Better Plants
U.S. DEPARTMENT OF ENERGY

In-Plant Trainings

Session 5 – Distribution System

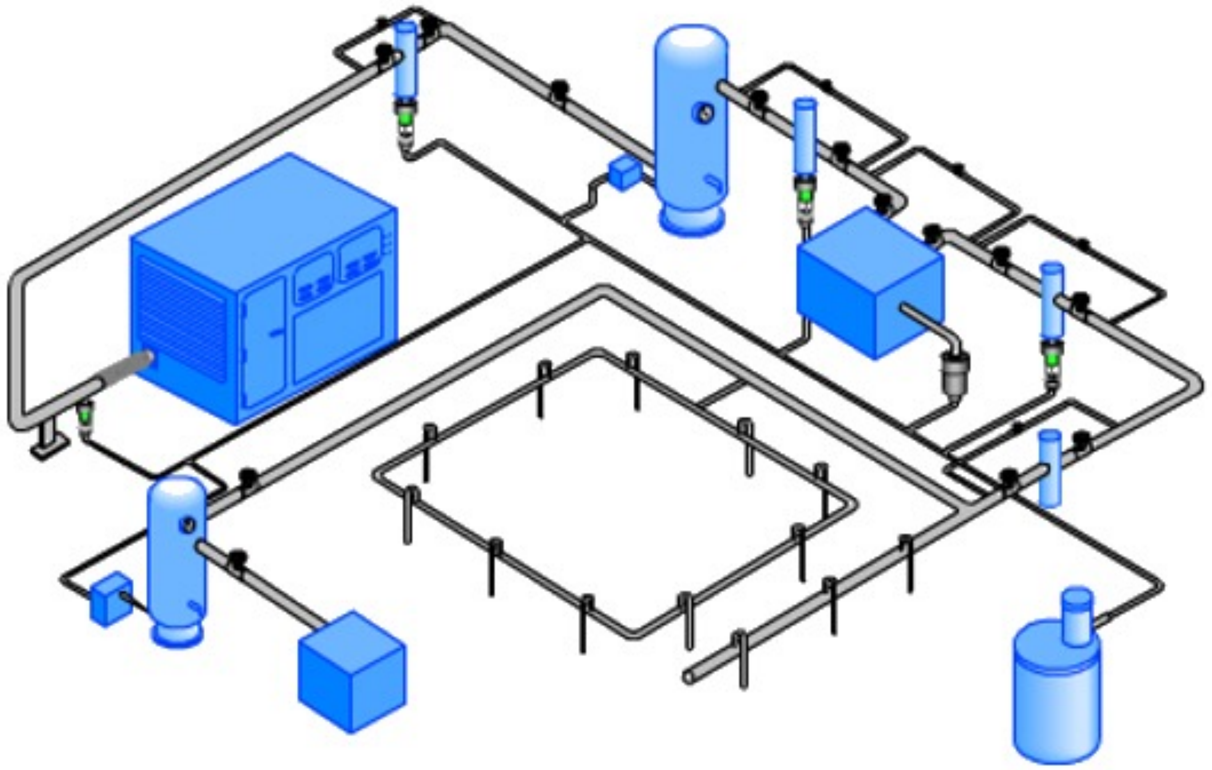
U.S. DEPARTMENT OF ENERGY

Session 5

Distribution System

Distribution System

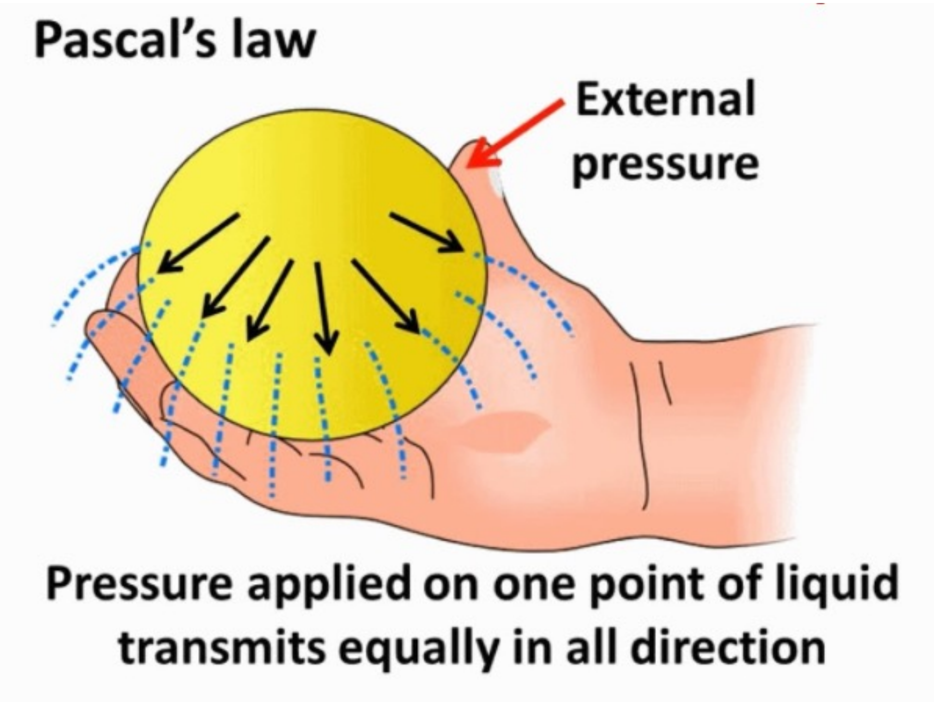
- The purpose of the distribution system is to ensure the right rate of flow of compressed air, at the right pressure, temperature and quality, for each end use application.

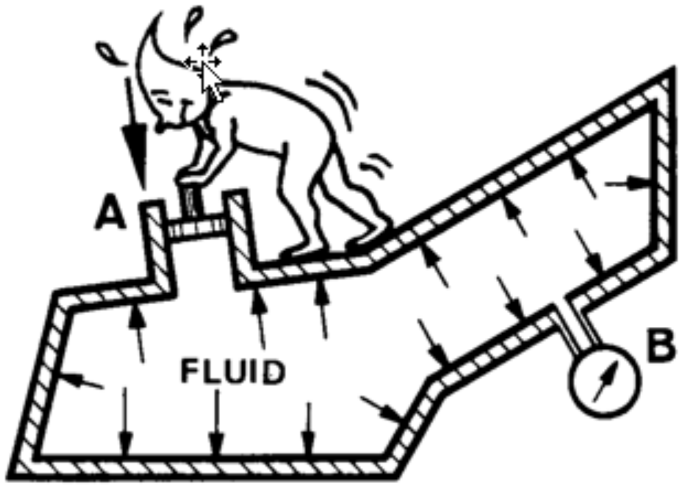


Pascal's Law

His principle of Hydrostatics is stated as follows:

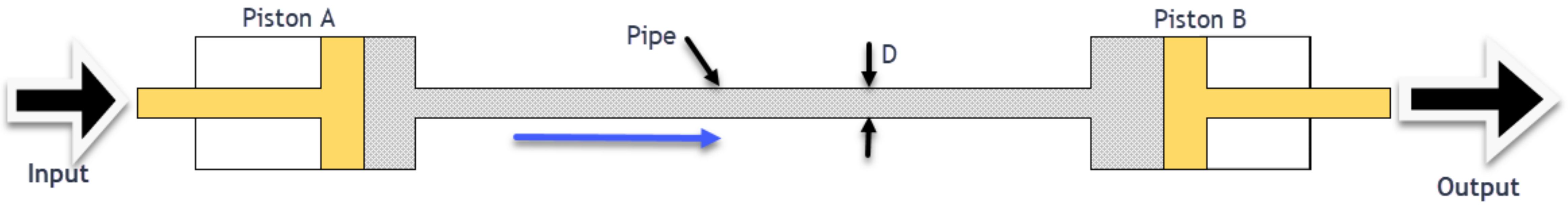
"pressure set up in a confined body of fluid acts equally in all directions and always at right angles to the containing surfaces"





Blaise Pascal (1623 – 1662). His discoveries are important to the technology of modern fluid power transmission.

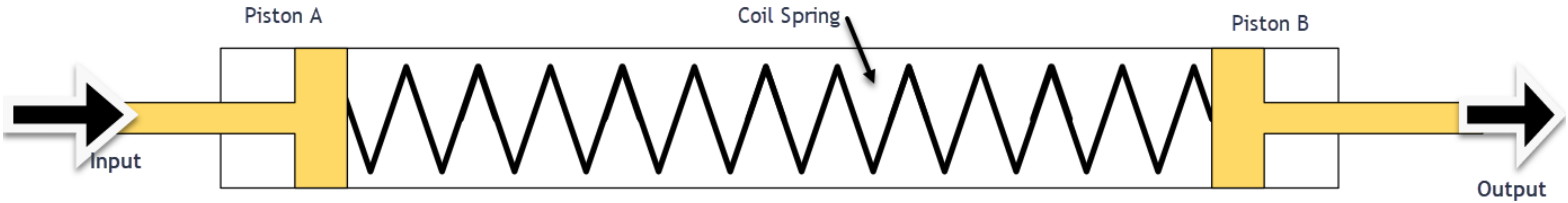
Transmission of Force Through Fluids



How large in diameter must this connecting pipe be?

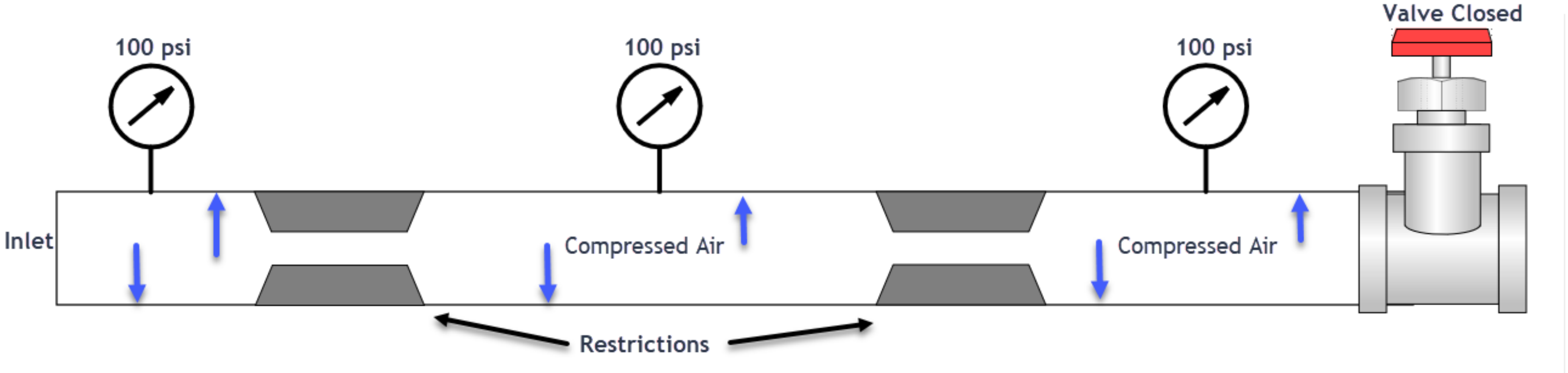
- If pistons A and B are used simply to transmit force with no movement of the pistons, they will do equally well no matter how small the diameter of the connecting pipe. PASCAL's law still applies.
- If the fluid must move through the pipe for transmitting work or power, the pipe diameter should be selected by the volume of free air that will be conveyed through it.
- If the diameter is too small, frictional losses might be too high and if the diameter is unnecessarily large, the plumbing costs might be excessive.

Transmission of Force Through Fluids



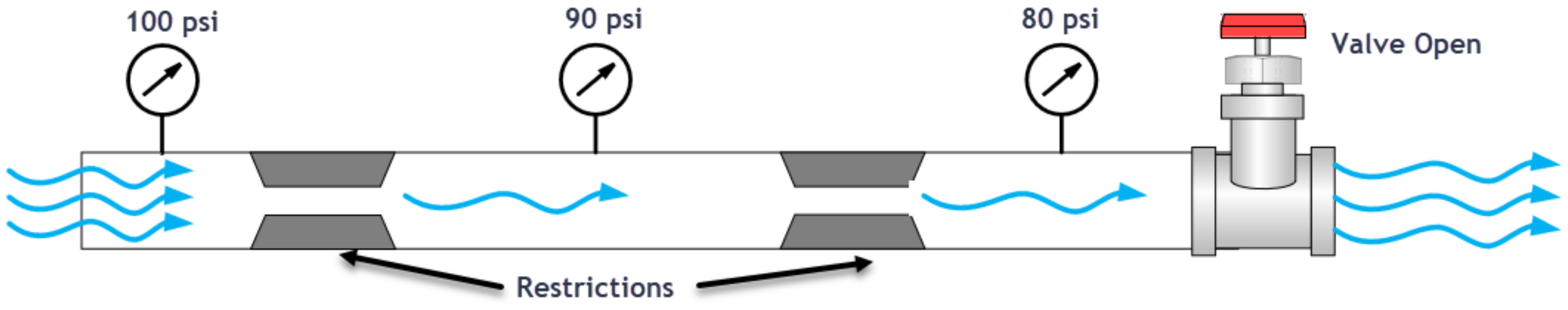
- Transmitting force through compressed air is like transmitting force through a spring.
- Force applied on piston A will produce a force output on piston B although the spring will compress to some extent while transmitting the force.
- While compressed air is an excellent medium for transmitting power, its greater compressibility does limit its use on certain applications where fluid rigidity is required to get a smooth (non-erratic) movement of a piston or similar device

Reducing Pressure Drops Throughout the System



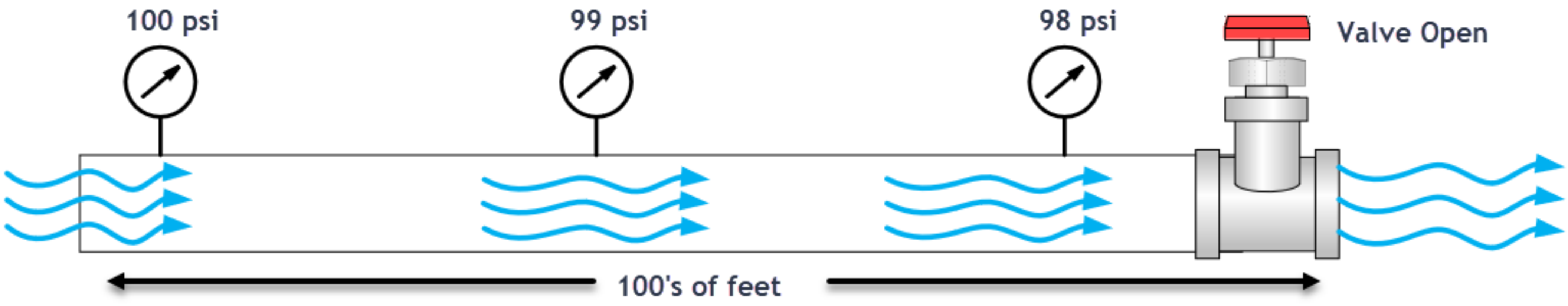
- A very important point to remember about pressure loss is that it only appears when fluid starts to flow.
- As long as the fluid is static, (non-moving) there is no pressure loss.
- Pure force without movement of compressed air can be transmitted through extremely long piping systems.
- This is analogous to an electrical circuit where there is no loss of voltage until current starts to flow.
- In above diagram, the air is not moving through the pipe, therefore pressure only can be transmitted through the pipe no matter how long the pipe is.
- This represents a confined body of fluid which obeys [PASCAL's]law.

Reducing Pressure Drops Throughout the System



- When an operator opens the valve, the fluid (compressed air) starts to flow
- The system no longer qualifies as a “confined body” under Pascal’s law
- Now the pipe diameter and restrictions in the pipe become very significant
- A large part of the inlet 100 psi may be used up in pushing the flow of air through the various restrictions.
- Full inlet pressure is no longer available on the outlet end of the pipe.
- Since the restrictions consume a part of the inlet pressure, they also consume the same proportion of horsepower which is being transported through the pipe

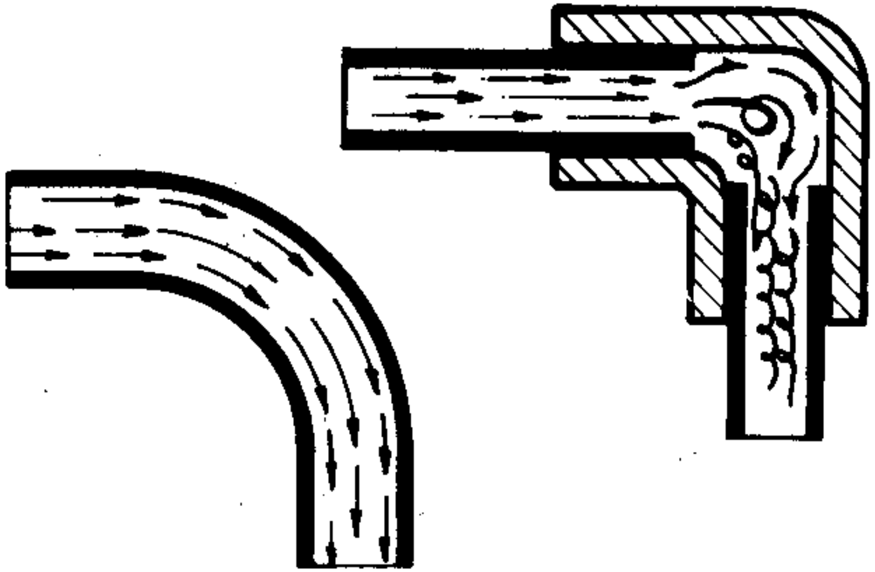
Reducing Pressure Drops Throughout the System



- When major restrictions are removed and the pipe is made sufficiently large to carry the flow, a relatively small proportion of inlet pressure will be sacrificed to flow losses.

