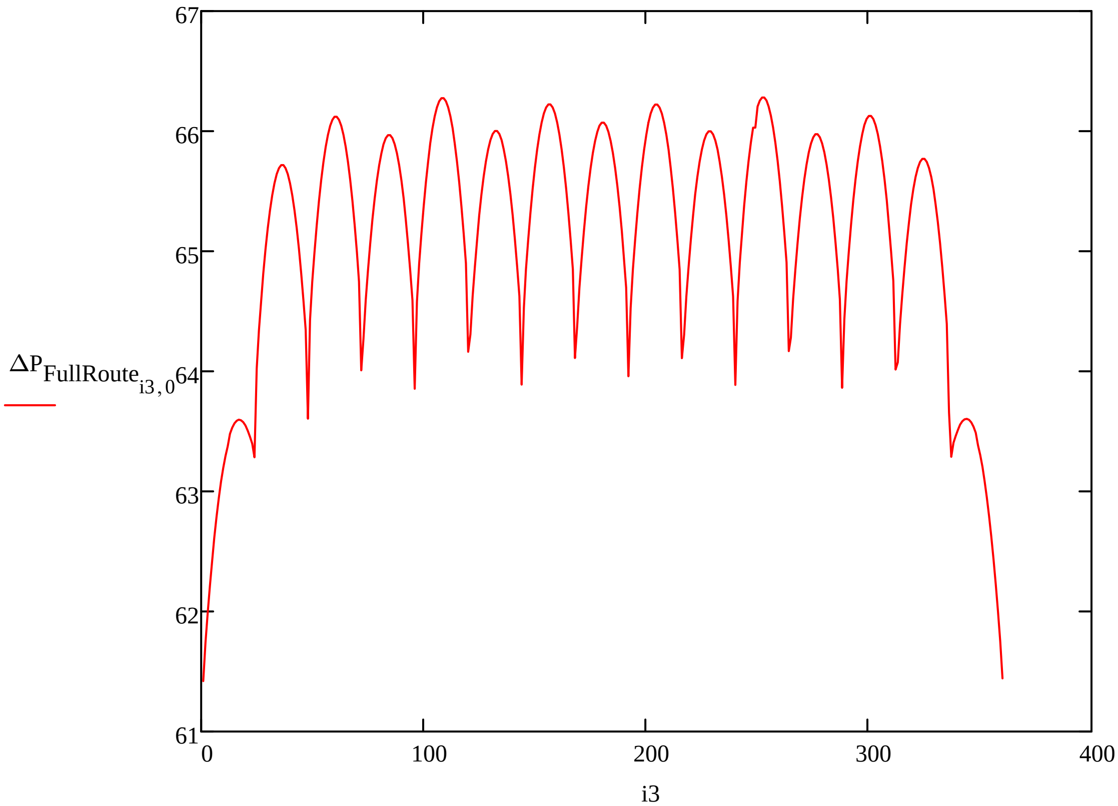
$\Delta P_{M7L} = 13.6185$ $\Delta P_{M7R} = 13.2613$

$\Delta P_{M8L} = 13.1121$

Full system pressure losses

$$i3 := 1, 2 .. 361$$

Full system pressure losses by di-block # and right/left routing number



Pressure drop: $$Avg := \frac{\sum_{i=0}^{360} \Delta P_{FullRoute_i}}{360} = 65.1197 \text{ psi}$$

$$\Delta P_{15max} := \max(\Delta P_{FullRoute}) = 66.2791$$

$$\Delta P_{15min} := \Delta P_{FullRoute_{1,0}} = 61.4192$$

$$PercentDiff_{\Delta P15} := \frac{(\Delta P_{15max} - \Delta P_{15min})}{\left[\frac{(\Delta P_{15max} + \Delta P_{15min})}{2}\right]} = 7.6115\,\%$$

