Designing Piping Systems for Low Pressure Drop

Tom Taranto, Data Power Services

Keynote Speaker

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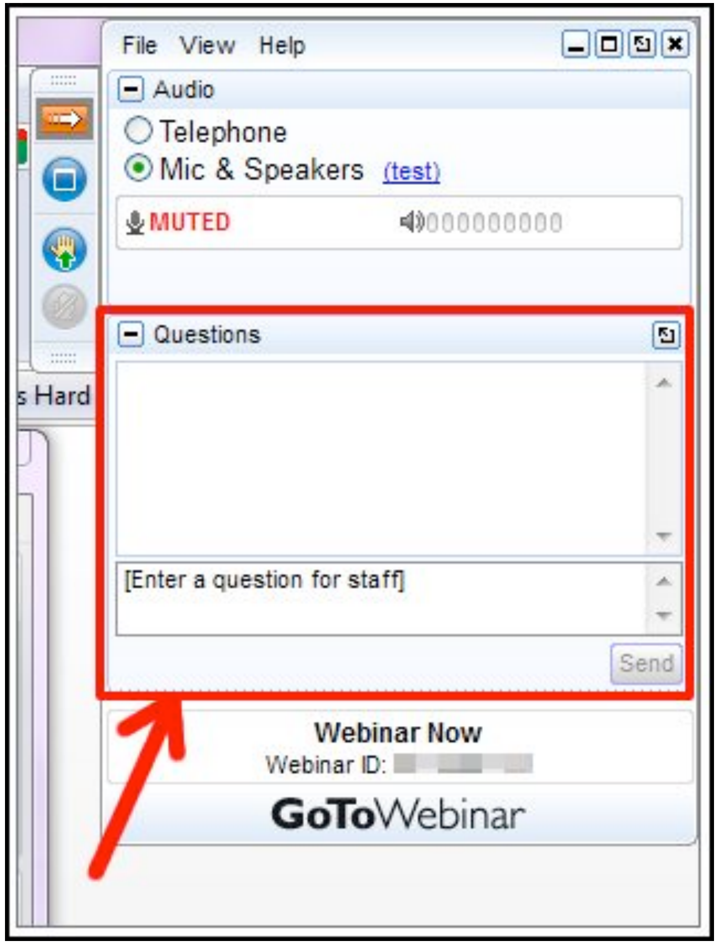
Q&A Format



• Panelists will answer your questions during the Q&A session at the end of the Webinar.

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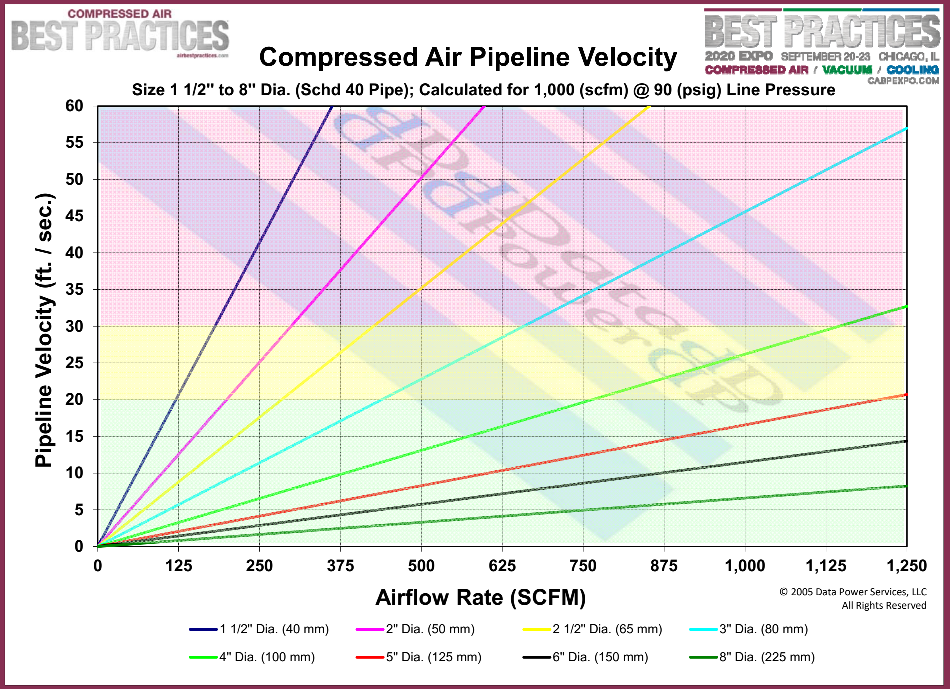
Handouts



COMPRESSED AIR
BEST PRACTICES
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Compressed Air Pipeline Velocity
BEST PRACTICES
2020 EXPO SEPTEMBER 20-23 CHICAGO, IL
COMPRESSED AIR / VACUUM / COOLING
CABPEXPO.COM
Size 1 1/2" to 8" Dia. (Schd 40 Pipe); Calculated for 1,000 (scfm) @ 90 (psig) Line Pressure
Pipeline Velocity (ft. / sec.)
60
55
50
45
40
35
30
25
20
15
10
5
0
0
125
250
375
500
625
750
875
1,000
1,125
1,250
Airflow Rate (SCFM)
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1 1/2" Dia. (40 mm)
2" Dia. (50 mm)
2 1/2" Dia. (65 mm)
3" Dia. (80 mm)
4" Dia. (100 mm)
5" Dia. (125 mm)
6" Dia. (150 mm)
8" Dia. (225 mm)

The Magazine for ENERGY EFFICIENCY in Compressed Air Systems
COMPRESSED AIR
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March 2020
Refineries
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Disclaimer

All materials presented are educational. Each system is unique and must be evaluated on its own merits.

Introducing the Thursday Webinar Series: March & April 2020

When: Thursday, March 26, 2 pm EST and every week through April 2020
Next Up: **Best Practices Shared by Subscribers -**
Advanced Trends in Compressed Air & Vacuum Systems Levels 1 & 2

Speaker Bio: Roderick Munoz Smith
2006-Present: Publisher, Best Practices Magazines & Expo
1992-2006: Former VP Sales & Marketing,
Quincy Compressor and SPX Hankison

Phase 1 (late 1990's)

- 5 x 1000 hp, 450 hp trim
- Compressor Room kW and pressure data logging
- Plant Pressure 135 psig
- Car production: 240,000 autos
- Had one $ and kWh metric for compressed air for whole plant

Phase 2 (2002-today)

- 2 x 1000 hp, 450 hp trim
- Monthly compressed air kWh budgets for each of 4 major production areas – **flow meters** measure each area like a utility
- Master Compressed Air System Measurement and Management
- Plant Pressure 105 psig
- Car production: 240,000 autos

HONDA

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Designing Piping Systems for Low Pressure Drop

Introduction

Rod Smith, Publisher

Compressed Air Best Practices® Magazine

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About the Speaker

Tom Taranto
Data Power Services

- Owner, Data Power Services
- Conducts compressed air system assessments, equipment testing and compressed air system training throughout the world with over 40 years of industry experience
- U.S. DOE Energy Expert, Compressed Air Challenge technical committee member, Compressed Air Challenge qualified instructor and instructor for Qualified AIRMaster+ Specialist Training

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Compressed Air Piping
Designing Piping Systems for Low Pressure Drop

March 19, 2020

Tom Taranto / Data Power Services, LLC

Agenda

- Cost of Pressure Loss
- Design Parameters
- Piping System Design & Layout
- Identifying & Correcting Pipeline Pressure Loss

Cost of Pressure Loss

Compressed air system piping

Cost of Pressure Loss

- Energy Cost
  - Increasing compressor discharge pressure is a common solution to overcome excessive pressure loss.
  - For positive displacement compressors, compressor power increases by 1% for each 2 psig increase in compressor discharge pressure
- Performance Impact
  - Pressure required by pneumatic equipment for proper operation.
  - Inadequate or unstable pressure can cause
    - production interruption
    - product quality issues
    - reduced production output
    - increased scrap rate
    - added cost for rework

Fuel System Machinery Plant – Dept of Energy Case Study

June 2001

OFFICE OF INDUSTRIAL TECHNOLOGIES

ENERGY EFFICIENCY AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY

BENEFITS

- Saves $226,000 annually
- Reduces energy use
- 40% reduction in compressed air energy costs per unit of production
- Increases reliability
- Reduces CO_2 emissions

APPLICATIONS

Compressed air systems are found throughout industry and consume a significant portion of th...

COMPRESSED AIR SYSTEM REDESIGN RESULTS IN INCREASED PRODUCTION AT A FUEL SYSTEM PLANT

Summary

In 1999, Caterpillar Fuel Systems performed a compressed air system improvement project at its fuel injector plant in Pontiac, Illinois. The project's implementation greatly improved the compressed air system's reliability and efficiency. As a result, the plant achieved important energy savings through reduced energy consumption, was able to increase production by 18% without purchasing additional compressors, and solved an air supply problem to a critical production area. Had the plant not increased its production, it would have been able to take

Fuel System Machinery Plant – Dept of Energy Case Study

Phase 1—The first phase of the evaluation discovered several issues that contributed to the plant's inability to adequately supply the HIP assembly area. The first problem was the high pressure drop in the air treatment and distribution systems. The pressure drop was due to undersized and poorly functioning filters, dryers, and aftercoolers and ranged from 7 to 18 psig. This led to a fluctuating pressure in the main header of 96 to 108 psig. Pressure loss/drop is a function of a compressed air system's dynamics—the interaction of airflow rate with the inherent resistance of the pipeline and air system components. The pressure drop was exacerbated by the configuration of the distribution system. The evaluators determined that the dimensions of the main header (6 inches) were undersized for the system's airflow. This led to a high degree of resistance to airflow within the piping that exceeded the optimal design parameters. In addition, three 4-inch pipelines that were served by the main header were found unconnected to the piping loop, causing an unbalanced airflow across the system. Together, these factors combined to create