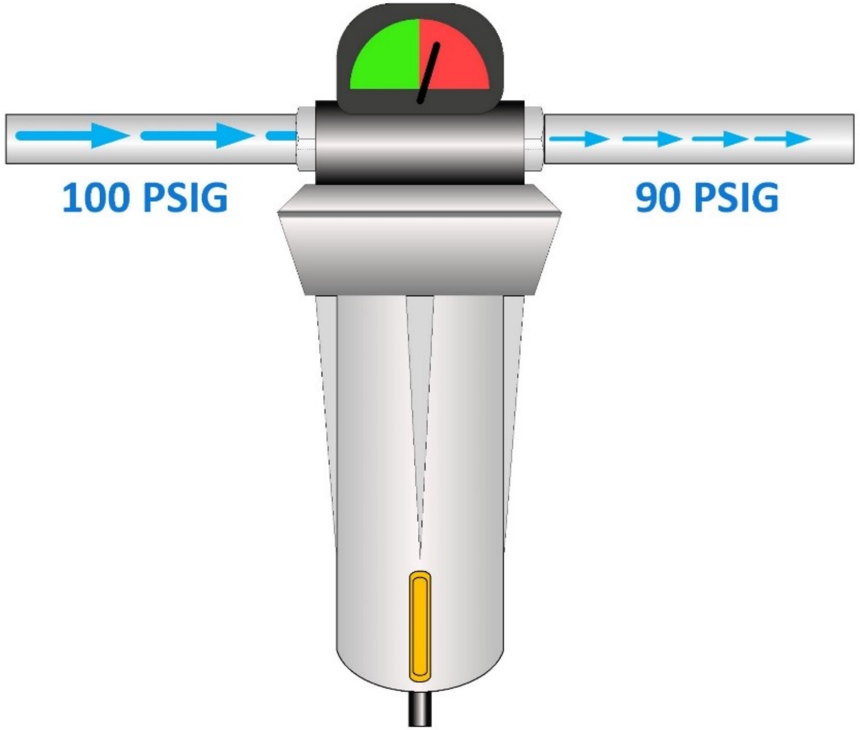
Pipe Fittings

- Every fitting adds its share to the overall power loss in the system
- A certain amount of energy is lost every time the fluid changes direction
- It must decelerate to zero velocity, in the direction it was going, then accelerate back up to speed in the new direction
- The kinetic energy lost in changing direction escapes from the system in the form of heat
- The fluid has a better chance of remaining in laminar flow if bends are kept smooth and gradual



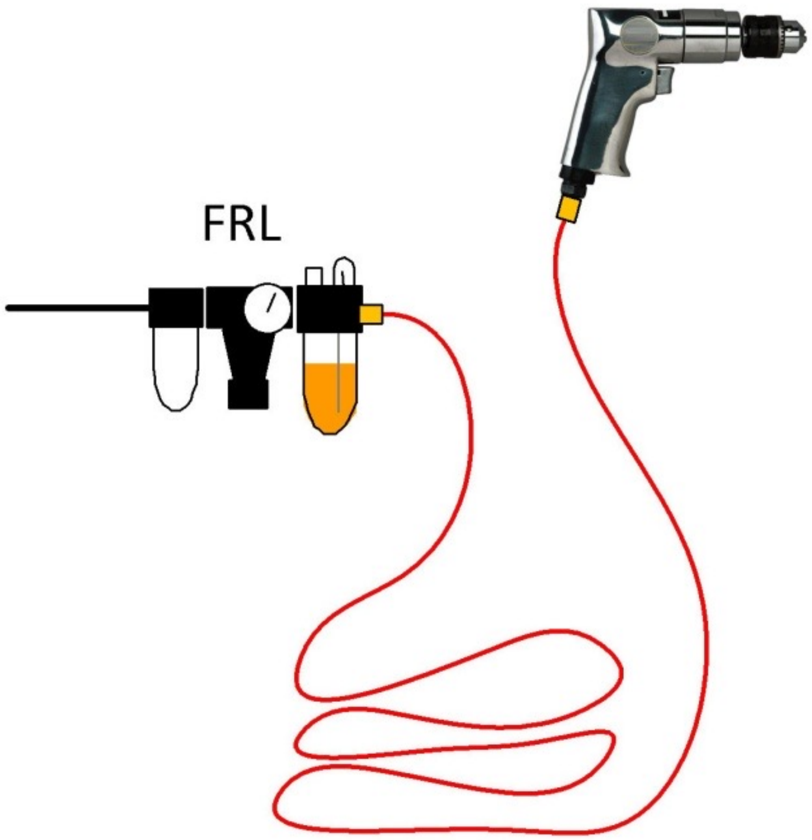
Pressure Drop

- Any type of obstruction, restriction or roughness in the system will cause resistance to air flow and cause pressure drop.



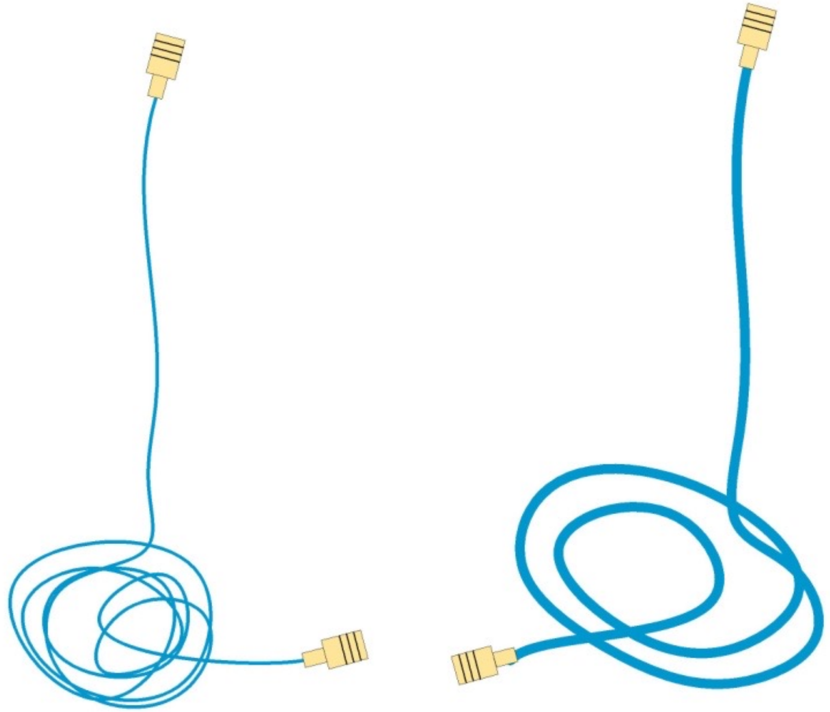
Pressure Drop

- Highest pressure drops usually are found at the points of use including undersized or leaking hoses, plastic tubing, disconnects, filters, regulators and lubricators.



Pressure Drop

- Production engineers often specify end-use equipment to operate at an average system pressure.
- This results in higher system operating costs.
- For applications that use a significant amount of compressed air, such as large air cylinders, it is wise to specify a brand or model that operates at lower pressures.
- Necessary equipment such as hoses, pressure regulators and filters should be purchased with the goal of minimal pressure loss.
- The added cost of the components should be recouped quickly from the resulting energy savings.

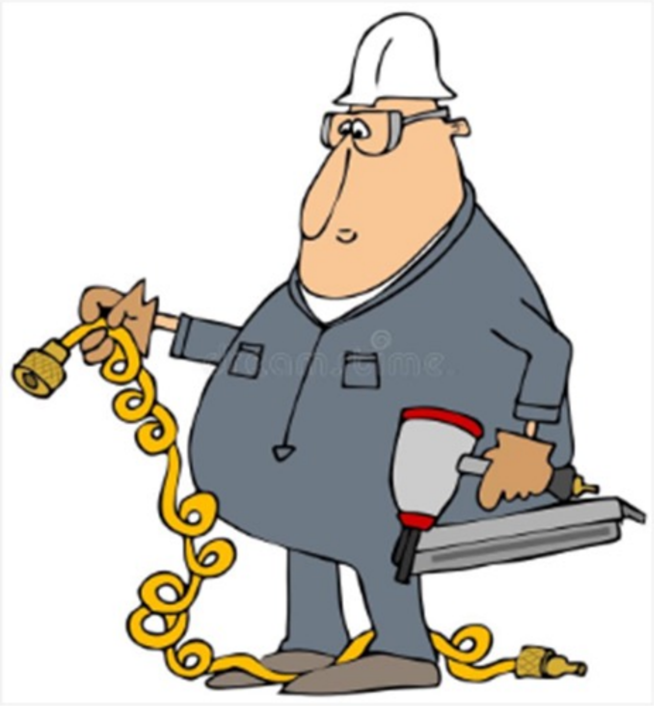


Rubber Hose

Air Flow CFM	Air Pressure Loss (PSI) in Standard power tool hoses Based on 100 psi Line Pressure														
	Hose Number and Size														
	1/4" x 10'	5/16" x 8'	3/8" x 10'	1/2" x 12 1/2	1/2" x 25'	1/2" x 50'	3/4" x 12.5'	3/4" x 25'	3/4" x 50'	1/2" x 50' + 1/4" x 10'	1/2" x 50' + 3/8" x 10'	1/2" x 50' + 5/16" x 10'	1/2" x 50' + 1/2" x 12.5'	3/4" x 50' + 1/2" x 25'	3/4" x 50' + 3/4" x 12.5'
10 - 11	5.0	0.9								5.3	0.7	1.4			
11 - 12	5.9	1.0								6.2	0.8	1.6			
12 - 13	6.8	1.2	0.4							7.2	0.9	1.9			
13 - 14	8.0	1.4	0.5							8.4	1.1	2.2			
14 - 15	9.3	1.3	0.6							9.8	1.3	2.5			
15 - 16	11.0	1.9	0.7							11.6	1.5	2.9			
16 - 18	14.0	2.4	0.8							15.0	1.9	3.5	1.7		
18 - 20	19.6	3.0	1.0							21.4	2.4	4.5	2.0		
20 - 25		4.3	1.4	0.7	1.0	1.3					3.5	6.4	2.6	1.3	
25 - 30		6.6	2.1	1.0	1.5	2.3					5.2	9.8	3.8	1.9	
30 - 35		9.5	3.1	1.3	2.1	3.6					7.3	13.7	5.3	2.6	
35 - 40		12.8	4.2	1.7	2.8	5.2					9.6	18.4	7.1	3.5	
40 - 50		19.3	6.3	2.4	4.1	8.0					14.0		10.4	5.2	1.8
50 - 60			9.6	3.7	6.3	12.2					21.8		16.0	7.8	2.3
60 - 70			13.5	5.3	9.0	17.4	0.9	1.4	1.9				22.8	11.1	3.0
70 - 80			18.7	7.1	12.4		1.1	1.7	2.5					15.0	3.7
80 - 90			25.0	9.0	16.1		1.4	2.2	3.2					19.8	4.6
90 - 100				11.0			1.7	2.7	4.0						5.8
100 - 120							2.3	3.5	5.6						7.9
120 - 140							3.2	4.8	8.0						11.2
140 - 160							4.6	6.6	11.0						15.5
160 - 180							5.6	8.7	15.2						20.4
180 - 200							7.2	11.0							
200 - 220							9.0								

Rubber hose creates large pressure resulting in working pressure that is insufficient

Rubber Hose

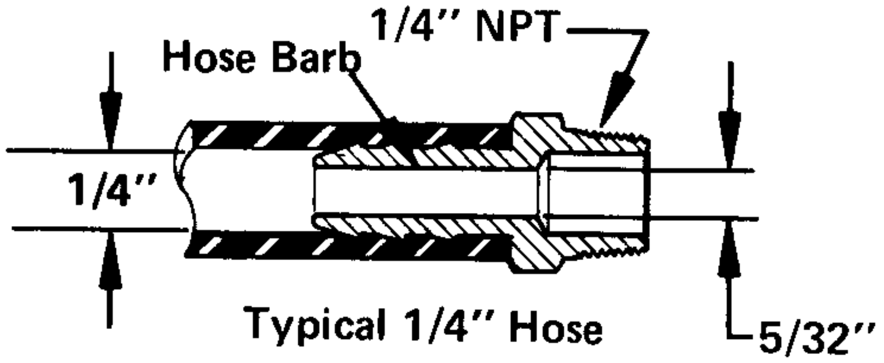


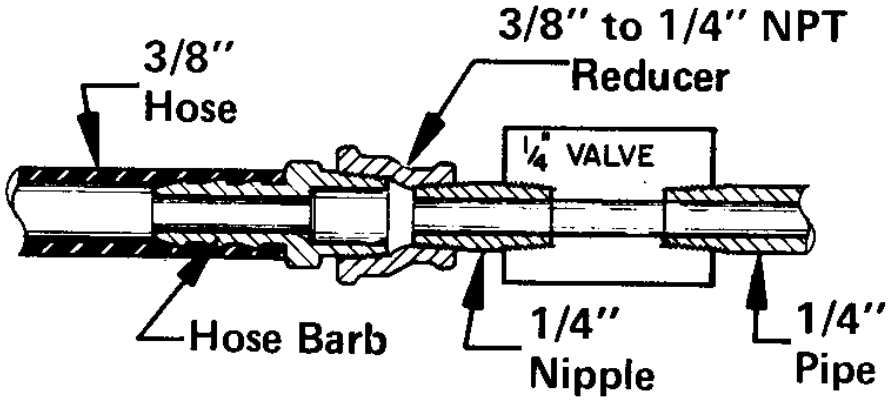
Air Flow CFM	Air Pres				
	1/4" x 10'	5/16" x 8'	3/8" x 10'	1/2" x 12 1/2	1/2 2
10 - 11	5.0	0.9			
11 - 12	5.9	1.0			
12 - 13	6.8	1.2	0.4		
13 - 14	8.0	1.4	0.5		
14 - 15	9.3	1.3	0.6		
15 - 16	11.0	1.9	0.7		
16 - 18	14.0	2.4	0.8		
18 - 20	19.6	3.0	1.0		
20 - 25		4.3	1.4	0.7	1

Rubber hose creates large pressure resulting in working pressure that is insufficient

Hose Fittings

- A restriction to flow is introduced wherever a hose fitting is attached to a length of hose
- The hose barb must fit inside the hose, and this reduces the inside diameter for a short distance.
- To reduce the restriction at a hose fitting, use a larger size hose and bush down at the porthole





Pressure Drop

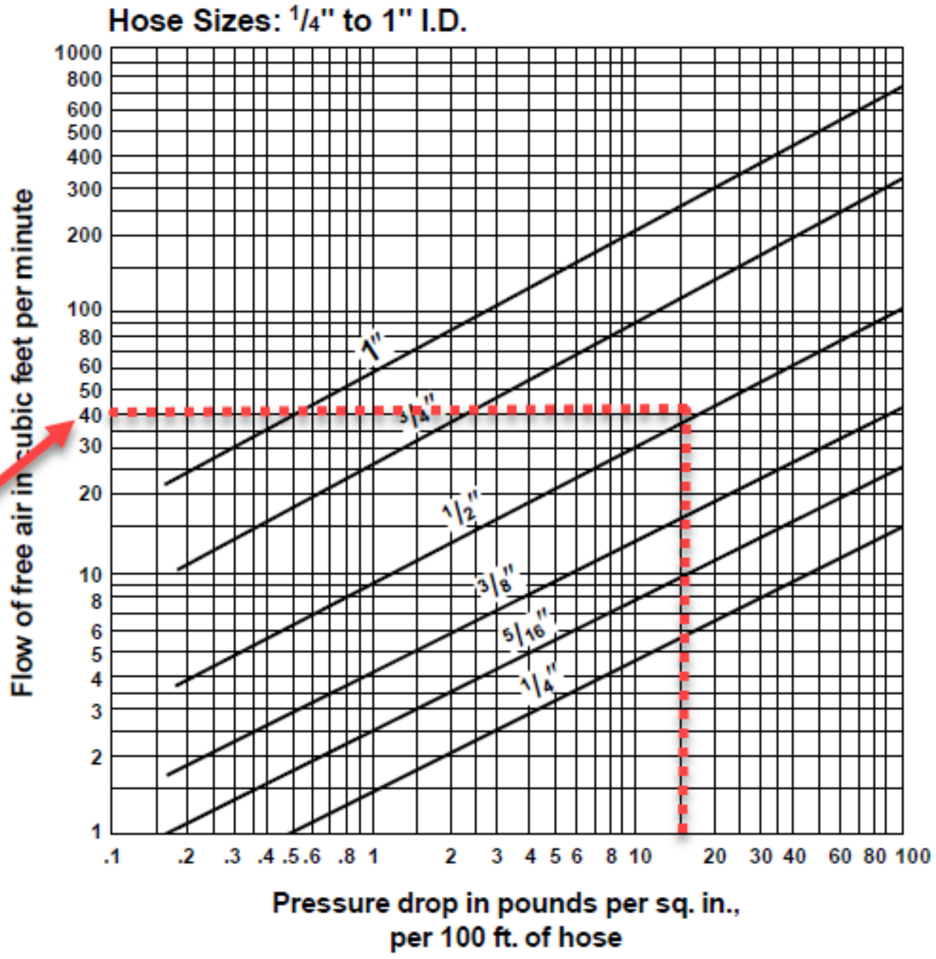
Air Flow Through Hose

Hose Sizes: 1/4" to 1" I.D.

This chart is for approximating and should serve only as a guide in sizing air hose. Pressure drops are directly proportional to hose lengths, i.e. if hose length doubles, pressure drop doubles.

Example:

- 100' x 1/2" I.D. hose at 40 CFM has a pressure loss of 17 1/2 psi.
- 200' x 1/2" I.D. will lose 35 psi.
- 50' x 1/2" I.D. will lose between 8 to 9 psi.



Formula to determine pressure drops for hose lengths other than 100':

$$\text{(Pressure Drop per Chart Figure)} \times \frac{\text{(Ft. of Hose)}}{100} = \text{Pressure drop for hose used}$$

Reducing Pressure Drops Throughout the System

- Sometimes reducing pressure drops throughout the system can help solve problems with the applications in the system that require the highest pressures.
- Pressure drop is a term used to characterize the reduction in air pressure from the compressor discharge to the actual point of use.
- Pressure drop occurs as the compressed air travels through the treatment and distribution system.
- The velocity of compressed air in a header should not exceed 20ft/sec and in distribution piping should not exceed 30ft/sec to minimize the pressure drop.
- Pressure drop increases as the square of the rate of flow.
- If a second compressor is brought online and doubles the flow rate, the pressure drop will increase by a factor of 4.
- The actual pressure at the point of use may not be increased!

Reducing Pressure Drops Throughout the System

- The following equation is for calculating Velocity:

$$V_{fps} = \frac{cfm \times P_a}{60 \times a \times (P_2 + P_a)}$$

- Where:
  - V = Velocity in feet per second,
  - P_a = local barometric pressure
  - cfm = air flow, free air in ft^3/min
  - a = cross sectional area of pipe bore inches ft2
  - d = pipe bore diameter in inches
  - P_2 = gauge pressure in header or pipe

$$a = \frac{\pi \times d^2}{4 \times 144}$$

Solve for Diameter *(d)*

- The following equation is for calculating Velocity:

$$a = \frac{144 \times cfm \times P_a}{V \times 60 \times (P_d + P_a)}$$

$$a_{sq.in} = \frac{\Pi \times d^2}{4}$$

$$d = \sqrt{\frac{a \times 4}{\Pi}}$$

Using the MEASUR Tool Calculator for Velocity

VELOCITY IN THE PIPING

Air Flow	500	SCFM
Pipe Pressure	100	psig
Atmospheric Pressure	14.5	psia

Compressed Air Velocity in the Piping

Pipe Size (in)		Pipe Size (in)	
1/2	506.55 ft/s	5	7.6 ft/s
3/4	286.73 ft/s	6	5.26 ft/s
1	176.7 ft/s	8	3.04 ft/s
1 1/4	101.31 ft/s	10	1.93 ft/s
1 1/2	74.49 ft/s	12	1.36 ft/s
2	45.23 ft/s	14	1.12 ft/s
2 1/2	31.73 ft/s	16	0.86 ft/s
3	20.56 ft/s	18	0.68 ft/s
3 1/2	15.37 ft/s	20	0.55 ft/s
4	11.94 ft/s	24	0.38 ft/s

Pressure Drop and Flow Relationship

- Pressure drop increases as the square of the rate of flow.
- Doubling the flow rate means four times the pressure drop through the same piping.

$$\Delta P_2 = \Delta P_1 \times \left(\frac{Flow_2}{Flow_1} \right)^2$$

Loss of Air Pressure Due To Friction

Cfm free air	2'' ID	3'' ID	4'' ID
500	19.2	2.34	1.09
600	27.6	3.36	1.56
700	37.7	4.55	2.13

In psi per 1000 feet of pipe, 100 psig inlet pressure. Losses are proportional to length

Air pressure loss due to friction is usually expressed in psi per feet of pipe with a given inlet pressure.

Loss of air pressure due to friction, is a function of cfm, pipe inside diameter, pipe length, and initial pressure.

