GMRC

Predicting the Power Loss of Reciprocating Compressor Manifolds

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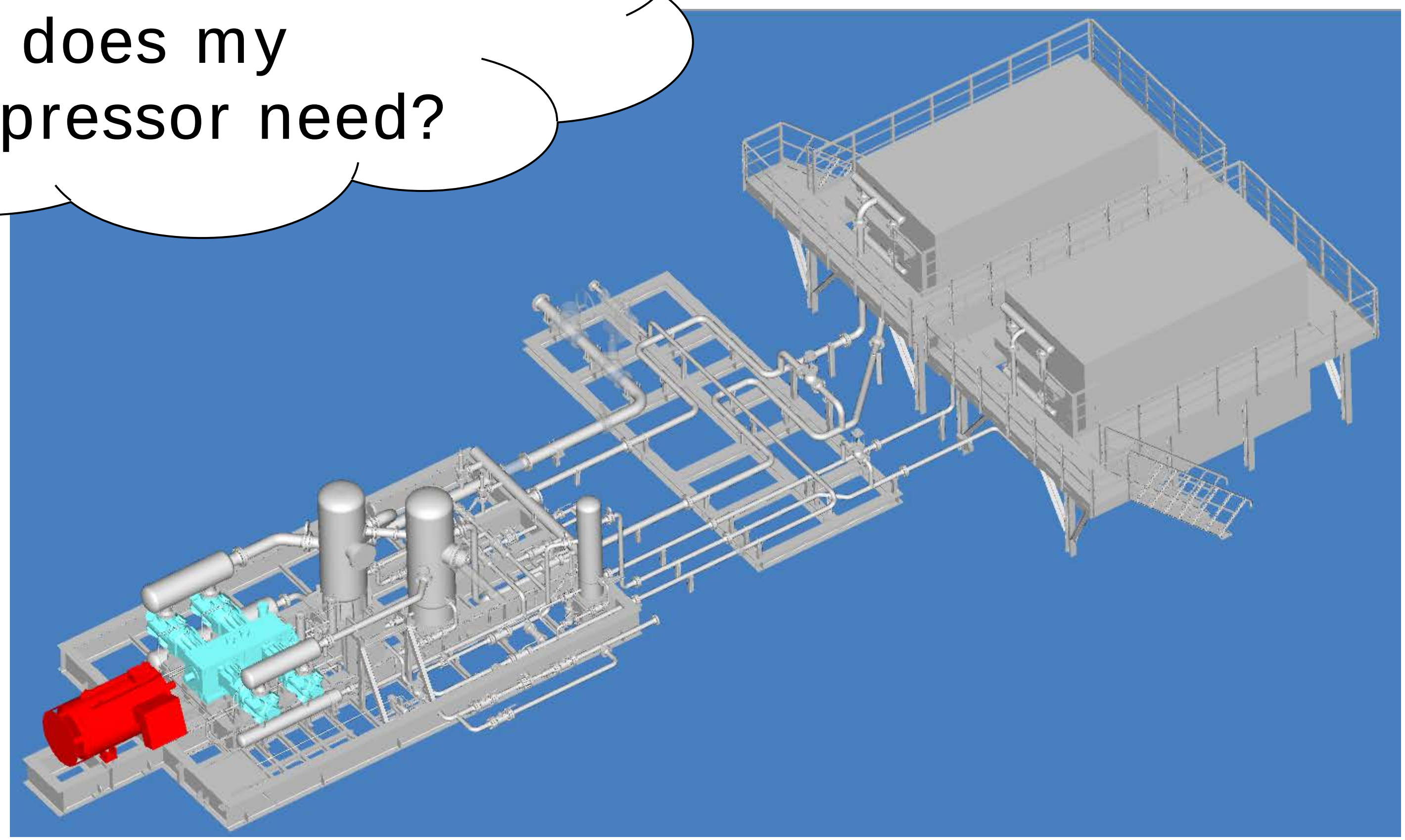
Project Motivation

How much power does my compressor need?



Compressor Performance Calculation

Est. Flow::	5.820 MMscfd
Load/Flow:	147.1 HP/MMscfd
Est. Total Load:	855.9 HP
Run Speed:	738

Stage/Service Data:

Flow Rate:	MMscfd	5.82	5.82
Load:	HP	449.3	377.1
Specific Gravity:	-	0.5660	0.5660
K Value (Cp/Cv):	-	1.2788	1.2671

Why Estimated Total Load?

- Compression (ideal) power ✓
- Mechanical Efficiency ✓
- Manifold (bottle) power loss ?
- Orifice power loss ?
- Other system loss ?

Base Clr:	%	10.22	18.78	-	-
Added Clr:	%	0.00	0.00	-	-
Total Clr:	%	10.22	18.78	-	-

How do you calculate the unknown power losses?

BOLD *= Out of Limit* FILE: RybinskES602 Final.hsr

Compressor Performance Calculation

Unknown Power Losses are estimated by the pressure drop

Order Status: Order: IPS 790743

Stage/Service Data:

		Stage-1	Stage-2
Flow Rate:	MMscfd	5.82	5.82
Load:	HP	449.3	377.1
Specific Gravity:	-	0.5660	0.5660

		Stage-1	Stage-2
Suction Press.:	**psiA**	57.42	168.36
Ps@Flange:	**psiA**	48.72	148.49
Pd@Flange:	**psiA**	168.36	391.59
Discharge Press.:	**psiA**	168.36	383.76

Model:	-	07 Series	06 Series		
Operating Mode:	-	D/A Cyl	D/A Cyl		
Head End	Stage	Stg-1	Stg-2	-	-
Bore:	in	21	13	-	-
MAWP:	psiA	263.9106	813.9106	-	-
RDP:	psiA	238.9106	740.9106	-	-
Tail Rod Dia:	in	0	0	-	-
Est. Td:	deg F	239.5	262.3	-	-
VVCP Open:	in : Turns	No VVCP	No VVCP	-	-
Base Clr:	%	11.05	20.06	-	-
Added Clr:	%	0.00	0.00	-	-
Total Clr:	%	11.05	20.06	-	-
Vol. Eff. Suct.:	%	75.21	71.80	-	-
Vol. Eff. Disch.:	%	28.53	33.45	-	-

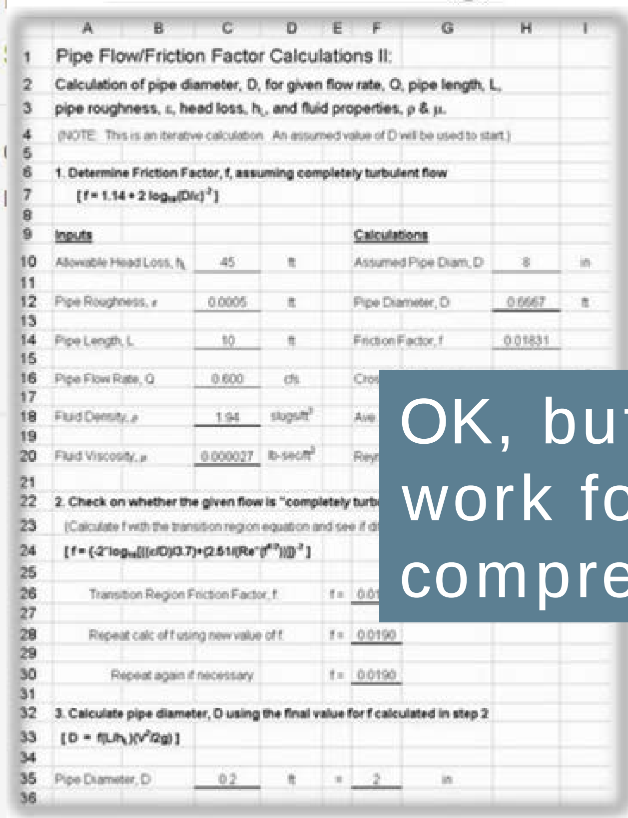
How much, assume 1%, 2%? Is it accurate?

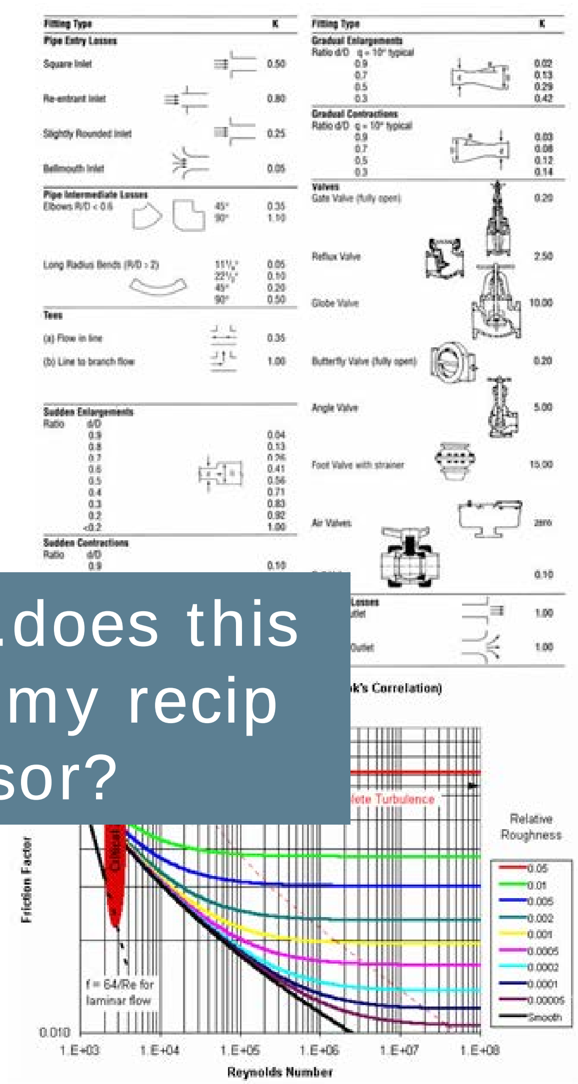
Flow:	MMscfd	2.92	2.89	-	-
Valve Spacers:	HE#/CE#	0 / 0	0 / 0	-	-
Rod Loads					
Gas-Compress.:	%	74.3	59.5	-	-
Gas-Tension:	%	72.3	55.2	-	-
Net-Compress.:	%	84.0	67.4	-	-
Net-Tension:	%	85.2	64.5	-	-
Pin Reversal:	Deg/Mag%	173/96	175/91	-	-
Throw Loading	HP	449.3	377.1	-	-

***BOLD** = Out of Limit* **FILE:** RybinskES602 Final.hsr

Pressure Drop Calculation… easy, right?

$$h_{loss} = K\frac{V^2}{2g}$$

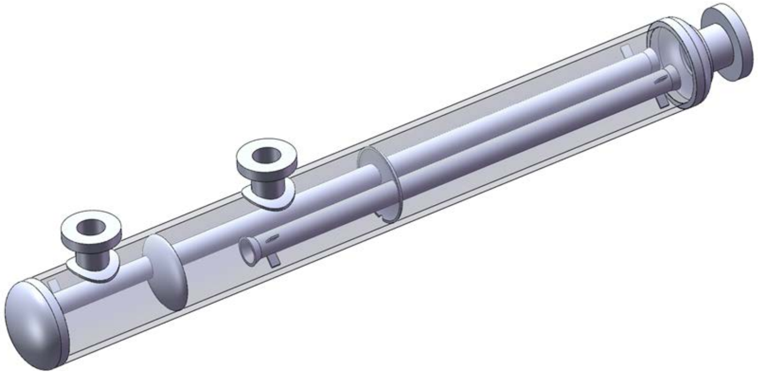




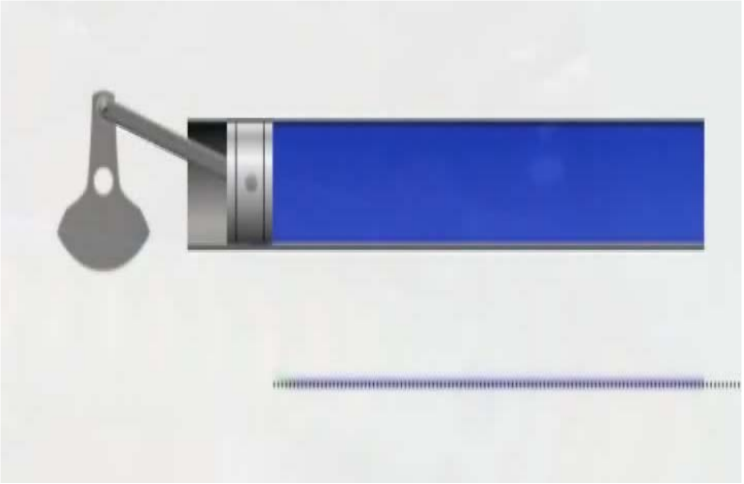
OK, but…does this work for my recip compressor?

Challenges to Industry

- Manifolds (pulsation bottles) have complicated geometry. K-factors are not published.



- Recip compressors create high flow fluctuations.



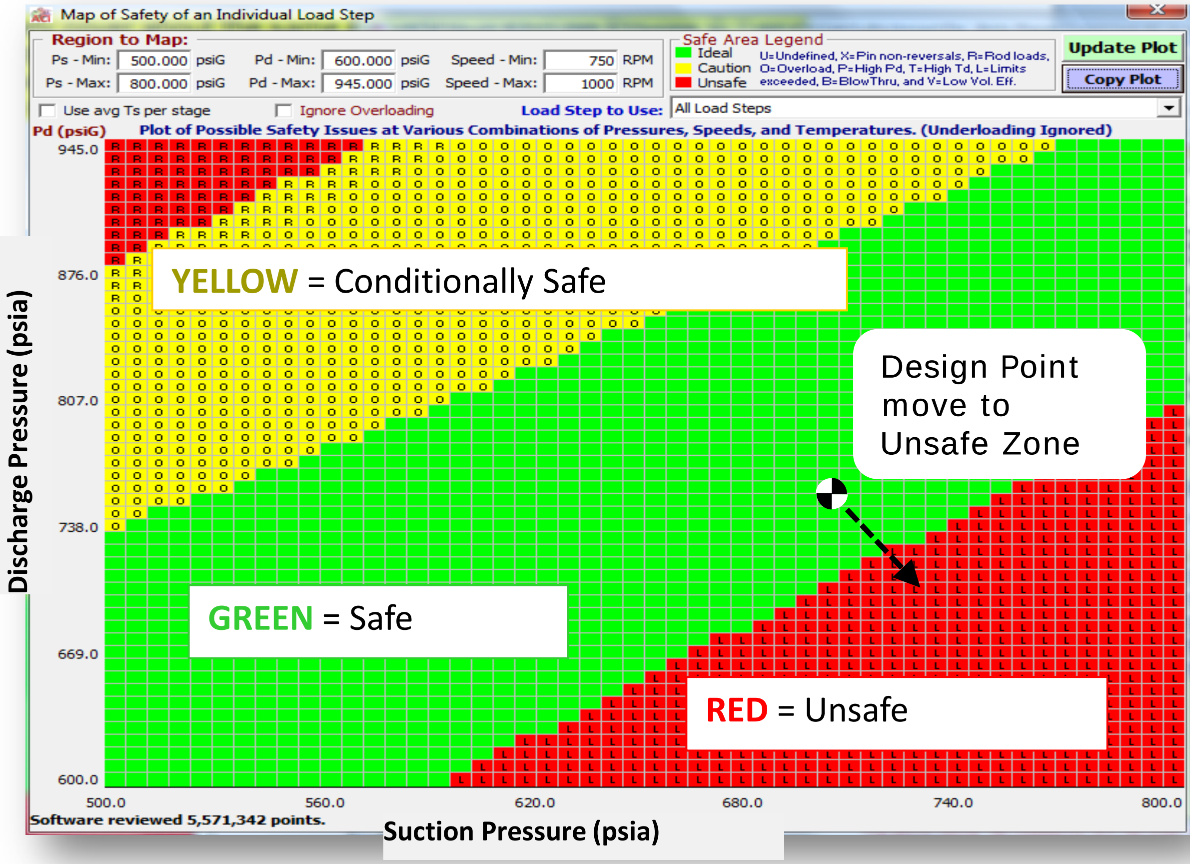
- How to relate pressure drop to power loss?