Design Parameters

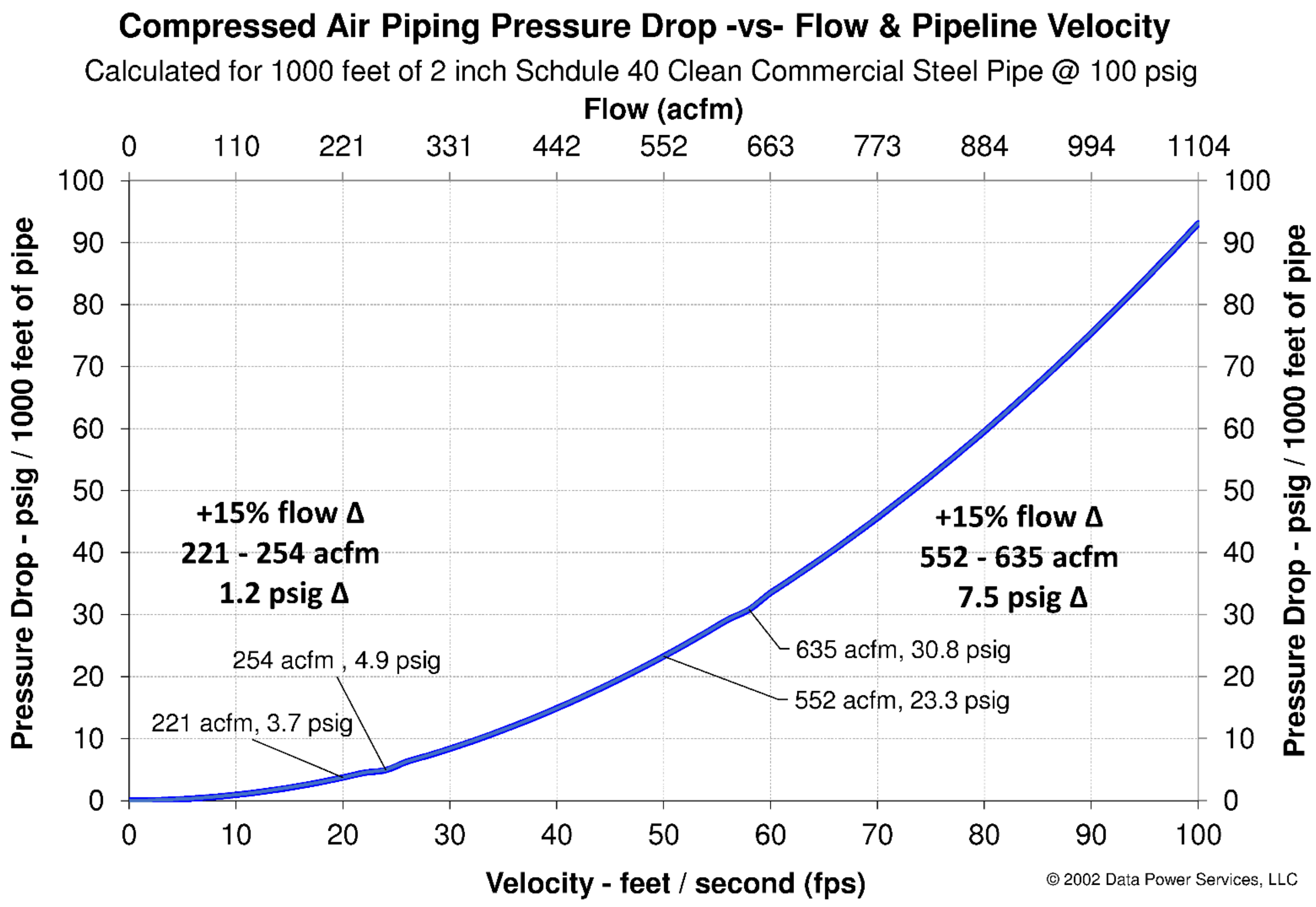
Fluid Velocity

Pipe Length

Roughness of Pipe Material

Pressure Loss −vs− Fluid Velocity

- Compressor Air Pipeline Velocity
  - 45 to 55 fps - Traditional Design Velocity
  - 20 to 30 fps – Current Best Practice
- High velocity leads to
  - Increased pressure loss
  - Pressure fluctuations



Pressure Loss –vs– Pipe Length

General Reference Data

CAGI Compressed Air & Gas Institute

- Pressure Loss is directly proportional to the pipe length.
- What about pipe fittings & valves?

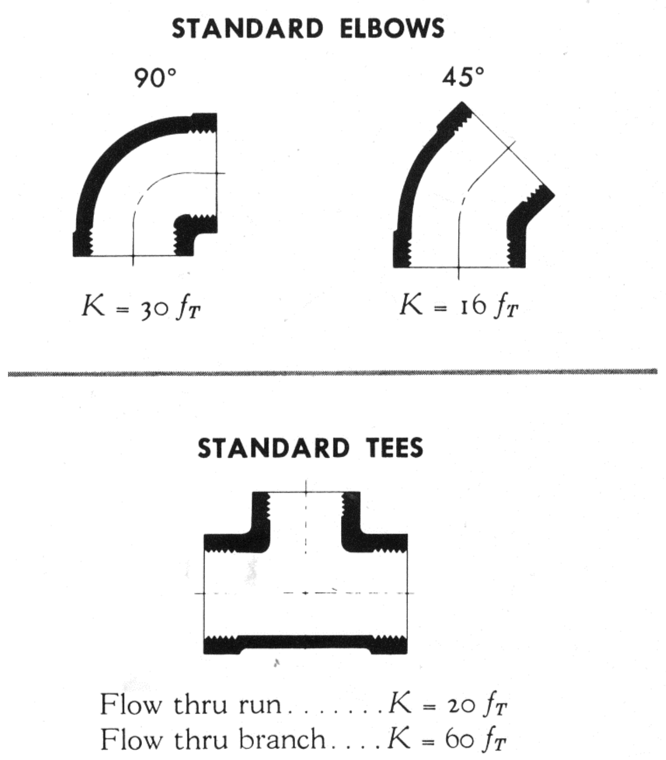
Table 8.14 Loss of Air Pressure Due to Friction

Cu ft Free Air Per Min	Equivalent Cu ft Compressed Air Per Min	Nominal Diameter, In.											
		$^1/_2$	$^3/_4$	1	1 $^1/_4$	1 $^1/_2$	2	3	4	6	8	10	12
10	1.28	6.50	.99	0.28									
20	2.56	25.9	3.90	1.11	0.25	0.11							
30	3.84	58.5	9.01	2.51	0.57	0.26							
40	5.12	....	16.0	4.45	1.03	0.46							
50	6.41	....	25.1	9.96	1.61	0.71	0.19						
60	7.68	....	36.2	10.0	2.32	1.02	0.28						
70	8.96	....	49.3	13.7	3.16	1.40	0.37						
80	10.24	....	64.5.	17.8	4.14	1.83	0.49						
90	11.52	....	82.8	22.6	5.23	2.32	0.62						
100	12.81	....	....	27.9	6.47	2.86	0.77						
125	15.82	....	....	48.6	10.2	4.49	1.19						
150	19.23	....	....	62.8	14.6	6.43	1.72	0.21					
175	22.40	....	....	....	19.8	8.72	2.36	0.28					
200	25.62	....	....	....	25.9	11.4	3.06	0.37					
250	31.64	....	....	....	40.4	17.9	4.78	0.58					
300	38.44	....	....	....	58.2	25.8	6.85	0.84	0.20				
350	44.80	....	....	....	....	35.1	9.36	1.14	0.27				
400	51.24	....	....	....	....	45.8	12.1	1.50	0.35				
450	57.65	....	....	....	....	58.0	15.4	1.89	0.46				
500	63.28	....	....	....	....	71.6	19.2	2.34	0.55				
600	76.88	....	....	....	....	....	27.6	3.36	0.79				
700	89.60	....	....	....	....	....	37.7	4.55	1.09				
800	102.5	....	....	....	....	....	49.0	5.89	1.42				
900	115.3	....	....	....	....	....	62.3	7.6	1.80				
1,000	128.1	....	....	....	....	....	76.9	9.3	2.21				
1,500	192.3	....	....	....	....	....	....	21.0	4.9	0.57			

In psi in 1000-ft of pipe, 100-lb gage initial pressure. For longer or shorter lengths of pipe the friction loss is proportional to the length, i.e., for 500 ft, one-half of the above; for 4,000 ft, four times the above, etc.

Pressure Loss –vs– Pipe Length

- Pressure Loss is directly proportional to the pipe length.
- What about pipe fittings & valves?
  - Equivalent Length L/D method*
    - 90^{O} elbow L/D = 30
    - 90^{O} long radius elbow L/D = 16
    - 2” Sched 40 I.D. = 2.067” = 0.172 ft.
    - 90^{O} elbow = 5.16 ft.
    - 90^{O} long radius elbow = 3.44 ft.



Crane Technical Paper No. 410
Metric Version also available SI Units

*Baumeister – Mark’s Standard Handbook for Mechanical Engineers, 8^{th} ed. Table 11; p 3-58.

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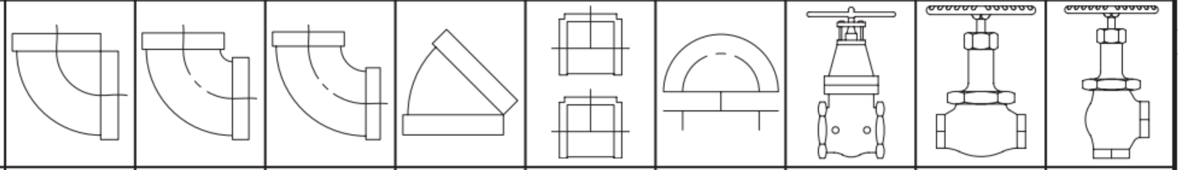
Engineering Data

Bulletin 90

Engineering Data

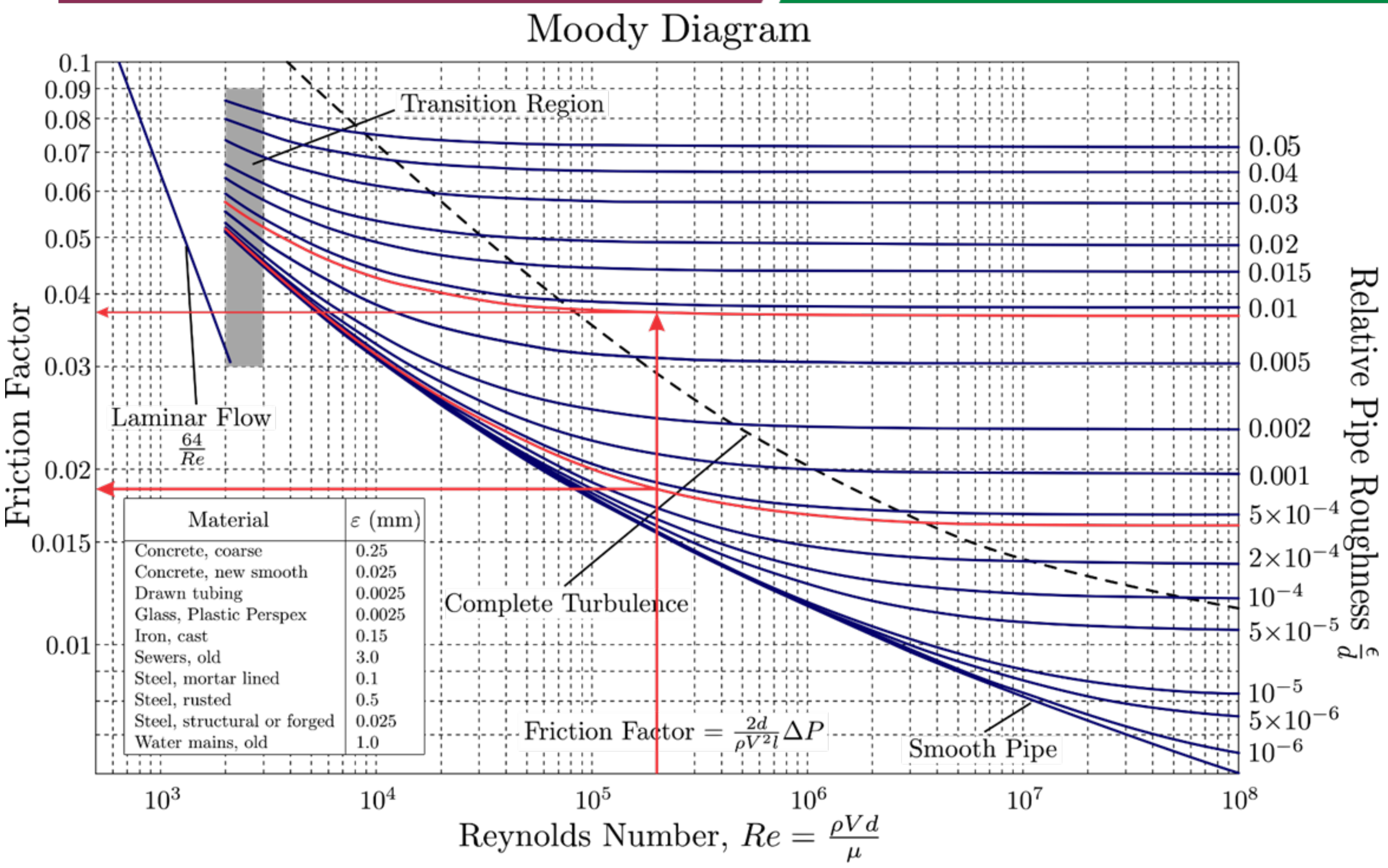
Table 3 - Friction Losses Through Pipe Fittings in Terms of Equivalent Lengths of Standard Pipe



Size of Pipe (Small Dia.)	Standard Elbow	Medium Radius Elbow	Long Radius Elbow	45° Elbow	Tee	Return Bend	Gate Valve Open	Globe Valve Open	Angle Valve Open
	Length of Straight Pipe Giving Equivalent Resistance Flow								
½"	1.5	1.4	1.1	.77	3.4	3.8	.35	16	8.4
¾"	2.2	1.8	1.4	1.0	4.5	5.0	.47	22	12
1"	2.7	2.3	1.7	1.3	5.8	6.1	.60	27	15
1¼"	3.7	3.0	2.4	1.6	7.8	8.5	.80	37	18
1½"	4.3	3.6	2.8	2.0	9.0	10	.95	44	22
2"	5.5	4.6	3.5	2.5	11	13	1.2	57	28
2½"	6.5	5.4	4.2	3.0	14	15	1.4	66	33
3"	8.1	6.8	5.1	3.8	17	18	1.7	85	42
3½"	9.5	8.0	6.0	4.4	19	21	2.0	99	50
4"	11.0	9.1	7.0	5.0	22	24	2.3	110	58
4½"	[illegible]	10	[illegible]	[illegible]	24	27	[illegible]	130	[illegible]

*Baumeister – Mark’s Standard Handbook for Mechanical Engineers, 8th ed. Table 11; p 3-58.