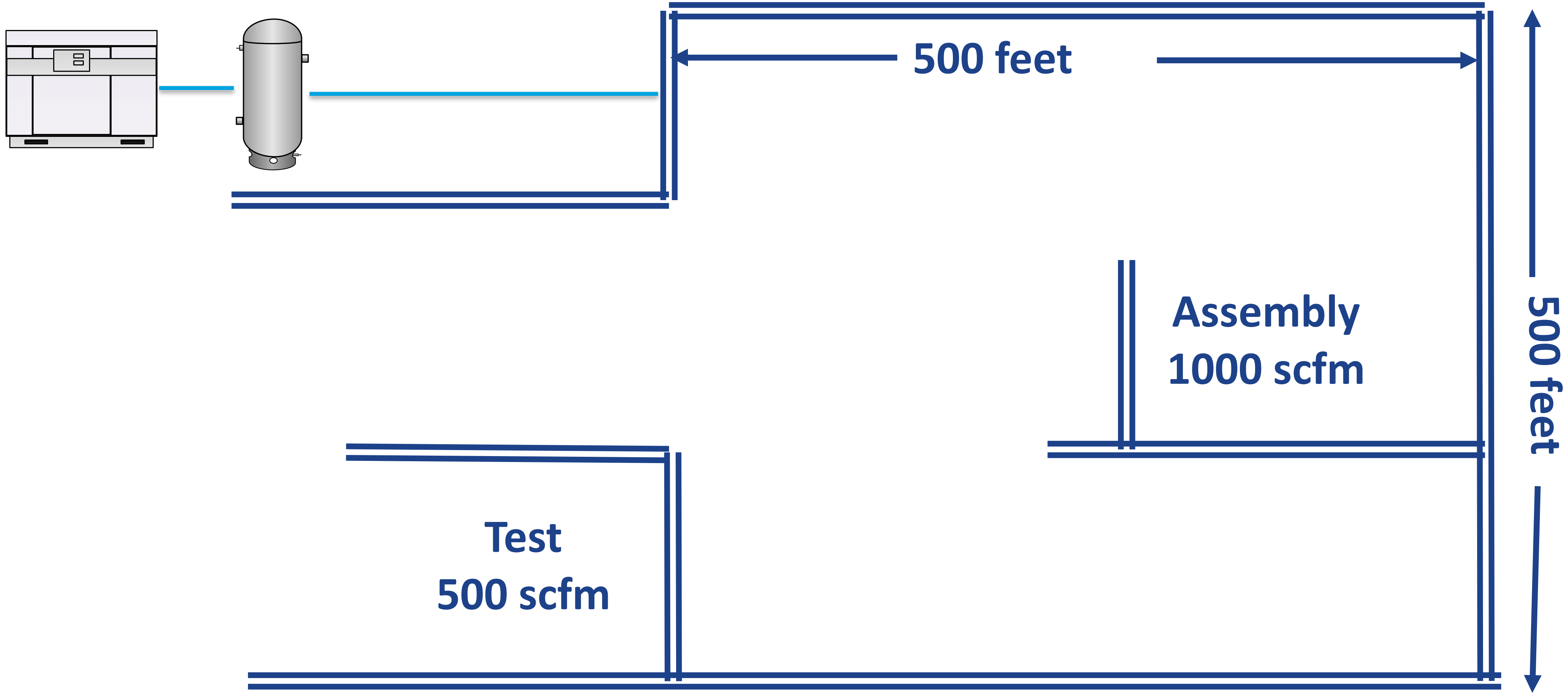
Loss of Air Pressure Due To Friction

- Effect of age and use on pipe friction:
- Friction loss in pipe is sensitive to changes in diameter and the roughness of the walls.
  - For a given rate of flow and a fixed friction factor, the pressure drop per foot of pipe varies inversely with the fifth power of the diameter.
  - Therefore a 2% reduction in diameter causes an 11% increase in pressure drop.
  - A 5% reduction in diameter increases pressure drop 29%.
  - In older existing steel piping systems, the interior of pipe becomes encrusted with scale, dirt, and other foreign matter - all leading to increased pressure drop.
- Remember…. The pressure drop through the system increases as the square of airflow rate (velocity).
- High volume intermittent demands can create peak airflow rates causing significant pressure excursions.

Loss of Air Pressure Due To Friction

- Effect of age and use on pipe friction:

WHAT PIPE SIZE IS NEEDED



Pressure Drop – Loss at 100 psig

General Reference Data

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.

General Reference Data

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
2,000	256.2	....	....	....	....	....	....	37.4	8.8	0.99	0.24		
2,500	316.4	....	....	....	....	....	....	58.4	13.8	1.57	0.37		
3,000	384.6	....	....	....	....	....	....	84.1	20.0	2.26	0.53		
3,500	447.8	....	....	....	....	....	....	....	27.2	3.04	0.70	0.22	
4,000	512.4	....	....	....	....	....	....	....	35.5	4.01	0.94	0.28	
4,500	576.5	....	....	....	....	....	....	....	45.0	5.10	1.19	0.36	
5,000	632.8	....	....	....	....	....	....	....	55.6	6.3	1.47	0.44	0.17
6,000	768.8	....	....	....	....	....	....	....	80.0	9.1	2.11	0.64	0.24
7,000	896.0	....	....	....	....	....	....	....	....	12.2	2.88	0.87	0.33
8,000	1,025	....	....	....	....	....	....	....	....	16.1	3.77	1.12	0.46
9,000	1,153	....	....	....	....	....	....	....	....	20.4	4.77	1.43	0.57
10,000	1,280	....	....	....	....	....	....	....	....	25.1	5.88	1.77	0.69
11,000	1,410	....	....	....	....	....	....	....	....	30.4	7.10	2.14	0.83
12,000	1,540	....	....	....	....	....	....	....	....	36.2	8.5	2.54	0.98
13,000	1,668	....	....	....	....	....	....	....	....	42.6	9.8	2.98	1.15
14,000	1,795	....	....	....	....	....	....	....	....	49.2	11.5	3.46	1.35
15,000	1,923	....	....	....	....	....	....	....	....	56.6	13.2	3.97	1.53
16,000	2,050	....	....	....	....	....	....	....	....	64.5	15.0	4.52	1.75
18,000	2,310	....	....	....	....	....	....	....	....	81.5	19.0	5.72	2.22
20,000	2,560	....	....	....	....	....	....	....	....	....	23.6	7.0	2.74
22,000	2,820	....	....	....	....	....	....	....	....	....	28.5	8.5	3.33
24,000	3,080	....	....	....	....	....	....	....	....	....	33.8	10.0	3.85
26,000	3,338	....	....	....	....	....	....	....	....	....	39.7	11.9	4.65
28,000	3,590	....	....	....	....	....	....	....	....	....	46.2	13.8	5.40
30,000	3,850	....	....	....	....	....	....	....	....	....	53.0	15.9	6.17

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 Drop – By Size and Flow Chapter 8 CAGI Handbook

CAGI

Table 8.16 Factor for Calculating Loss of Air Pressure Due to Pipe Friction Applicable for any Initial Pressure*

Cu ft Free Air Per Min	Nominal Diameter, In.												
	$^1/_2$	$^3/_4$	1	$1\ ^1/_4$	$1\ ^1/_2$	$1\ ^3/_4$	2	3	4	6	8	10	12
5	12.7	1.2	0.5										
10	50.7	7.8	2.2	0.5									
15	114.1	17.6	4.9	1.1									
20	202	30.4	8.7	2.0	0.9								
25	316	50.0	13.6	3.2	1.4	0.7							
30	456	70.4	19.6	4.5	2.0	1.1							
35	811	95.9	26.2	6.2	2.7	1.4							
40	....	125.3	34.8	8.1	3.6	1.9							
45	....	159	44.0	10.2	4.5	2.4	1.2						
50	....	196	54.4	12.6	5.6	2.9	1.4						
60	....	282	78.3	18.2	8.0	4.2	2.2						
70	....	385	106.6	24.7	10.9	5.7	2.9						
80	....	503	139.2	32.3	14.3	7.5	3.8						
90	....	646	176.2	40.9	18.1	9.5	4.8						
100	....	785	217.4	50.5	22.3	11.7	6.0						
110	....	950	263	61.2	27.0	14.1	7.2						
120	....	....	318	72.7	32.2	16.8	8.6						
130	....	....	369	85.3	37.8	19.7	10.1	1.2					
140	....	....	426	98.9	43.8	22.9	11.7	1.4					
150	....	....	490	113.6	50.3	26.3	13.4	1.6					
160	....	....	570	129.3	57.2	29.9	15.3	1.9					
170	....	....	628	145.8	64.6	33.7	17.6	2.1					
180	....	....	705	163.3	72.6	37.9	19.4	2.4					
190	....	....	785	177	80.7	42.2	21.5	2.6					
200	....	....	870	202	89.4	46.7	23.9	2.9					
220	....	....	....	244	108.2	56.5	28.9	3.5					
240	....	....	....	291	128.7	67.3	34.4	4.2					
260	....	....	....	341	151	79.0	40.3	4.9					
280	....	....	....	395	175	91.6	46.8	5.7					
300	....	....	....	454	201	105.1	53.7	6.6					
320	....	....	....	....	....	....	61.1	7.5					
340	....	....	....	....	....	....	69.0	8.4	2.0				
360	....	....	....	....	....	....	77.3	9.5	2.2				
380	....	....	....	....	....	....	86.1	10.5	2.5				
400	....	....	....	....	....	....	94.7	11.7	2.7				
420	....	....	....	....	....	....	105.2	12.9	3.1				
440	....	....	....	....	....	....	115.5	14.1	3.4				
460	....	....	....	....	....	....	125.6	15.4	3.7				
480	....	....	....	....	....	....	137.6	16.8	4.0				
500	....	....	....	....	....	....	150.0	18.3	4.3				
525	....	....	....	....	....	....	165.0	20.2	4.8				
550	....	....	....	....	....	....	181.5	22.1	5.2				
575	....	....	....	....	....	....	197	24.2	5.7				
600	....	....	....	....	....	....	215	26.3	6.2				
625	....	....	....	....	....	....	233	28.5	6.8				
650	....	....	....	....	....	....	253	30.9	7.3				
675	....	....	....	....	....	....	272	33.3	7.9				
700	....	....	....	....	....	....	294	35.8	8.5				
750	....	....	....	....	....	....	337	41.4	9.7				
800	....	....	....	....	....	....	382	46.7	11.1				
850	....	....	....	....	....	....	433	52.8	12.5				
900	....	....	....	....	....	....	468	59.1	14.0				
950	....	....	....	....	....	....	541	65.9	15.7				
1,000	....	....	....	....	....	....	600	73.0	17.3	1.9			
1,050	....	....	....	....	....	....	658	80.5	19.1	2.1			

Compressed Air & Gas Institute • 1300 Sumner Avenue • Cleveland, OH 44115
Phone: 216/241-7333 • Fax: 216/241-0105 • E-mail: cagi@cagi.org

Pipe Loss Calculation

The following formula is used to calculate losses in a piping system

$$\frac{\text{Correction factor}}{\text{Compression Ratio*}} \times \frac{\text{Pipe Length}}{10000} = \text{Pipe Loss (psig)}$$

*compression ratio = discharge pressure in psia/inlet pressure psia

example... 120 psig discharge = 134.70/14.7 = 9.16

PIPE DIAMETER IN INCHES

Pump cfm free air	1	1 1/2	2	2 1/2	3	3 1/2	4	5	6	8	10	12
80	139.2	14.3	3.8	1.5								
100	217.4	22.3	6.0	2.3								
120	318.0	32.2	8.6	3.3								
150	490.0	50.3	13.4	5.2	1.6							
200	870.0	89.4	23.9	9.3	2.9							
250	163.0	140.0	37.4	14.5	4.6							
300		201.0	53.7	20.9	6.6	3.5						
350			73.2	28.5	9.0	4.2	2.2					
400			94.7	37.1	11.7	5.4	2.7					
450			120.6	46.9	14.8	6.9	3.6					
500			150.0	58.0	18.3	8.5	4.3					
550			181.5	70.2	22.1	10.2	5.2					
600			215.0	83.5	26.3	12.2	6.2					
650			253.0	98.0	30.9	14.3	7.3	2.2				
700			294.0	113.7	35.8	16.6	8.5	2.6				
750			337.0	130.5	41.5	19.0	9.7	2.9				
800			382.0	148.4	46.7	21.7	11.1	3.3				
850			433.0	168.0	52.8	24.4	12.5	3.8				
900			468.0	188.0	59.1	27.4	14.0	4.2				
950			541.0	209.4	65.9	30.5	15.7	4.7				
1000			600.0	232.0	73.0	33.8	17.3	5.2	1.9			
1200			850.0	344.0	105.2	48.8	25.0	7.5	2.8			
1400						66.3	33.9	10.2	3.8			
1600						86.6	44.3	13.4	5.1			
1800						97.8	50.1	16.9	6.4			
2000						135.0	69.3	20.9	7.8	1.8		
2250						173.0	87.6	28.9	10.9	2.5		
2500						229.0	108.2	32.6	12.3	2.9		
2750						256.0	131.0	39.6	14.9	3.5		
3000						305.0	156.0	47.0	17.7	4.1		
4000						488.0	277.0	83.6	31.4	7.3	2.2	
5000							433.0	131.0	49.1	11.5	3.4	
6000								188.0	70.7	16.5	5.0	1.9

Pipe Loss Calculation

The following formula is used to calculate losses in a piping system

$$\frac{\text{Correction factor}}{\text{Compression Ratio*}} \times \frac{\text{Pipe Length}}{1000} = \text{Pipe Loss (psig)}$$

*compression ratio = discharge pressure in psia/inlet pressure psia

example... 120 psig discharge = 134.70/14.7 = 9.16

What pipe size is needed?

To determine the pressure drop in psi, the factor listed in the table for a given capacity and pipe diameter should be divided by the ratio of compression (from free air) at entrance of pipe, multiplied by the actual length of the pipe in feet, and divided by 1000.

Let's try using 3-inch pipe to the assembly area:

$$\frac{\text{Correction factor}}{\text{Compression ratio}} \times \frac{\text{Pipe length}}{1000}$$

$$\frac{73}{7.8} \times \frac{700}{1000} = 6.55 \text{ psi}$$

Let's try using 4-inch pipe to the assembly area:

$$\frac{\text{Correction factor}}{\text{Compression ratio}} \times \frac{\text{Pipe length}}{1000}$$

$$\frac{17.3}{7.8} \times \frac{700}{1000} = 1.55 \text{ psi}$$

This is a 5 psi difference between the two pipe sizes…Since each 1 psi is a .5% increase of energy,

5 psi will equate to a 2.5 % increase in energy overall

What pipe size is needed?

If this were a 200 horse power compressor using $ 112,429 annually in electricity… the additional pressure drop would equate to 2.5% times $ 112,429 or:

$ 2,810.73 annually !!!

Enough to have certainly paid for the minimal difference between the 3” and 4” pipe !!!

3” BIP costs $ 3.25/ft

4” BIP costs $ 4.75/ft

Conclusion:

There are no cost savings associated with reducing material expense in air line systems!!!

What pipe size is needed?

- The purpose of the chart is to make approximate estimations of the pressure loss through piping. The estimates do not take into account leaks and other factors affecting the piping system.
- A typical rule of thumb is to keep the line loss below 5%. However, the ultimate decision rests with the customer based upon his system and design requirements.

For every 90-degree pipe elbow multiply pipe diameter by 20 to equal additional pipe length in inches.

For every globe valve multiply pipe diameter by 30 to equal additional pipe length in inches.

For every gate valve multiply pipe diameter by 3 to equal additional pipe length in inches.

For every angle valve multiply pipe diameter by 16 to equal additional pipe length in inches.

For every tee multiply pipe diameter by 6 to equal additional pipe length in inches.

Frictional Loss in Pipe Example:

A customer has a new installation using 1200 ACFM, at 100 psig and wants to use 4" pipe with a total run of 2000 feet

12 elbows, 2 gate valves and 1 tee.

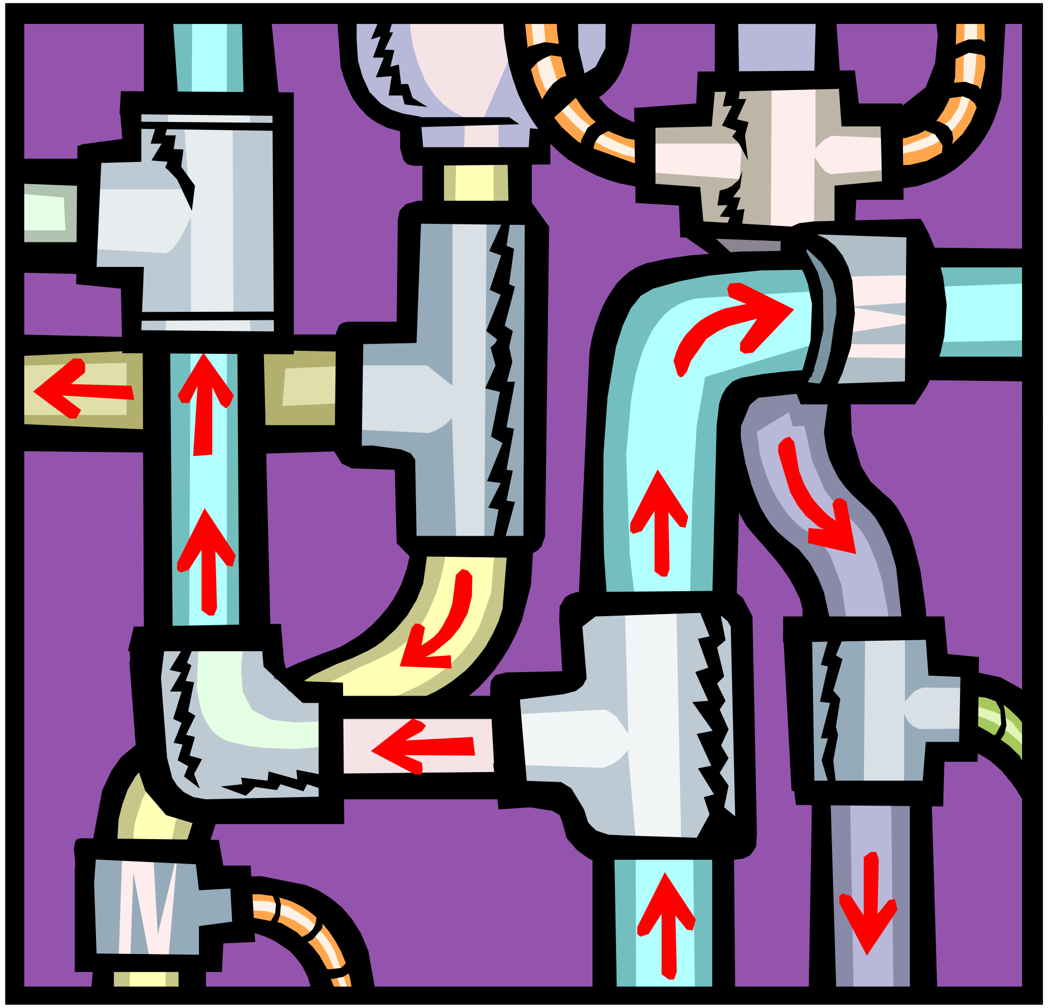
Assume the facility is at sea level. First cross reference 1200 CFM from the chart to find the FACTOR, which is 25.0. Figure the Compression Ratios, 114.7psia/14.7psia = 7.8 Compression Ratios

11 elbows @ 4" is 4 x 20 x 11 = 880 / 12 = 80 feet additional
2 gate valve is 4 x 3 x 2 = 24 / 12 = 2 feet additional
1 tee is 4 x 6 x 1 = 24 / 12 = 2 feet additional

2000 + 80 + 2 + 2 = 2084 total feet in inlet piping.