How important is power loss?

Inaccurate power calculation effects performance and reliability (3% to 12% error in results)

Consequences:

- Driver size inadequate
- Unable to meet contract flow
- Reliability (rod load, reversal, and discharge temperature)
- Inefficient operation



Overall Project Objectives

1. Develop a methodology to predict the mean and pulsating power losses across Reciprocating Compressor Manifolds (bottles).

2. Validate the methodology via experimental means, either from:

   - Measurements of actual recip. compressor in the field, or
   - Scale-down test rig involving a custom-design bottle and a Pulse-generator.

3. Ultimate Goal is to:

   - Recommend a standard methodology to quantify the pulsating flow power loss.
   - Come up with adjustment factor(s) to be applied to the mean pressure drop coefficient (K) in the presence of pulsating flow.

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1. Develop a methodology to predict the mean and pulsating power losses across Reciprocating Compressor Manifolds (bottles).

   Completed 2013

2. Validate the methodology via experimental means, either from:
   - Measurements of actual recip. compressor in the field, or
   - **Scale-down test rig involving a custom-design bottle and a Pulse-generator.**

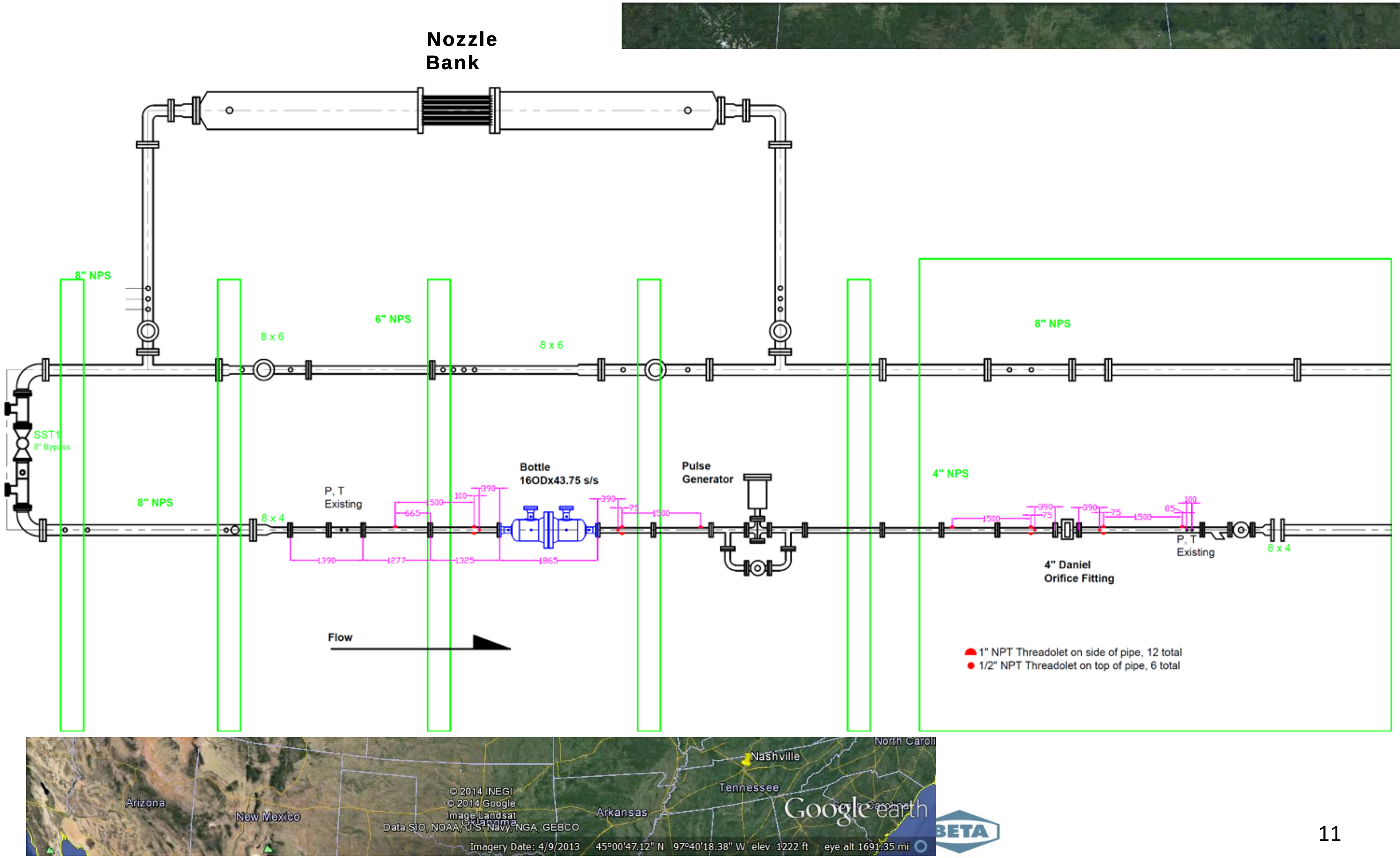
   Focus of this presentation

3. Ultimate Goal is to:
   - Recommend a standard methodology to quantify the pulsating power loss.
   - Come up with adjustment factor(s) to be applied to the mean pressure drop coefficient (K) in the presence of pulsating flow.

Outline

1. Test Program
2. Measurements and Results
3. Key Findings
4. Next Steps

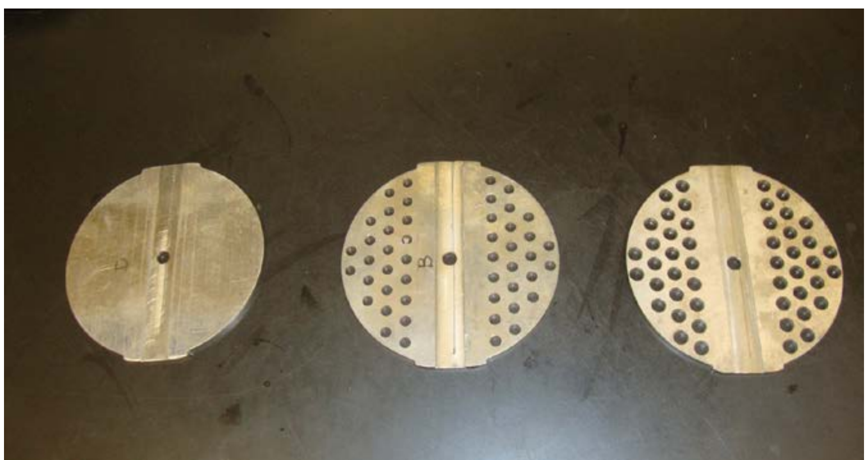
Test Setup at TCPL's GDTF in Didsbury, Alberta

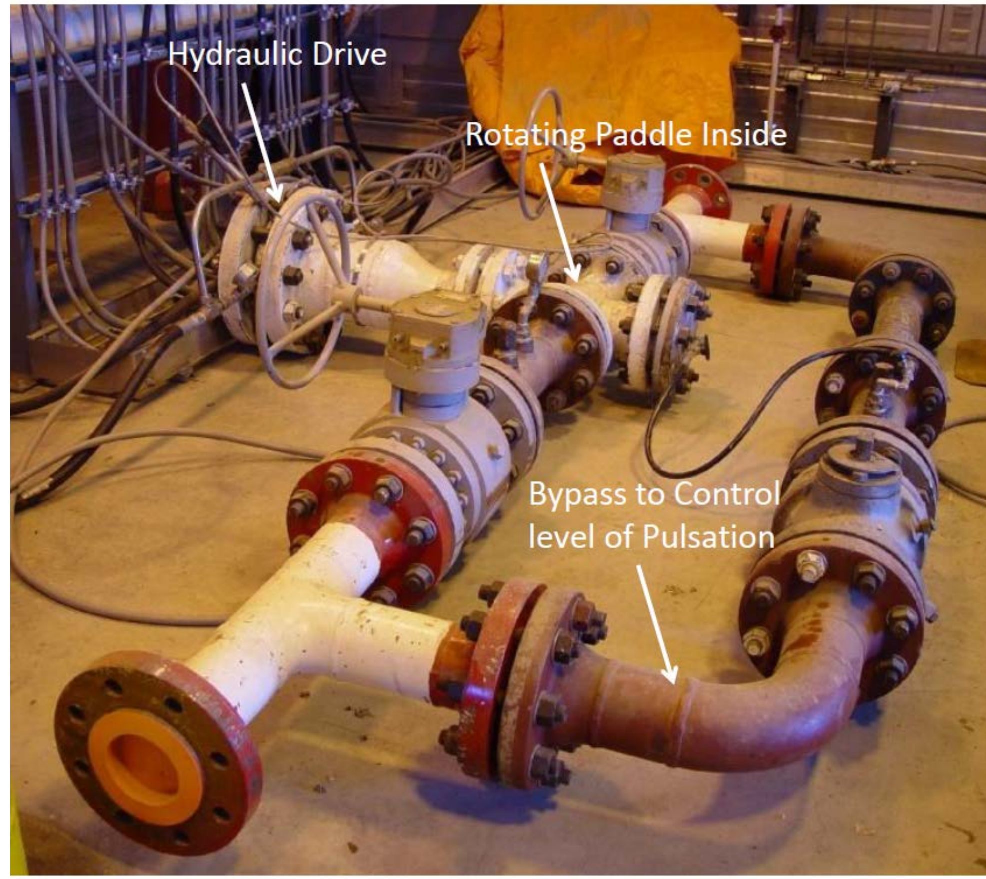


Pulse Generator

Pulsations will be created by a hydraulically driven rotating paddle

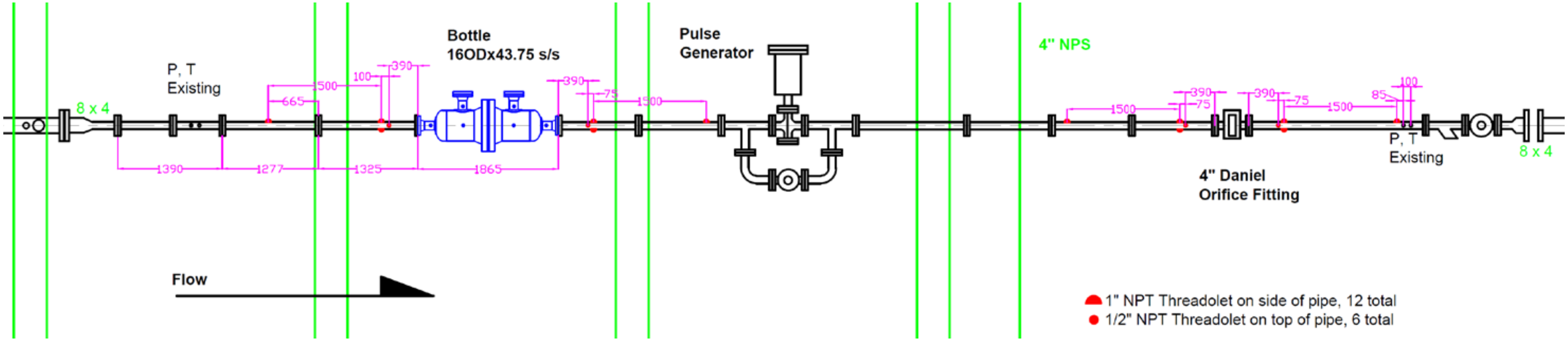
- Not a recip compressor
- Operate at 300 to 1200 rpm.
- Double acting
- Pulse amplitude 1% to 2% line pressure



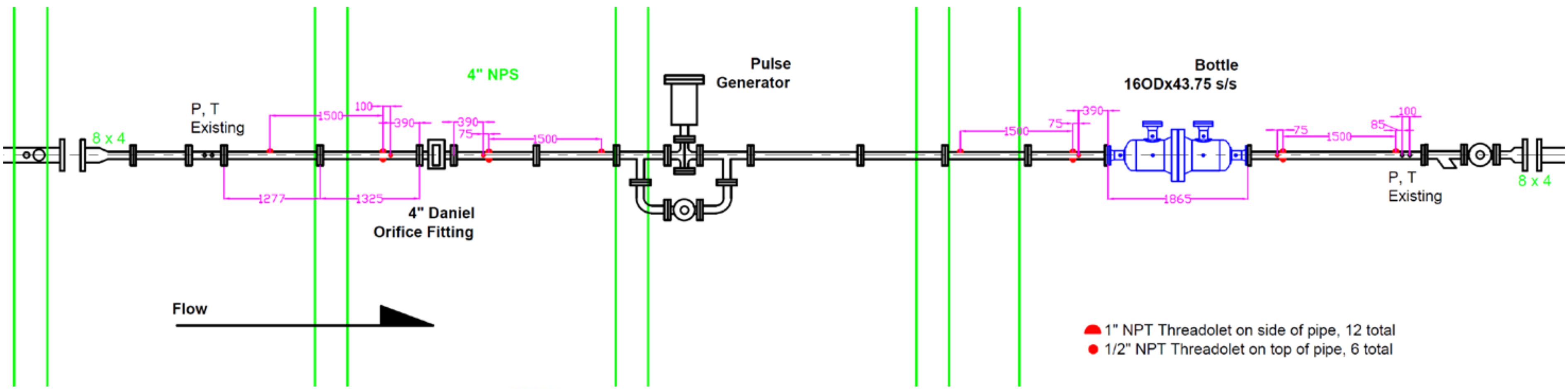


Test Setup Details

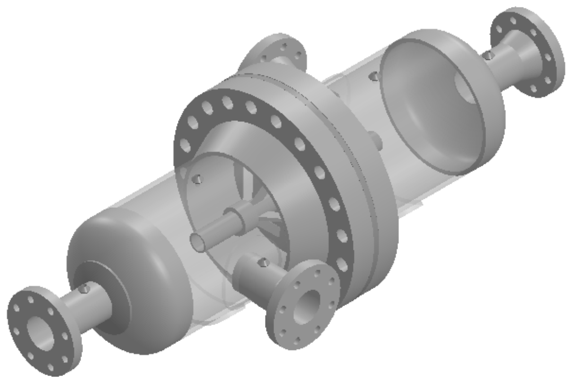
<u>Configuration A:</u> Bottle Upstream, Orifice Downstream



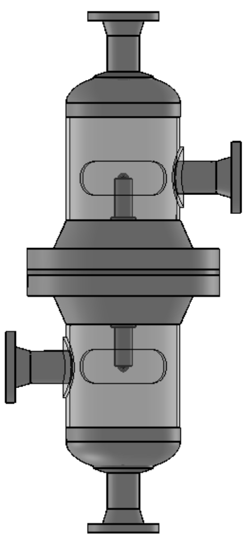
<u>Configuration B:</u> Orifice Upstream, Bottle Downstream

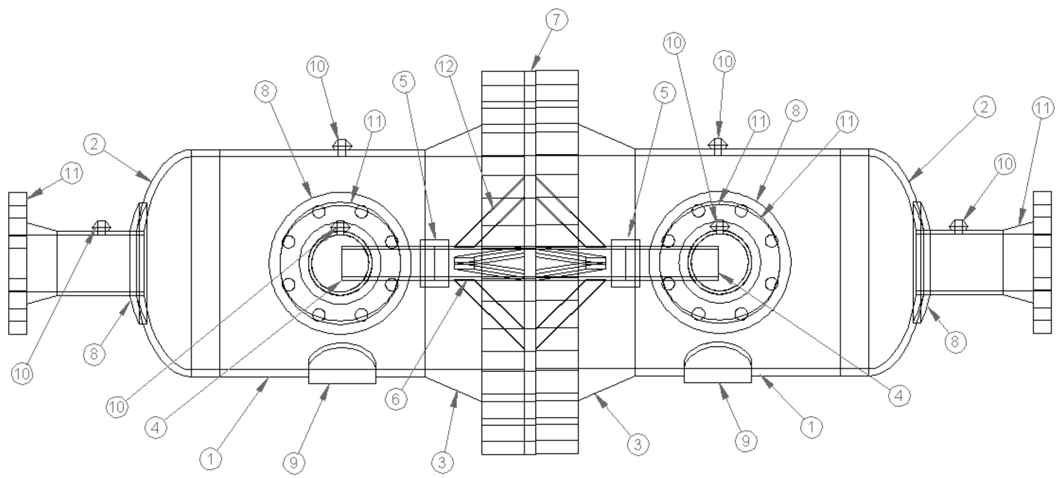


Custom Bottle Design (donated by Peerless Mfg.)