Maximum percentage flow difference within all 15 Di-Blocks

$$\sqrt{1 + PercentDiff_{\Delta P15}} - 1 = 3.7359 \cdot \%$$

Analysis to obtain true di-block row flow rates

System pressure drop: $Avg = 65.1197$ psi

Ratio for row flow adjustment based on route pressure drop:

$$Q_{ratio} := \left| \begin{array}{l} \text{for } j \in 1..360 \\ \quad Q_{ratio_j} \leftarrow \left(\dfrac{Avg}{\Delta P_{FullRoute_j}} \right)^{\frac{1}{2}} \\ \text{return } Q_{ratio} \end{array} \right.$$

Average row flow rate: $Q := \dfrac{Q_{main}}{mLsTOgpm \cdot 15 \cdot 24} = 7.05$ mL/s

Flow adjustment: $Flows := Q \cdot Q_{ratio}$

Sum of all row flows vs. actual total to prove accuracy:

$\sum_{z=0}^{360} Flows_z = 2538.2351$ mL/s $\dfrac{Q_{main}}{mLsTOgpm} = 2538$ mL/s

*shows less than a 1 mL/s difference

Re-populating to a more convienently sized matrix:

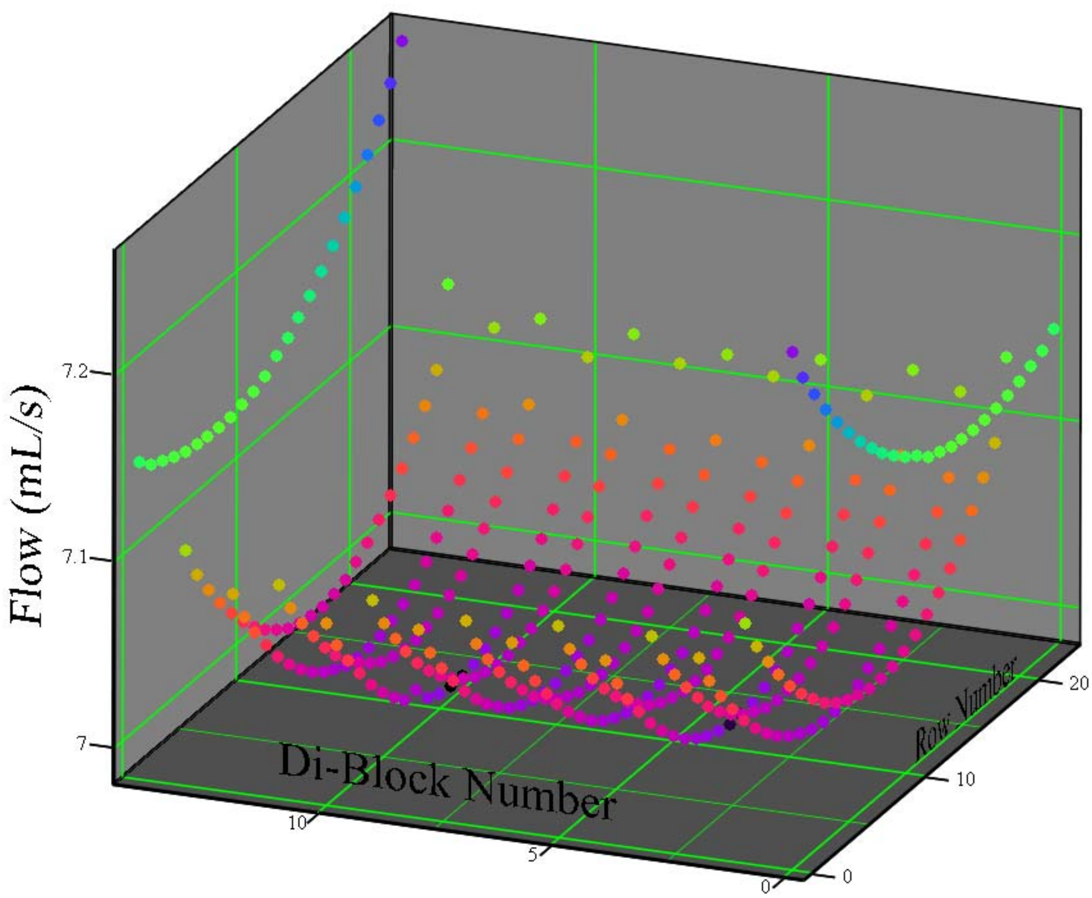
▸ matrix repopulation programming

▸ Flow rate matrix repopulation

FlowRates1 =

7.26	7.11	7.09	7.1	7.08	7.09	7.08	7.09	7.08	7.09	7.08	7.1	7.09	7.11	7.15
7.24	7.09	7.07	7.08	7.06	7.08	7.06	7.07	7.06	7.08	7.06	7.08	7.07	7.09	7.14
7.23	7.08	7.06	7.07	7.05	7.06	7.05	7.06	7.05	7.06	7.05	7.06	7.06	7.08	7.14
7.21	7.07	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.06	7.14
7.2	7.06	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.05	7.14
7.19	7.05	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.04	7.13
7.18	7.04	7.02	7.02	7.01	7.02	7.01	7.02	7.01	7.02	7.01	7.02	7.02	7.04	7.13
7.17	7.03	7.01	7.02	7	7.02	7	7.01	7	7.02	7	7.02	7.01	7.03	7.13