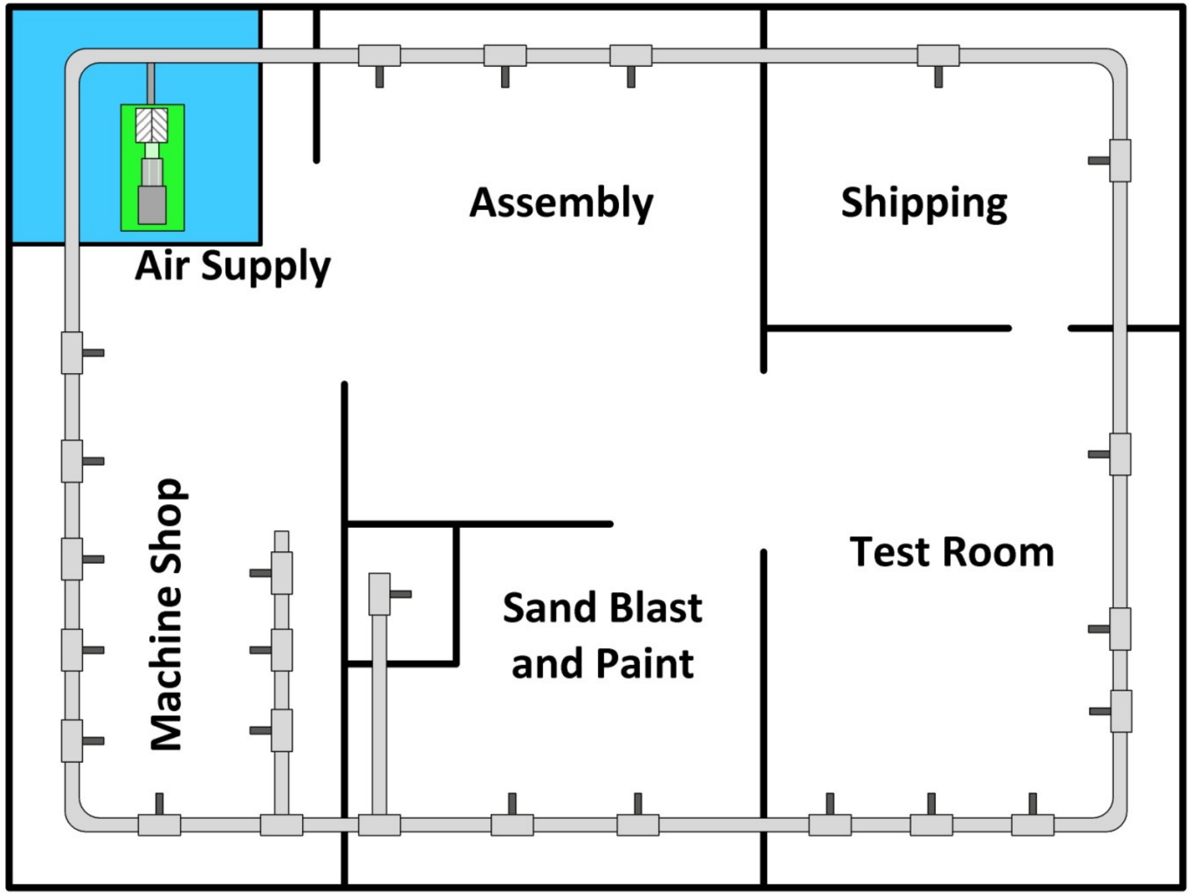
Now putting it altogether (25 / 7.8) (2084 / 1000) = 6.67 psi pressure drop

General Rules for Compressed Air Distribution System



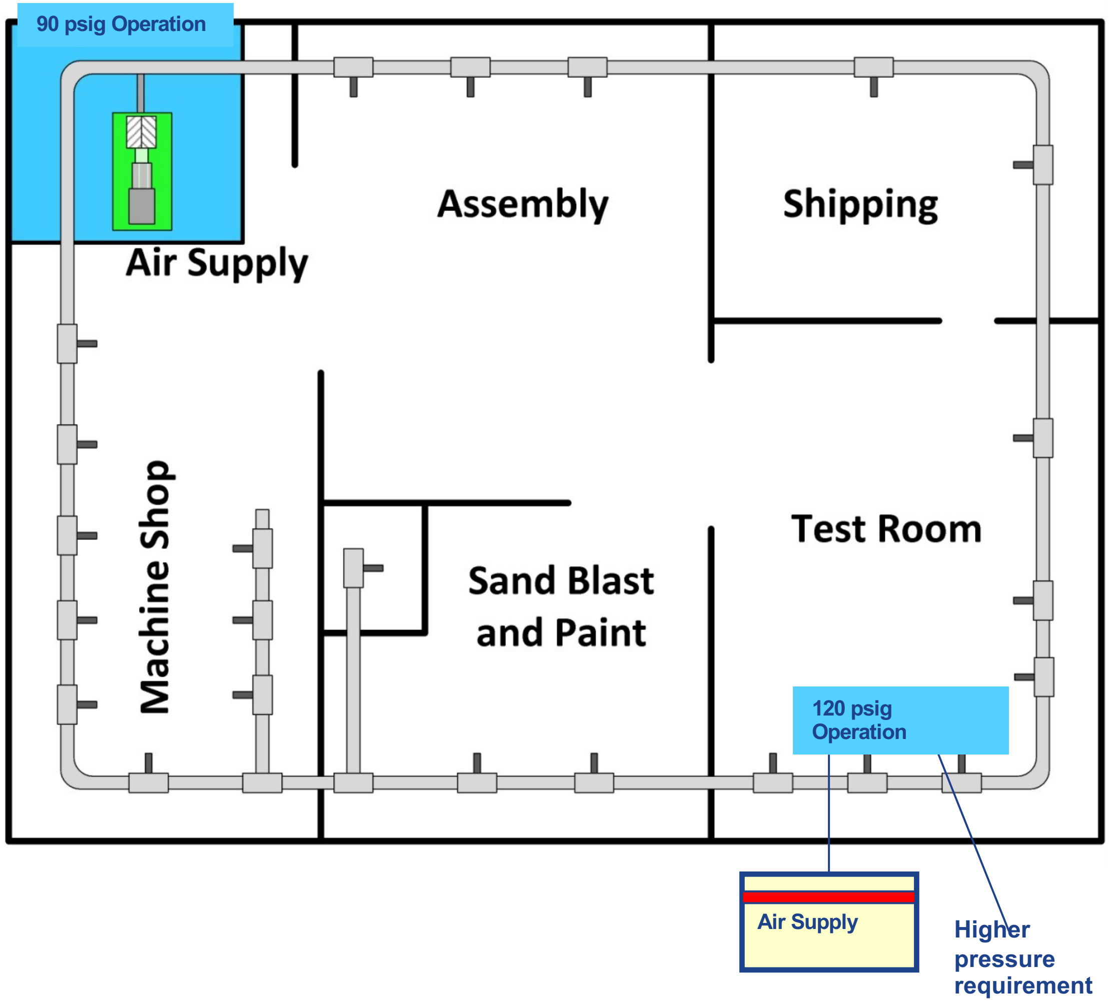
Location

- In some plants, a centralized compressor room can have benefits of a minimum of operators and maintenance requirements.
- The location should be chosen to minimize the distance or distances the compressed air has to travel to the points of use, particularly the larger volume applications.



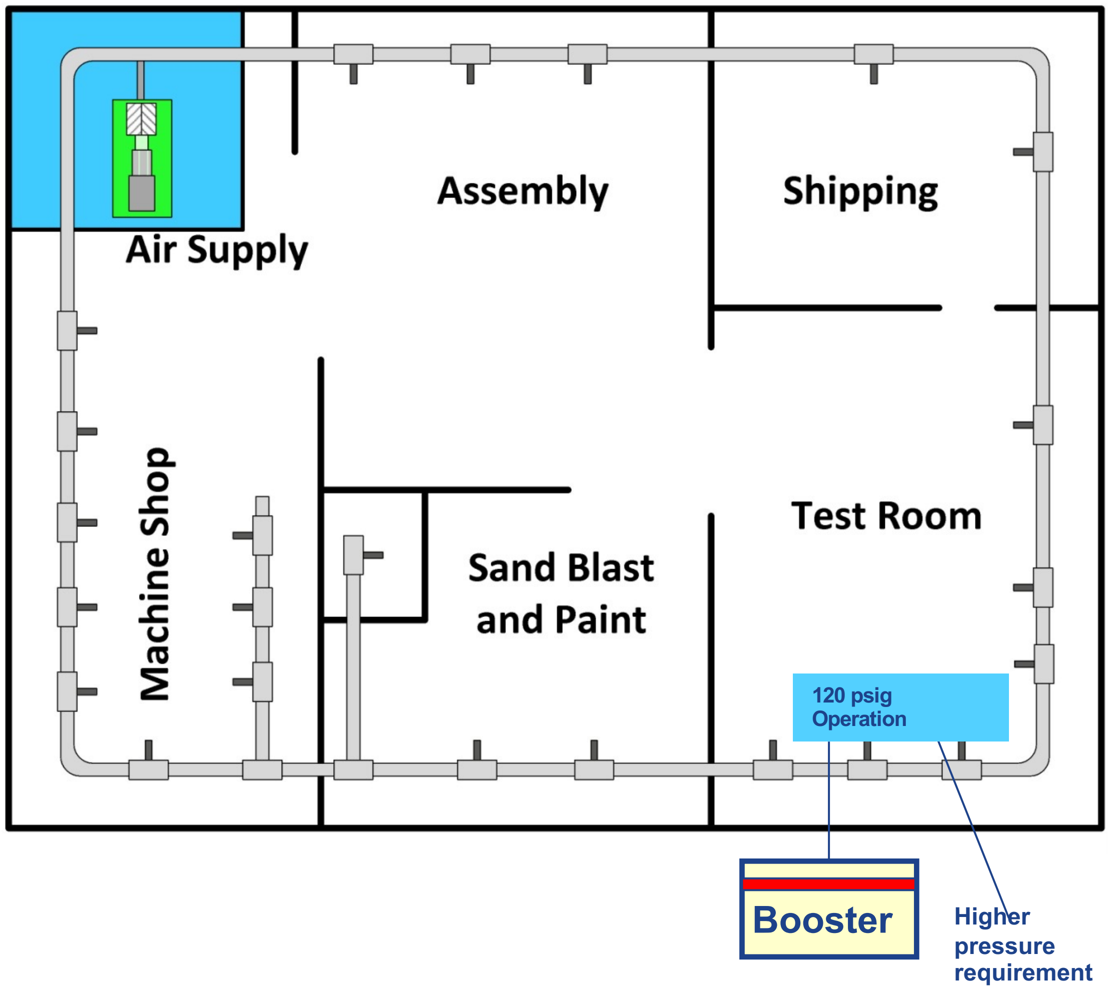
Serving a High-Pressure End Use

- There may be occasions where a separate, dedicated compressor or dedicated storage can be located adjacent to a high volume and or high-pressure point of use, avoiding system problems.
- For example, if a facility requires plant air at 90 psig, but has one application that requires air at 120 psig.
- Rather than providing 120 psig air to the whole plant, it would make sense to have a compressor or group of compressors provide plant air at 90 psig.
- One dedicated compressor could provide air to that one high pressure application at 120 psig.
- Another possibility is to modify the high-pressure requirement to run at 90 psig.



Serving a High-Pressure End Use

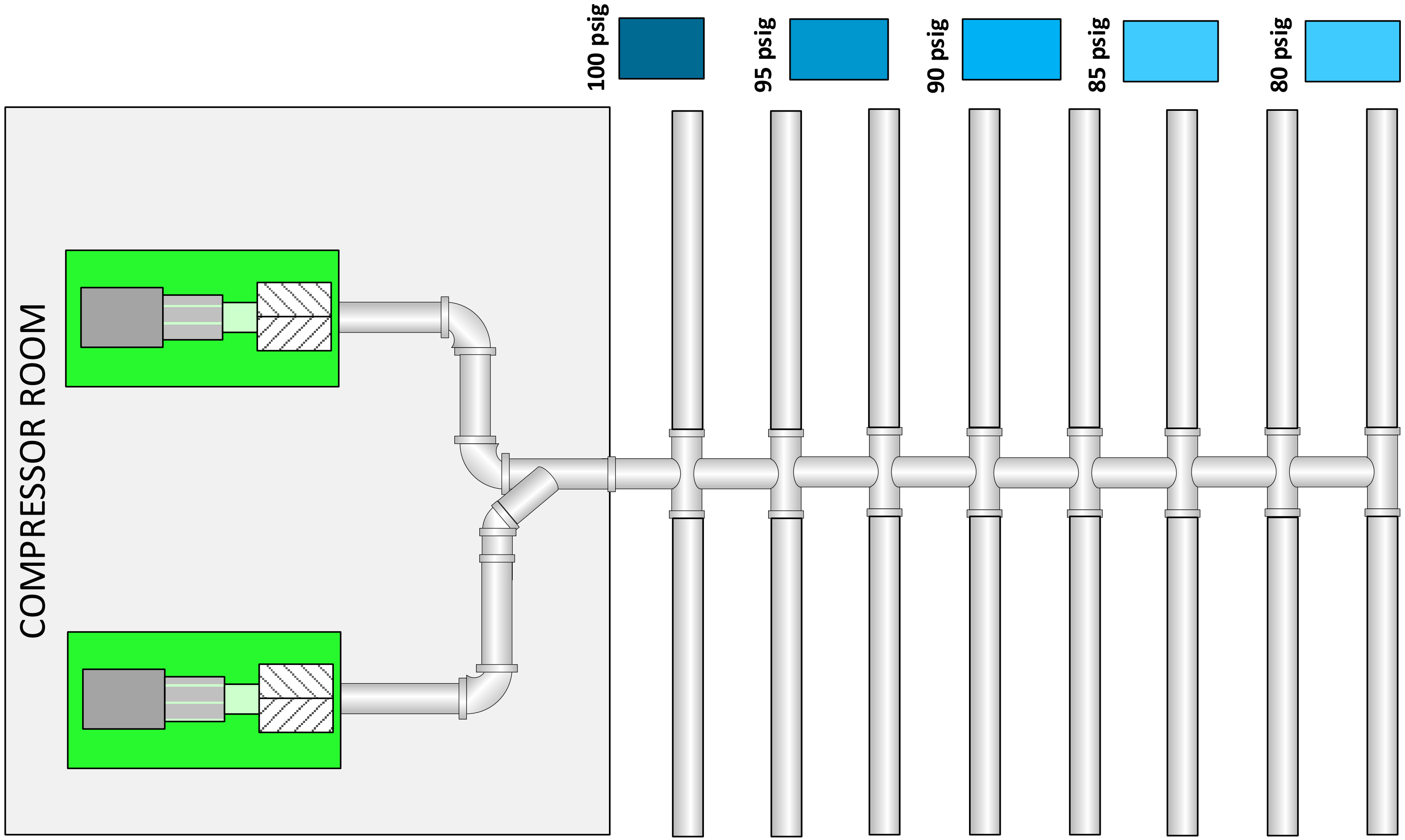
- Using the same example as previous, this diagram shows an alternative of using a booster rather than a dedicated compressor to pressurize to 120 psig.



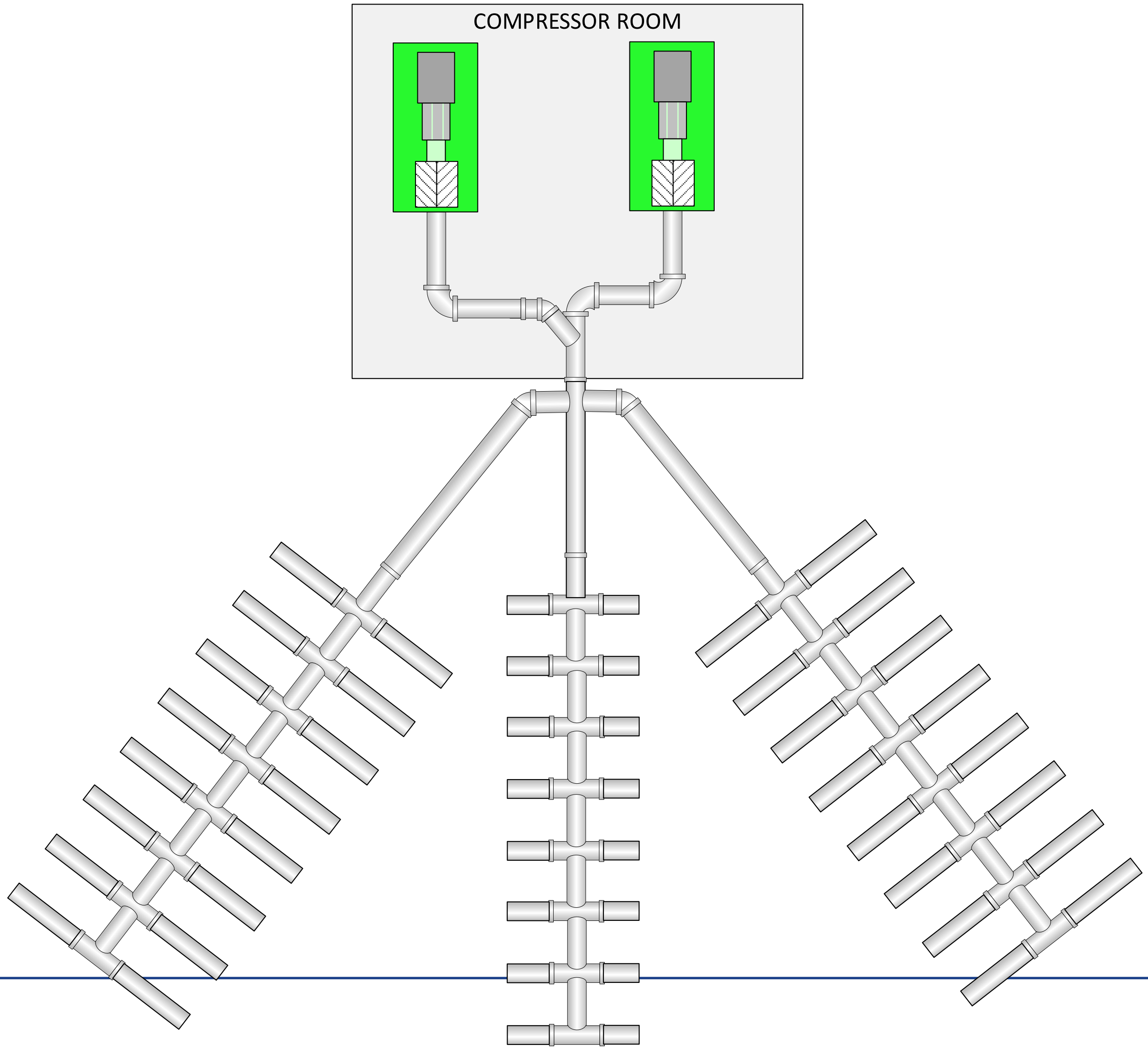
Piping Systems

- The dead end or grid system.
  - Simplest of the piping systems.
    - Least expensive to install.
  - Central main with small feeder lines.
  - The mains typically decrease in size away form the main header?
    - Feeder lines are generally of uniform size.
  - Only one flow path is available.
    - Workstations near the ends of the system are subject to insufficient air supply (air starvation) when upstream demand is heavy.