ITEM NO.	DESCRIPTION	QTY.
1	Shell, 16" OD, 15" ID, 12" Long	2
2	Head, 16" OD, 15" ID, 2" Tangent Length	2
3	Flange 16" 600 LBS	2
4	End Treatments, Straight Cut	2
5	Coupling	2
6	Choke Tube 2" Sch XS	1
7	Flat Plate, 0.75" Thick	1
8	RePad, 8.5" OD, 4.5" ID, 0.5" Thick	4
9	Saddle Support Weld Pad, 10" x 5" x 0.5"	2
10	1/2" Threadolet	6
11	Flange, 4" NPS 600 LBS, Nozzle 4" Sch STD	4
12	Gusset	8





It would be prefered that the nozzle in Item 11 be constructed with 4" S40 pipe. Although pressure vessel code must still be met.

BETA MACHINERY ANALYSIS
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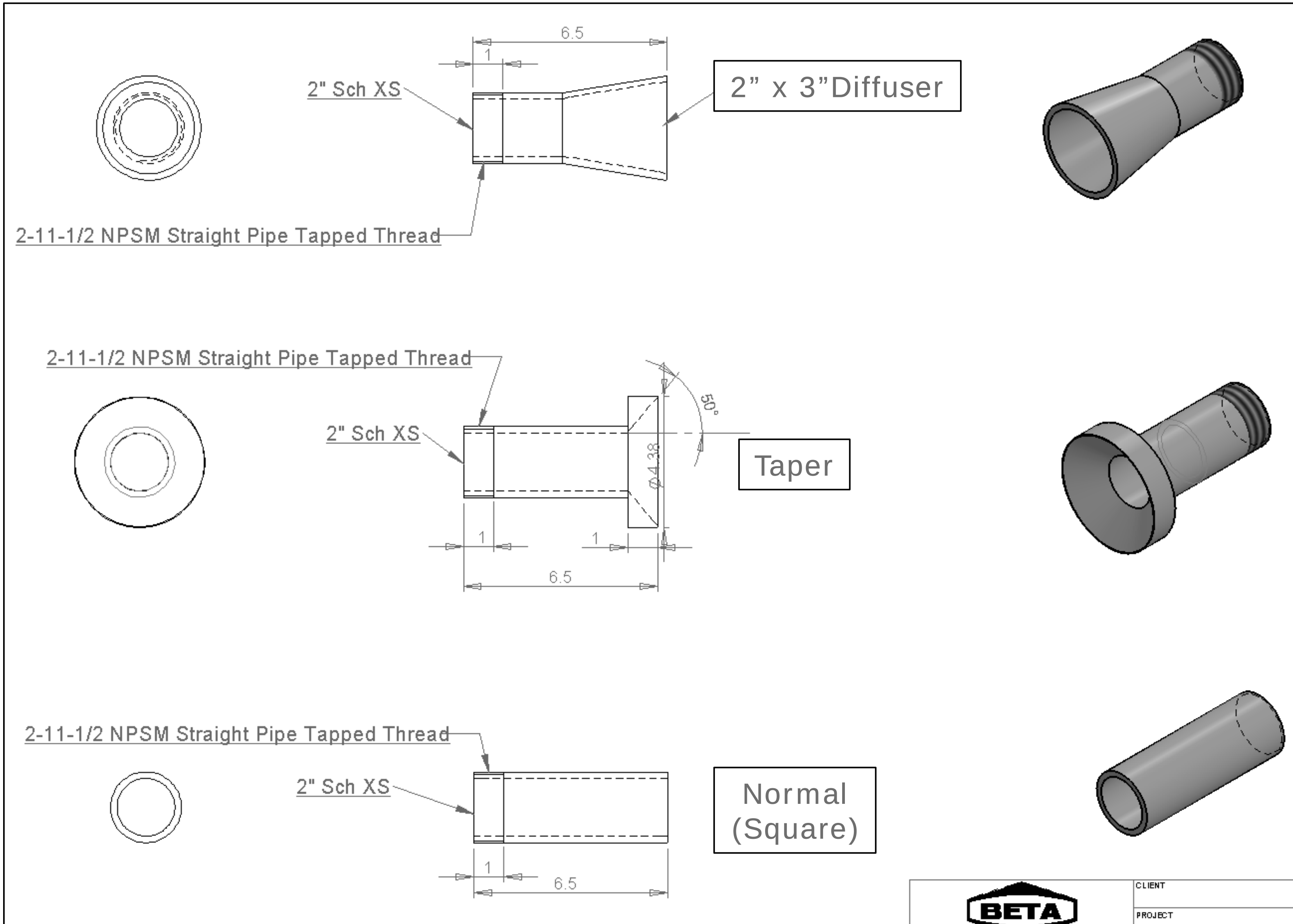
CLIENT	
PROJECT	
LOCATION	
TITLE	GMRC Pressure Drop Test Bottle
DRAWN BY: MG	DATE: 2014-Feb-5	SCALE: NTS
REF#: 208194	FIGURE:	REV: 01