Pressure Loss: clean –vs– rusted steel = 5.1 –vs– 6.7 psid per 1000 ft.



Steel Rusted

$$\frac{\varepsilon}{d} = \frac{0.5}{52.5\ mm}$$

$$= \mathbf{9.55x10^{-3}}$$

Steel

$$\frac{\varepsilon}{d} = \frac{0.025}{52.5\ mm}$$

$$= \mathbf{4.76x10^{-4}}$$

Pressure Loss 1000 ft of 2" pipe @ 300 acfm

Darcy Equation

$$\Delta P = \frac{\rho K v^2}{144(2g)}$$

Resistance Coefficient

$K = 145.3$

$\Delta P = 6.68$ psi

Resistance Coefficient

$K = 110.5$

$\Delta P = 5.08$ psi

Author:S Beck and R Collins, University of Sheffield 2008, Moody diagram. Lines created using Swami and Jaine formula. Plot created on Matlab. (Wikipedia User: Donebythesecondlaw at English Wikipedia) Conversion to SVG: Marc.derumaux
https://commons.wikimedia.org/w/index.php?curid=52681200

Piping System Design & Layout

Pipe Velocity Calculation

Pipeline Header Design

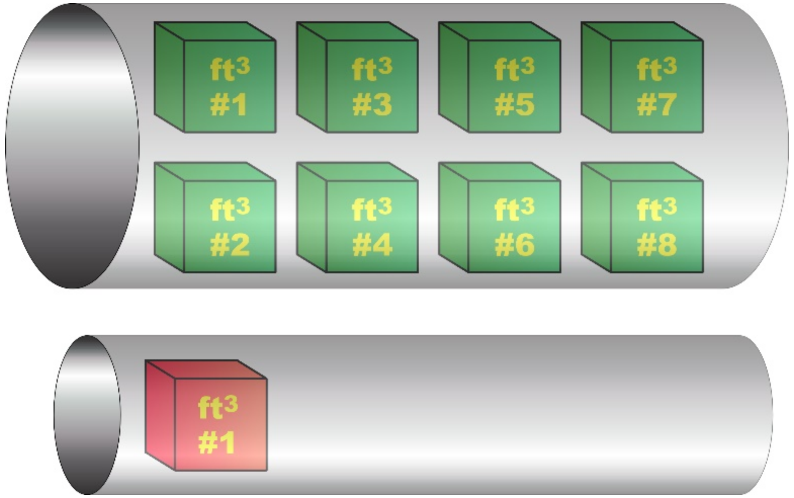
Point of Use Connection

Calculating Pipeline Velocity

- Which air is flowing in the pipe?
  - 8 cu. ft. of atmospheric (free) air

– OR –

  - 1 cu. ft. of compressed air
    - ratio = (100 +14.5) / 14.5 = 7.9



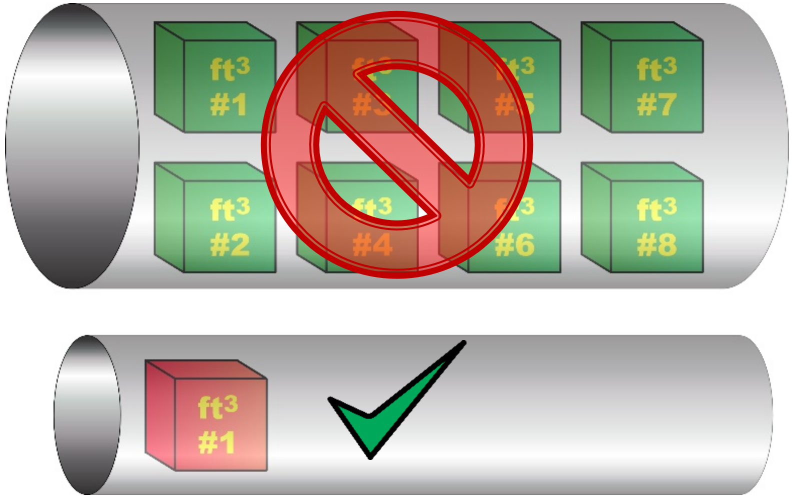
- $$v = \frac{Q_{acfm}\left(\frac{ft^3}{min}\right)}{60\left(\frac{sec}{min}\right) \times a\ (ft^2)} \times \frac{P_a}{(P_L + P_a)}$$

Calculating Pipeline Velocity

- Which air is flowing in the pipe?
  - ~~8 cu. ft. of atmospheric (free) air~~

– OR –

  - 1 cu. ft. of compressed air
    - ratio = (100 +14.5) / 14.5 = 7.9



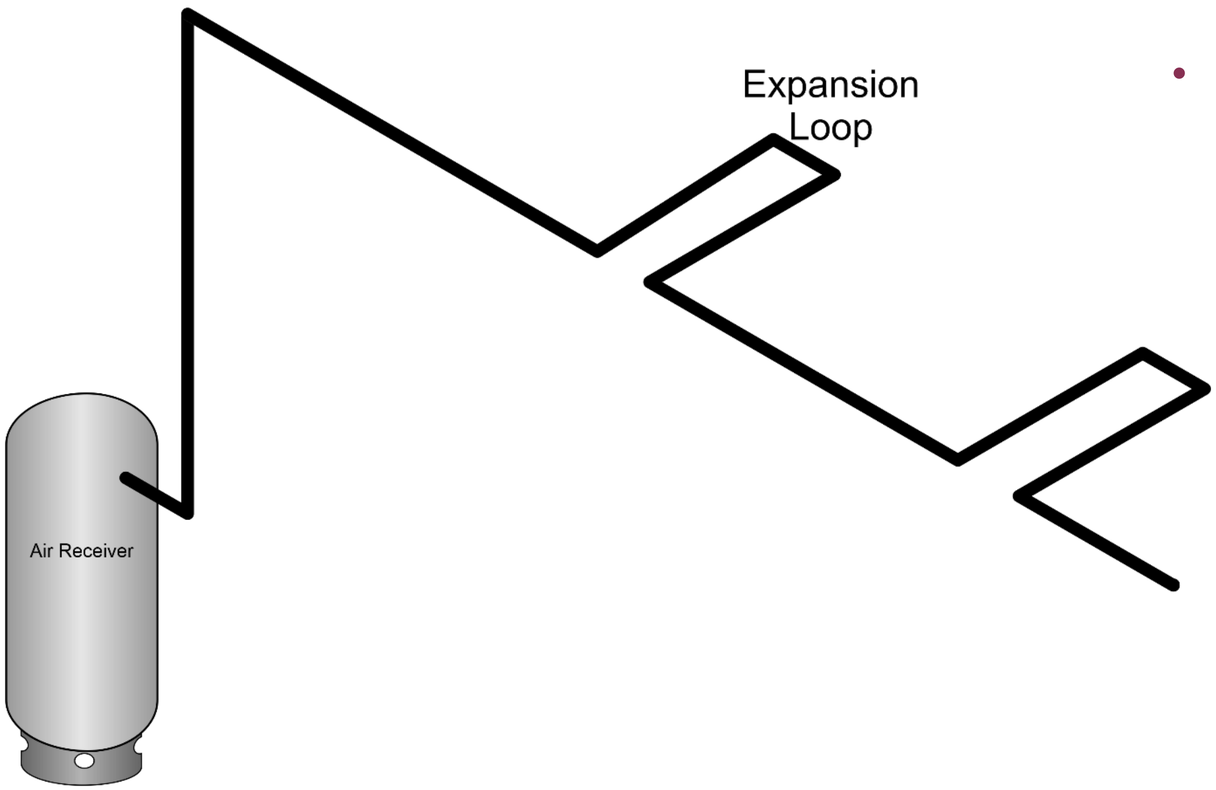
- $$v = \frac{Q_{acfm}\left(\frac{ft^3}{min}\right)}{60\left(\frac{sec}{min}\right) \times a\,(ft^2)} \times \frac{P_a}{(P_L + P_a)}$$

$$\left(\begin{array}{c} Area\ for \\ 2"\ Sched\ 40 \\ pipe \end{array}\right) \quad a = \frac{\pi \times d^2\,(in^2)}{4 \times 144\left(\frac{in^2}{ft^2}\right)} = \frac{3.14 \times 2.067^2}{576}\ 0.0233\,ft^2$$

$$v = \frac{300\left(\frac{ft^3}{min}\right)}{60\left(\frac{sec}{min}\right) \times 0.0233\,(ft^2)} \times \frac{14.5}{(100+14.5)}$$