The dead end or grid system



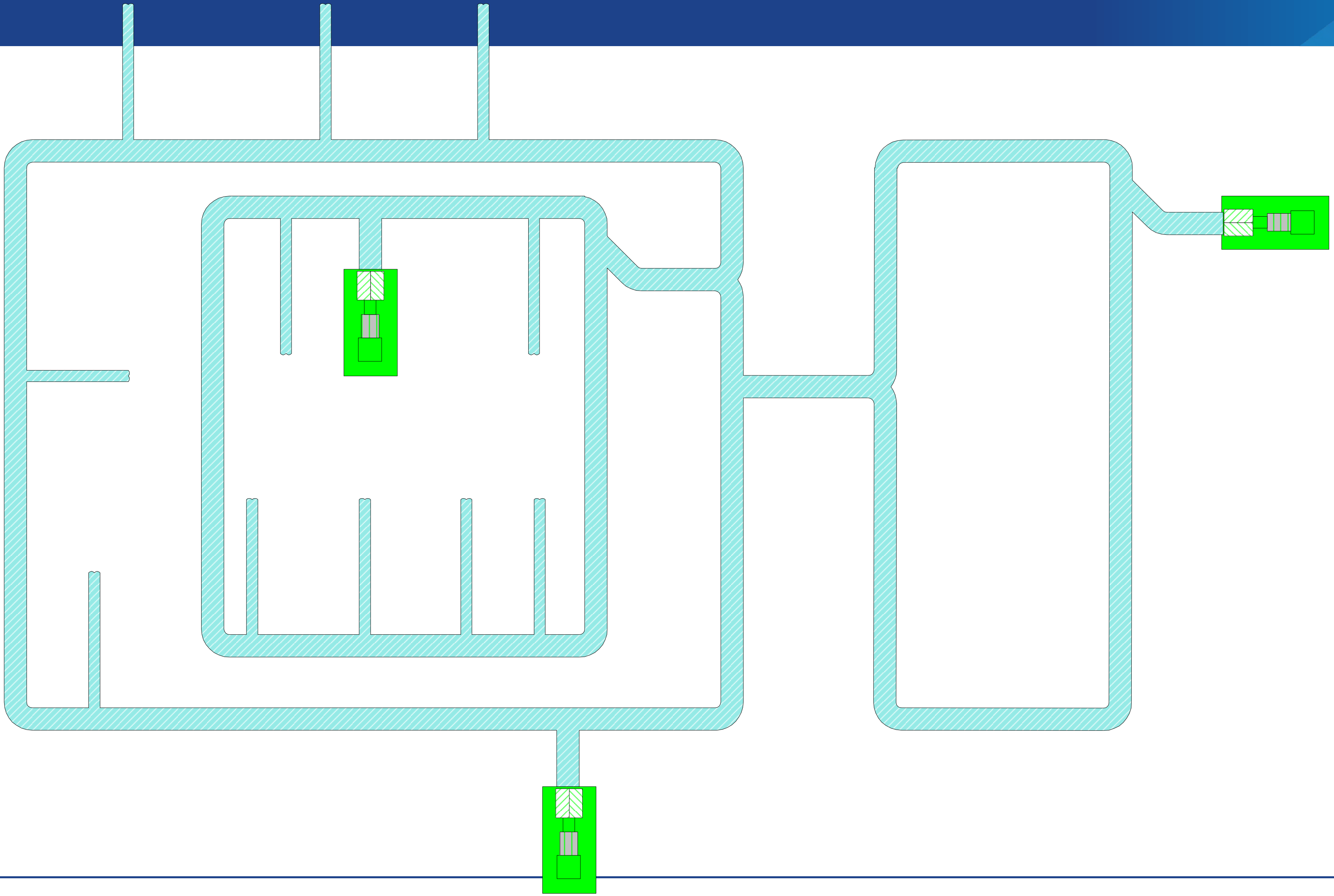
The dead end or grid system



Piping Systems

- Decentralized system.
  - May consist of two or more grids or loops.
    - Sometimes connected to form one large loop.
    - Each section has its own compressor.
  - Compressors are closer to the system using the air.
    - This allows shorter supply line.
    - Lower pressure drops.
    - Result is more uniform pressure throughout.
  - Very versatile and can easily be changed as needed.

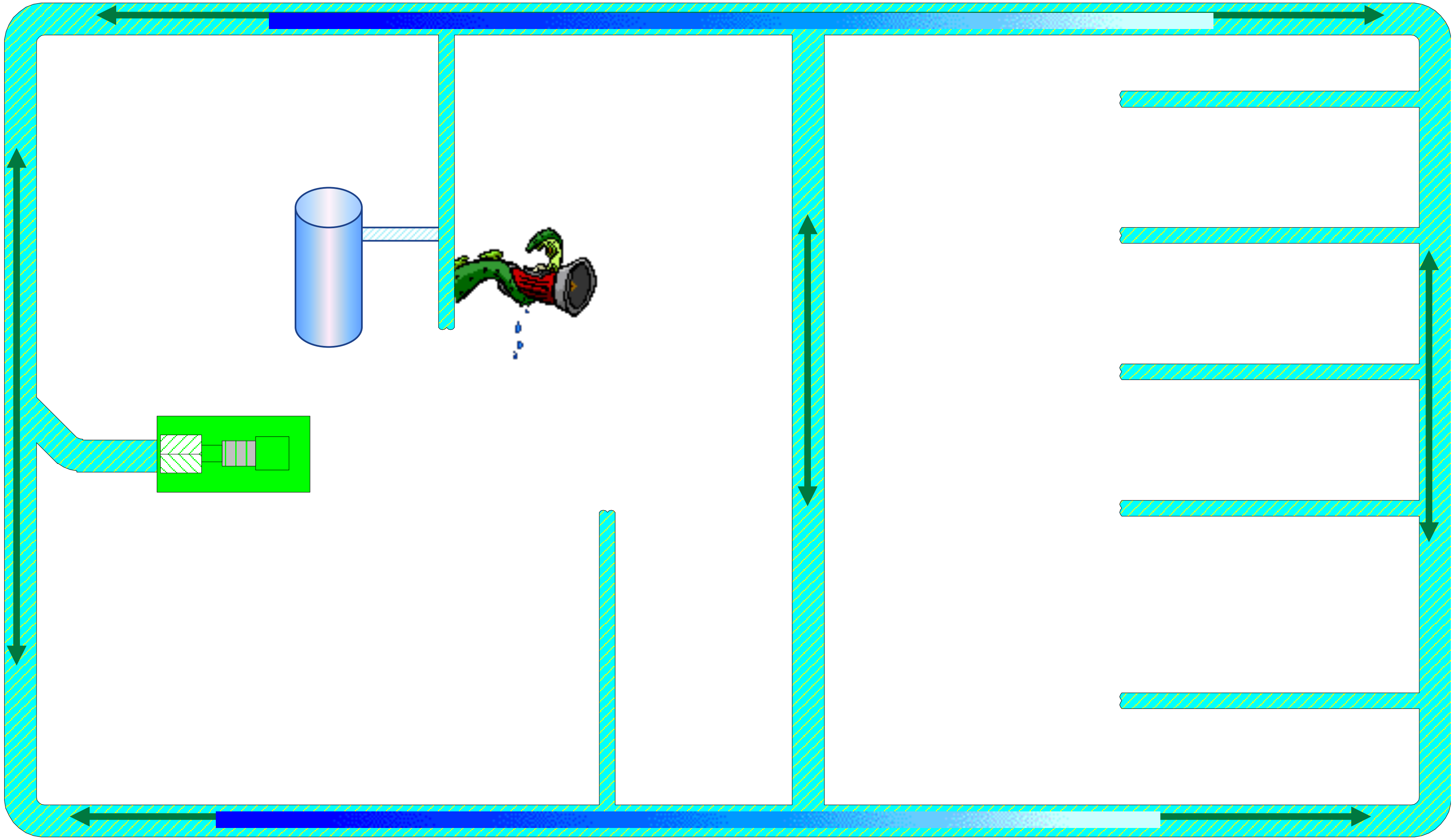
Decentralized system



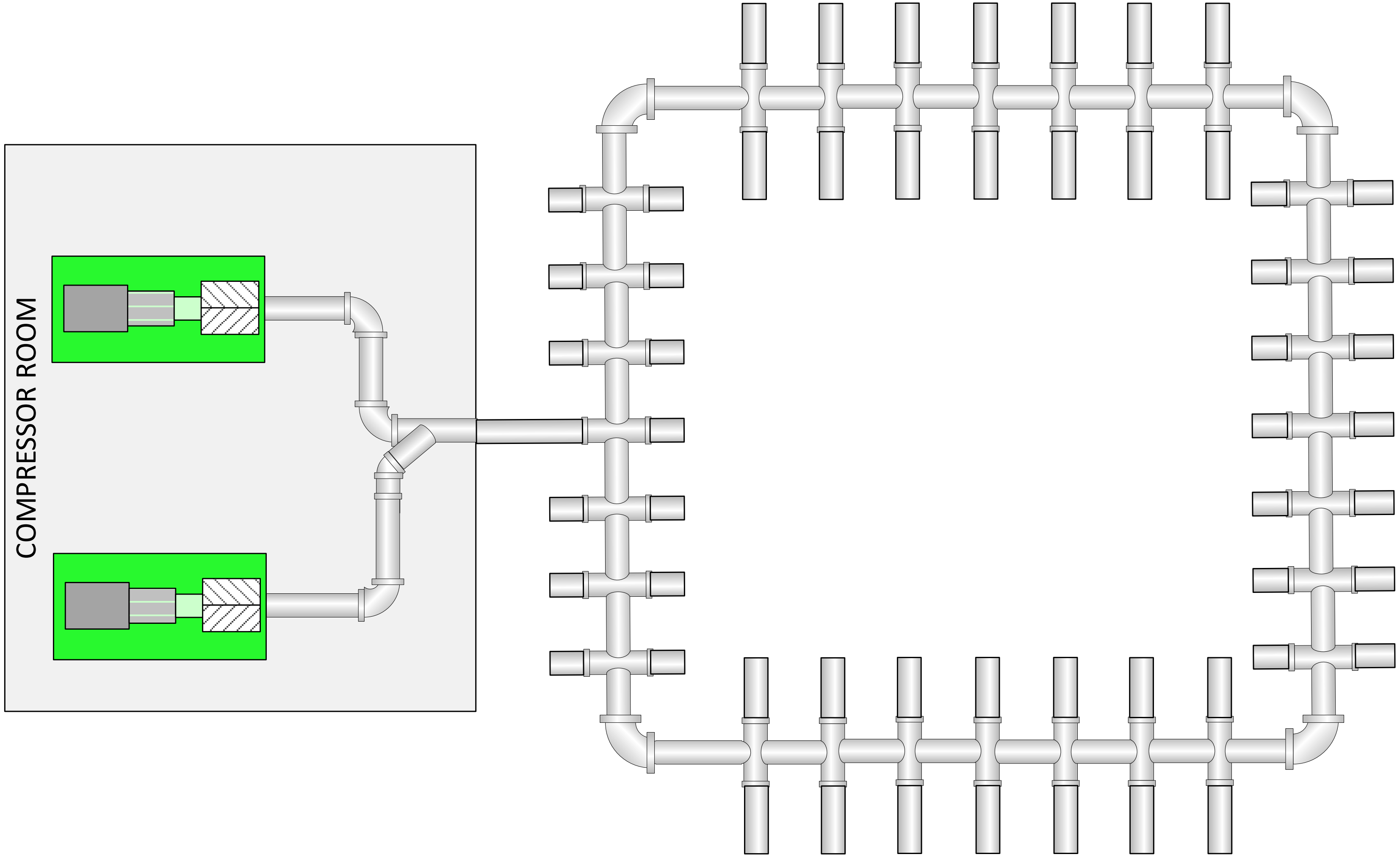
Piping Systems

- Loop system.
  - Highly recommend and most common.
  - Allows the optimum pipe size and assures equal distribution through the plant.
  - At points of heavy momentary demands for air, a receiver can be used to store the energy.