End Treatments

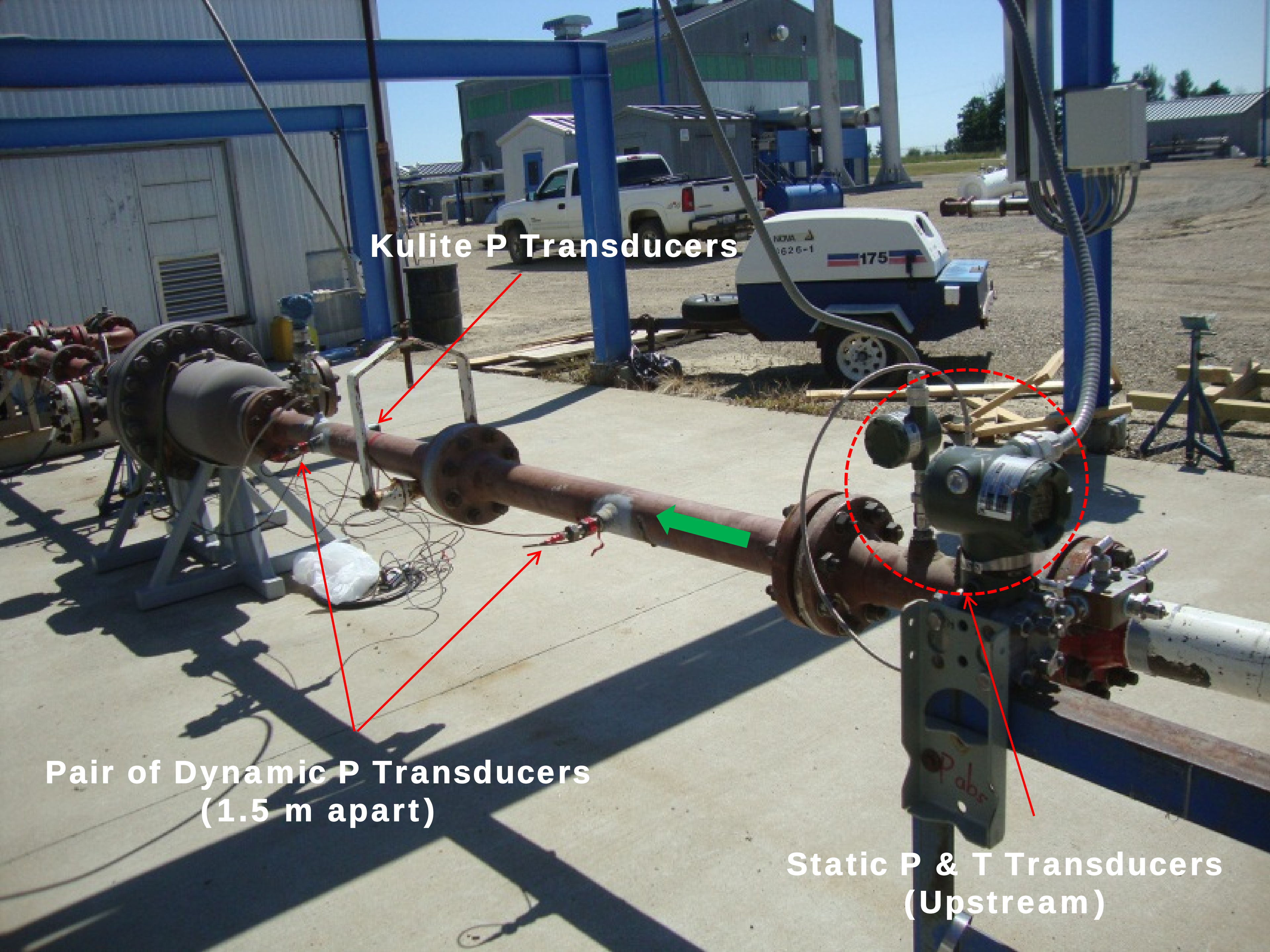


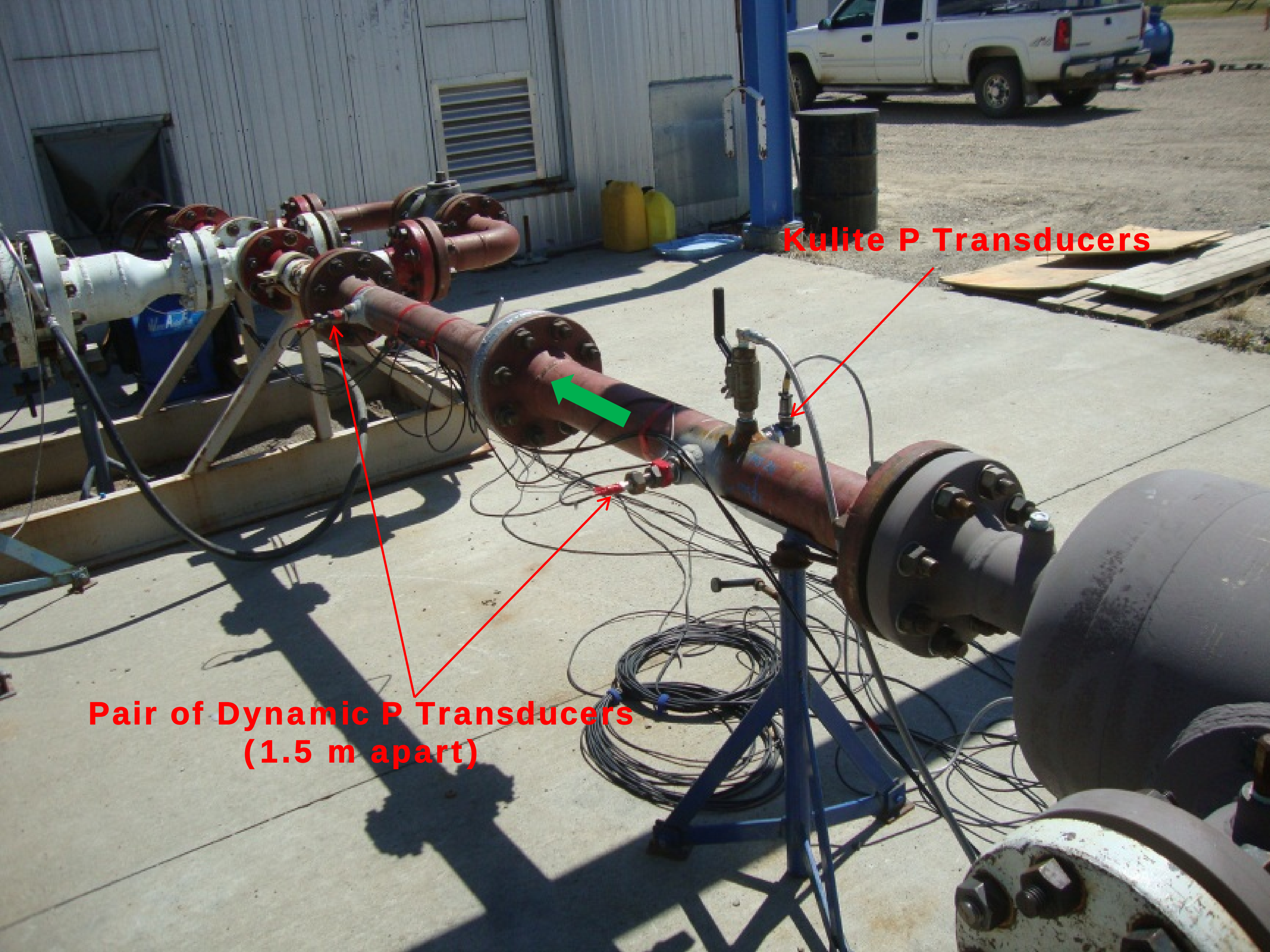

Square End Treatment
2014/07/10


Diffuser End Treatment
2014/07/10

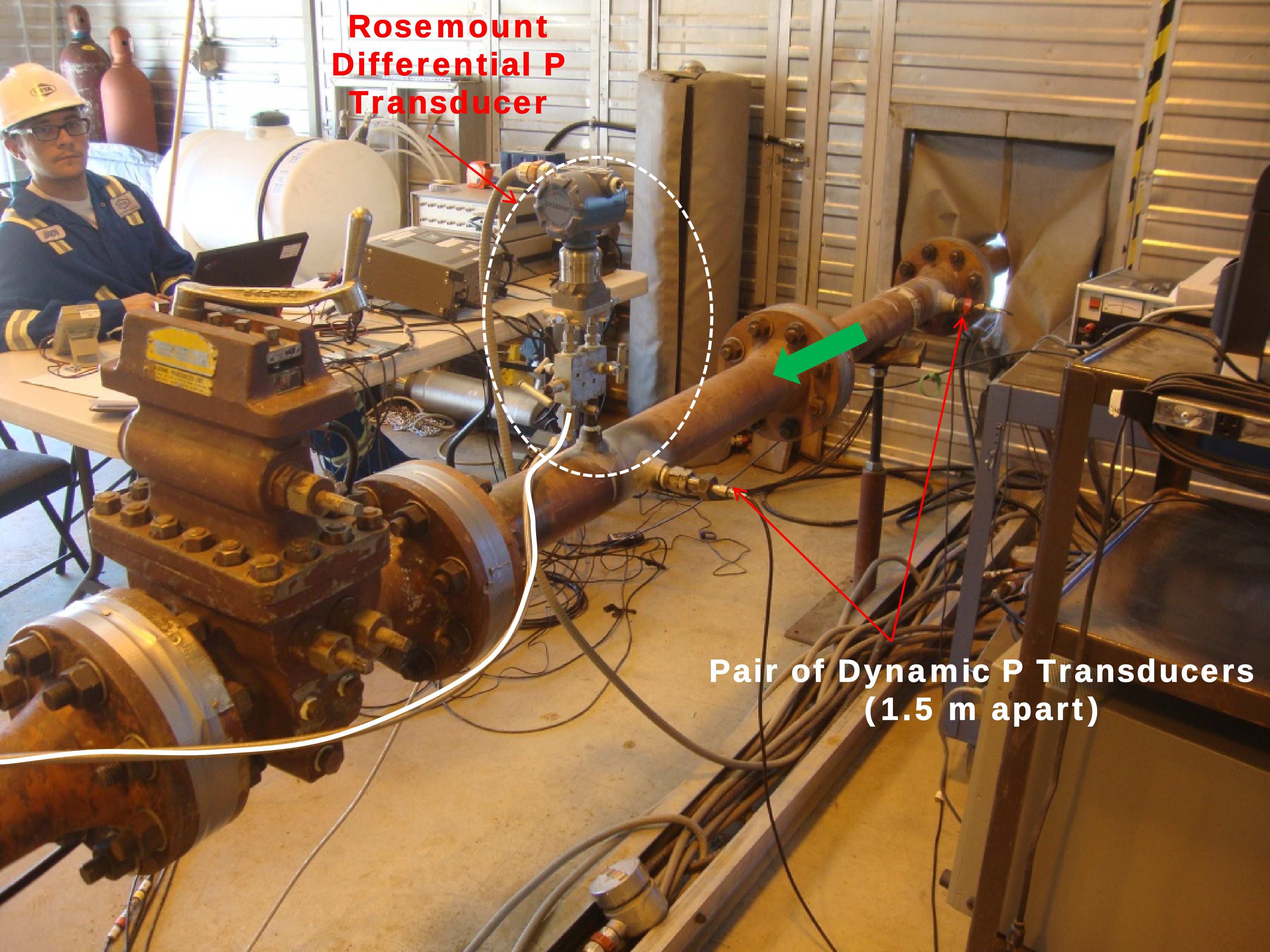
Photos of Configuration A Setup

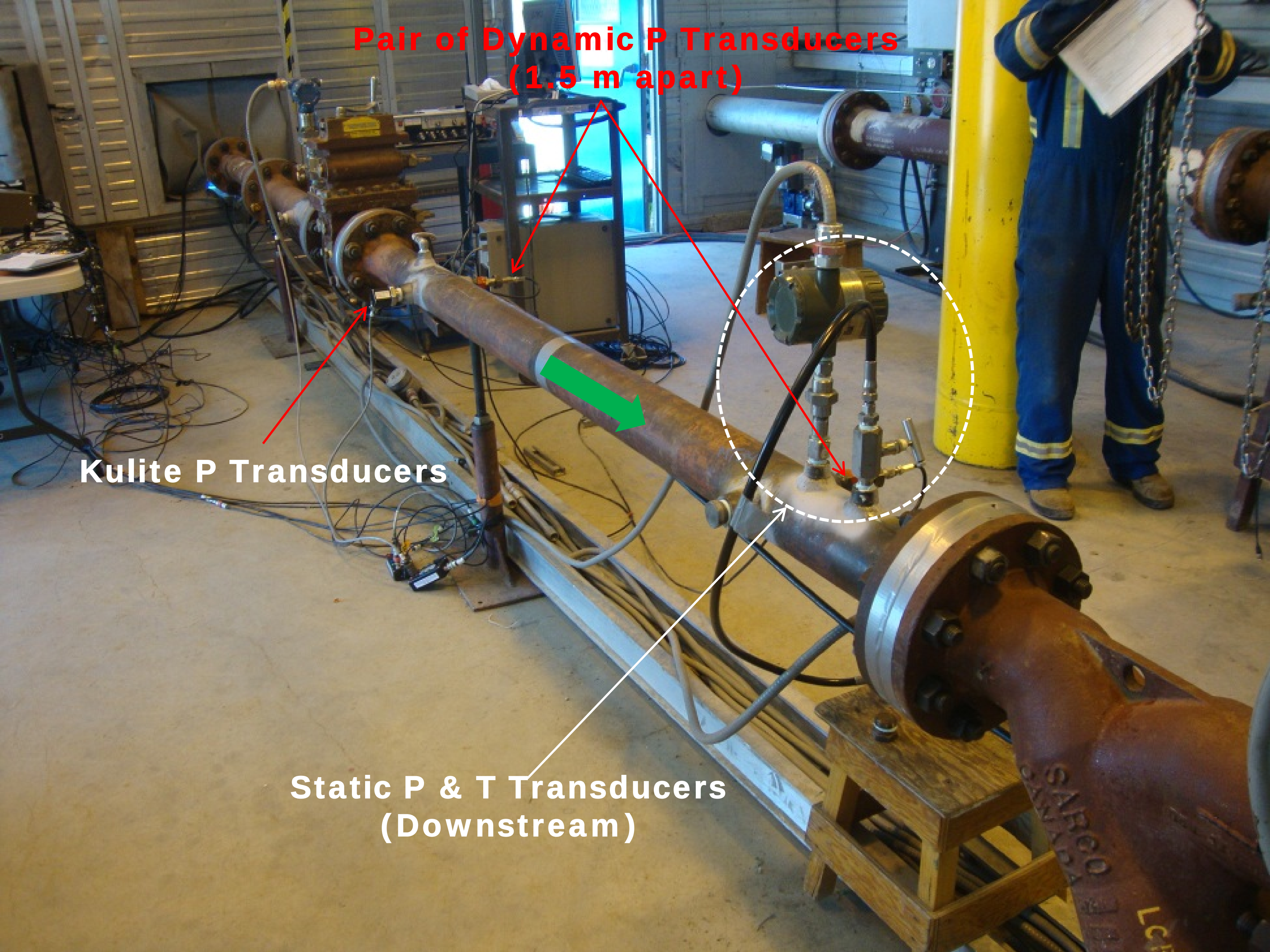

Sonic Nozzles Bank
Flow Direction
Pulse Generator


Kulite P Transducers
Pair of Dynamic P Transducers
(1.5 m apart)
Static P & T Transducers
(Upstream)

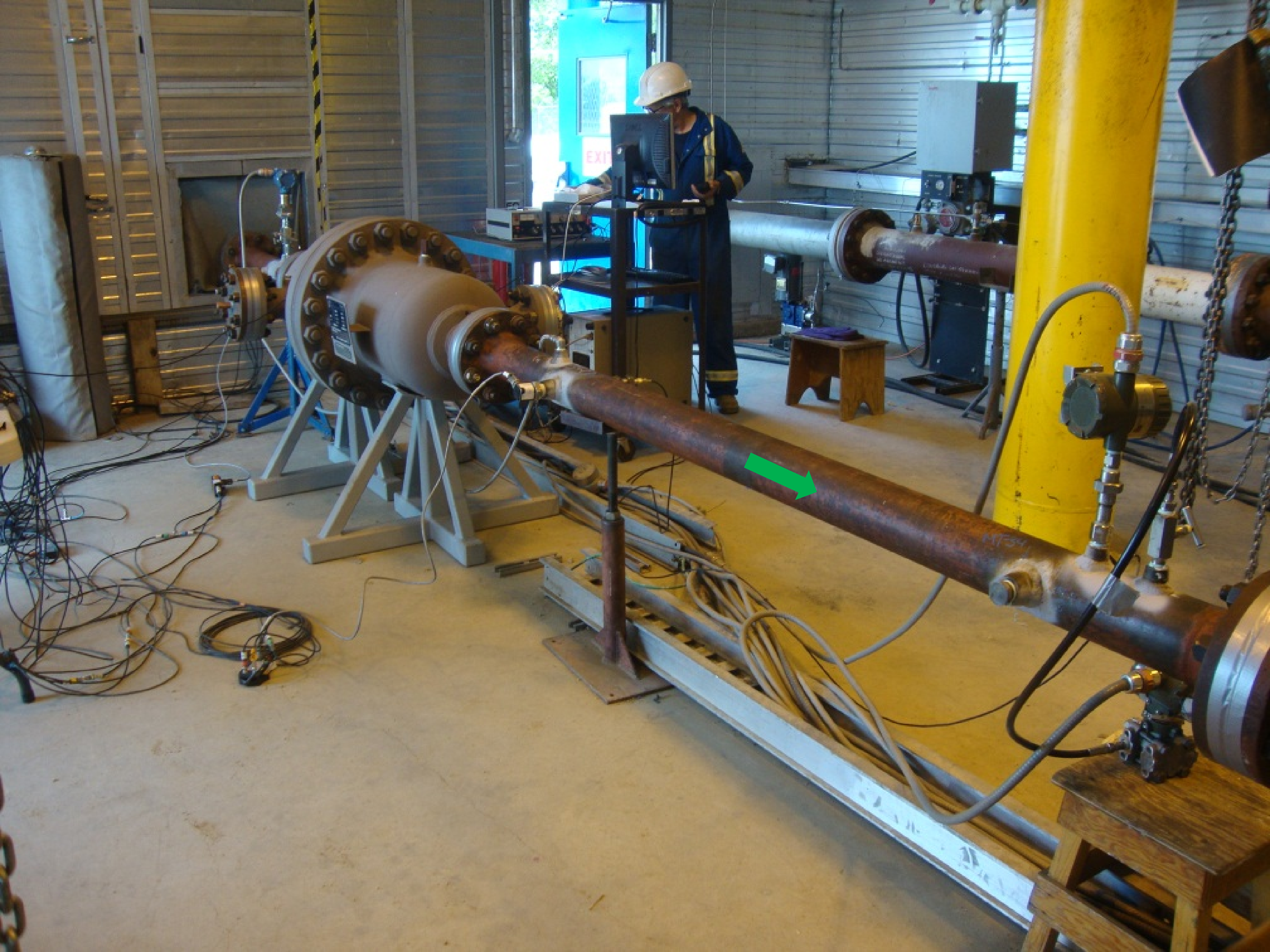

Kulite P Transducers
Pair of Dynamic P Transducers
(1.5 m apart)

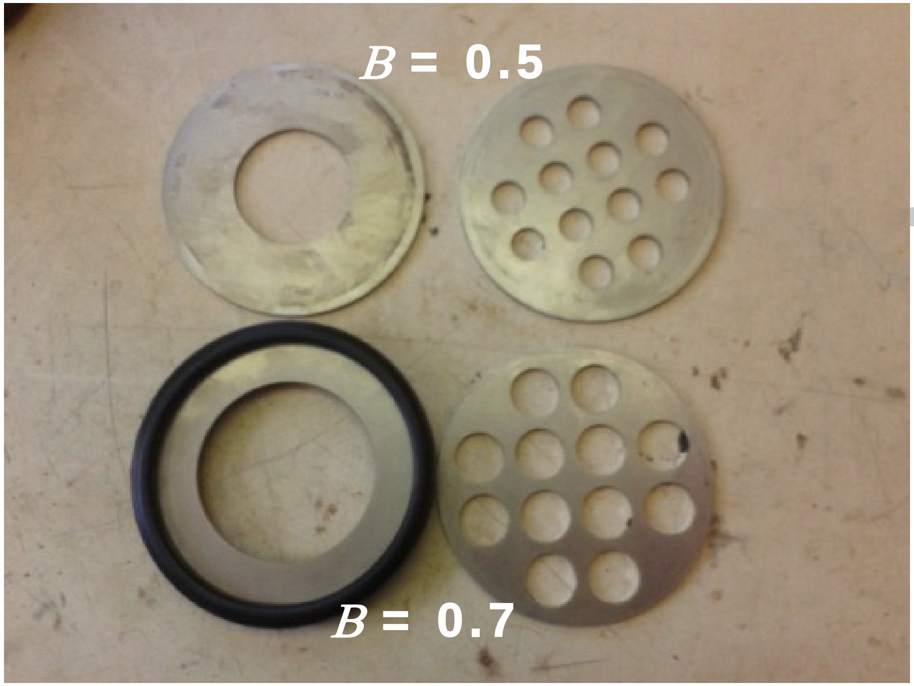

NOVA
6626-1
Rosemount
Differential P
Transducer


Rosemount
Differential P
Transducer
Pair of Dynamic P Transducers
(1.5 m apart)

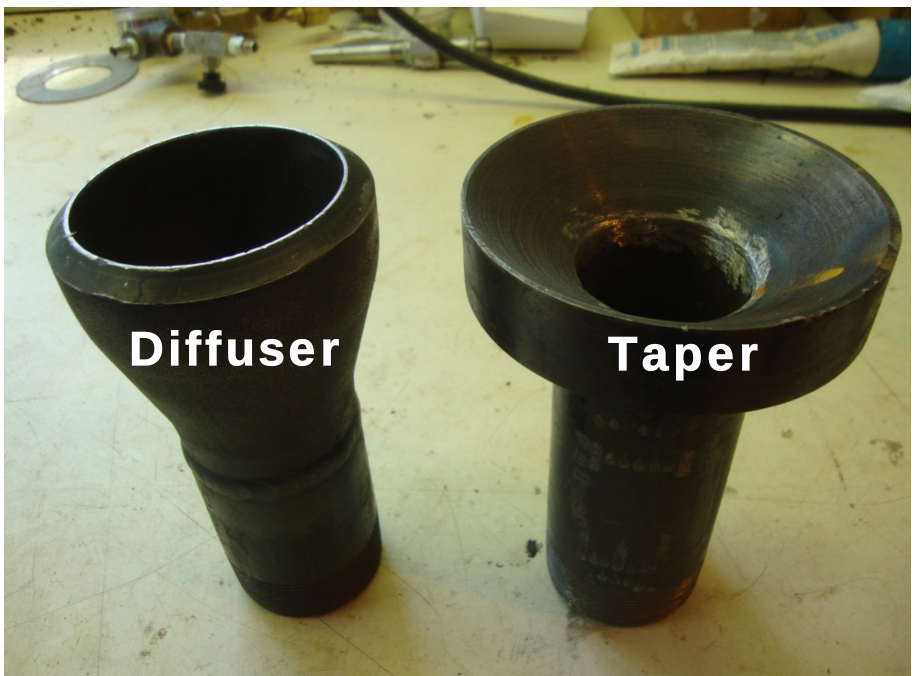

Pair of Dynamic P Transducers
(1.5 m apart)
Kulite P Transducers
Static P & T Transducers
(Downstream)