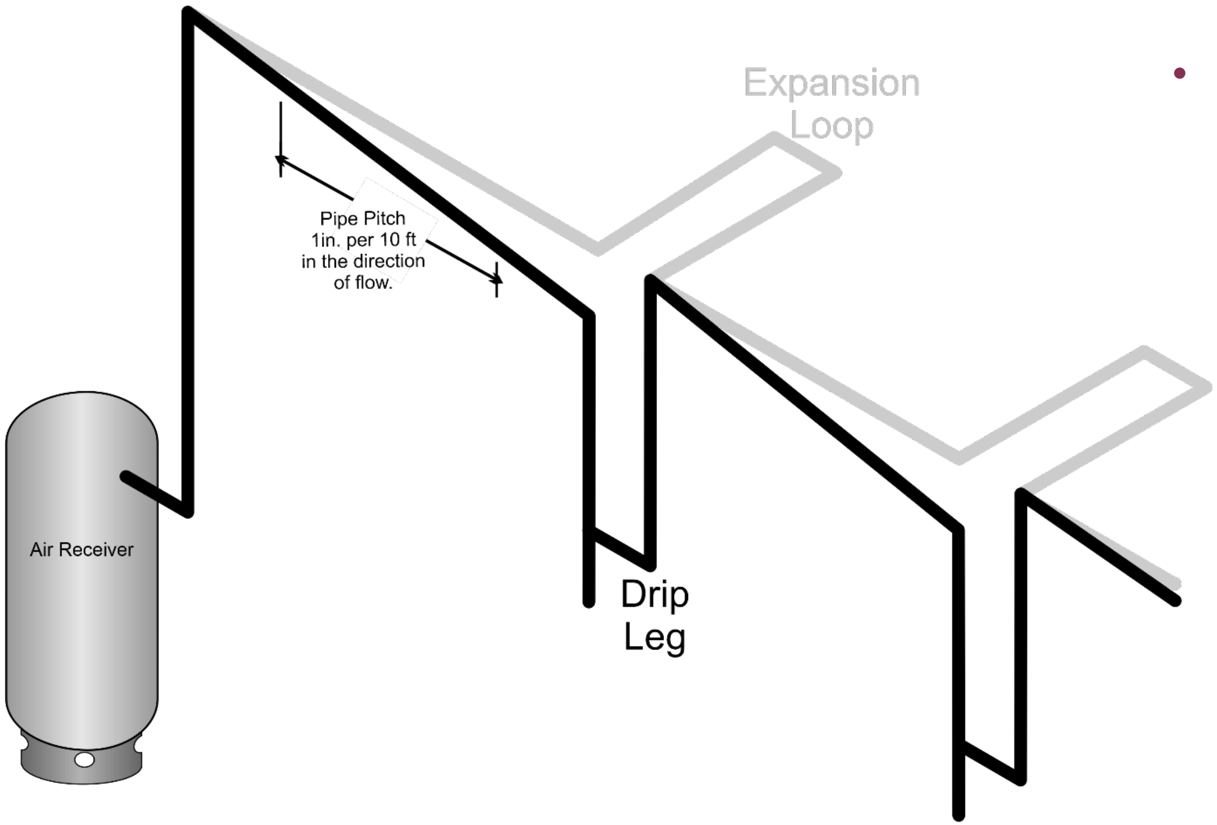
$$v = 27.2\,fps$$

Pipeline Header Design



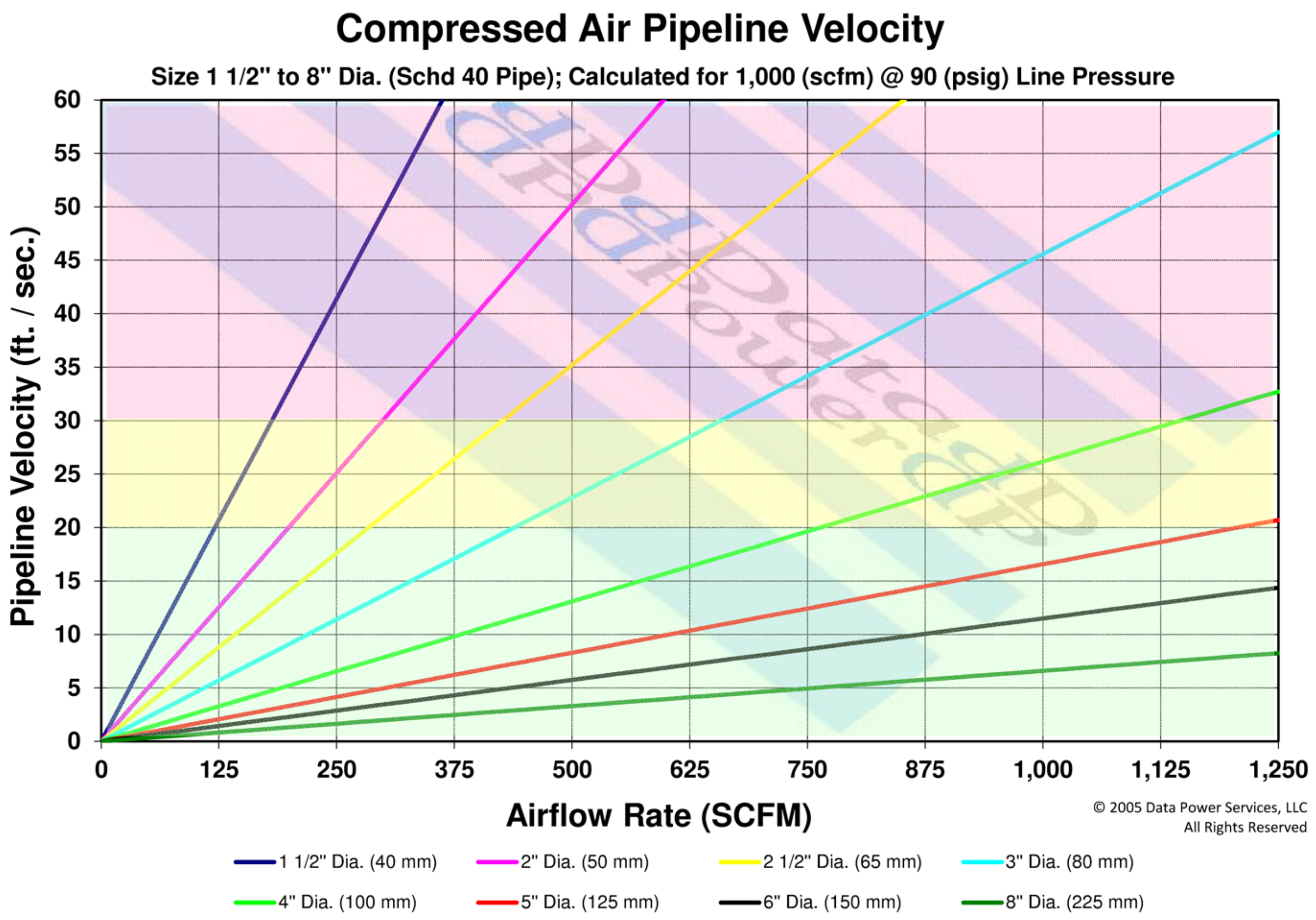
- Thermal Expansion Loops
  - Allow expansion and contraction for long pipeline lengths.
  - Commonly used for steam, water, natural gas, and many types of piping.

Pipeline Header Design



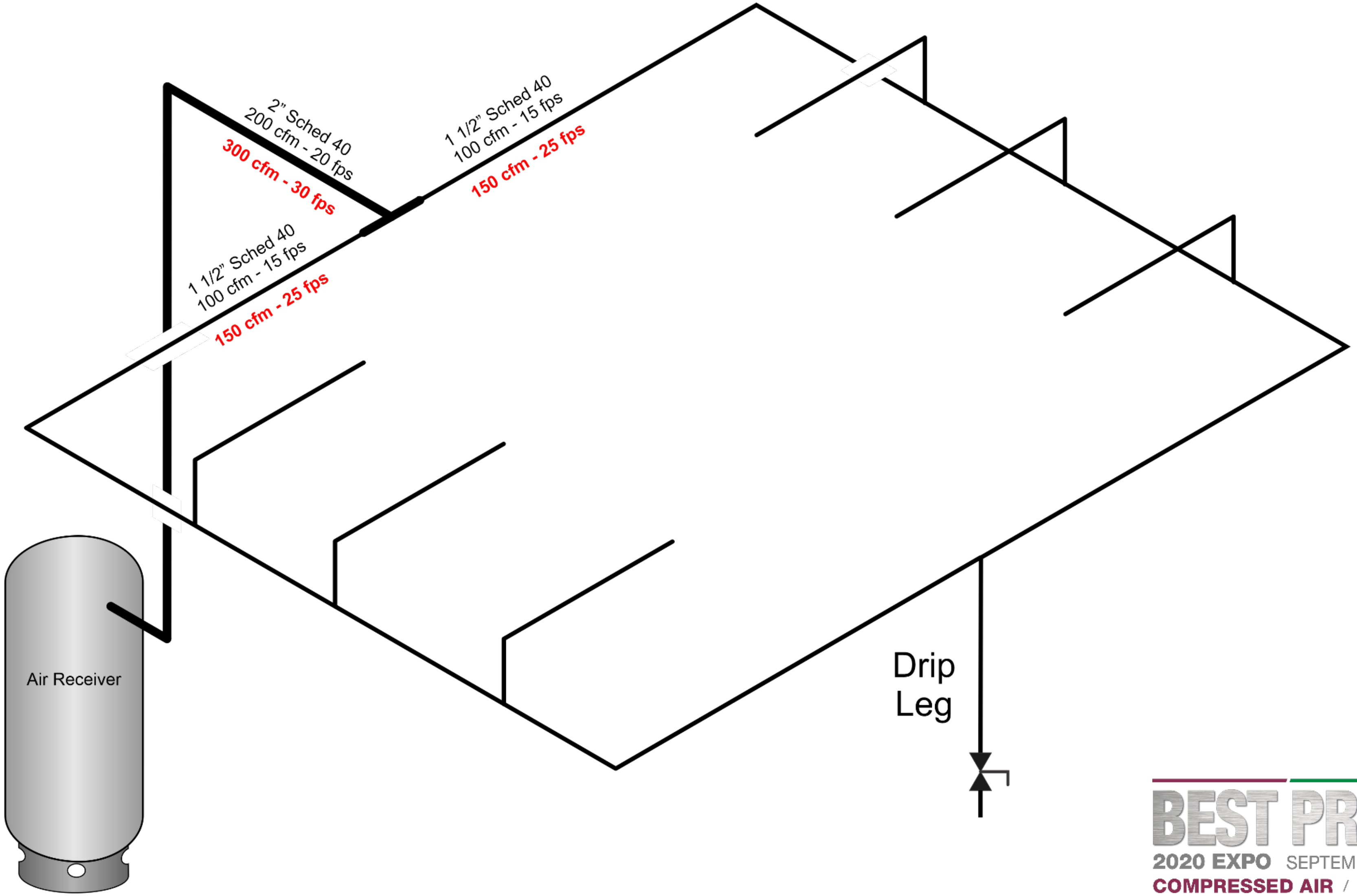
- Compressed Air Pipeline
  - Drip Leg & Thermal Expansion Loops are Combined.
  - Header pipe pitch 1” per 10’ in the direction of air flow

Compressed Air Piping – 200 cfm @ 90 psig Header System



Compressed Air Piping – Loop Header System

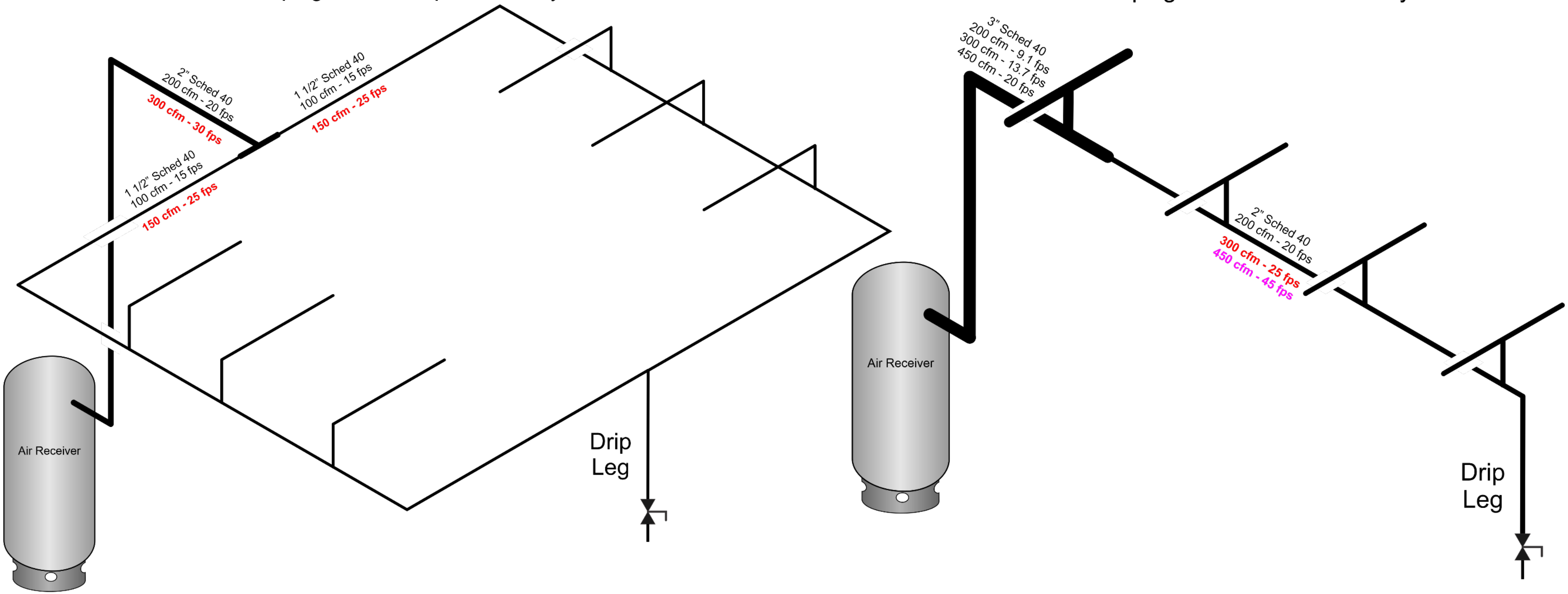
200 cfm - 90 psig 1-1/2" Loop Header System