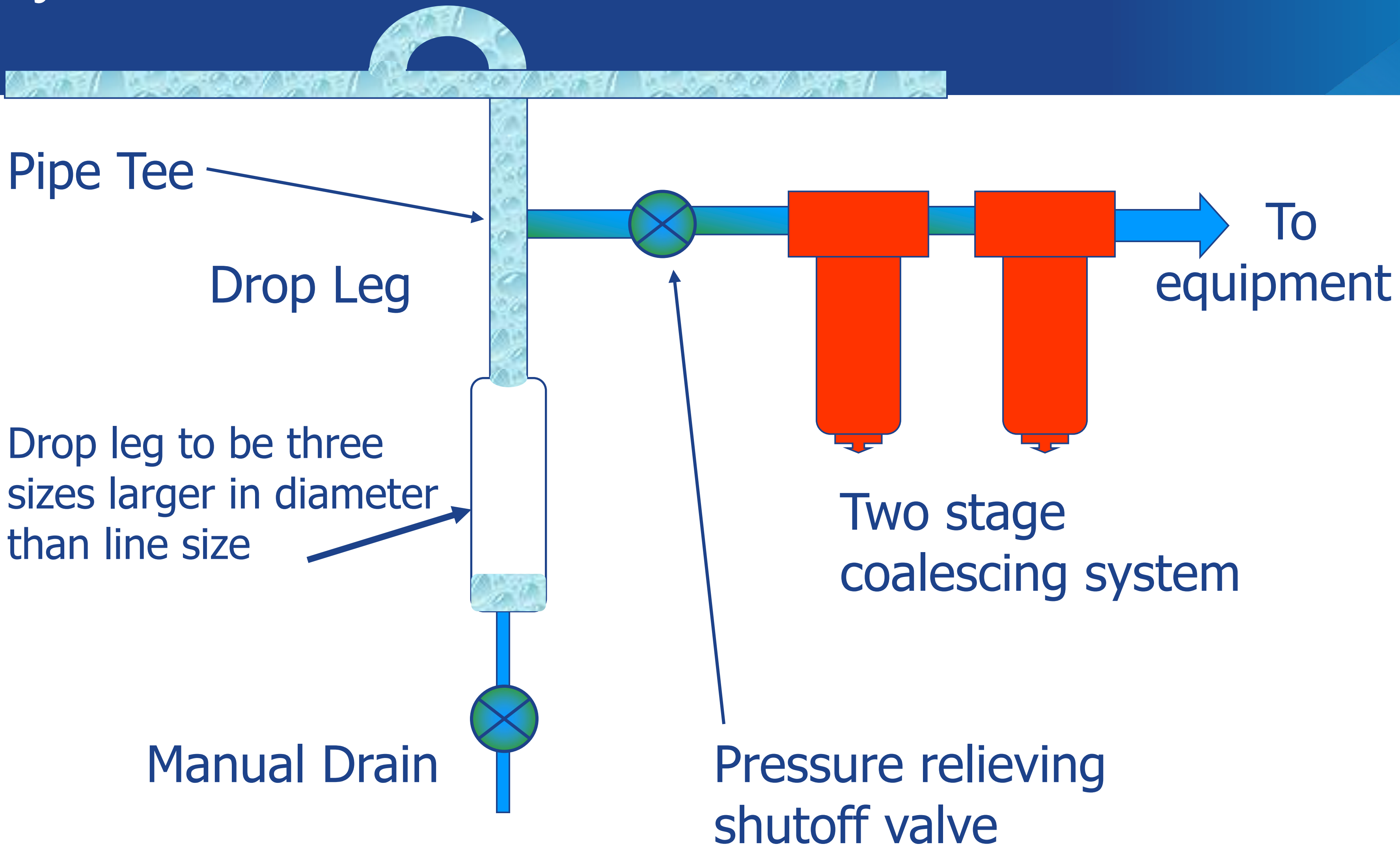
Loop system



Loop system

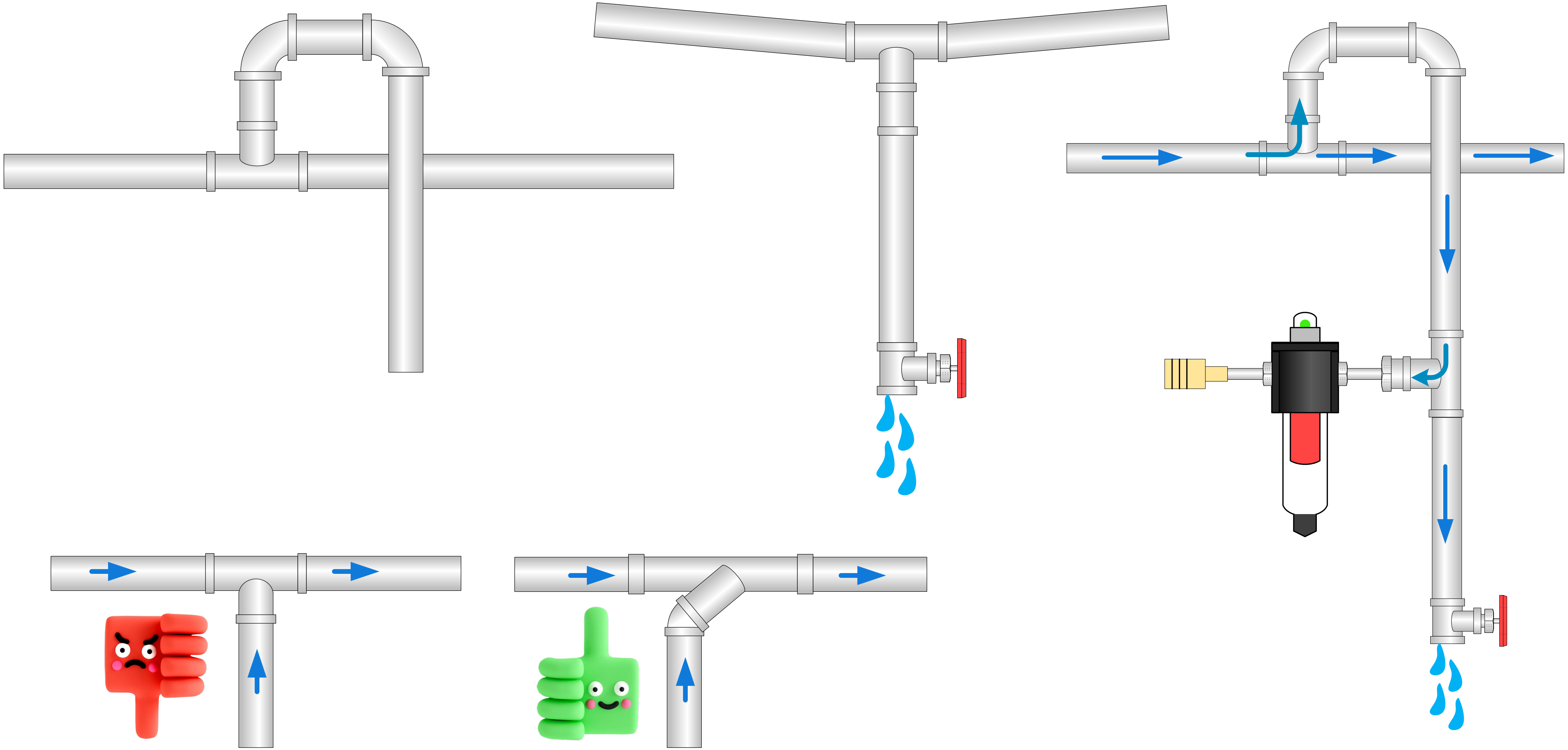


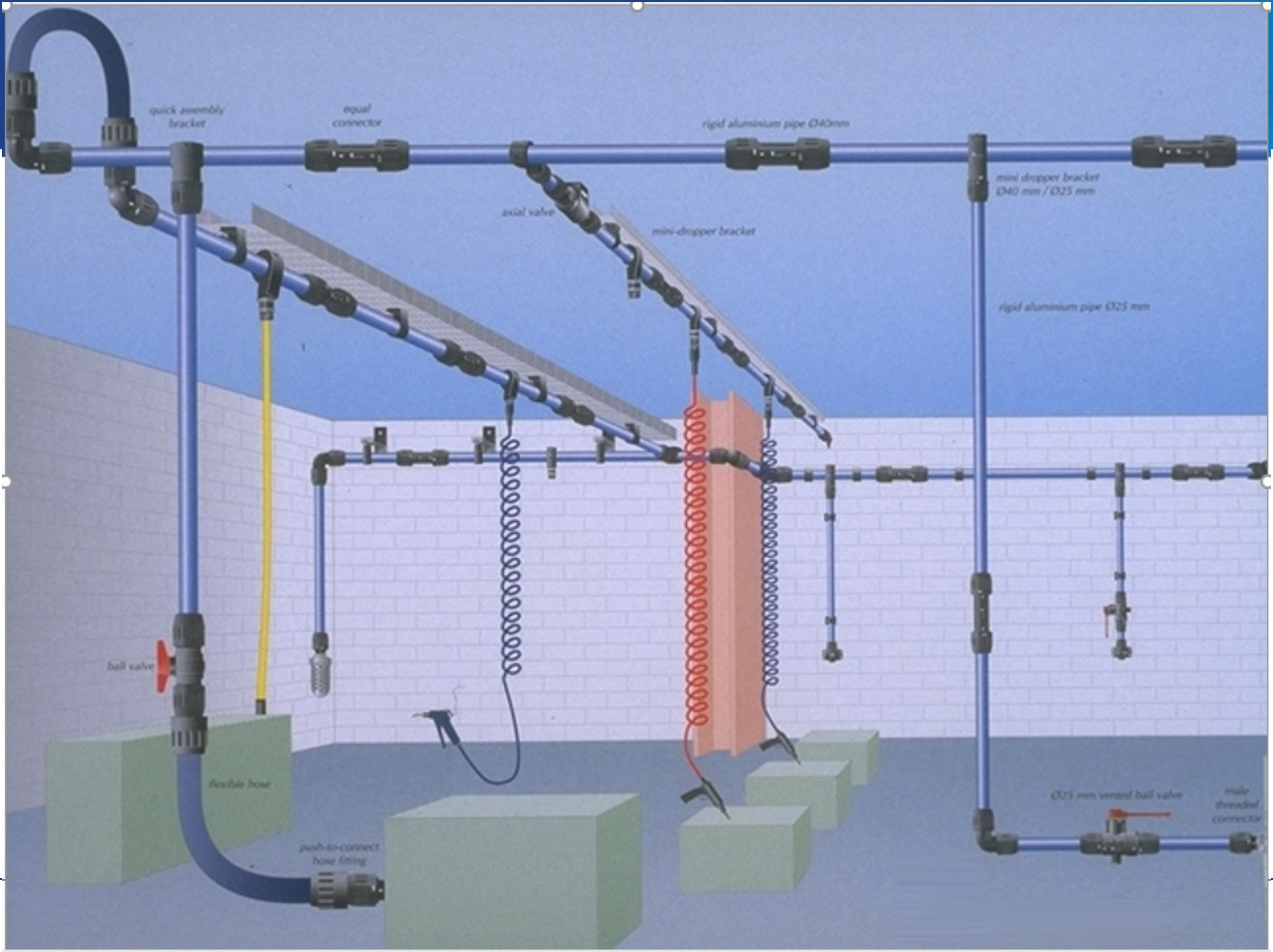
Piping Systems



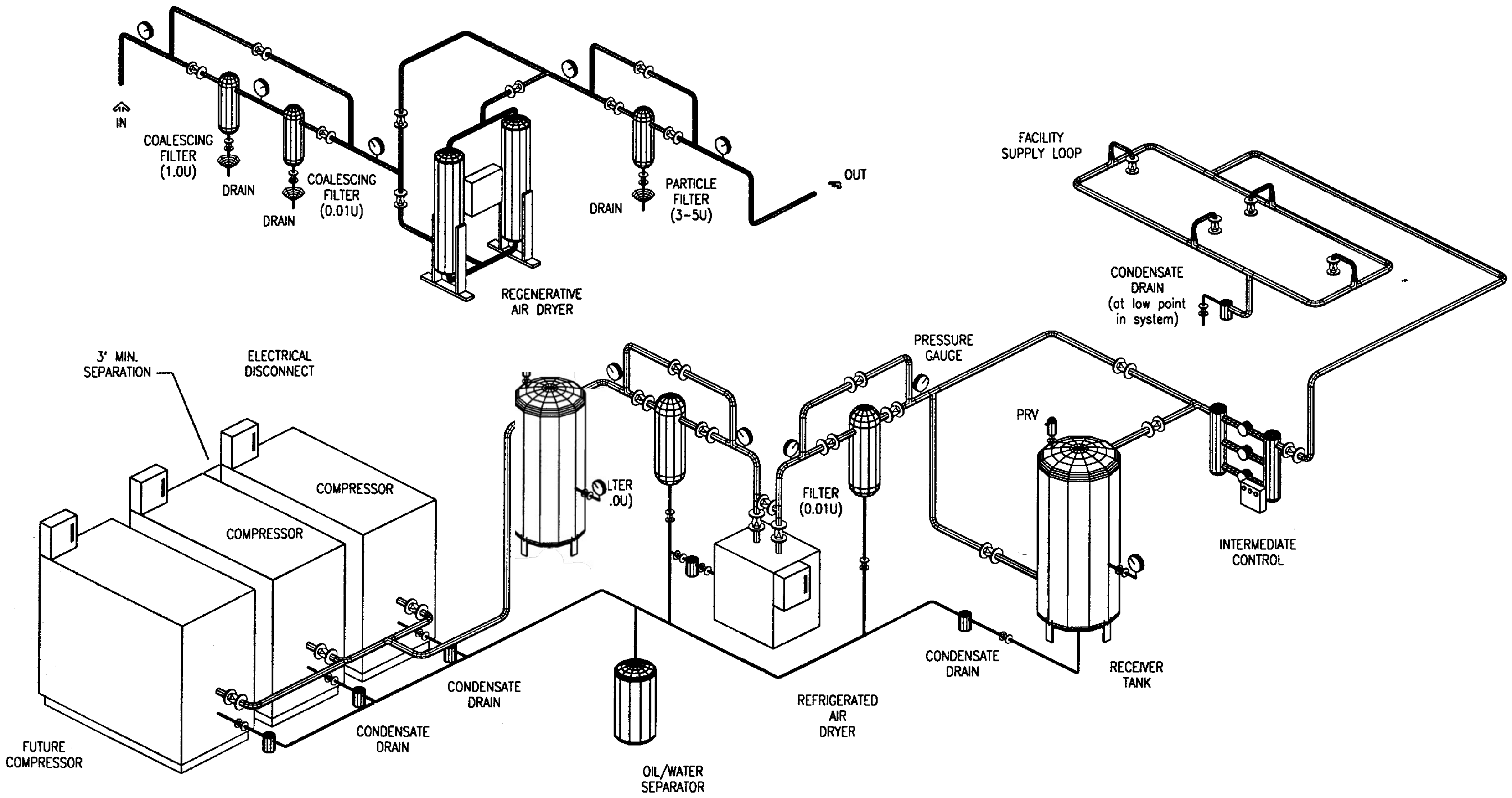
With no dryer, this arrangement will stop condensed liquids (oils and water) from entering a point of use device

Piping Systems

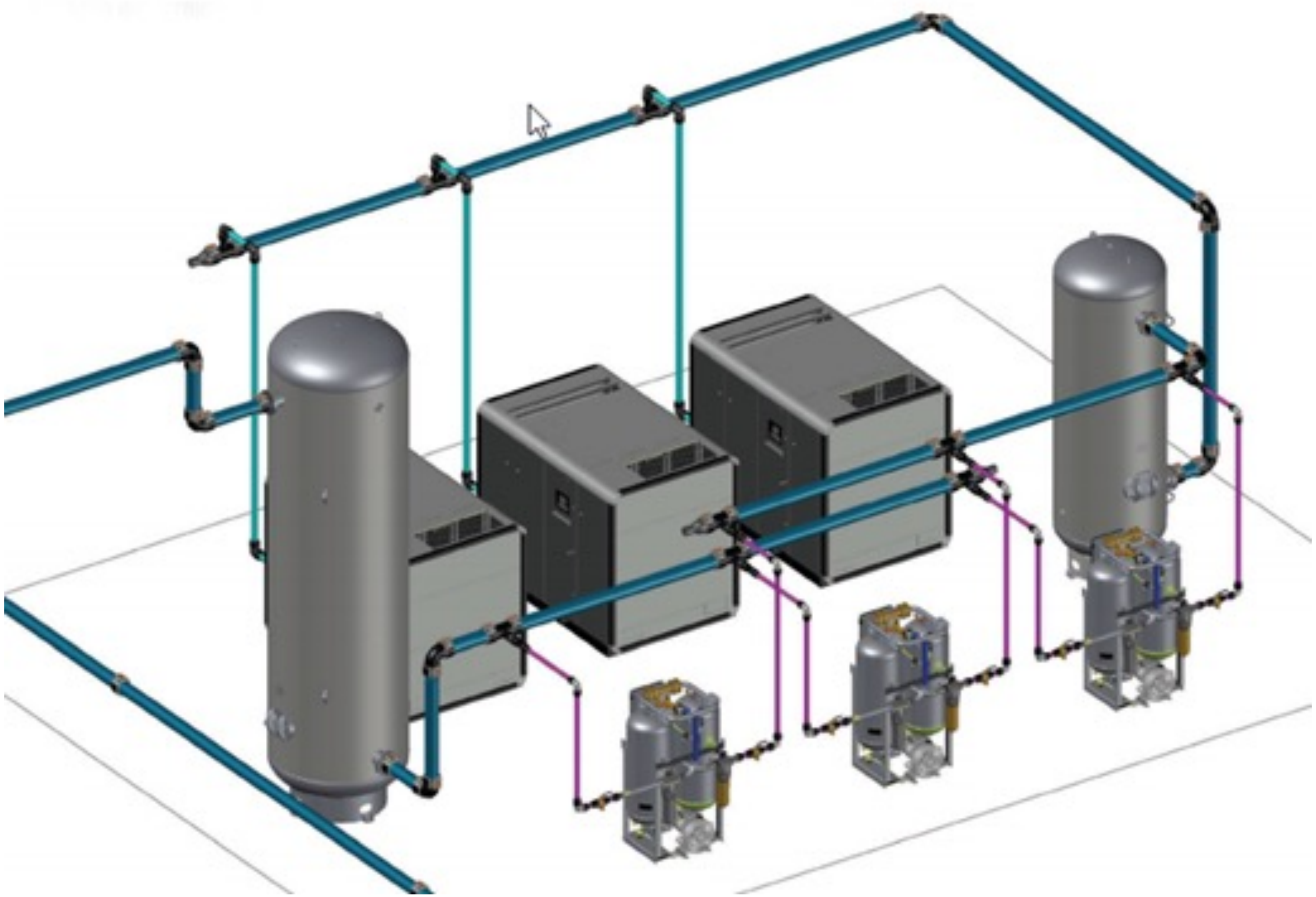



quick assembly bracket
equal connector
rigid aluminium pipe Ø40mm
mini dropper bracket Ø40 mm / Ø25 mm
axial valve
mini-dropper bracket
rigid aluminium pipe Ø25 mm
ball valve
flexible hose
push-to-connect hose fitting
Ø25 mm vented ball valve
male threaded connector

Piping Systems



Piping Systems



General Rules for Compressed Air Distribution System

- Pressure drops between the compressor and points of use are irrecoverable
- Pipe size should be large enough so that pressure drop does not exceed 2-3 % between receiver and point of use
- Design the piping for smooth flow with uniform bends

General Rules for Compressed Air Distribution System

- Arrange piping to avoid the following types of strains:
  - Strains due to the dead weight of the pipe itself
  - Strains due to expansion or contraction of the piping with temperature change
  - Strains due to internal pressure within the piping
- Plan ahead for future emergencies and plan an area for a temporary compressor
- Consider bypass lines on all items that may require future maintenance

General Rules for Compressed Air Distribution System

- Use a loop piping system if possible, both around the plant and within each area
- Create the correct size storage by using proper size receivers
- Outlets must always be taken from the top of the pipe line to prevent carryover of condensed moisture to air using devices
- Locate outlets from the main header as close as possible to the point of application

What's Wrong Here?

Better Plants U.S. DEPARTMENT OF ENERGY

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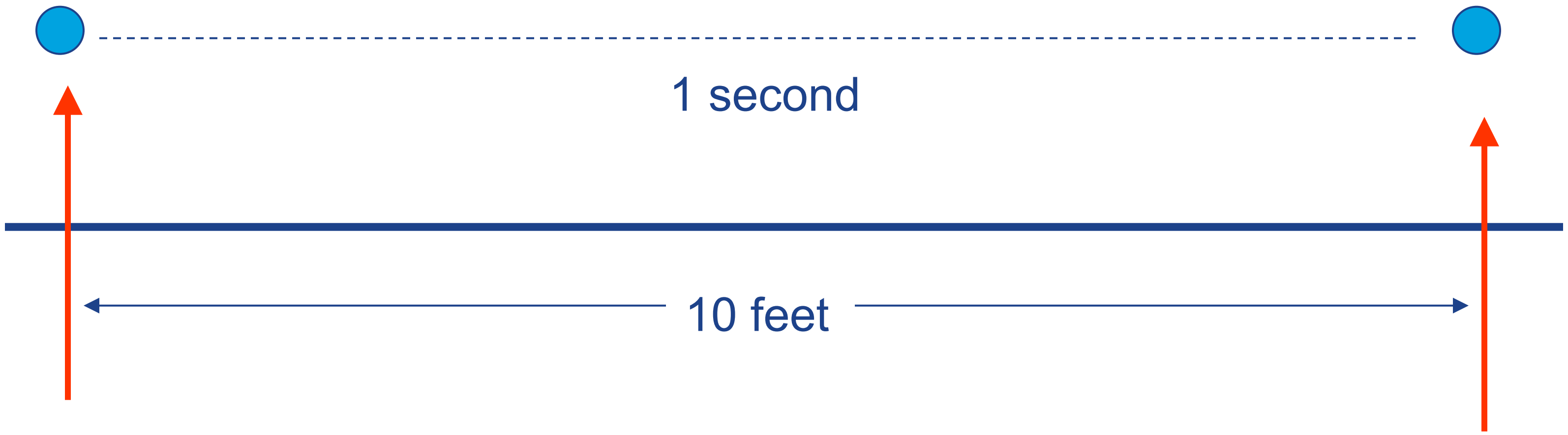
What's Wrong Here?

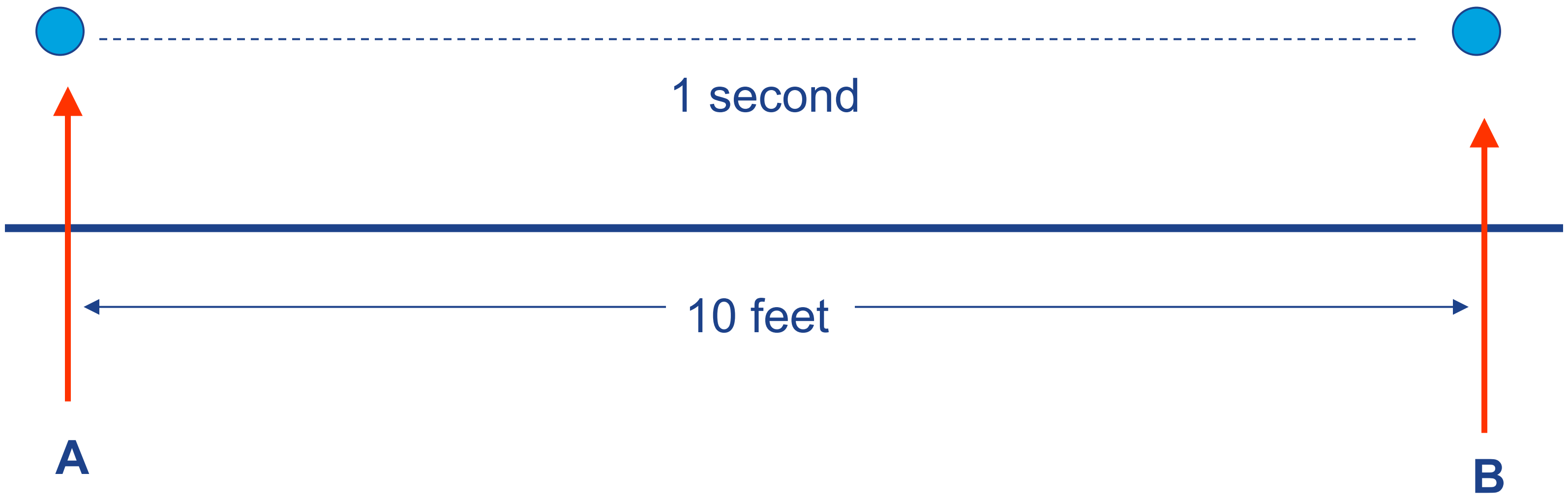
Measuring Flow

- Rate of flow actually refers to the velocity of the flow, or how rapidly the substance moves
- A flow rate is the measure of the distance a particle of a substance moves in a give period of time



Measuring Flow

- Feet per second is a unit commonly used to measure flow rate
- If a molecule of the fluid in the pipe takes one second to move from point A to point B, and the distance between these points is 10 feet
  - The flow rate would be 10 feet per second



Volumetric Flow Rate

- Indicates the volume of a fluid that passes over a point, over a period of time
- Expressed in cubic feet per sec or minute.
- Must know flow velocity and pipe inside diameter
- Using the formula
- $Q = A \times V$
  - Q = volumetric flow rate
  - A = cross sectional area of pipe
  - V = flow velocity

Volumetric Flow Rate

- Example:
  - Fluid has a velocity of 20 feet per second
  - Pipe has inside diameter of 6 inches
    - Q = A x V
      - = (πd^2/ 4x144) x 20 ft/sec
      - = .19 ft^2 x 20 ft/sec
      - = 3.8 ft^3/sec or 228 ft^3/min

Mass Flow Rate

- Determines the amount of mass that passes a specific point over a period of time
- Mass flow rate applications, determine the weight or mass of the substance flowing through the system

Mass Flow Rate

- Provided the volumetric flow rate and the fluid density are known
- Mass flow rate can be calculated using the following equation
  - $W = Q \times \rho$
    - W = mass flow rate
    - Q = volumetric flow rate
    - ρ = density

Mass Flow Rate

- Example:
  - Fluid has a volumetric flow rate of 228 ft^3/min
  - Fluid has a density of .075 lbs/ft^3 at 70ºF
    - $W = Q \times \rho$
      - = 228 ft3/min x .075 lbs/ft^3
      - = 17.10 lbs/min
- When mass flow is measured, the effects of temperature and pressure on the density of the fluid must be considered.
- 1 lb. / .0750 lb./cu.ft. = 13.3 cubic feet per pound of air.
- Mass flow = 13.3 cu.ft./lb x 17.1 lbs/min = 227.43 scfm

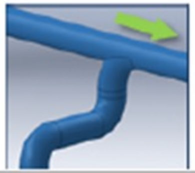
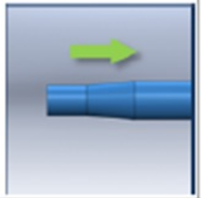
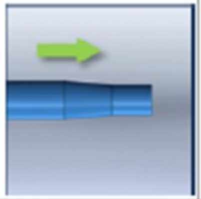
Weight of Dry Air at Various Pressures and Temperatures at Sea Level

Temp of Air		GAUGE PRESSURE POUNDS															
		0	5	10	20	30	40	50	60	70	80	90	100	110	120	130	140
°F	°C	WEIGHT IN POUNDS PER CUBIC FOOT															
-20	-28.9	.0900	.1205	.1515	.2125	.2744	.3360	.3970	.4580	.5190	.5800	.6410	.702	.7635	.8250	.886	.948
-10	-23.3	.0882	.1184	.1485	.2090	.2685	.3283	.3880	.4478	.5076	.5674	.6272	.687	.7470	.807	.868	.928
0	-17.8	.0864	.1160	.1455	.2040	.2630	.3215	.3800	.4385	.4970	.5555	.6140	.672	.7310	.790	.849	.908
10	-12.2	.0846	.1136	.1425	.1995	.2568	.3145	.3720	.4292	.4863	.5433	.6006	.658	.7160	.774	.832	.889
20	-6.7	.0828	.1112	.1395	.1955	.2516	.3071	.3645	.4205	.4770	.5330	.5890	.645	.7010	.757	.813	.869
30	-1.1	.0811	.1088	.1366	.1916	.2465	.3015	.3570	.4121	.4672	.5221	.5771	.632	.6870	.742	.797	.852
40	4.4	.0795	.1067	.1338	.1876	.2415	.2954	.3503	.4038	.4576	.5114	.5652	.619	.6730	.727	.781	.835
50	10	.0780	.1045	.1310	.1939	.2367	.2905	.3432	.3960	.4487	.5014	.5541	.607	.6600	.713	.766	.819
60	15.6	.0764	.1025	.1283	.1803	.2323	.2840	.3362	.3882	.4402	.4927	.5447	.596	.6490	.700	.752	.804
70	21.1	.0750	.1005	.1260	.1770	.2280	.2791	.3302	.3808	.4316	.4824	.5332	.584	.6350	.686	.737	.788
80	26.7	.0736	.0988	.1239	.1738	.2237	.2739	.3242	.3738	.4234	.4729	.5224	.572	.6220	.673	.723	.774
90	32.2	.0723	.0970	.1208	.1707	.2195	.2688	.3182	.3670	.4154	.4639	.5122	.561	.6110	.660	.709	.759
100	37.8	.0710	.0954	.1197	.1676	.2155	.2638	.3122	.3602	.4079	.4555	.5033	.551	.5990	.648	.696	.745
110	43.3	.0698	.0937	.1176	.1645	.2115	.2593	.3070	.3542	.4011	.4481	.4950	.542	.5890	.637	.685	.732
120	48.9	.0686	.0921	.1155	.1618	.2080	.2549	.3018	.3481	.3944	.4403	.4866	.533	.5790	.626	.673	.720
130	54.4	.0674	.0905	.1135	.1590	.2045	.2505	.2966	.3446	.3924	.4296	.4770	.524	.5700	.616	.662	.708
140	60	.0663	.0889	.1115	.1565	.2015	.2465	.2915	.3364	.3813	.4262	.4711	.516	.5610	.606	.651	.696
150	65.6	.0652	.0874	.1096	.1541	.1985	.2425	.2865	.3308	.3751	.4193	.4636	.508	.5520	.596	.640	.685
175	79.4	.0626	.0840	.1054	.1482	.1910	.2335	.2755	.3181	.3607	.4033	.4450	.488	.5310	.573	.616	.658
200	93.3	.0603	.0809	.1014	.1427	.1840	.2248	.2655	.3054	.3473	.3882	.4291	.470	.5110	.552	.592	.663