Photos of Configuration B Setup

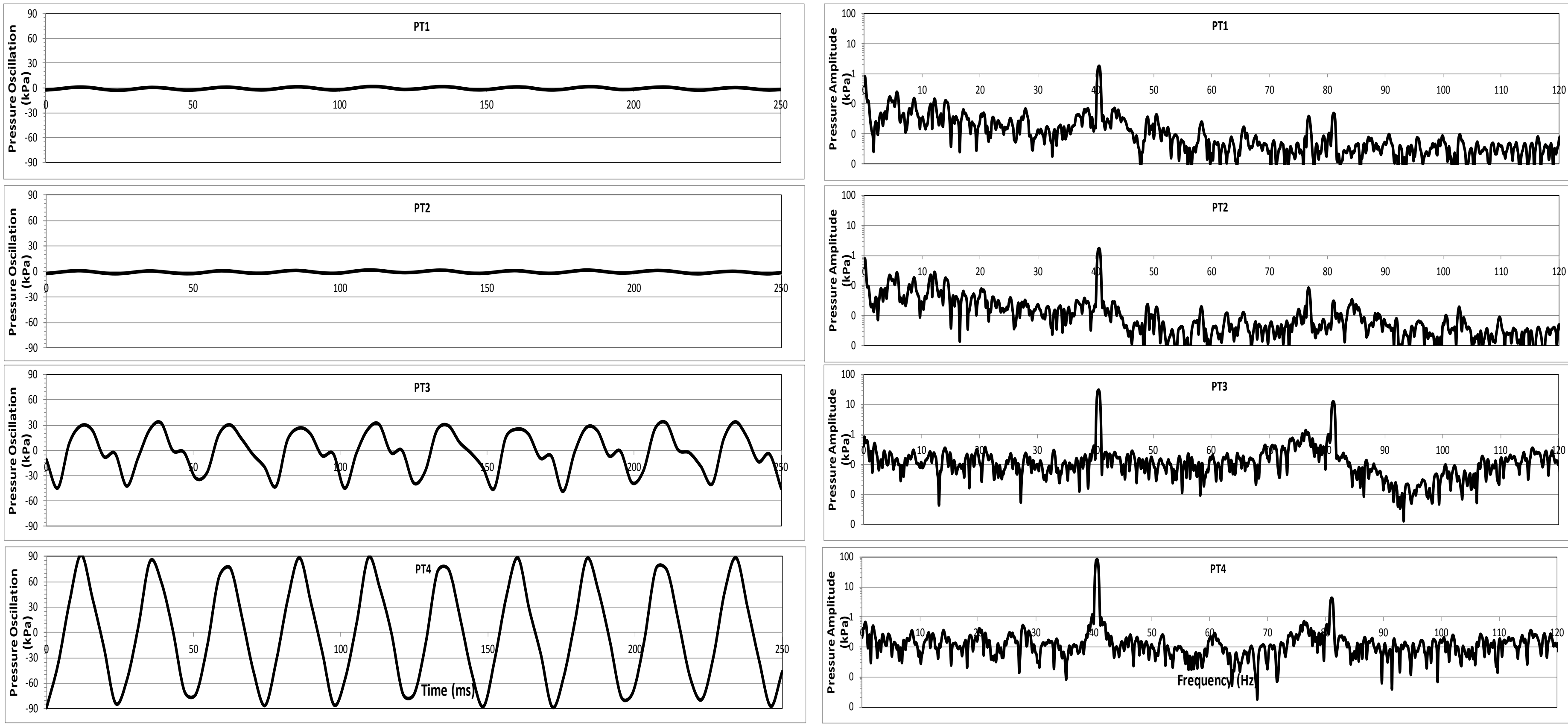

EXIT


$B =$ 0.5
$B =$ 0.7

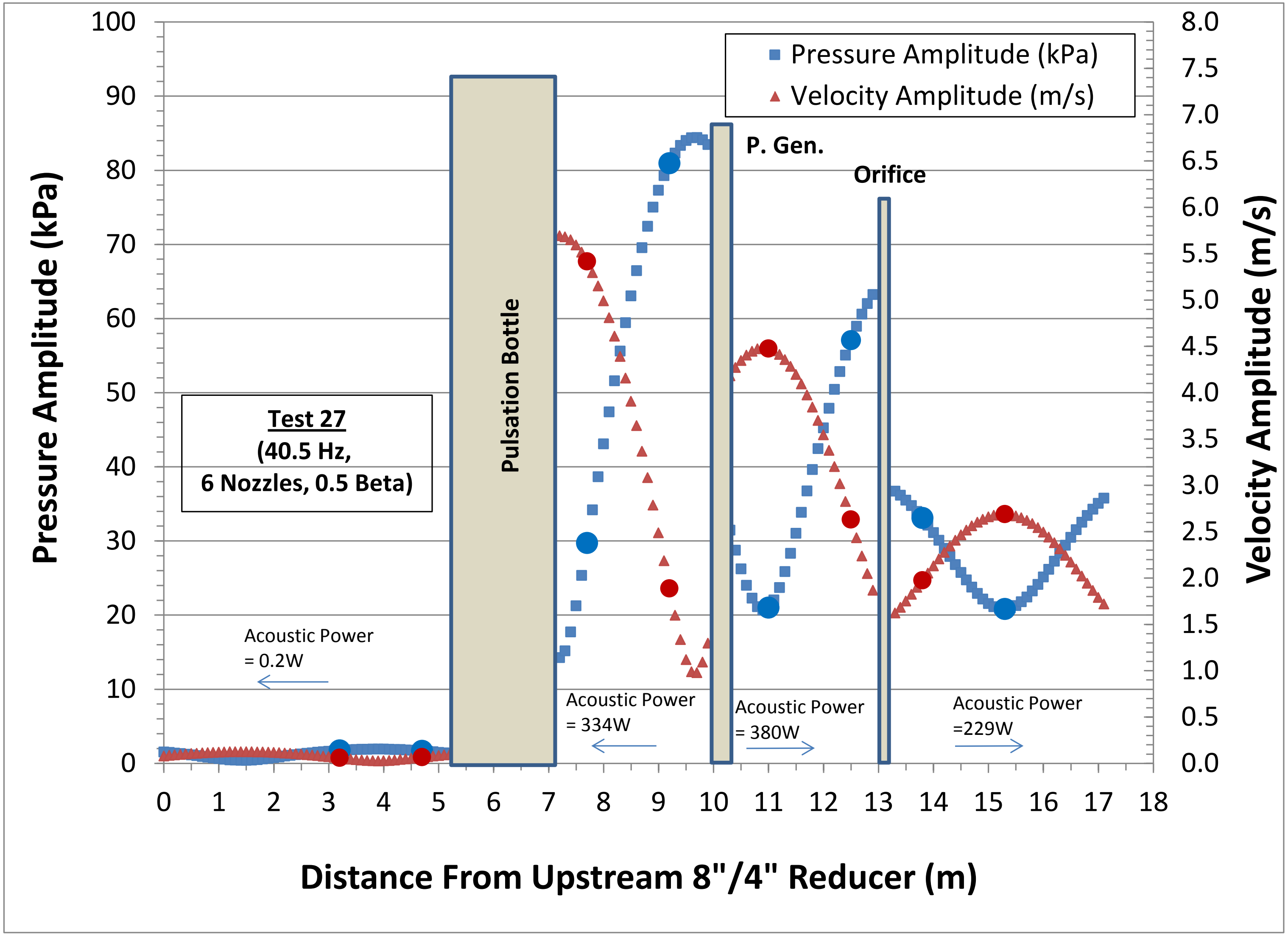

NB 1427
CERTIFIED BY:
PEERLESS MFG. CO. - 7
W
MAX. ALLOW. WORK PRESS. 1440 PSIG @ 133 °F
MIN. DESIGN METAL TEMP. -49 °F AT 1440 PSIG
RT-1
MAX. ALLOW. EXT. PRESS. -- PSIG @ -- °F
PROV. OR STATE NO. --
YR. BUILT 2014
SHOP ORDER NO. 214808-1-1
MFG. SERIAL NO. 214808-10A
MFG. BY: PMFG CO FOR BURGESS-MANNING


Diffuser
Taper

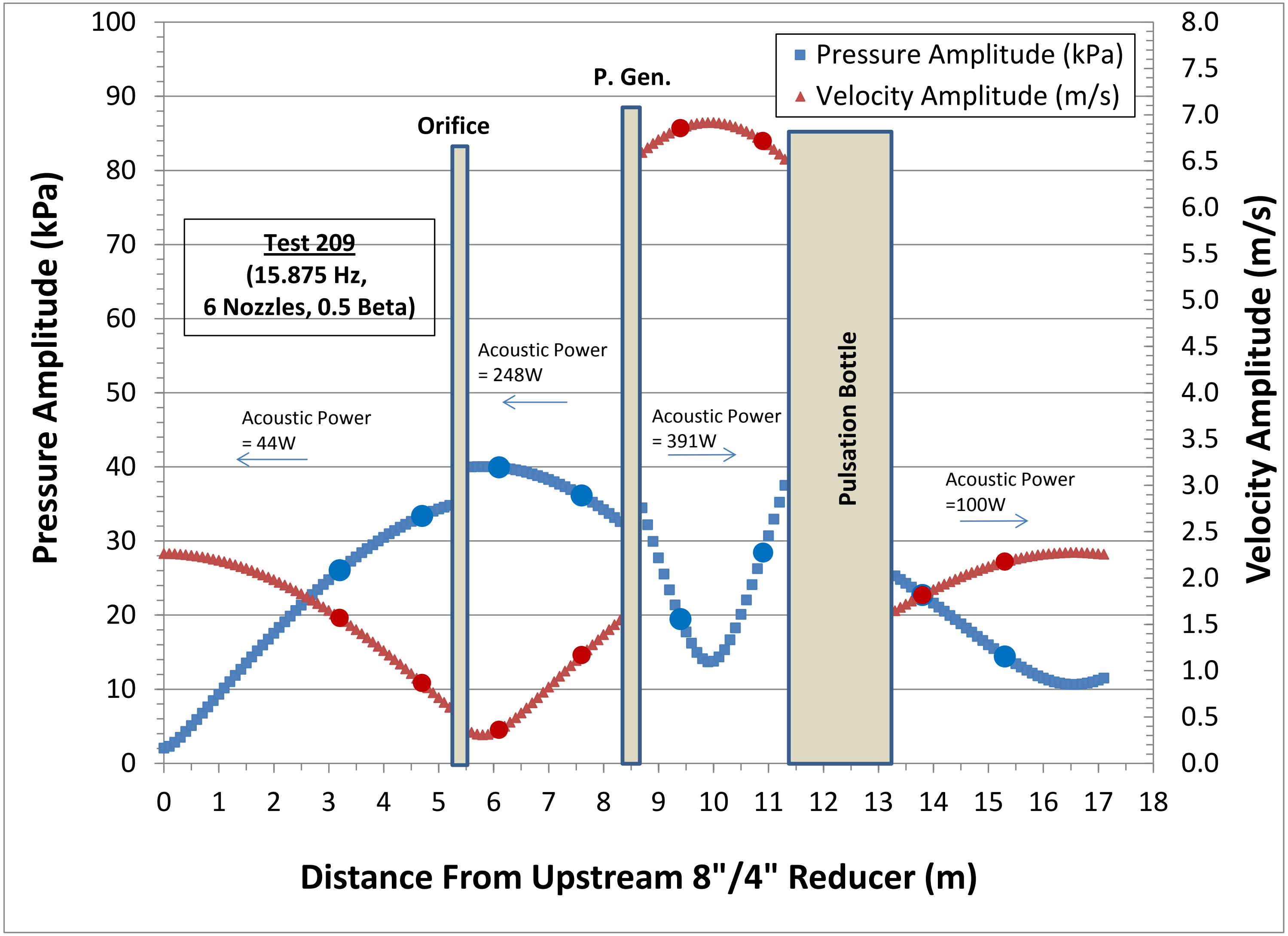
Example of Pulsating Pressure Measurements (Across the Bottle)



Example of 1st Harmonic $\vec{P}_k$ *and* $\vec{u}_k$ Mapping (Configuration A)



Example of 1st Harmonic $\vec{P}_k$ *and* $\vec{u}_k$ Mapping (Configuration B)



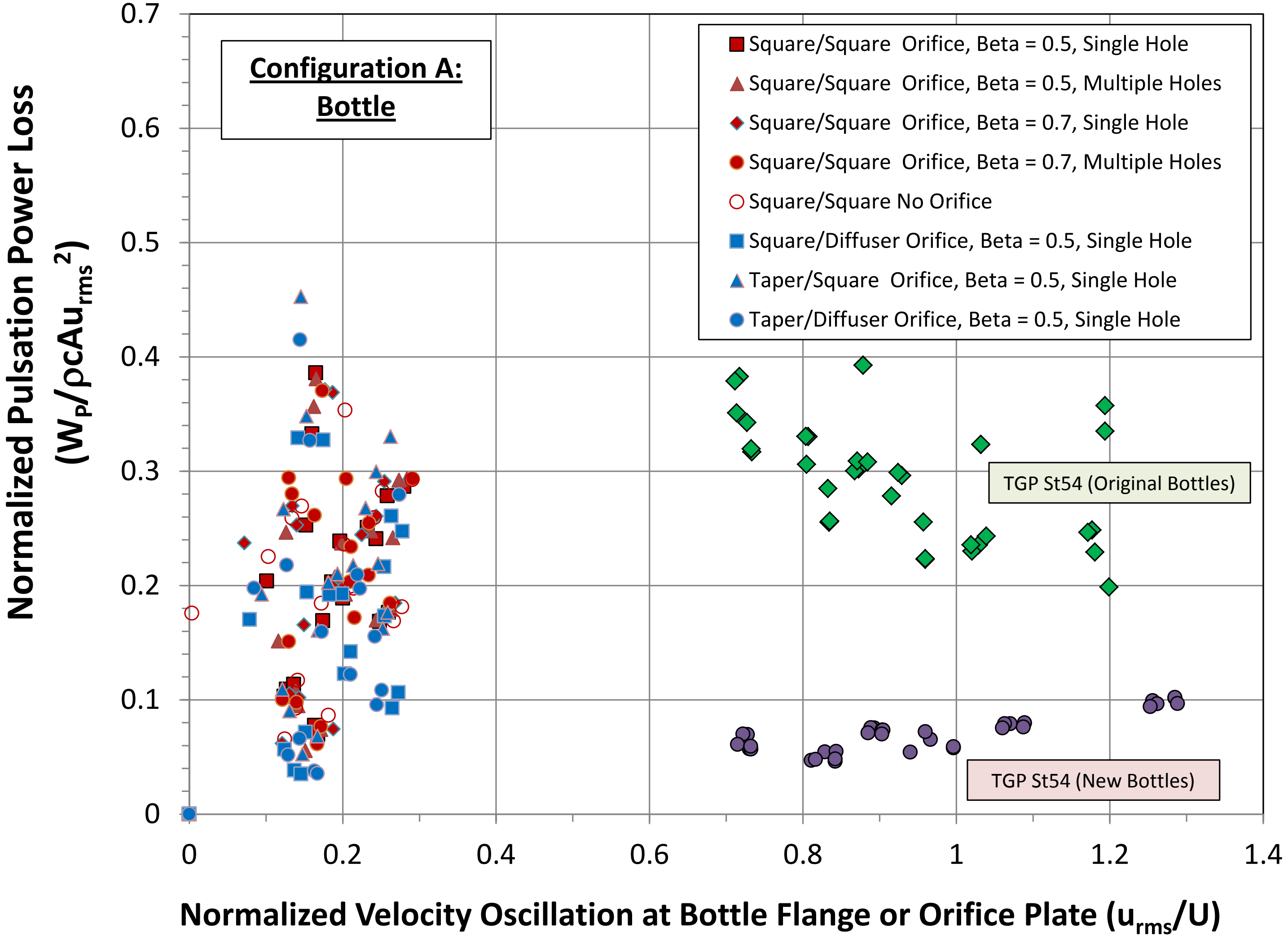
Test Results
(Configuration A)

Configuration A Test Scope

Configuration A Test Scope				
Test	**Number of Sonic Nozzles**	**End Treatments**	**Orifice β**	**Hole(s)**
1	3 and 6	Square/Square	1	-
1a	3 and 6	Square/Square	0.5	Single
1b	3 and 6	Square/Square	0.5	Multiple
1c	3 and 6	Square/Square	0.7	Single
1d	3 and 6	Square/Square	0.7	Multiple
2	3 and 6	Square/Diffuser	0.5	Single
3	3 and 6	Taper/Diffuser	0.5	Single
4	3 and 6	Taper/Square	0.5	Single
4a	High flow	Taper/Square	O.7	Single

For each of the sub-configuration and flow rate, a total of 10 tests were conducted at the following frequencies: 0, 11, 13, 15, 17, 22, 27, 31, 35, and 41 Hz. (Total for Configuration A = 180 Tests).

Normalized Pulsating Power Loss (Bottle)



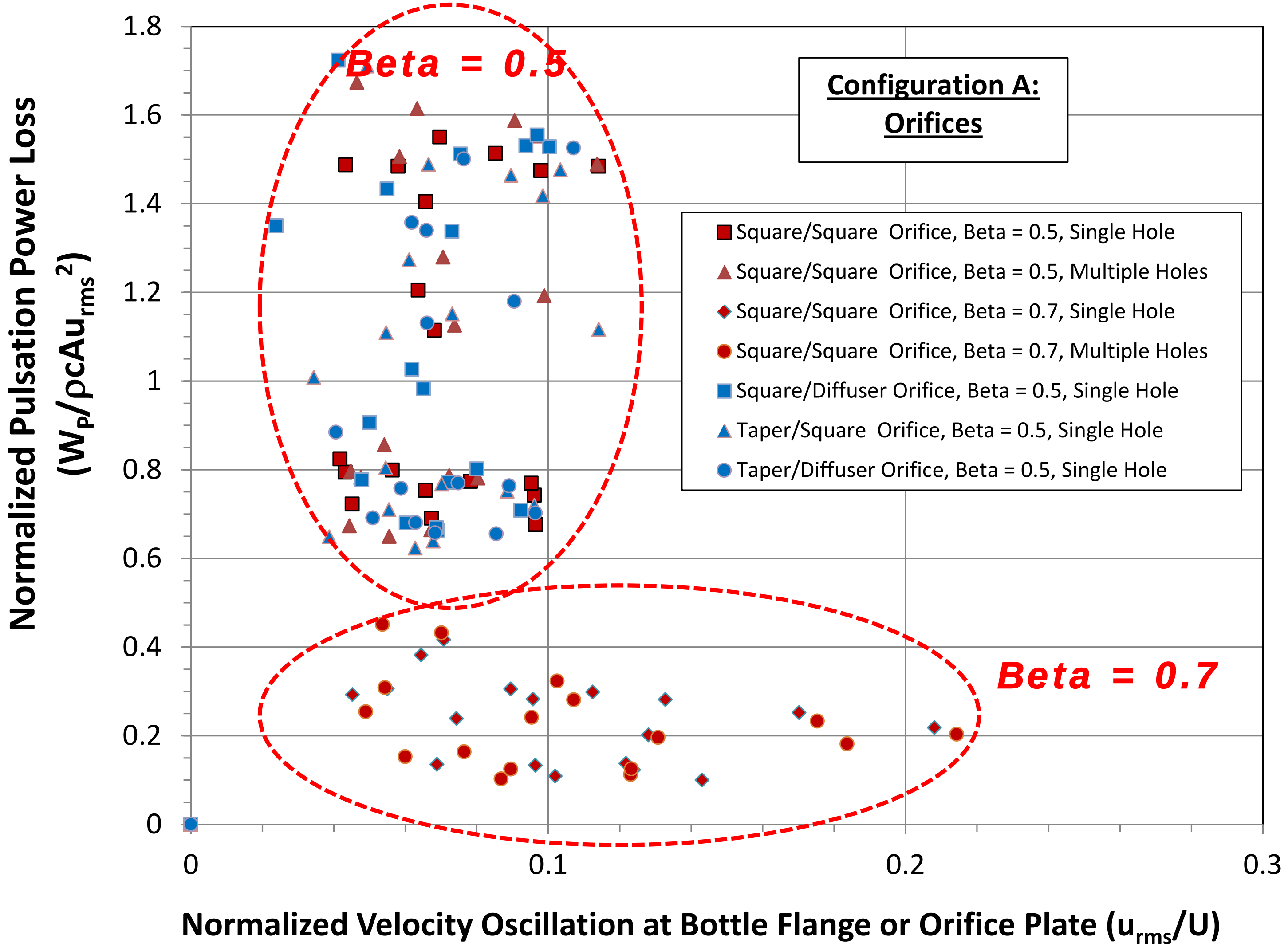
Normalized Velocity Oscillation u_{rms}/U