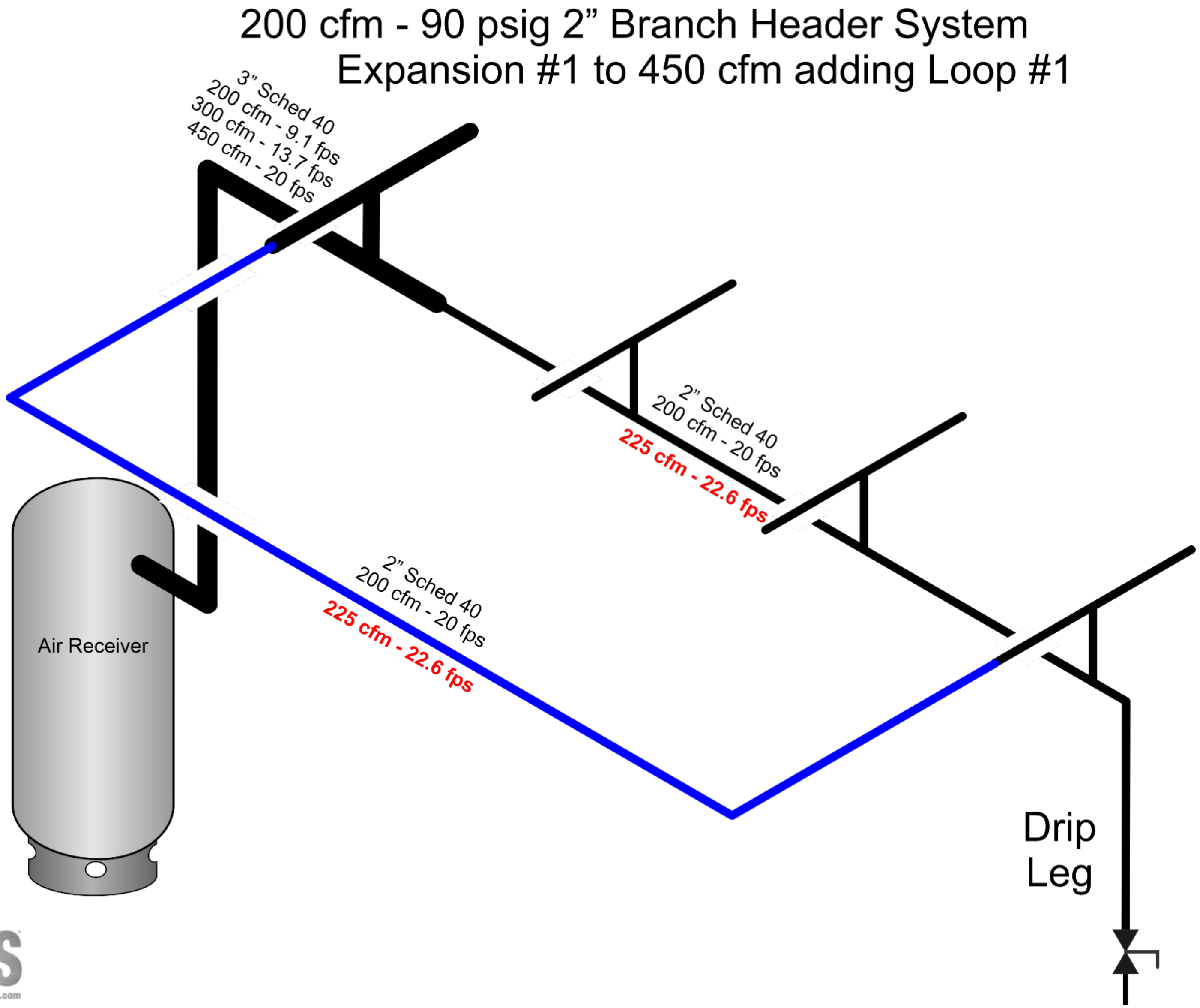
Compressed Air Piping – Loop -vs- Branch Header System

200 cfm - 90 psig 1-1/2” Loop Header System

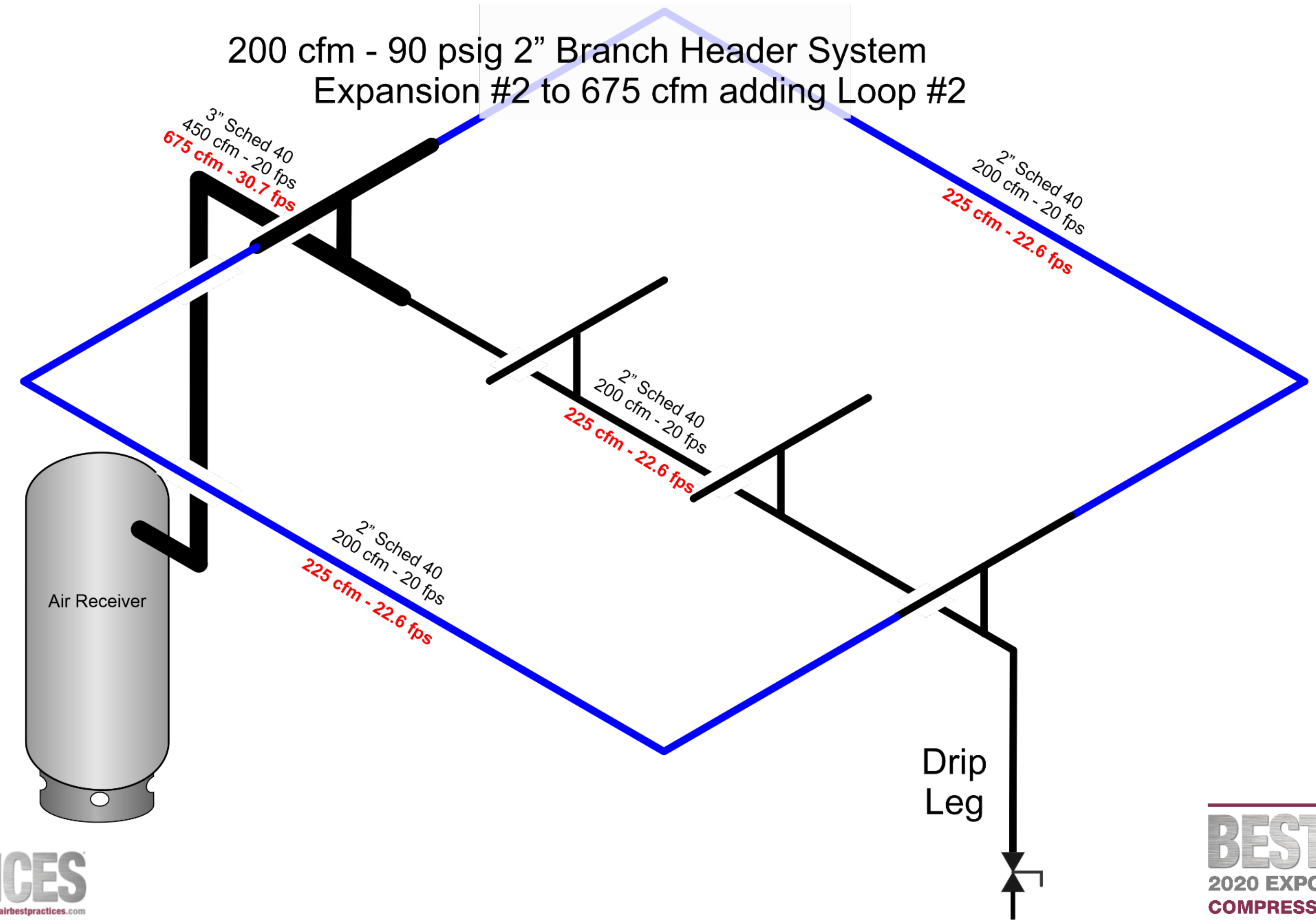
200 cfm - 90 psig 2” Branch Header System



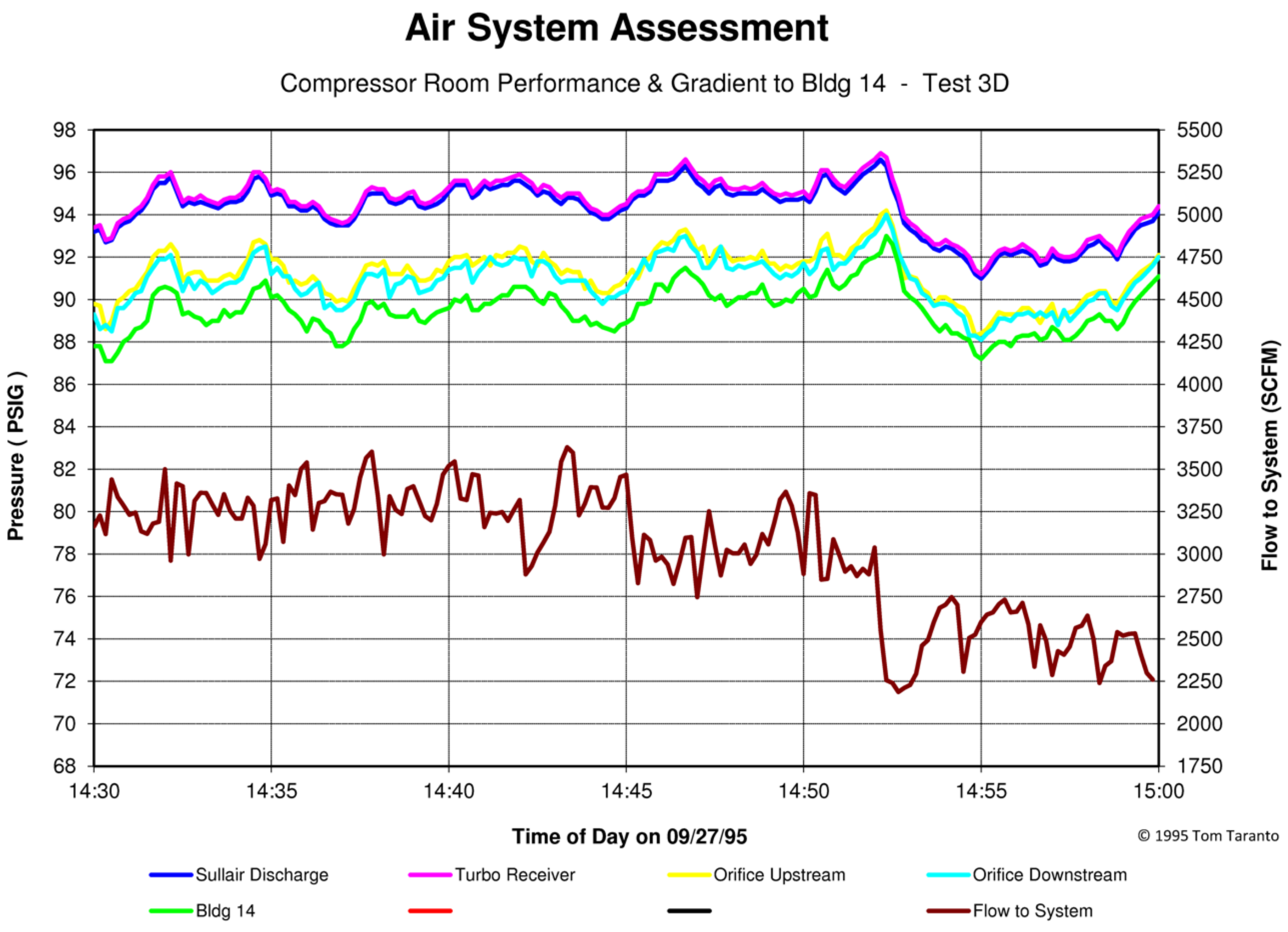
Original Branch System for 450 cfm adding Loop #1