1 lb. / .0750 $_{\text{lb./cu.ft.}}$ = 13.3 cubic feet per pound of air

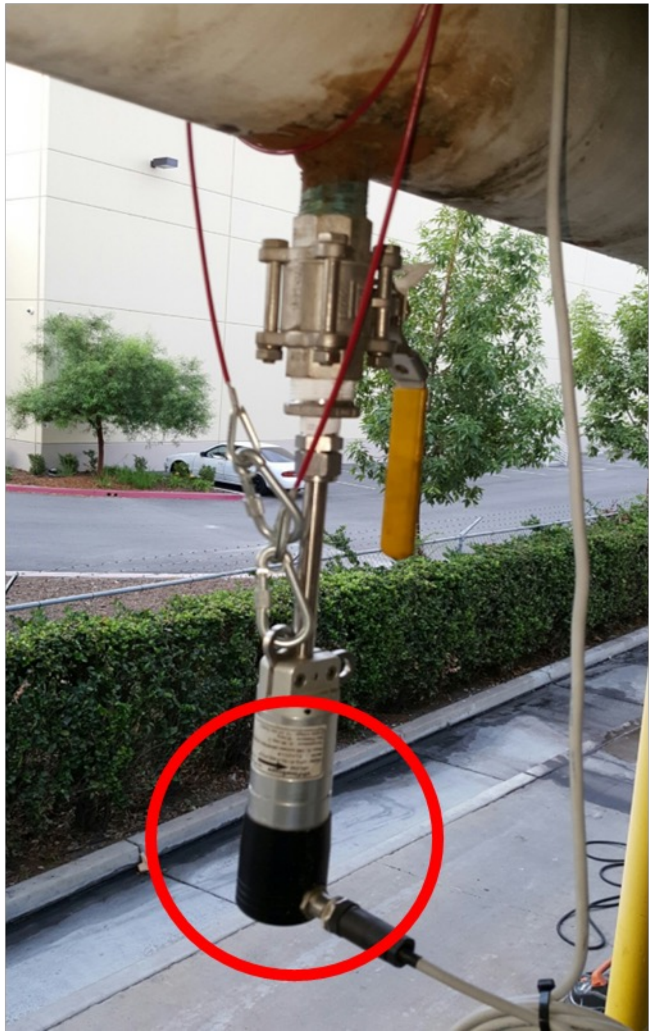
Mass Flow Rate Measurement with Thermal Mass Meter

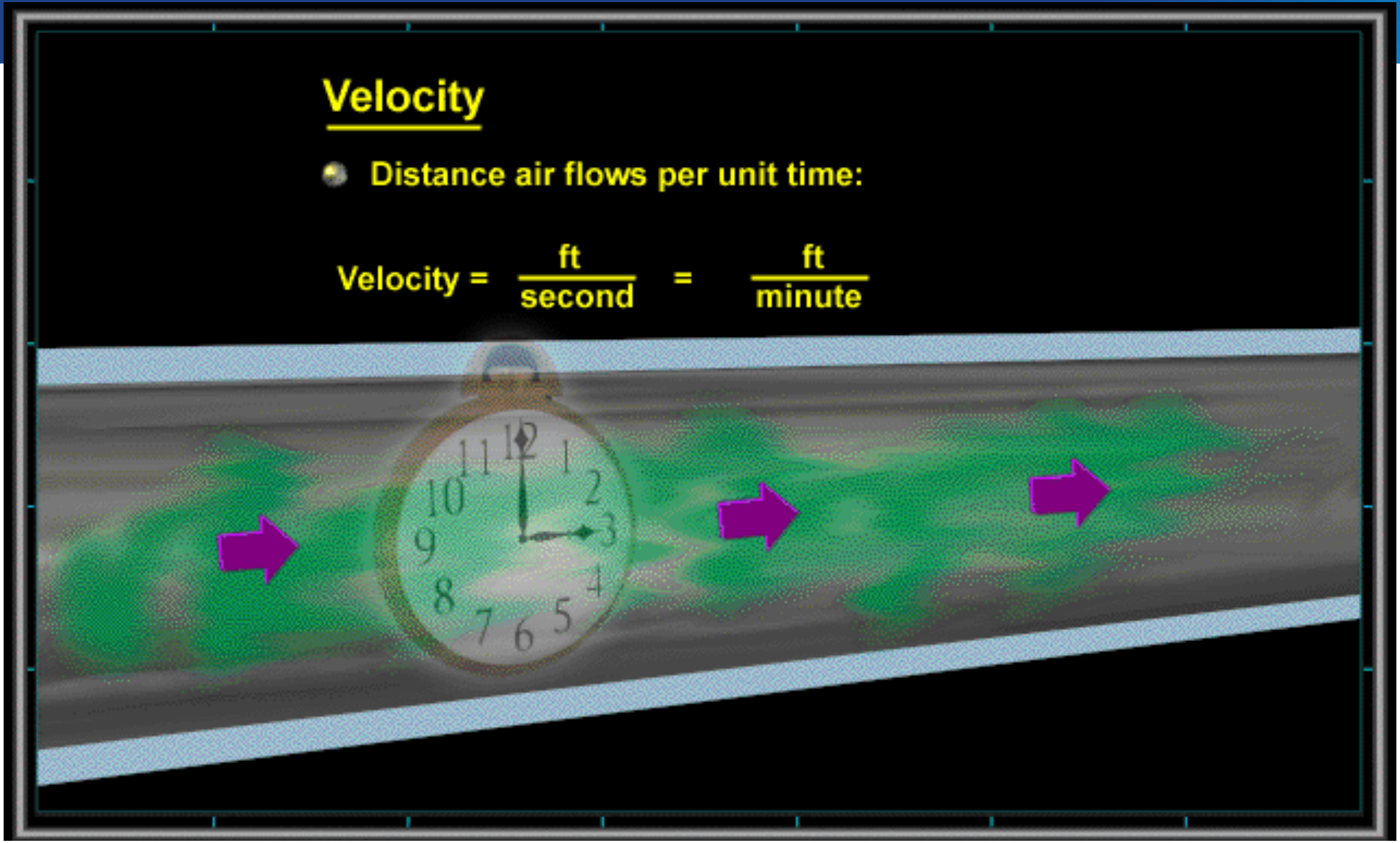
- 20 diameters upstream length (even 40*D preferred)
- 5 diameters downstream length (10*D preferred. The longer the better)

Picture	Description	Upstream length	Downstream length	Effect
	Complex feed-in situation (header)	40 * D[1]	10 * D[1]	Flow profile will be distorted
	Double elbow, multiple elbows following each other	40 * D[1]	10 * D[1]	Distorted profile + swirl
	Diameter change from small to large (gradual or instant)	40 * D[1]	5 *D[1]	Jet shaped flow
	Diameter change from large to small (gradual change, between 7 and 15 degrees)	10 * D[1]	5 * D[1]	Flattened flow profile
	Single elbow	30 * D[1]	10 * D[1]	Distorted flow profile

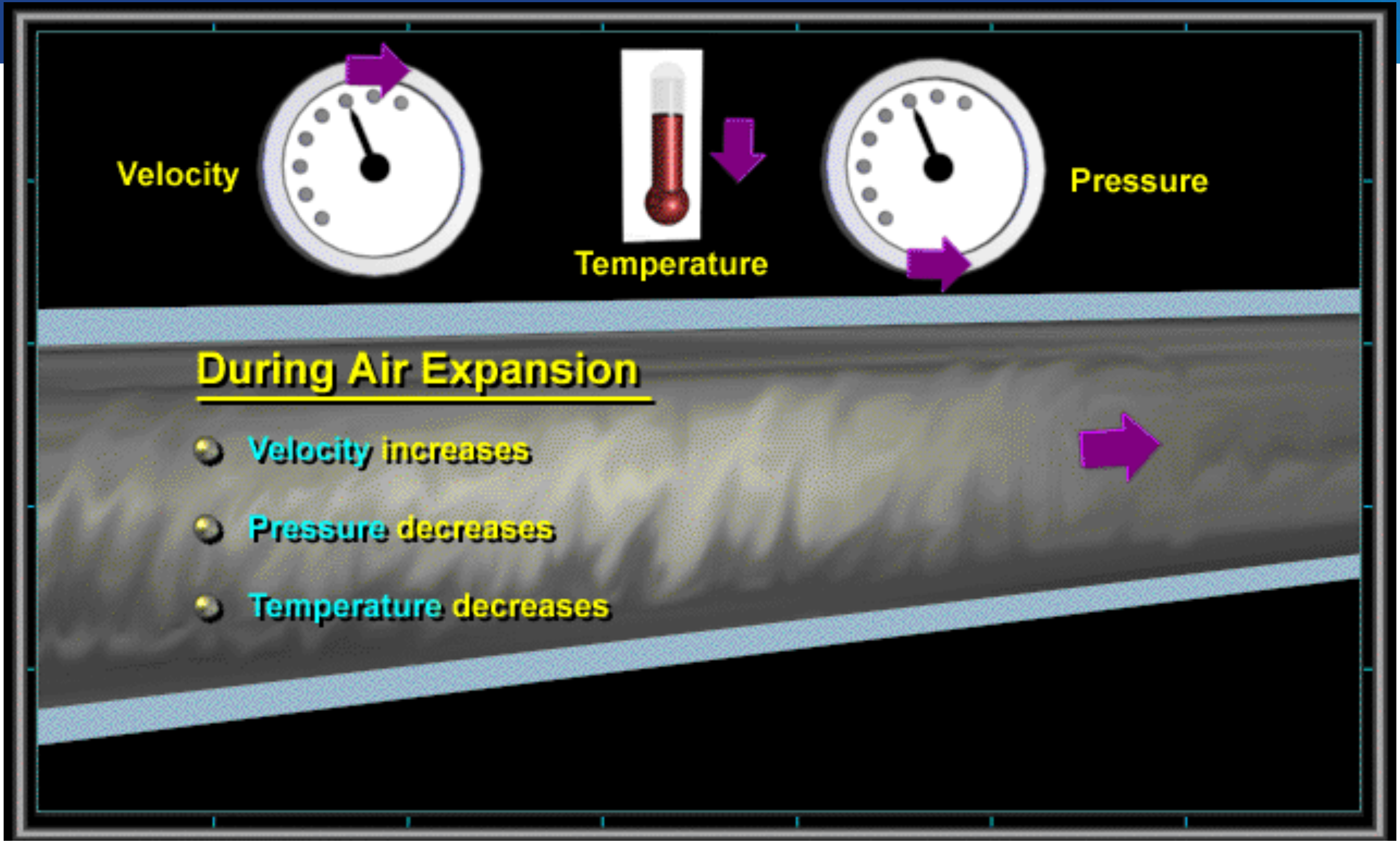
[1] = inner diameter

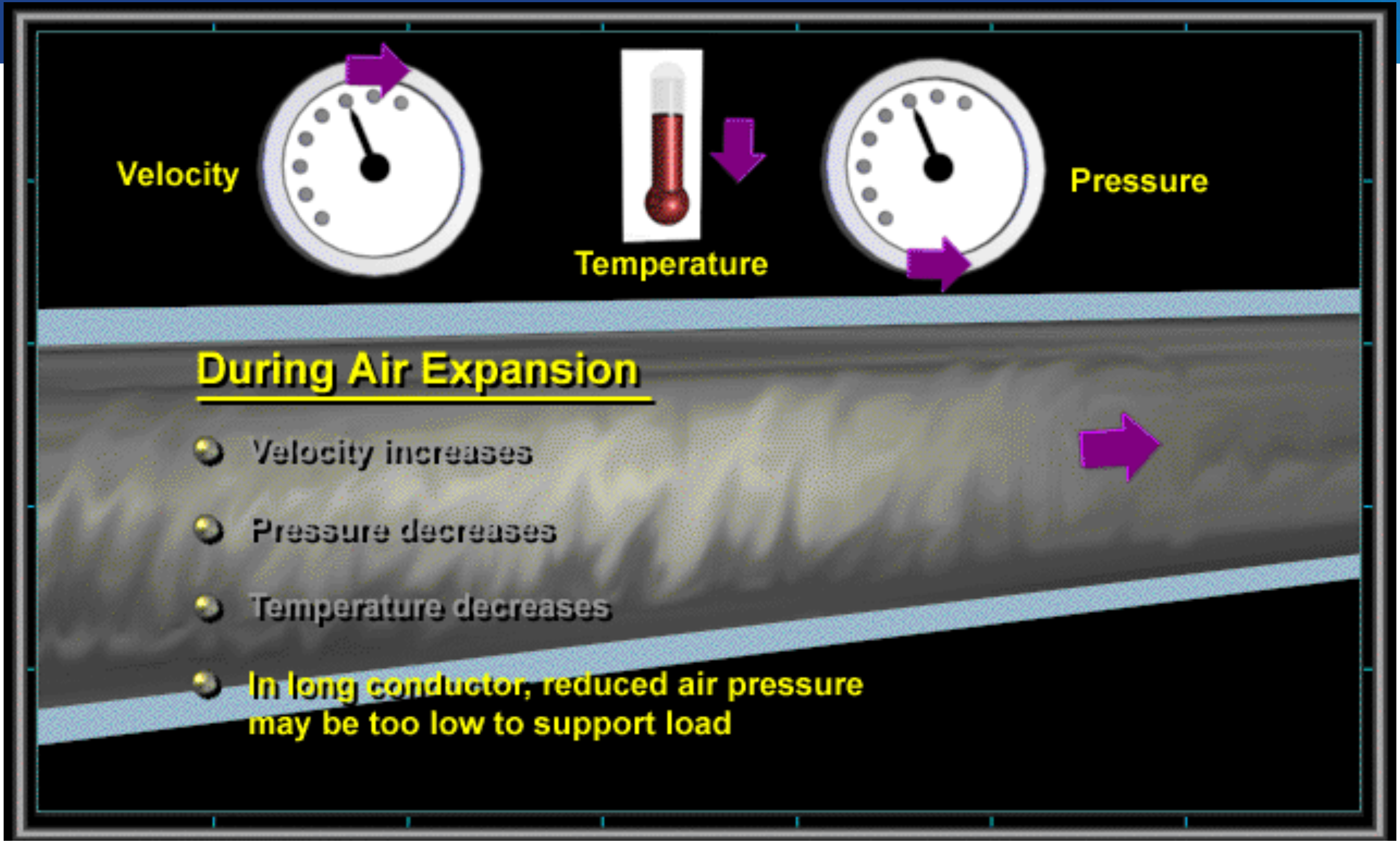
Mass Flow Rate Measurement (How Not to Install)




Velocity
Distance air flows per unit time:
Velocity = ft / second = ft / minute


Air Velocity
Air expands during flow, increasing velocity

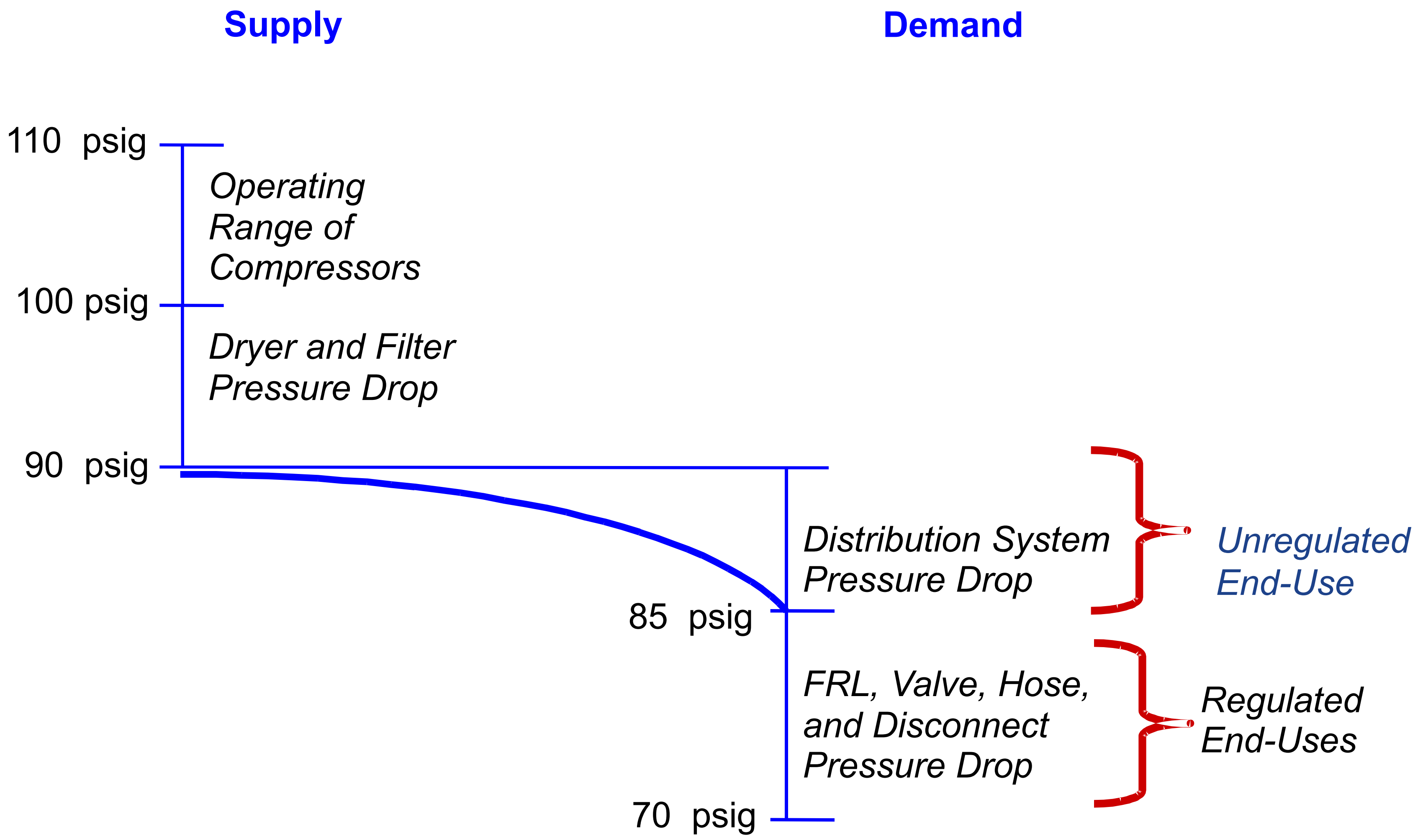

Velocity
Temperature
Pressure
During Air Expansion
Velocity increases
Pressure decreases
Temperature decreases