7.16	7.03	7	7.01	7	7.01	7	7.01	7	7.01	7	7.01	7	7.02	7.13
7.16	7.02	7	7.01	6.99	7.01	7	7	7	7.01	6.99	7.01	7	7.02	7.14
7.15	7.02	7	7.01	6.99	7	6.99	7	6.99	7	6.99	7.01	7	7.02	7.14
7.15	7.02	7	7	6.99	7	6.99	7	6.99	7	6.99	7	7	7.02	7.14
7.14	7.02	7	7	6.99	7	6.99	7	6.99	7	6.99	7	7	7.02	7.15
7.14	7.02	7	7.01	6.99	7	6.99	7	6.99	7	6.99	7.01	7	7.02	7.15
7.14	7.02	7	7.01	6.99	7.01	7	7	7	7.01	6.99	7.01	7	7.02	7.16
7.13	7.03	7	7.01	7	7.01	7	7.01	7	7.01	7	7.01	7	7.02	7.16
7.13	7.03	7.01	7.02	7	7.02	7	7.01	7	7.02	7	7.02	7.01	7.03	7.17
7.13	7.04	7.02	7.02	7.01	7.02	7.01	7.02	7.01	7.02	7.01	7.02	7.02	7.04	7.18
7.14	7.05	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.03	7.02	7.04	7.19
7.14	7.06	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.04	7.03	7.05	7.2
7.14	7.07	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.05	7.04	7.06	7.21
7.14	7.08	7.06	7.07	7.05	7.06	7.05	7.06	7.05	7.06	7.05	7.06	7.06	7.08	7.23
7.15	7.09	7.07	7.08	7.06	7.08	7.06	7.07	7.06	7.08	7.06	7.08	7.07	7.09	7.24
7.15	7.13	7.11	7.12	7.1	7.12	7.11	7.11	7.11	7.12	7.1	7.12	7.11	7.13	7.26

Flow Balance



FlowRates1 $\Delta Q_{15max} := \max(Flow_{DB}) = 7.26$ $\Delta Q_{15min} := 6.99$

Calculating largest percent difference in flow for proof of accuracy:

$$PercentDiff_{\Delta Q15} := \frac{(\Delta Q_{15max} - \Delta Q_{15min})}{\left[\frac{(\Delta Q_{15max} + \Delta Q_{15min})}{2}\right]} = 3.789\%$$

Maximum percentage flow difference prediction within all 15 Di-Blocks

$$\sqrt{1 + PercentDiff_{\Delta P15}} - 1 = 3.7359 \cdot \%$$