Original Branch System for 450 cfm adding Loop #1

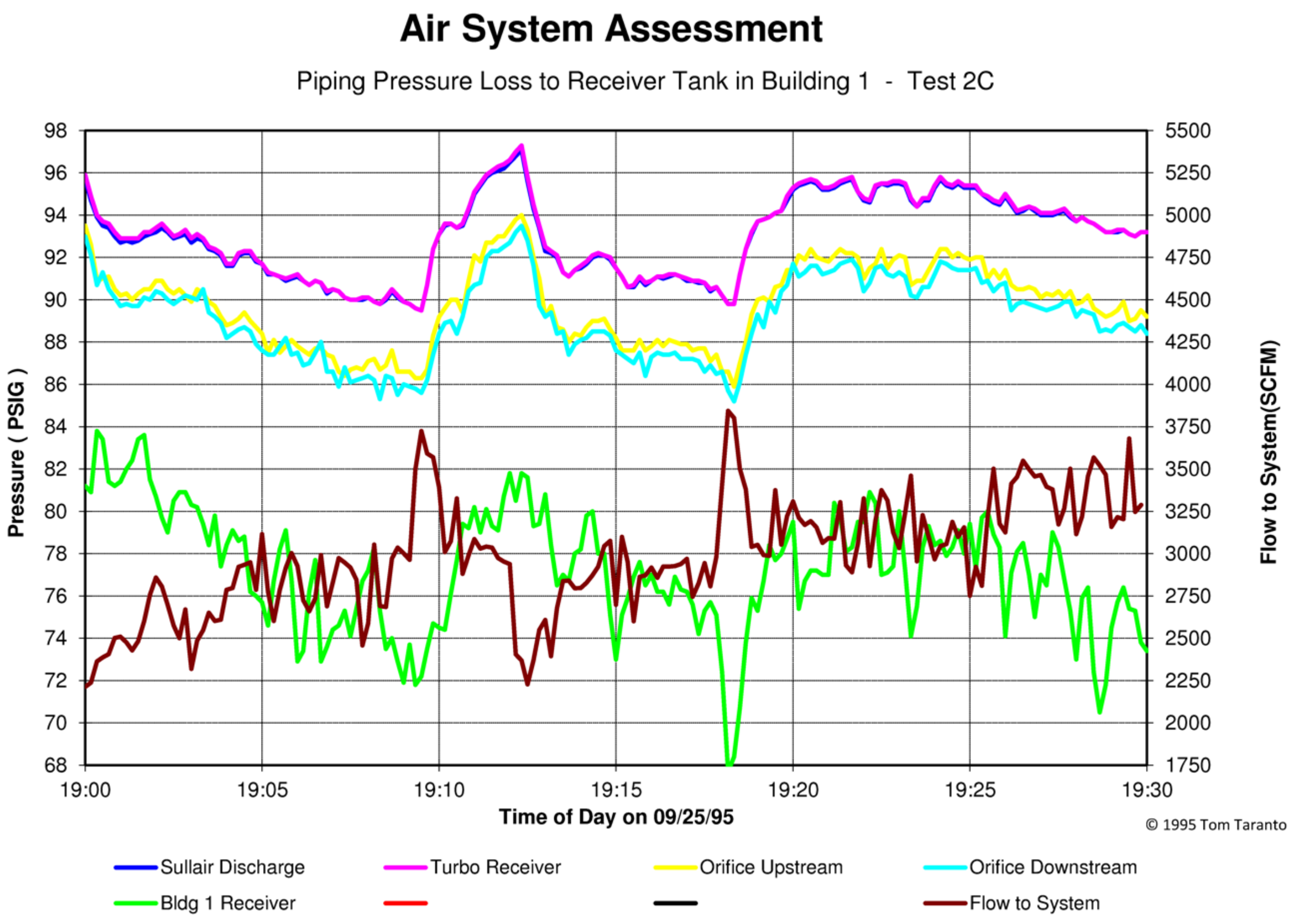


Identifying & Correcting Pipeline Pressure Loss



- Pipeline pressure gradient measurement Dp/Dx
- Correct pipeline velocity results in:
  - Low pressure gradient - low velocity
  - 2 psig pressure loss at the greatest flow rate 3,600 cfm
  - 1 psig pressure loss at the lowest flow rate 2,250 cfm
  - Distribution piping is tracking with supply pressure

Identifying & Correcting Pipeline Pressure Loss



- Pipeline pressure gradient measurement Dp/Dx

- High pipeline velocity results in:
  - High pressure gradient - high velocity
  - 18 psig pressure loss at the greatest flow rate 3,800 cfm
  - 11 psig pressure loss at the lowest flow rate 2,250 cfm
  - Distribution piping is not tracking with supply pressure
  - Inverse mirror image of air flow rate and distribution piping pressure

Lessons Learned

- Design piping for 20 fps velocity reduces energy use & cost and also stabilizes pressure.
- Traditional design velocity of 50 fps is inefficient and leads to pressure instability.
- Compressed air distribution system pipeline performance depends primarily on pipeline velocity, it doesn't matter if the distribution system is a loop or branch design.
- Pipe friction loss is normally a relatively small component of total pressure loss.
- For new compressed air distribution piping:
  - Starting with a branch system and building out to loop / grid system can supply future increased air demands.
  - Don't abandon your original investment in the branch system piping, when building out the distribution loop.
- Measure pipeline pressure gradients to identify opportunities to reduce distribution piping pressure loss.

Chat Your Questions

Data Power Services, LLC

Tom Taranto

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Thank You !

About the Speaker

Grayson Atkinson
Kaeser Compressors

- System Design Supervisor, Kaeser Compressors, Inc.
- Bachelor's Degree in Mechanical Engineering from Virginia Commonwealth University
- Completed the DOE Compressed Air Challenge I and II
- CAGI Certified Compressed Air System Specialist

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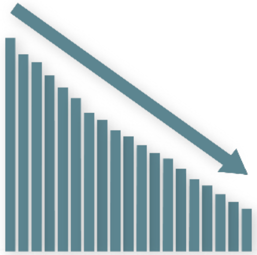
Designing Piping Systems for Low Pressure Drop Part 2

Grayson Atkinson, System Design Supervisor, Kaeser Compressors, Inc.

Excessive Pressure Drop in Plants

Increases Energy Use

- Increasing pressure at the compressor to overcome pressure drop consumes power unnecessarily



Reduces Productivity

- Equipment under performing
- Shutdowns on low pressure alarms- downtime
- Increased scrap of raw materials

Oversizing Systems

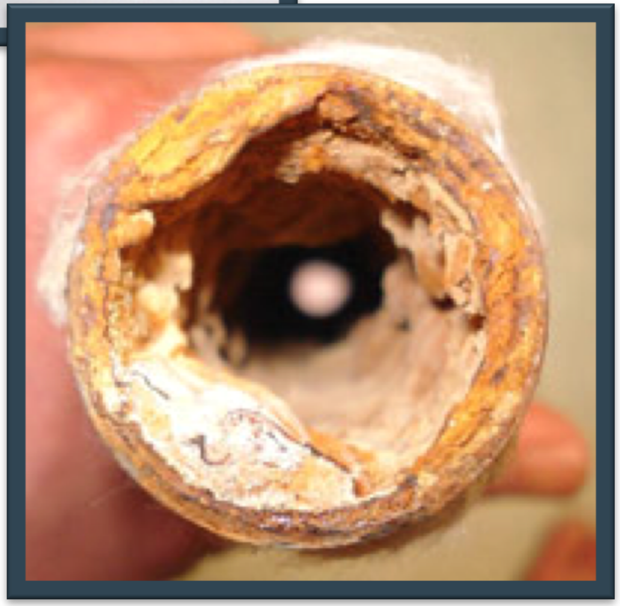
- Adding an additional compressors for more flow cannot overcome all restrictions such as clogged pipes

Piping Materials Overview

Material	Advantages	Disadvantages
Black Iron	• Moderate material costs • Available in multiple sizes	• Labor intensive installation • May rust and leak • Rough inside promotes contaminants build up and creates pressure drop
Galvanized Iron	• Moderate material costs • Available in multiple sizes • Some rust protection	• Often exterior is coated • Labor intensive installation • Rough inside promotes contaminants build up and creates pressure drop • May rust at joints and leak
Copper	• No rust, good air quality • Smooth interior—low pressure drop	• Requires quality brazing to prevent leaks • Susceptible to thermal cycling • Installation requires open flame
Stainless Steel	• No rust, good air quality • Smooth interior—low pressure drop	• Labor intensive installation • Expensive materials
PVC	• Lightweight • Inexpensive	• Lower safety • In certain areas, not compliant with certain codes • Carries static charge • Adhesives not compatible with compressor oils
Aluminum	• Corrosion resistant • Lightweight • Easy to install • Lower cost of ownership	• Limited pressure ratings • Material costs

Why Piping Materials Matter

- Rough interior surfaces increase turbulence (increase pressure drop)
- Rough surfaces accumulate contaminants (more pressure drop)
- Rust and corrosion add to contamination
- Types of fitting affect leakage



Pipe Sizing - Loss of Pressure Due to Friction

Pipe diameter has significant effect on pressure drop

Note: Based on 1,000 ft. of straight pipe @ 100 psig

Cu. Ft. Free Air Per Min.	Nominal Diameter in Inches								
	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
10	6.50	0.99	0.28	…	…	…	…	…	…
20	25.9	3.90	1.11	0.25	0.11	…	…	…	…
30	58.5	9.01	2.51	0.57	0.26	…	…	…	…
40	…	16.0	4.45	1.03	0.46	…	…	…	…
50	…	25.1	6.96	1.61	0.71	0.19	…	…	…
60	…	36.2	10.0	2.32	1.02	0.28	…	…	…
70	…	49.3	13.7	3.16	1.4	0.37	…	…	…
80	…	64.5	17.8	4.14	1.83	0.49	0.19	…	…
90	…	82.8	22.6	5.23	2.32	0.62	0.24	…	…
100	…	…	27.9	6.47	2.86	0.77	0.30	…	…
125	…	…	48.6	10.2	4.49	1.19	0.46	…	…
150	…	…	62.8	14.6	6.43	1.72	0.66	0.21	…
175	…	…	…	19.8	8.72	2.36	0.91	0.28	…
200	…	…	…	25.9	11.4	3.06	1.19	0.37	0.17

Courtesy of the Compressed Air and Gas Handbook, Fifth Edition, Copyright 1989

Pipe Sizing - Loss of Pressure Due to Friction

Pipe diameter has significant effect on pressure drop

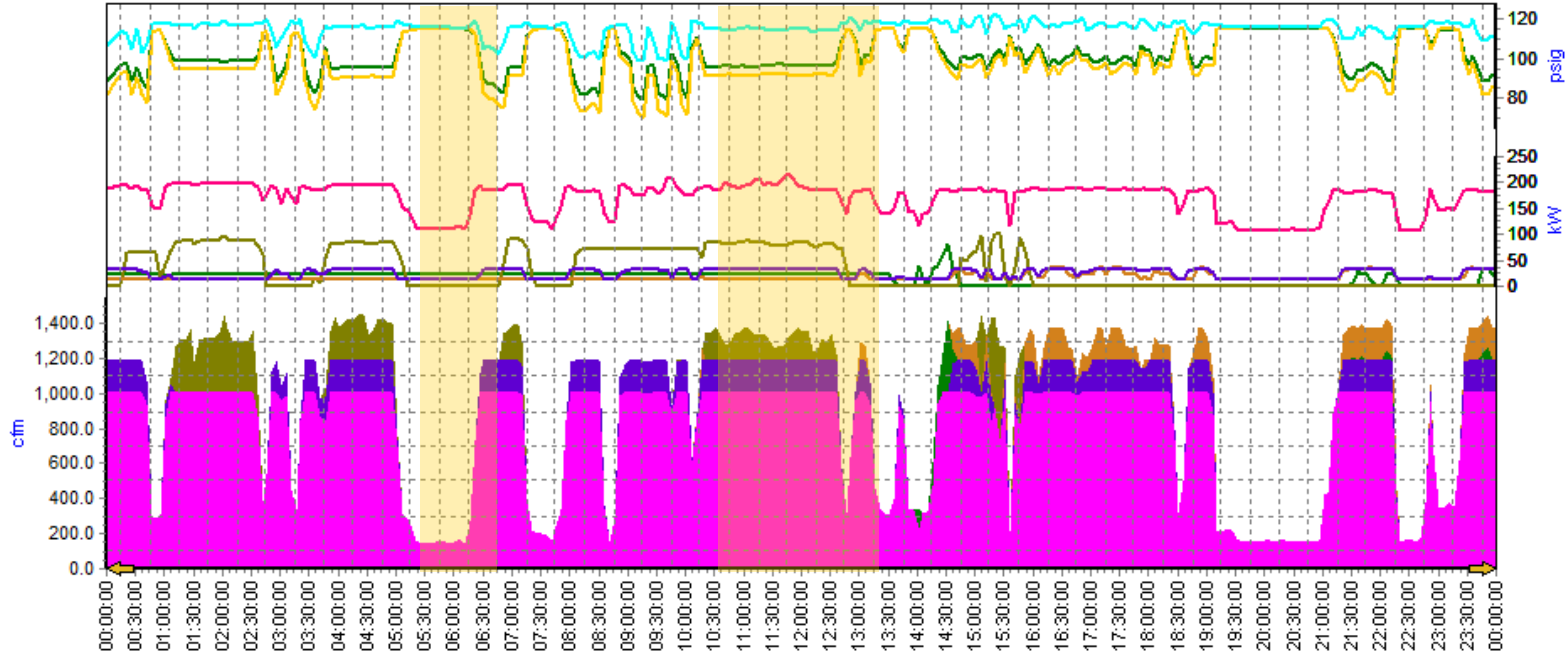
Note: Based on 1,000 ft. of straight pipe @ 100 psig