- TGP Station 54: 8350 HP compressor, 6 throw
  - $u_{rms}/U=0.7\text{-}1.3$
- Gathering compressor: 1775 HP, 4 throw
  - $u_{rms}/U=0.75$
- Vapour Recovery Compressor: 1200 HP, 6 throw
  - $u_{rms}/U=0.4$
- Test Setup: Hydraulic driven rotating paddle, 2 HP
  - $u_{rms}/U=0.3$ max

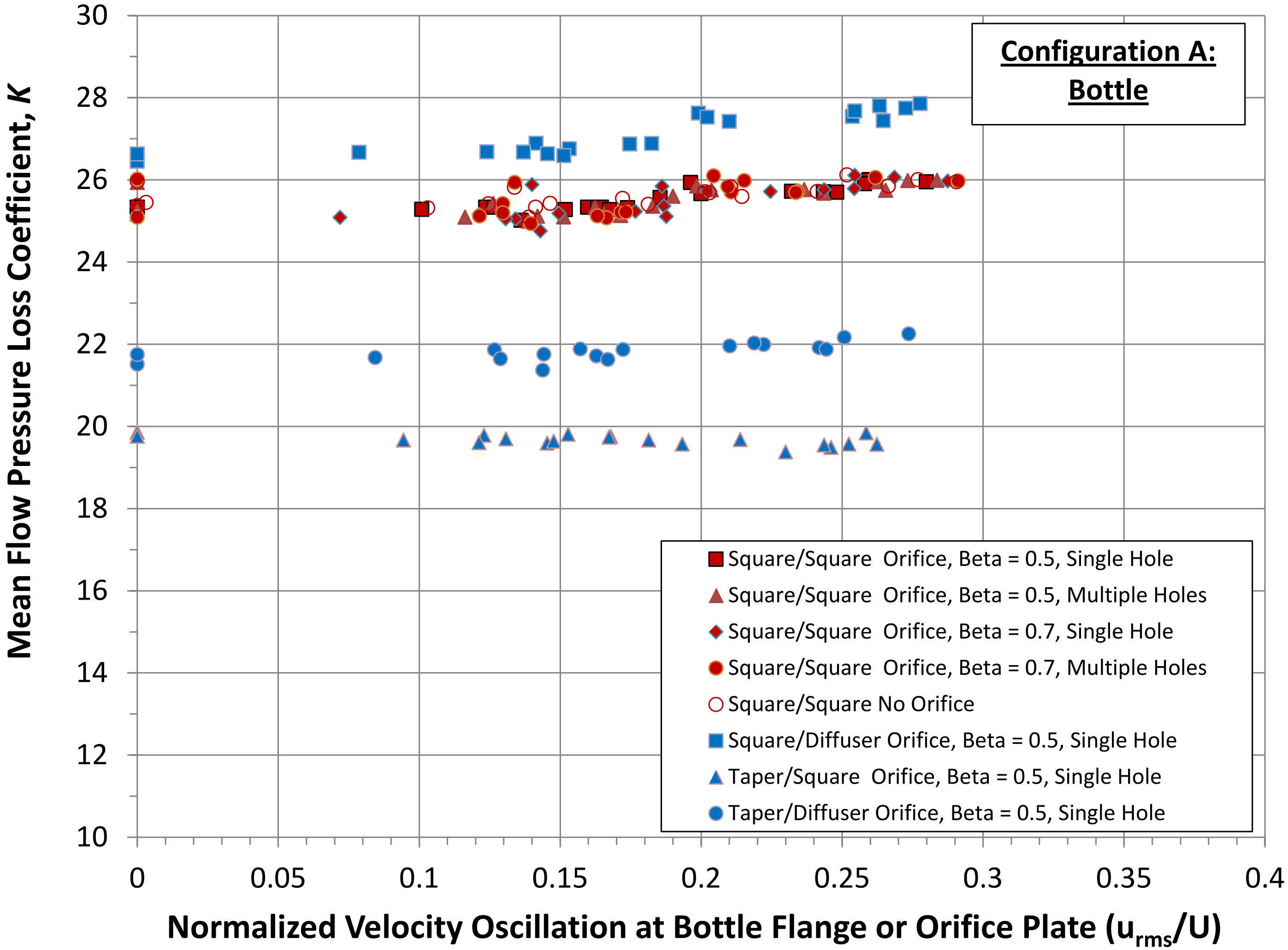
Current test setup representative of lower power/throw applications.

Pulse Generator modifications could generate $u_{rms}/U=0.6$

Normalized Pulsating Power Loss (Orifice)



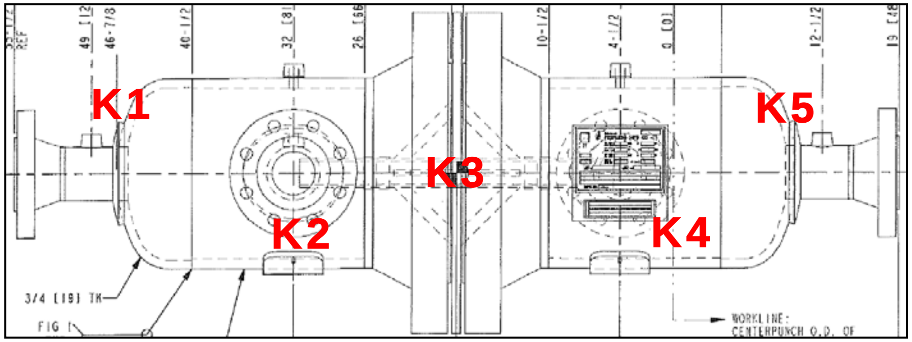
Normalized Mean Flow Pressure Loss Coefficient (Bottle) – zoomed in



Theoretical *K* Factor for the Bottle with Square End Treatments

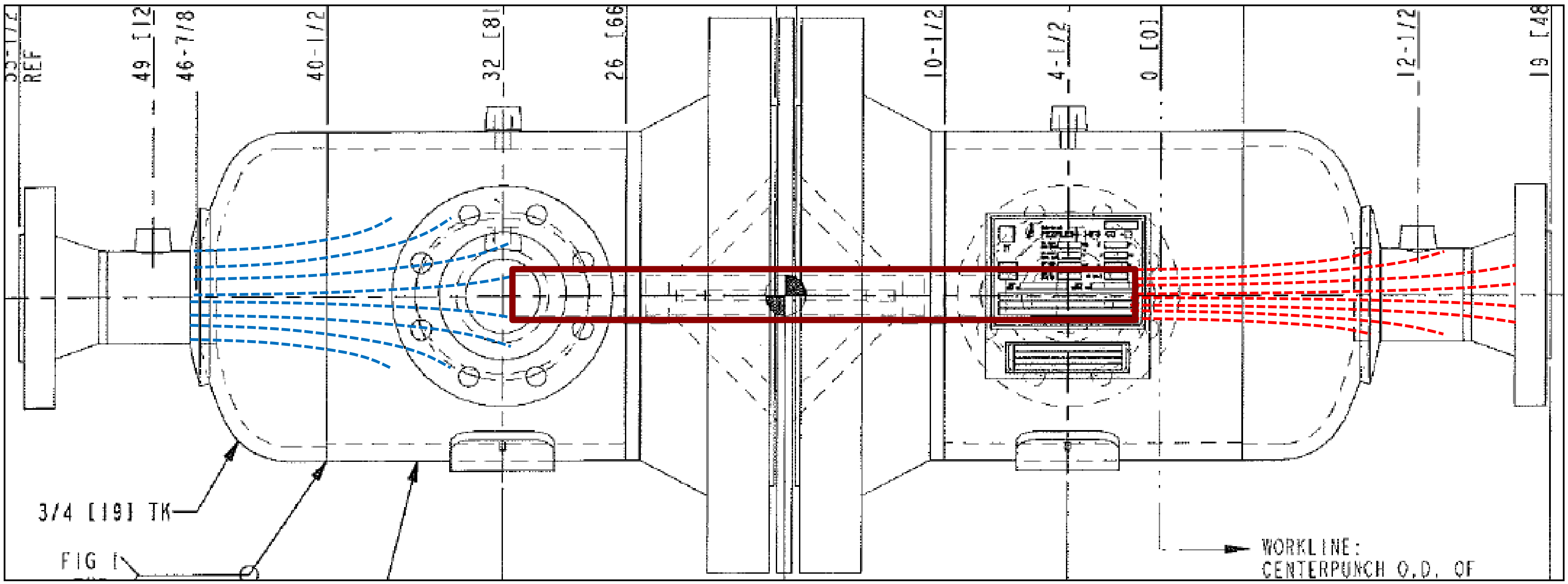
Bottle Theoretical K Coefficient		
NPS 4, ID (d2)	4.026	in
Choke Tube ID (d1)	1.939	in
Vessel ID (D)	14.29	in
Choke tube (L)	26	in

Element	**Local K-Factor**	**K-Factor (Ref NPS4)**
Entrance to Bottle, **K1**	0.85	0.85
Emtrance to Choke Tube (square), **K2**	0.49	9.11
Choke Tube (f=0.014), **K3**	0.19	3.49
Choke Tube Exit (square), **K4**	1.00	18.59
Entrance from Bottle to NPS4, **K5**	0.42	0.42
Sum (Overall K)		32.45
Measured K Factor		25



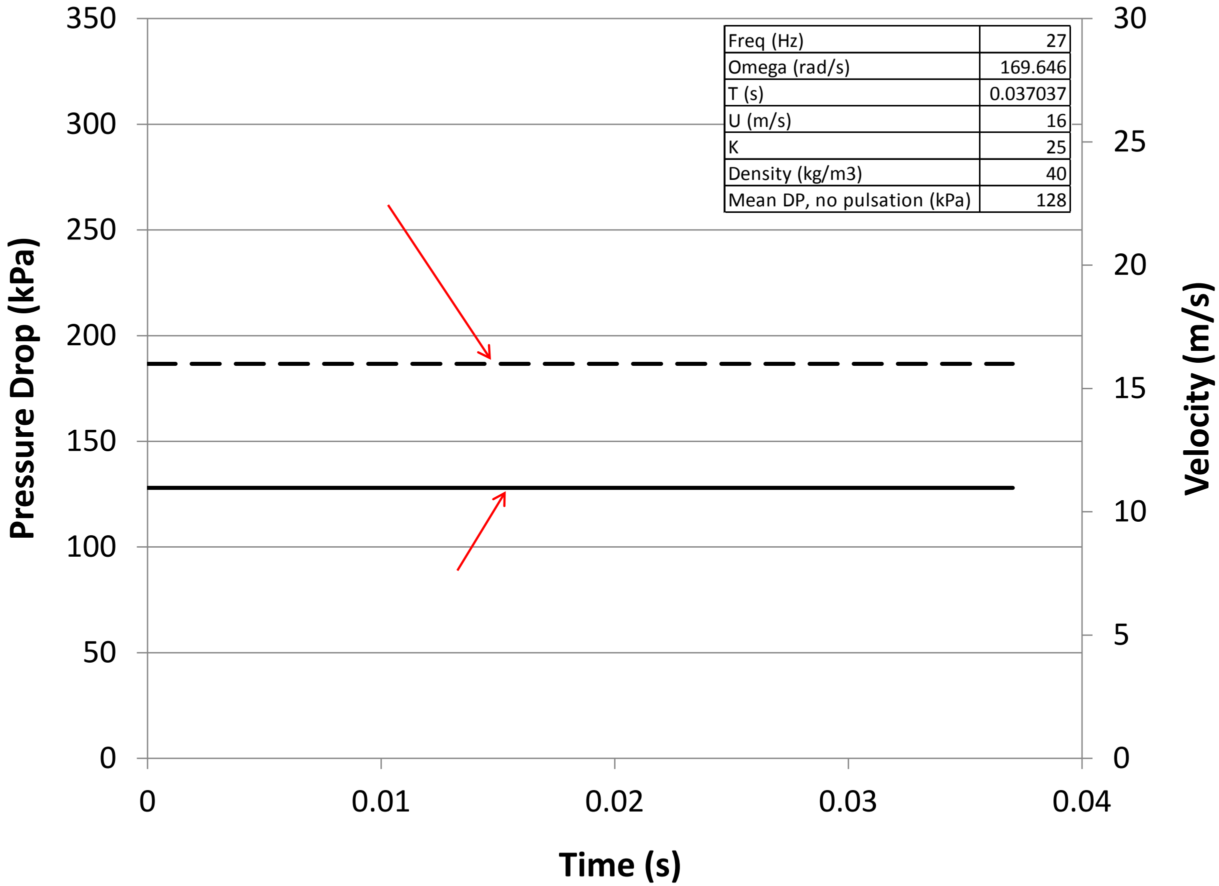
K is 21% lower than expected. Why?