Even a ½ inch increase/decrease can make all the difference

Cu. Ft. Free Air Per Min.	Nominal Diameter in Inches								
	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
10	6.50	0.99	0.28	…	…	…	…	…	…
20	25.9	3.90	1.11	0.25	0.11	…	…	…	…
30	58.5	9.01	2.51	0.57	0.26	…	…	…	…
40	…	16.0	4.45	1.03	0.46	…	…	…	…
50	…	25.1	6.96	1.61	0.71	0.19	…	…	…
60	…	36.2	10.0	2.32	1.02	0.28	…	…	…
70	…	49.3	13.7	3.16	1.4	0.37	…	…	…
80	…	64.5	17.8	4.14	1.83	0.49	0.19	…	…
90	…	82.8	22.6	5.23	2.32	0.62	0.24	…	…
100	…	…	27.9	6.47	2.86	0.77	0.30	…	…
125	…	…	48.6	10.2	4.49	1.19	0.46	…	…
150	…	…	62.8	14.6	6.43	1.72	0.66	0.21	…
175	…	…	…	19.8	8.72	2.36	0.91	0.28	…
200	…	…	…	25.9	11.4	3.06	1.19	0.37	0.17

Courtesy of the Compressed Air and Gas Handbook, Fifth Edition, Copyright 1989

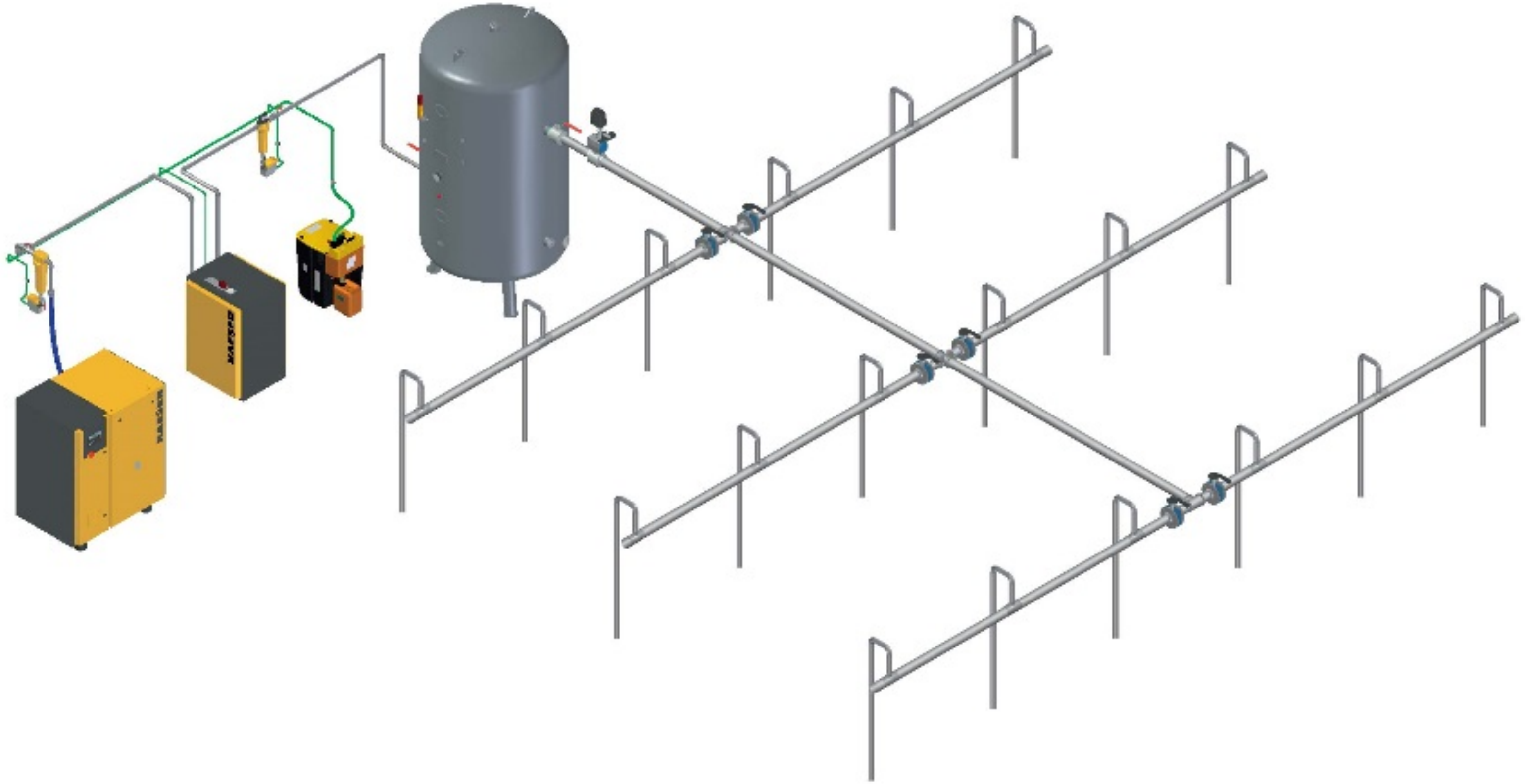
Case Study: Restrictions in Air Treatment?



Piping Layout

Branch or Line Piping System

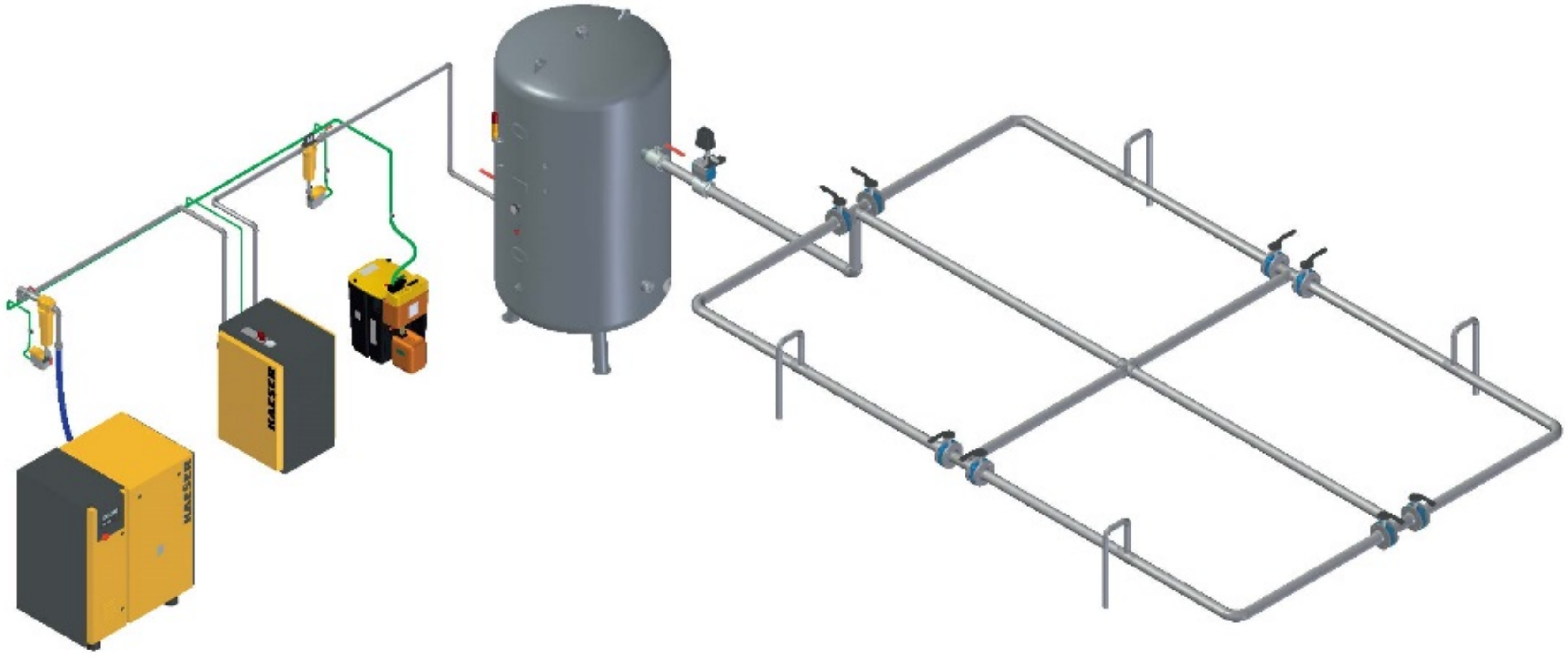
- Minimum expense but maximum pressure drop potential



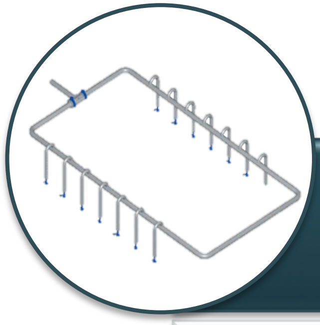
Distribution Piping Layout

Loop or Ring Piping System

- Potential to significantly reduced pressure drop



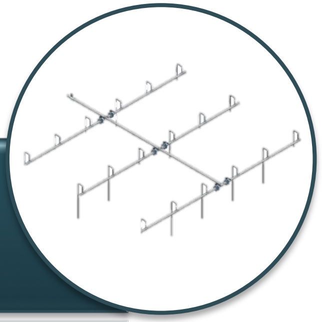
Distribution Piping Layout



Loop or Ring System

- **Advantages**
  - Lower pressure drop
  - Piping provides additional storage
  - Feeds the plant from two directions
  - Future sizing
- **Disadvantages**
  - Higher cost
  - Slightly more complex