Thoughts about why the Measured *K* Factor for the Bottle is Lower than Theoretical Value

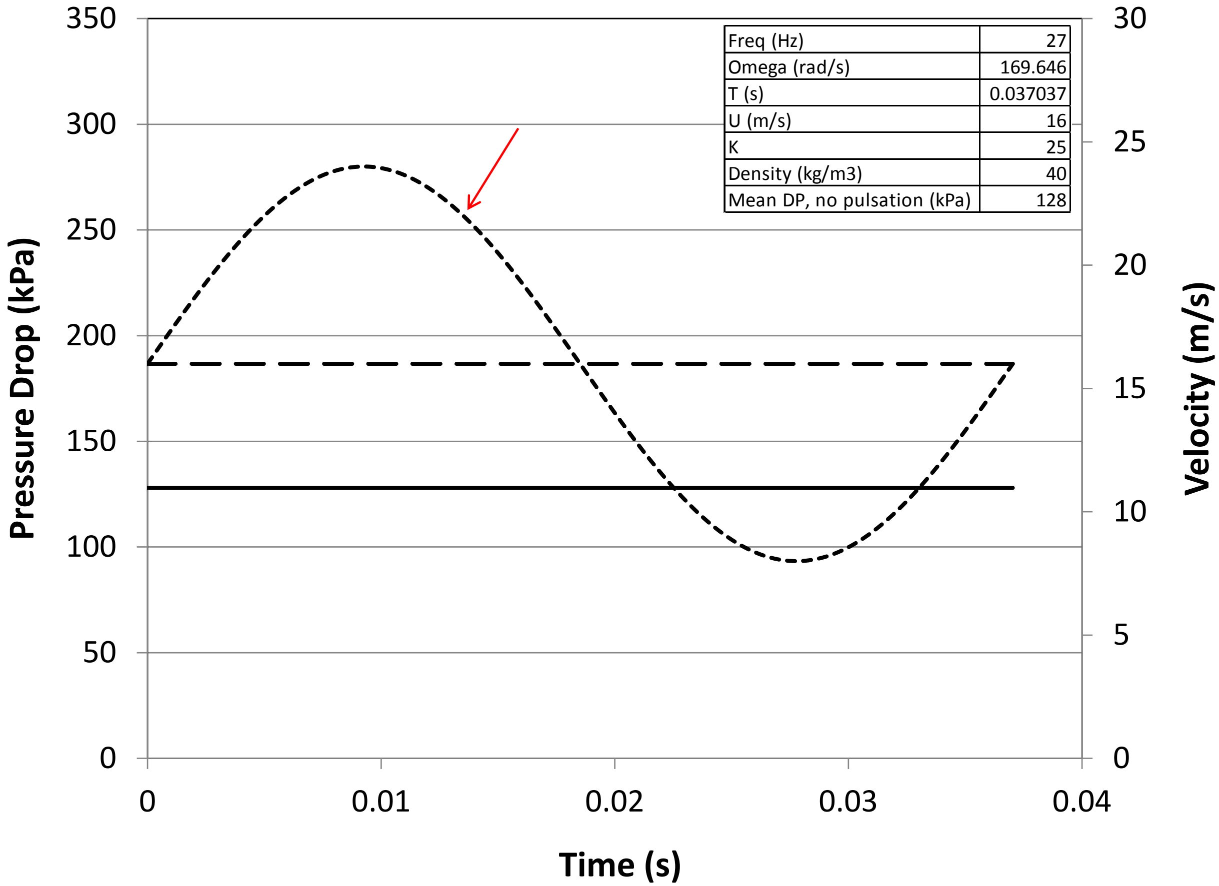


Flow

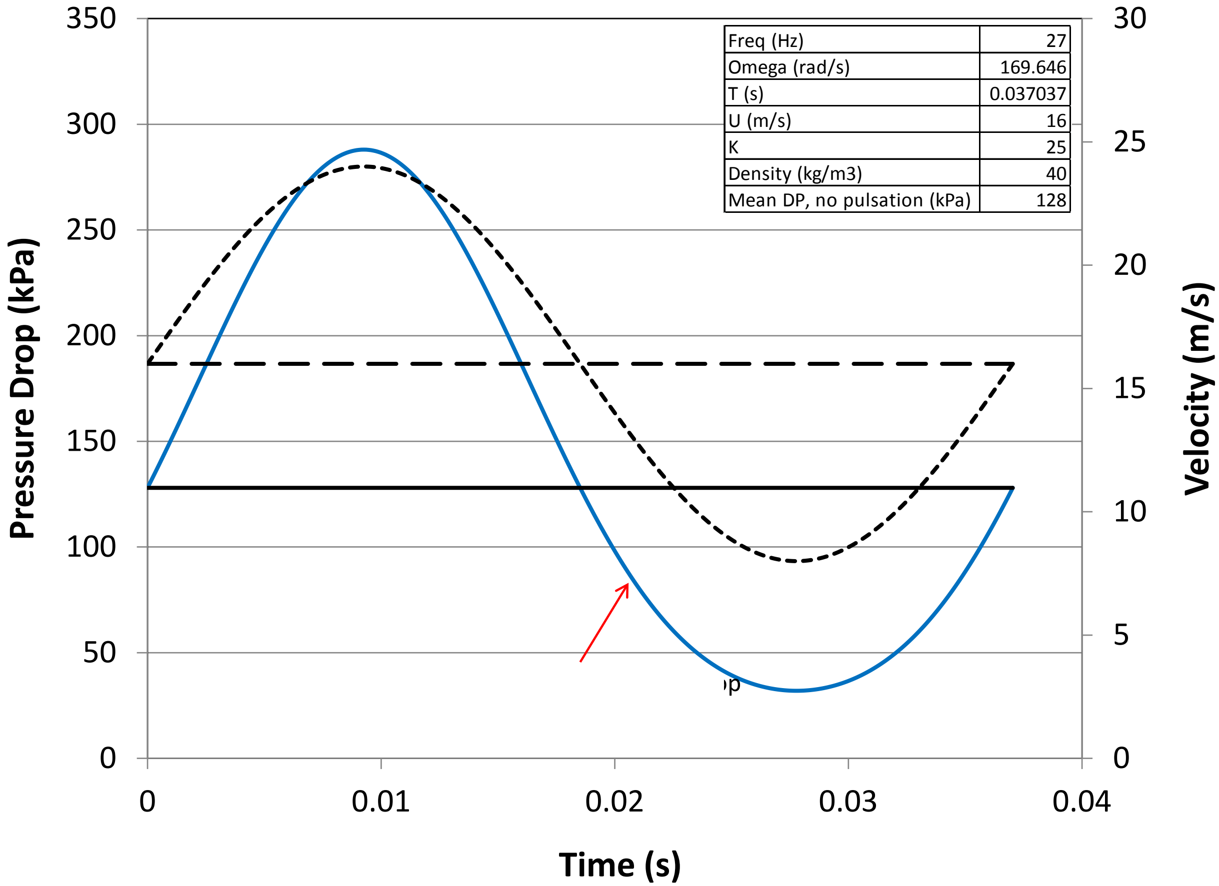
Quasi-Steady Hypothesis of Mean Flow Pressure Drop in the Presence of Pulsating Flow



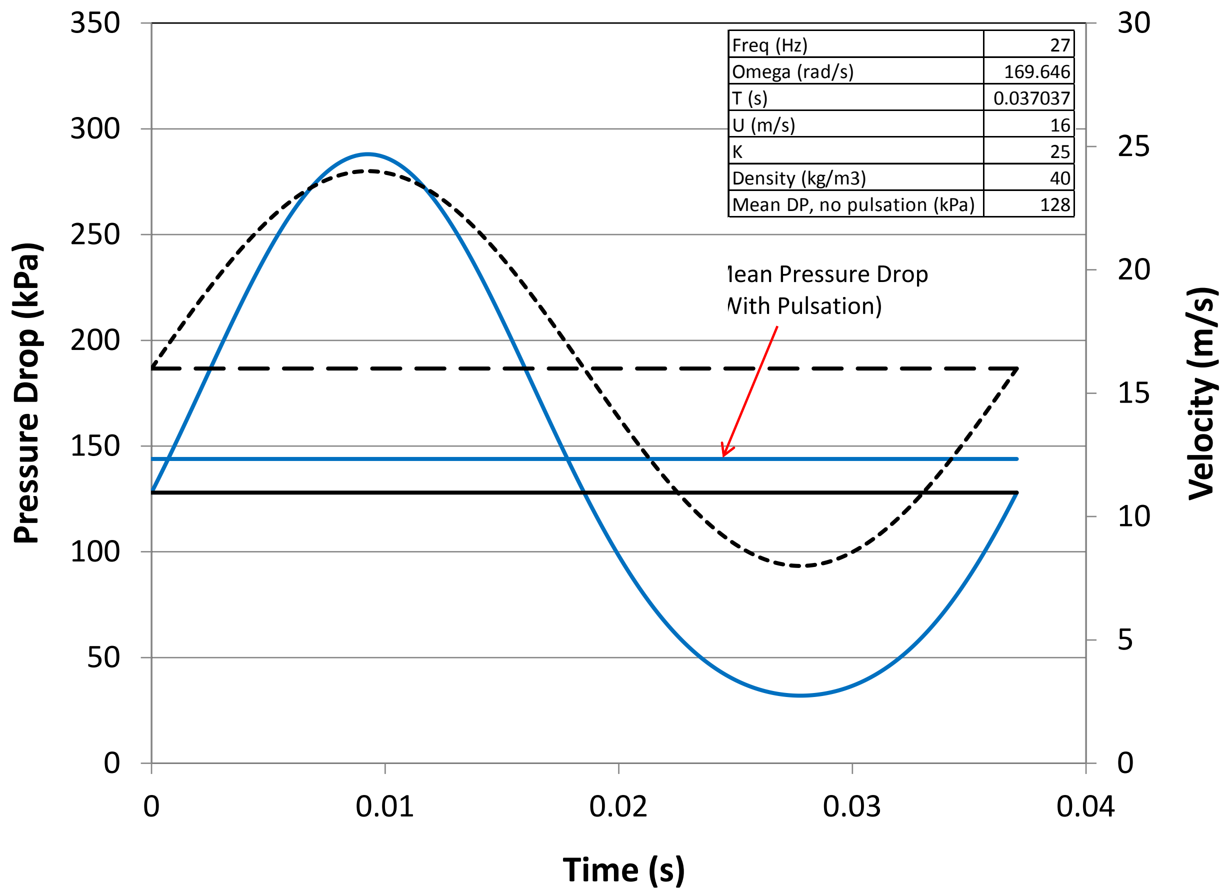
Quasi-Steady Hypothesis of Mean Flow Pressure Drop in the Presence of Pulsating Flow



Quasi-Steady Hypothesis of Mean Flow Pressure Drop in the Presence of Pulsating Flow

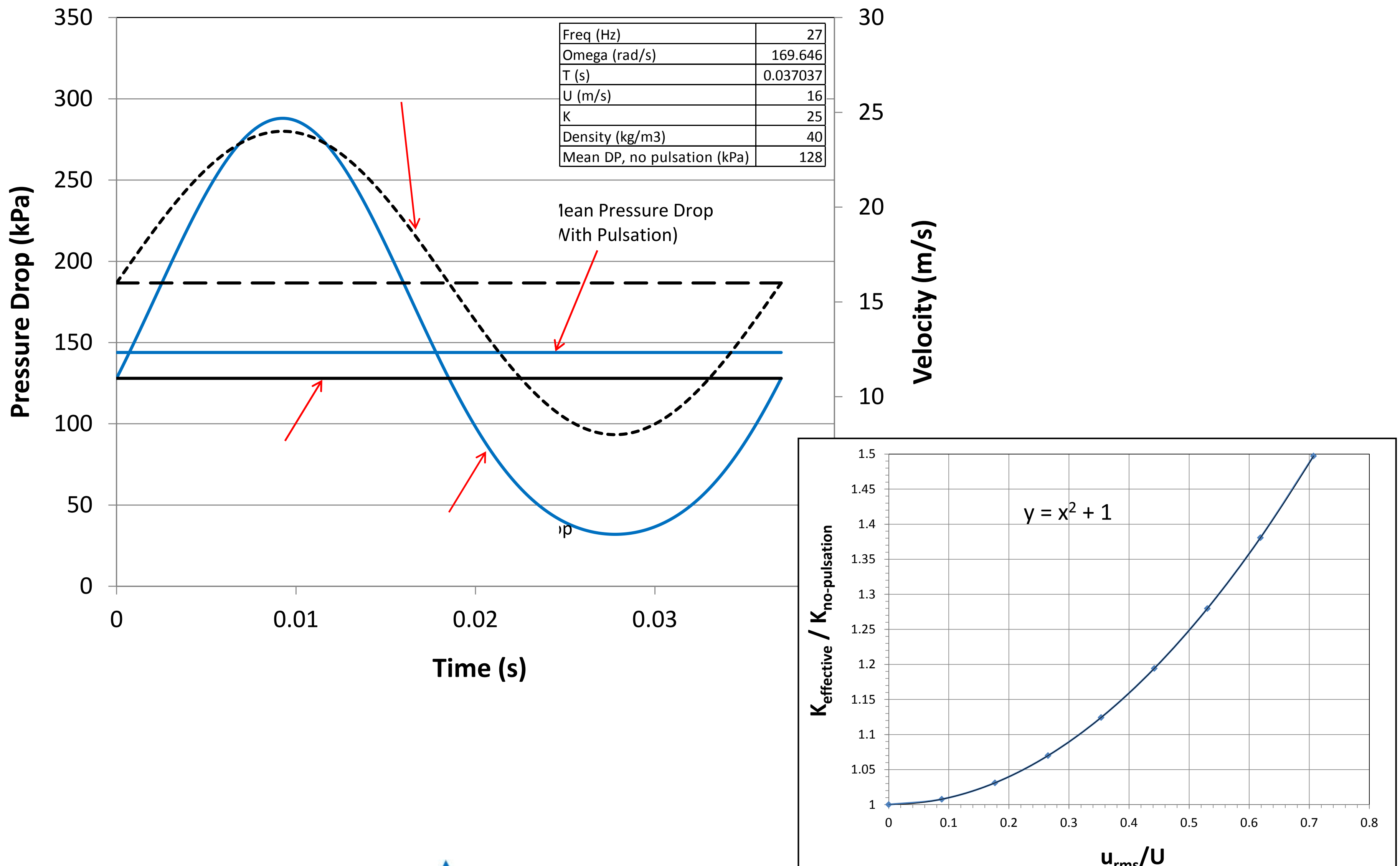


Quasi-Steady Hypothesis of Mean Flow Pressure Drop in the Presence of Pulsating Flow



Freq (Hz)	27
Omega (rad/s)	169.646
T (s)	0.037037
U (m/s)	16
K	25
Density (kg/m3)	40
Mean DP, no pulsation (kPa)	128

Quasi-Steady Hypothesis of Mean Flow Pressure Drop in the Presence of Pulsating Flow