Branch or Line System

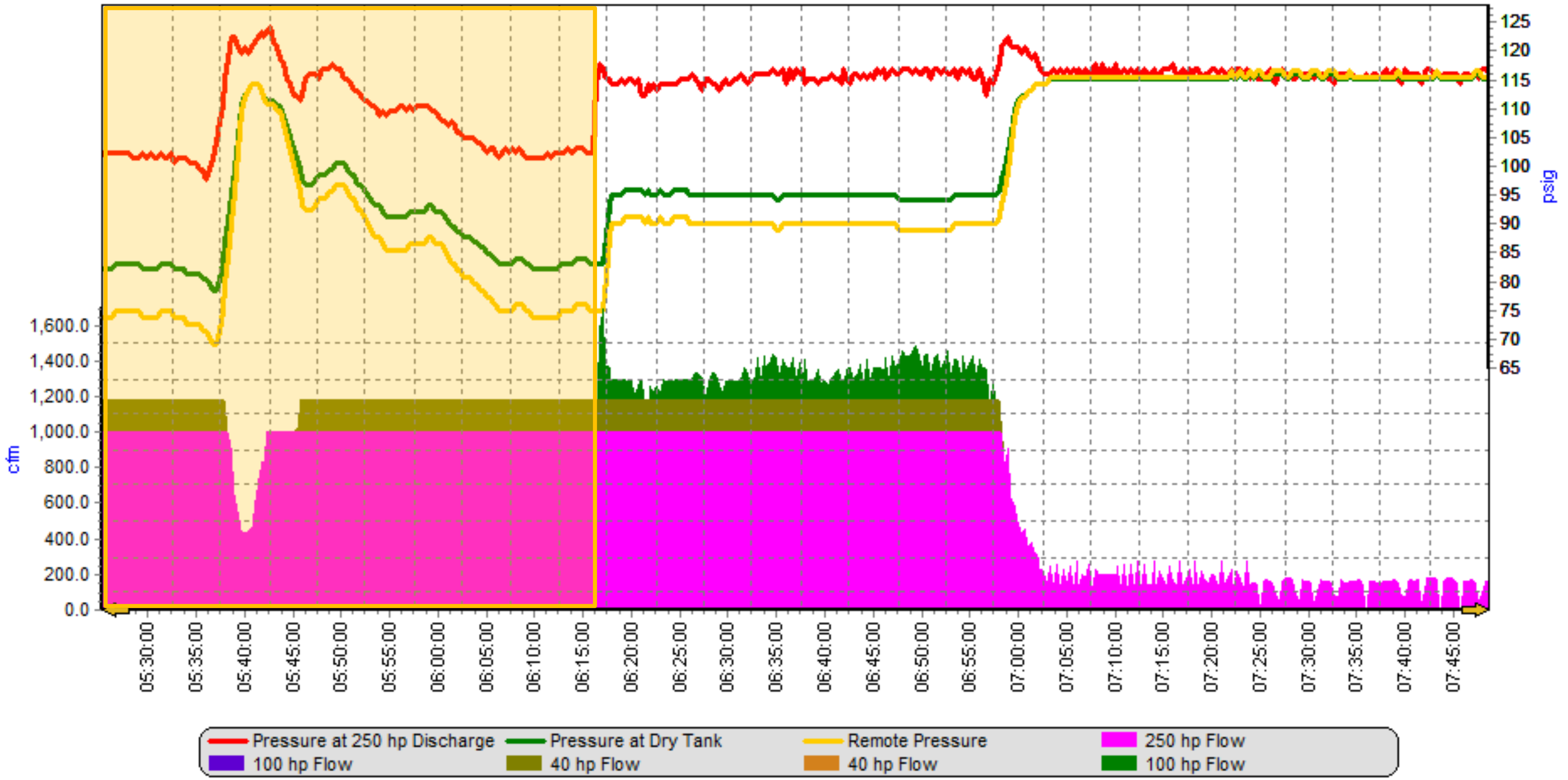


- **Advantages**
  - Lower cost
  - Easy to isolate
  - Less complex
- **Disadvantages**
  - Higher pressure drop possible
  - Feeds from only one direction

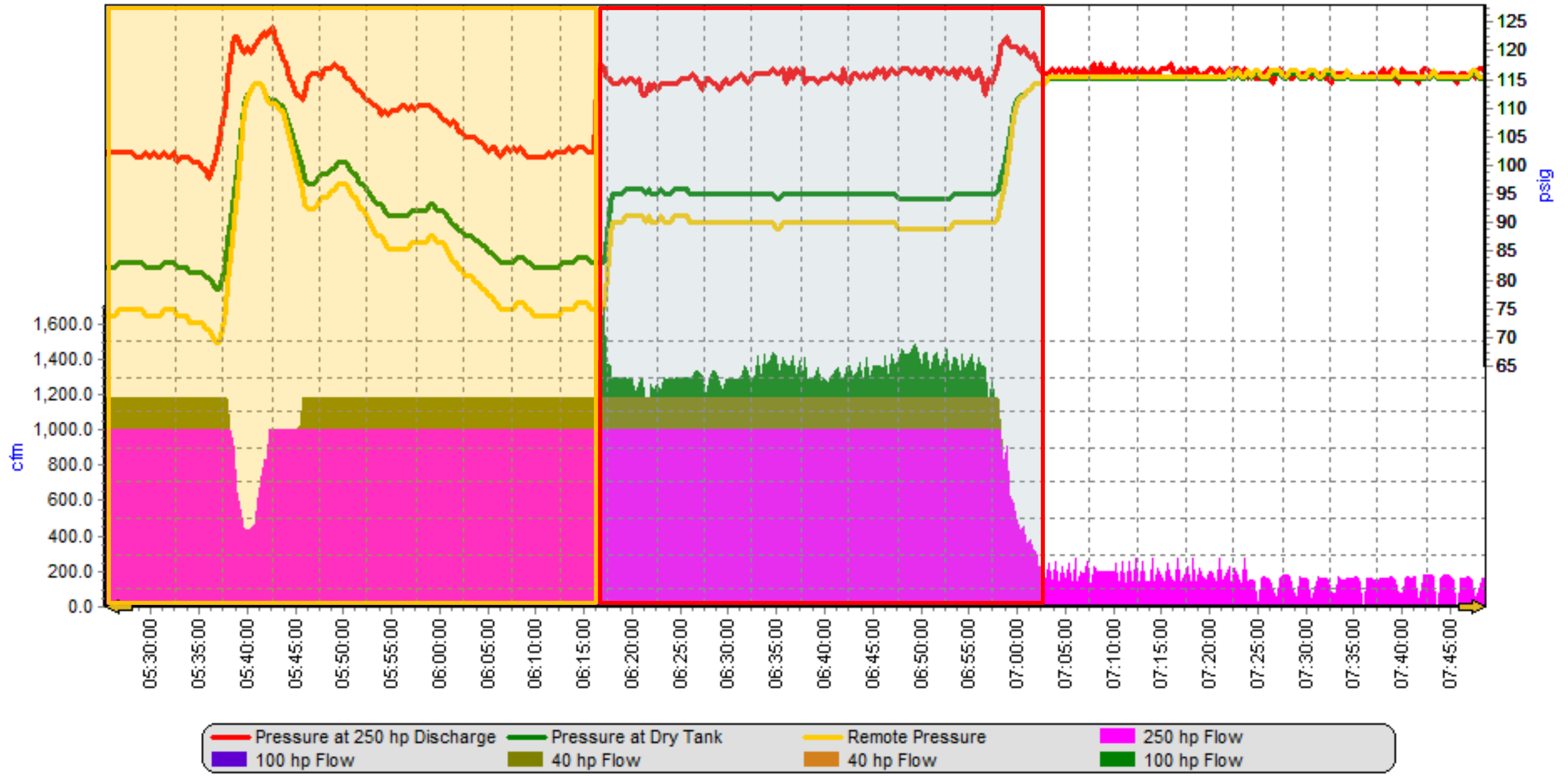
Piping Layout: Get the Facts

- Pipe type matters
- Pipe diameter makes all the difference
  - Target flows to 15 fps, 30 fps, 45 fps
  - Compressor Room, Distribution, and Point of Use
- Make your runs as straight as possible
- All pipe must be properly supported
- Consider Y connections versus T's
- Use 45 Degree Elbows Fittings versus 90 Degree Fittings if possible

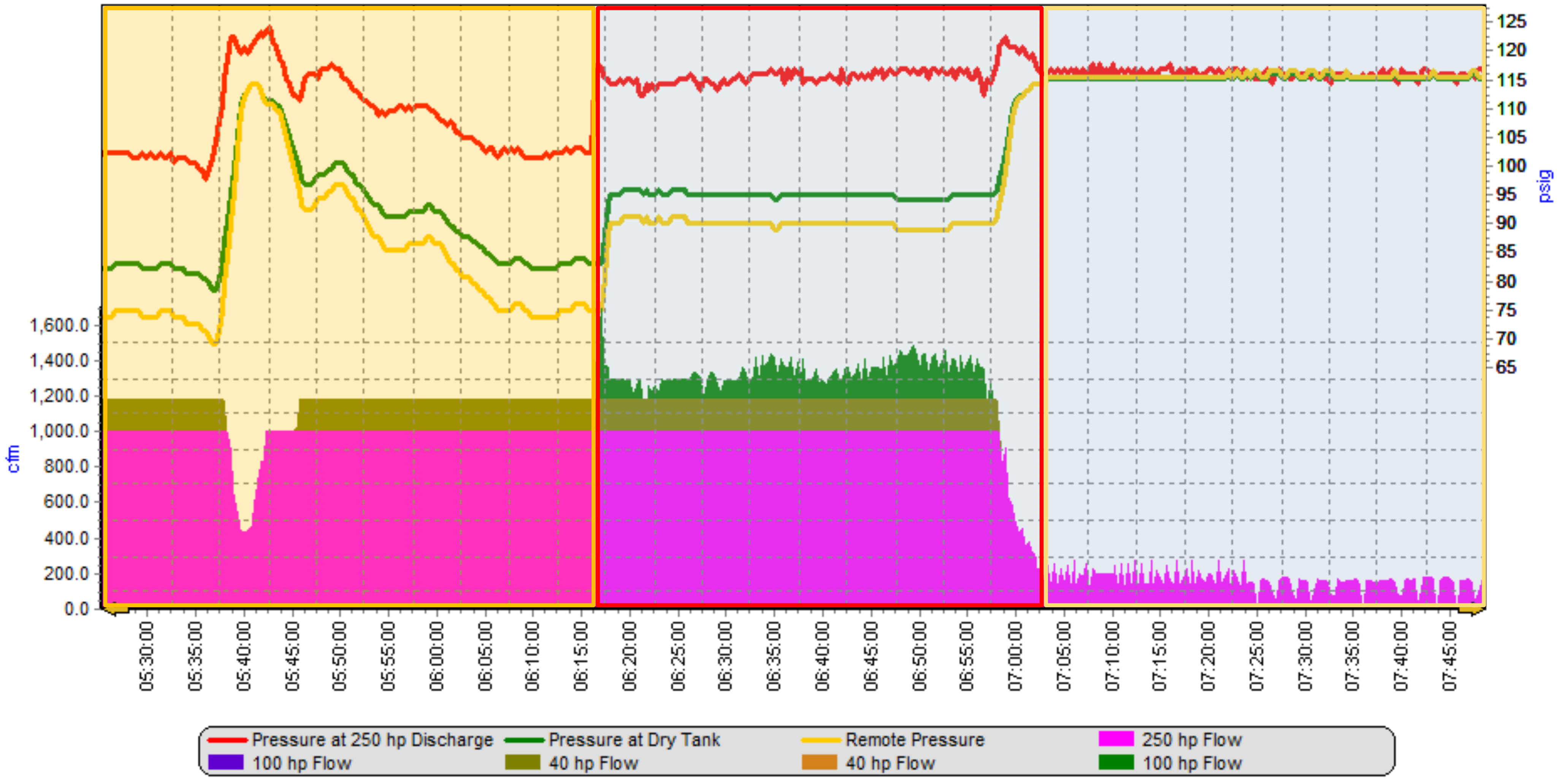
Pipe Size Case Study



Pipe Size Case Study



Pipe Size Case Study



Pipe Size Case Study

Pipe Size Case Study

Conclusion

- ✓ Use smooth pipe such as aluminum, stainless steel, or copper piping to avoid rust build-up and other interferences with flow
- ✓ Make sure you are using the correct piping size for the pressure and length of pipe
- ✓ Check your piping layout for the number of branches, bends, and T’s – If possible, go with a looped system
- ✓ Future-proof your piping installation
- ✓ Eliminate restrictions at point of use

For more information on piping, visit www.us.kaeser.com/resources

Designing Piping Systems for Low Pressure Drop

Q&A

Please submit any questions through the Question Window on your GoToWebinar interface, directing them to Compressed Air Best Practices Magazine. Our panelists will do their best to address your questions and will follow up with you on anything that goes unanswered during this session.
Thank you for attending!

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The next slide will show a statement related to today's topic that needs to be filled in. You will be provided the first letter of the words as a clue. Please submit your answers in your questions box.

Example

When I think of a beach vacation, I think of ________.

T_ _ _ _

T_ _ _ B_ _

S_ _ S_ _ _ _ _ _

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The next slide will show a statement related to today's topic that needs to be filled in. You will be provided the first letter of the words as a clue. Please submit your answers in your questions box.

Example
When I think of a beach vacation, I think of _______.

TOWEL

TIKI BAR

SEA SHELLS

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Based on the clues below, please submit your answers in the questions box.

When I think of piping system design parameters, I think of _______.

F_ _ _ _ V _ _ _ _ _ _ _ _

P _ _ _ L _ _ _ _ _ _

R _ _ _ _ _ _ _ _ _ O _ P _ _ _ M _ _ _ _ _ _ _ _

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Based on the clues below, please submit your answers in the questions box.

When I think of piping system design parameters, I think of _______.

FLUID VELOCITY

PIPE LENGTH

ROUGHNESS OF PIPE MATERIAL

Thank you for attending!

The recording and slides of this webinar will be made available to attendees via email later today.

PDH Certificates will be e-mailed to Attendees within two days.

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Best Practices Shared by Subscribers – Advanced Trends in Compressed Air & Vacuum Systems Levels 1 & 2

Rod Smith
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Best Practices Magazines & Expo

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