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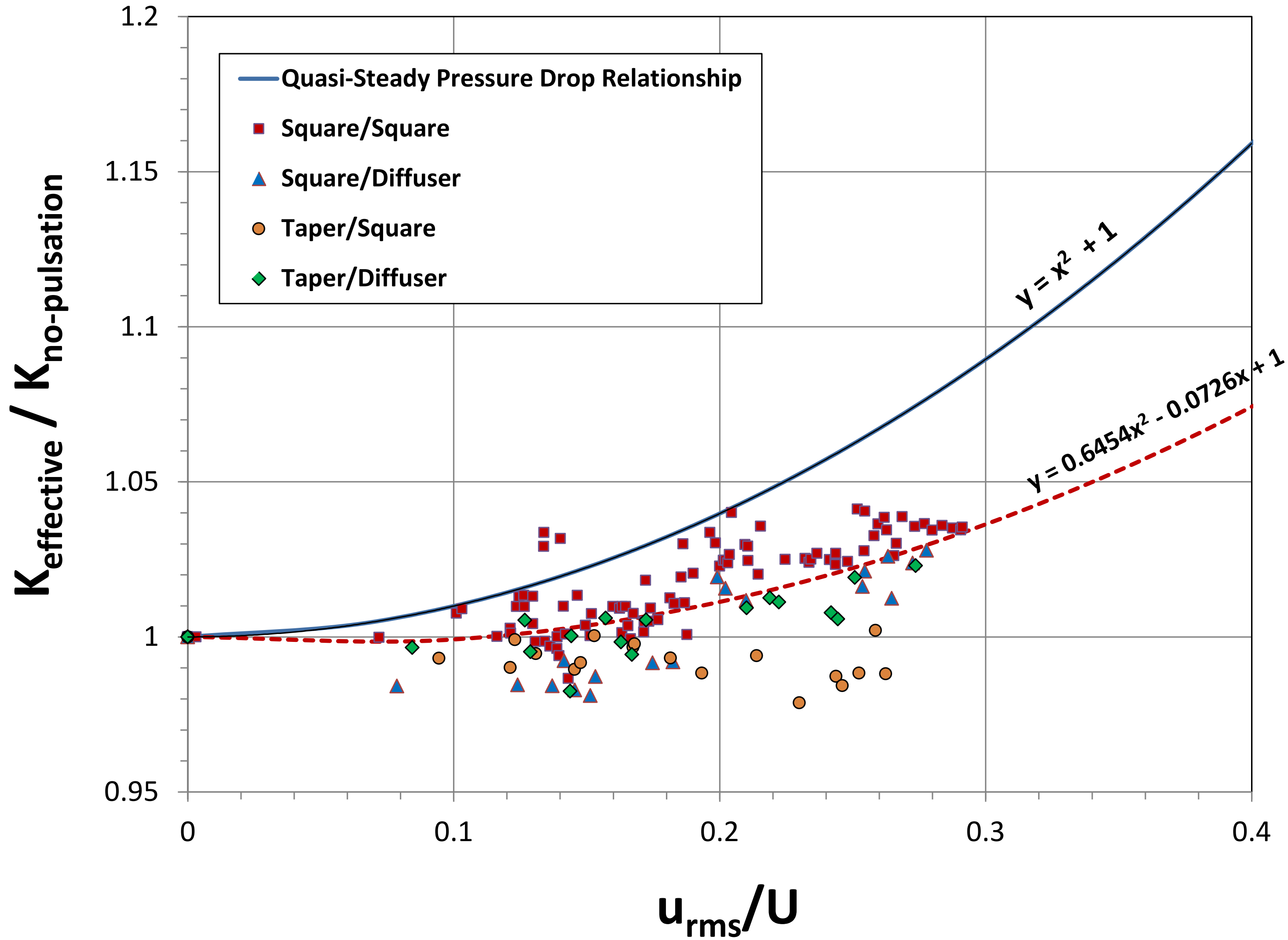
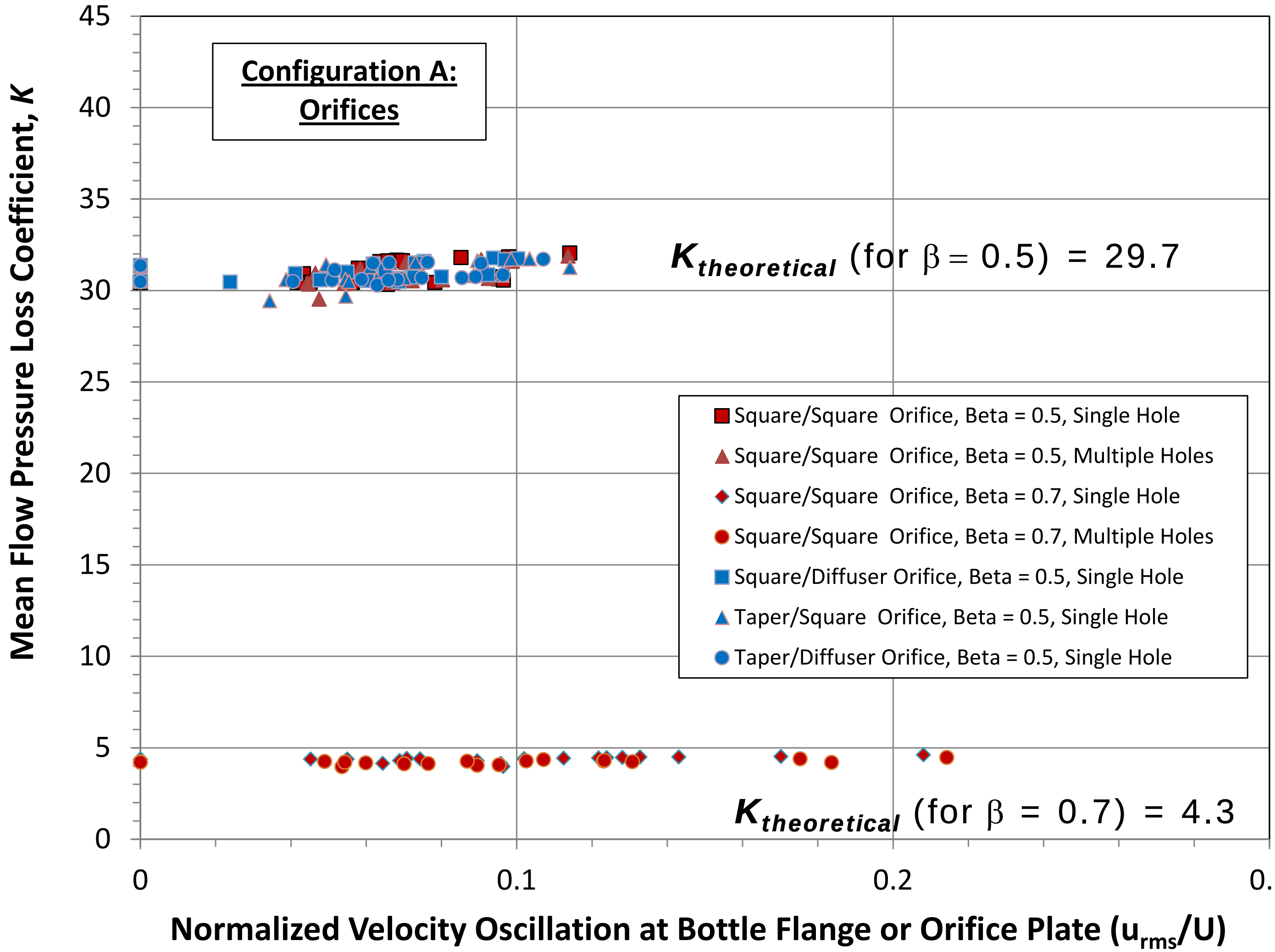
T (s)	0.037037
U (m/s)	16
K	25
Density (kg/m3)	40
Mean DP, no pulsation (kPa)	128

Current Measurements of Mean Flow Pressure Loss Coefficient (Representative of Suction Bottle)



Normalized Mean Flow Pressure Loss Coefficient (Orifice) – Referenced to NPS4



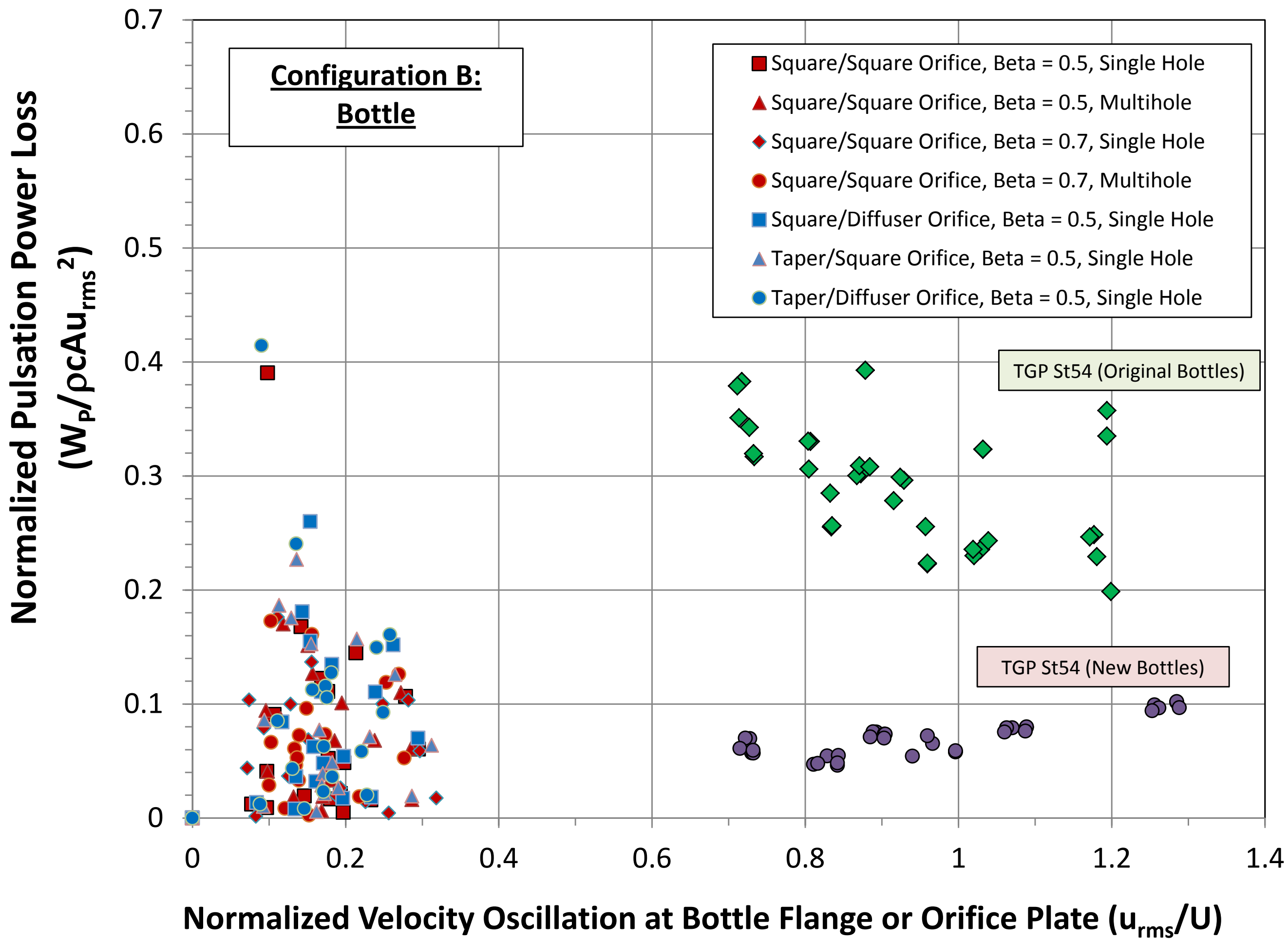
Test Results
(Configuration B)

Configuration B Test Scope

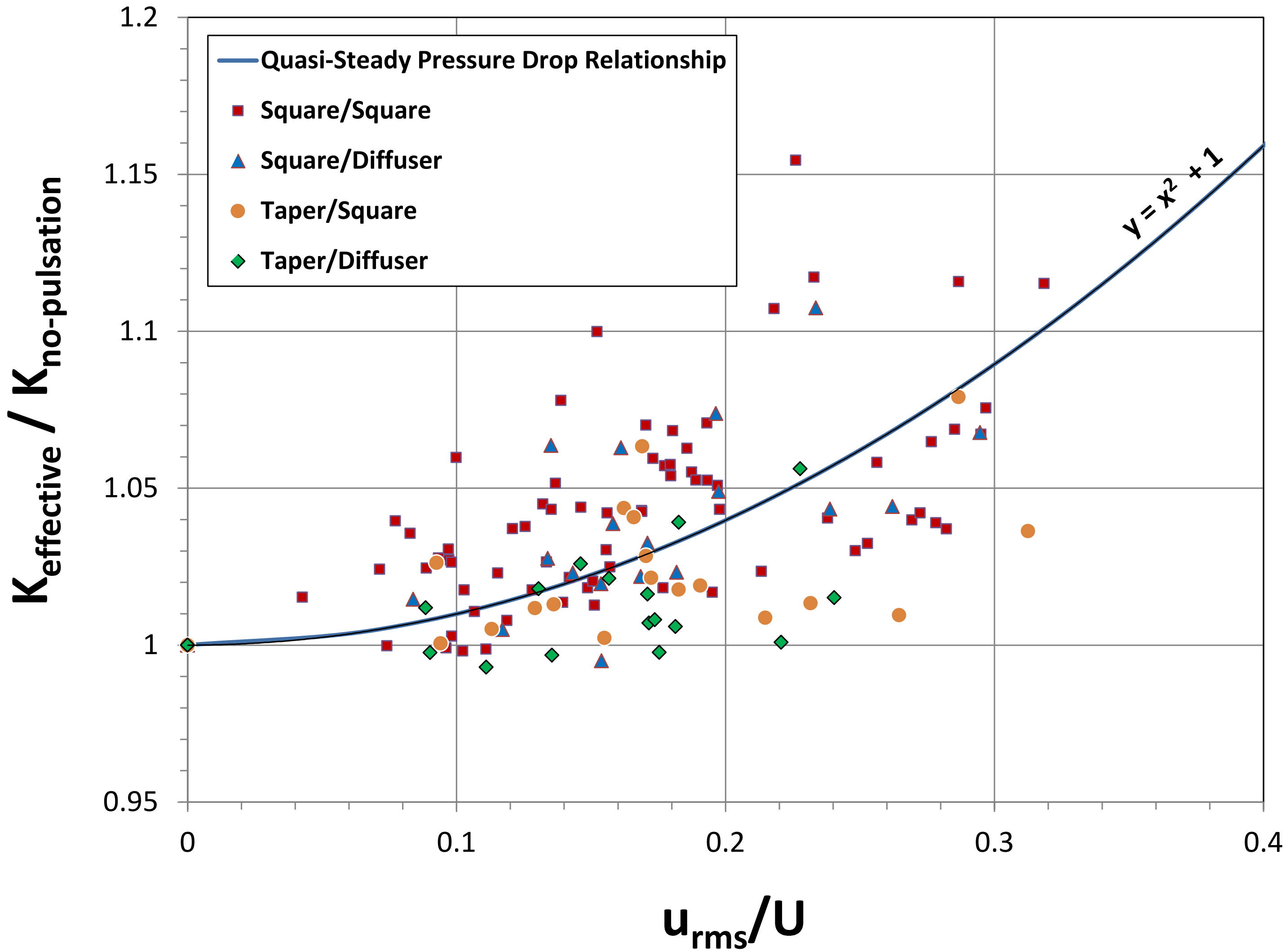
Configuration B Test Scope				
Test	**Number of Sonic Nozzles**	**End Treatments**	**Orifice β**	**Hole(s)**
1	3 and 6	Square/Square	1	-
1a	3 and 6	Square/Square	0.5	Single
1b	3 and 6	Square/Square	0.5	Multiple
1c	3 and 6	Square/Square	0.7	Single
1d	3 and 6	Square/Square	0.7	Multiple
2	3 and 6	Square/Diffuser	0.5	Single
3	3 and 6	Taper/Diffuser	0.5	Single
4	3 and 6	Taper/Square	0.5	Single

For each of the sub-configuration and flow rate, a total of 10 tests were conducted at the following frequencies: 0, 11, 13, 15, 17, 22, 27, 31, 35, and 41 Hz.
(Total for Configuration B = 160 Tests)

Normalized Pulsating Power Loss (Bottle)



Current Measurements of Mean Flow Pressure Loss Coefficient (Representative of Discharge Bottle)



NOVA Chemicals

BETA MACHINERY ANALYSIS

Summary of Site Testing

1. *Methodology*: Successful in validating the Flow Energy (acoustic power) methodology developed in Phase I.

2. *Bottle*: Differences measured between the bottle loss factor in steady flow and fluctuating flow as compared to published data. A 21% difference for steady flow, 5% for fluctuating flow in the test rig.

3. *Orifice*: Loss factor for single hole vs multi hole agreed well with published data. Some divergence at maximum test frequency of 41 Hz. Additional testing to investigate higher frequencies.

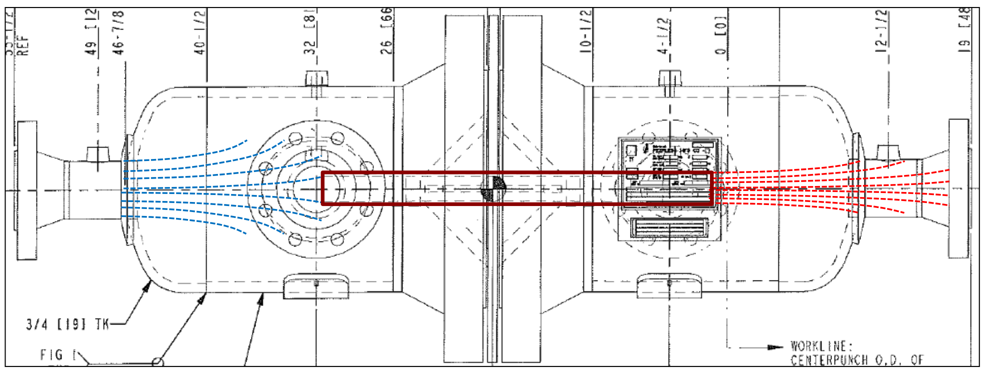
4. *Pulse Generator*: could create sufficient pressure fluctuations (2% of line) but flow fluctuations were lower than high power compressor cylinder ($u_{rms}/U < 0.3$).

2014 Project Plan

Task	Status
Field Test - Design test rig - Fabricate and Install - Execute Test Plan - Data Analysis	Testing completed July 25 Data review and analysis 95% completed.
Report	Complete by end of 2014
Optional Scope: Testing on reciprocating compressor facility	Need a site: TGP Stn 54, lots of information from Phase 1. Other site possible. Design test: - Fluctuation flow measurement - Compressor performance (P-V curves) and power measurements (torque, motor power)

Suggestions for Future Work

- Addition testing proposed at the TCPL site. Redesign of pulse generator or test rig required to create high flow fluctuations. CFD analysis of components.



- 4 possible journal publications resulting from the work completed.

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Predicting the Power Loss of Reciprocating Compressor Manifolds

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