Velocity
Temperature
Pressure
During Air Expansion
Velocity increases
Pressure decreases
Temperature decreases
In long conductor, reduced air pressure may be too low to support load

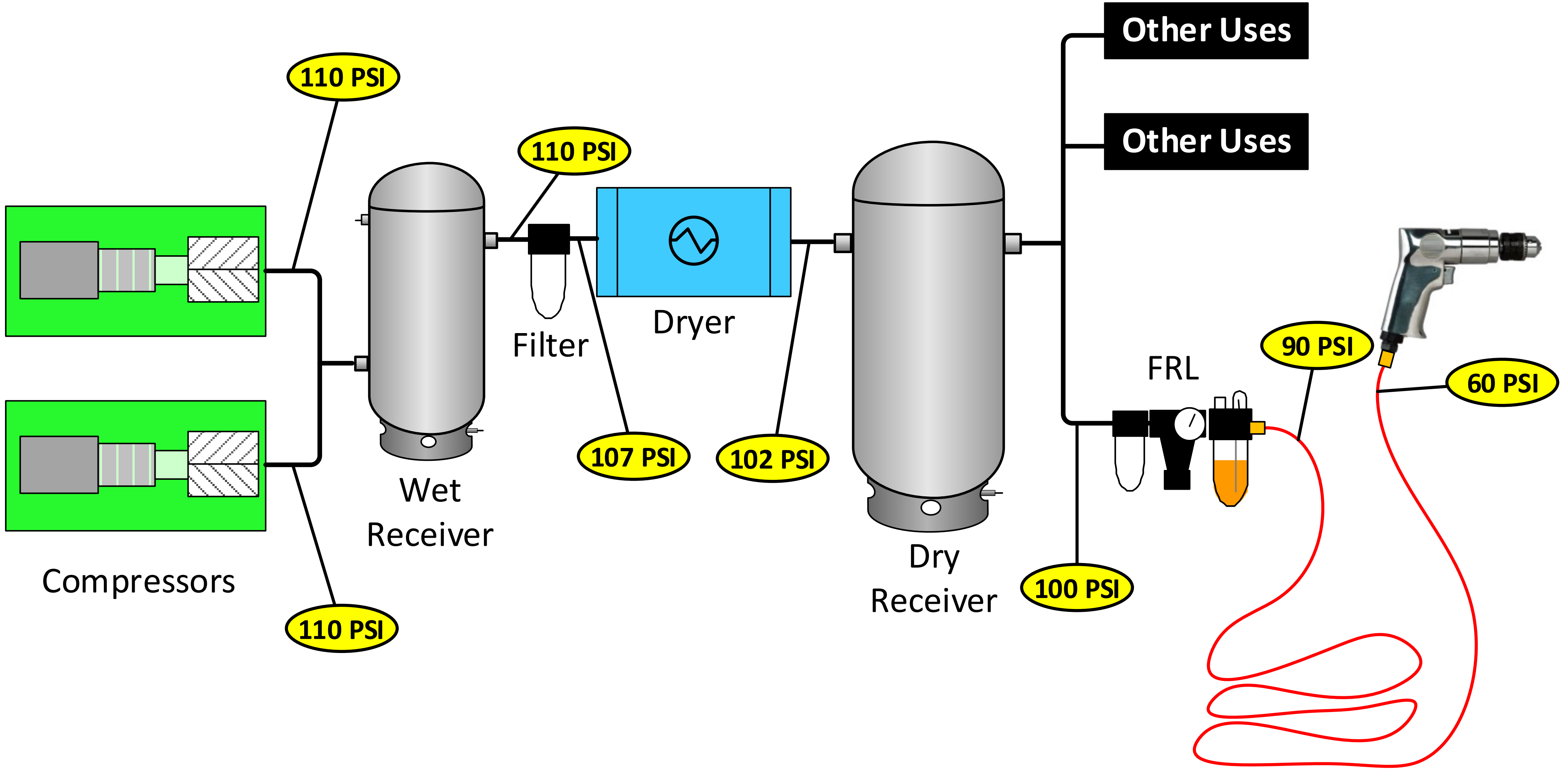
Pressure Profiles

- Pressure measurements need to be taken to:
  - Give feedback for control adjustments
  - Determine pressure drops across components
  - Determine system operating pressures
- The following pressure measurements should be taken:
  - Inlet Filter Losses
  - Observe Air/lubricant separator ΔP (if applicable)
  - Interstage on multistage compressors
  - Aftercooler, air treatment equipment
  - Various points in the distribution system

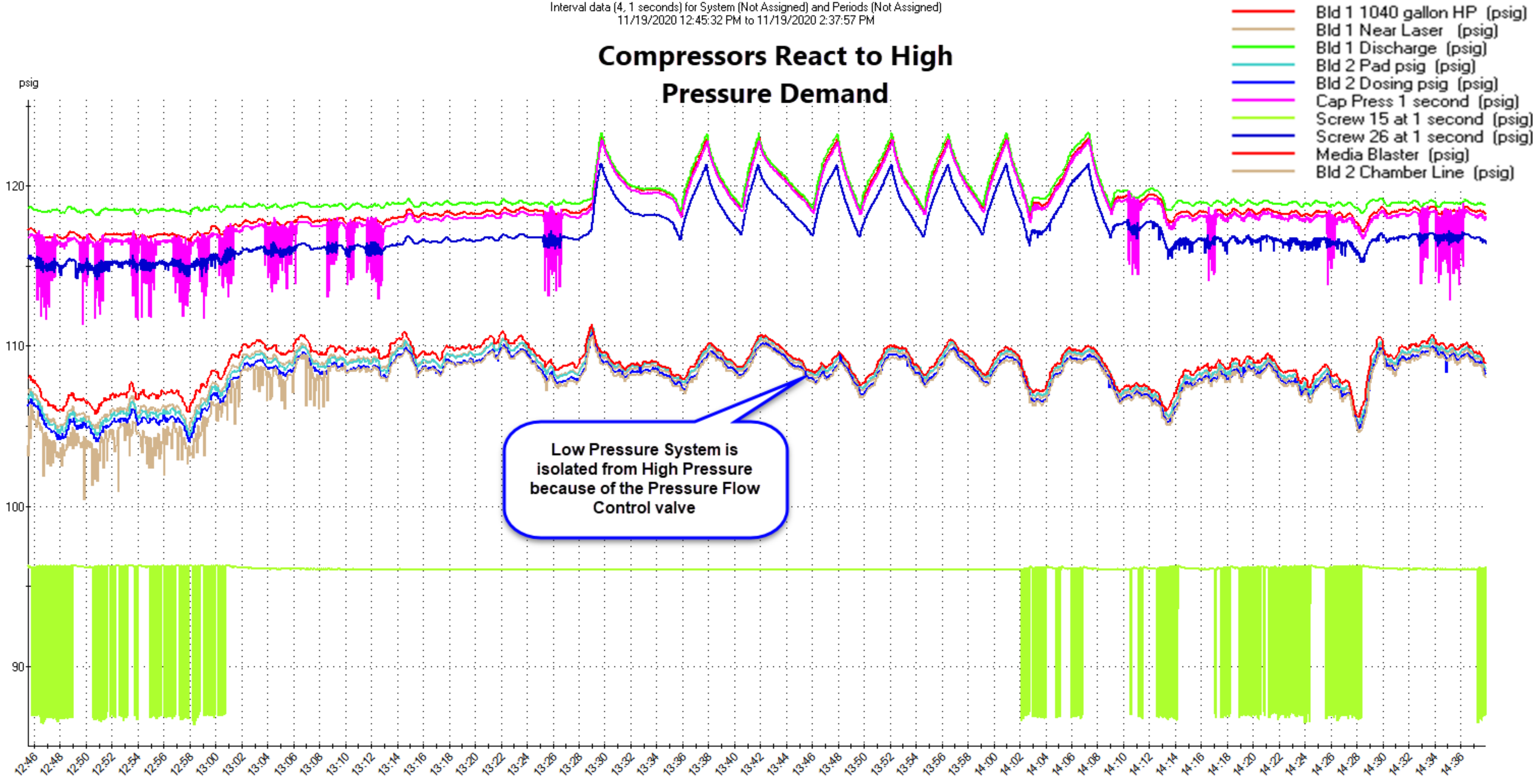
System Pressure Profile



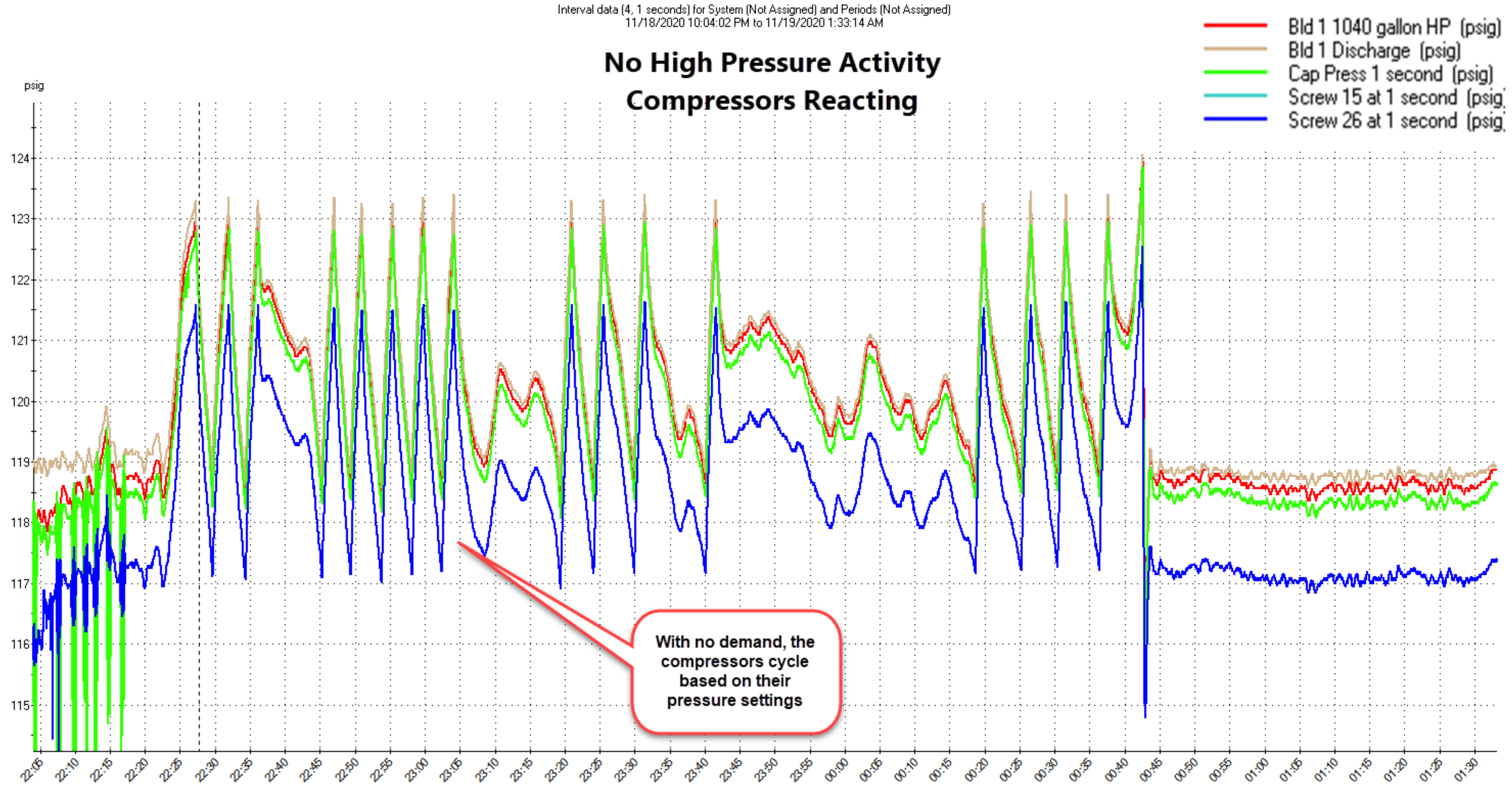
Developing a System Profile

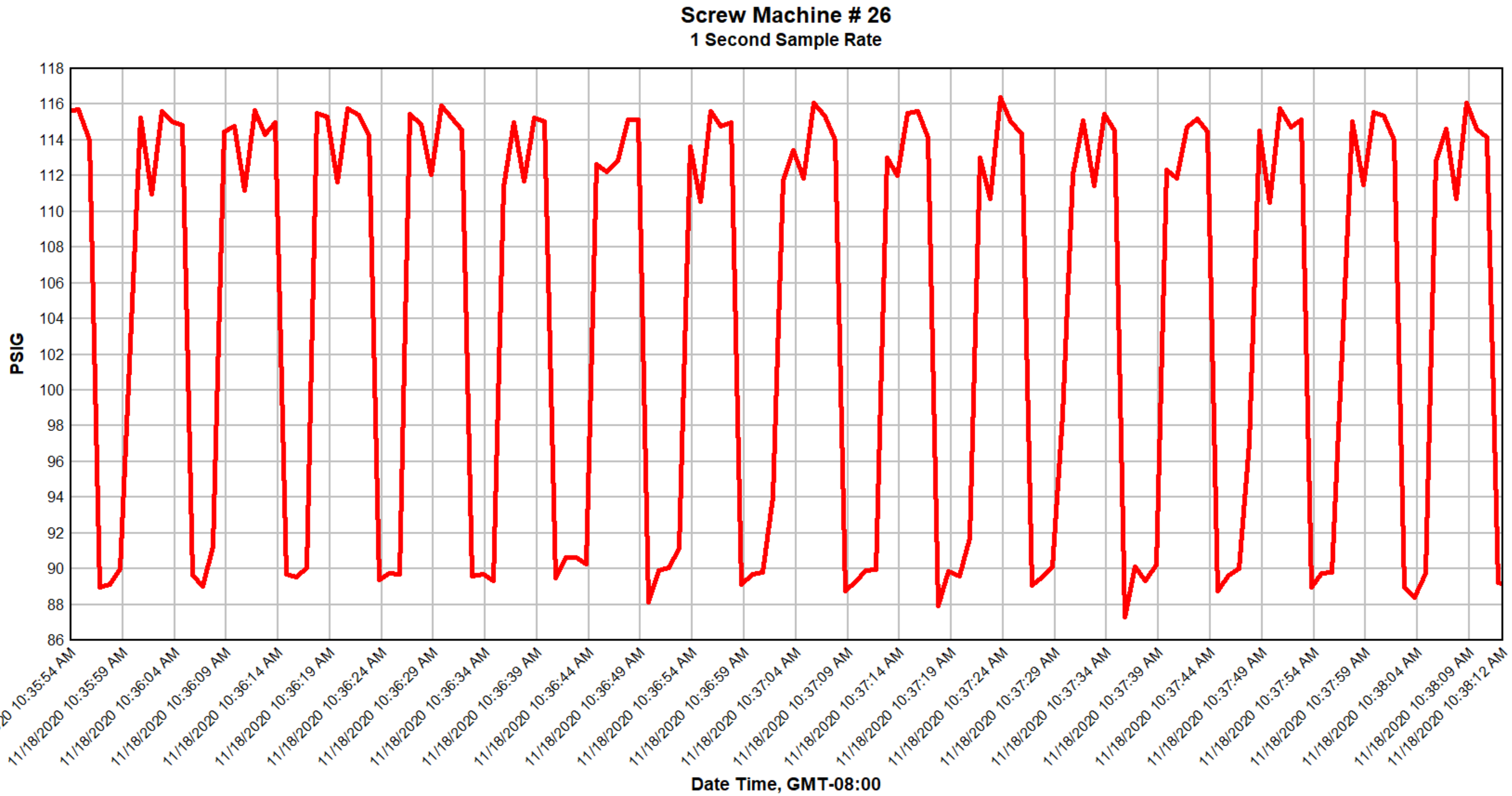


Compressors React to High Pressure Demand

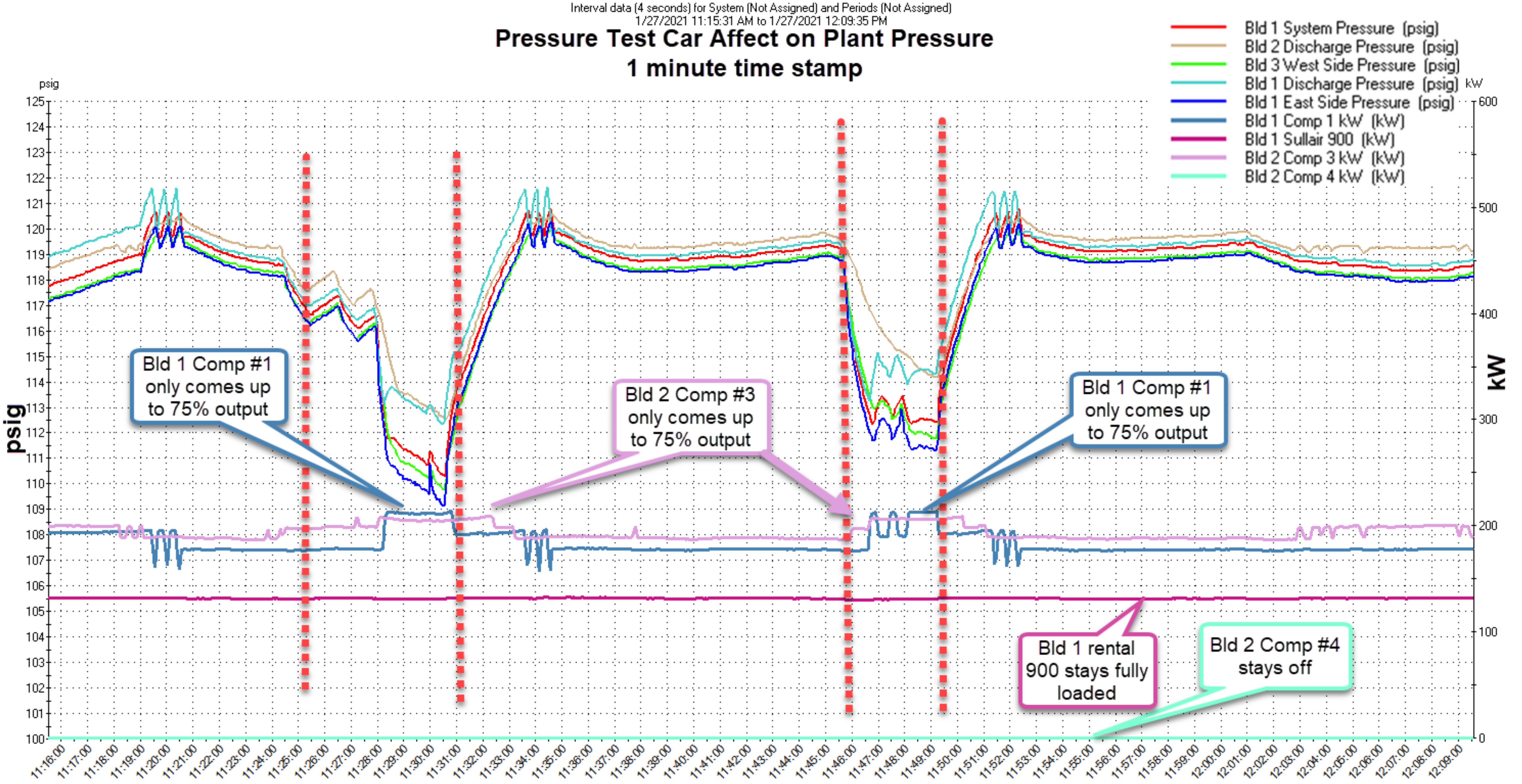


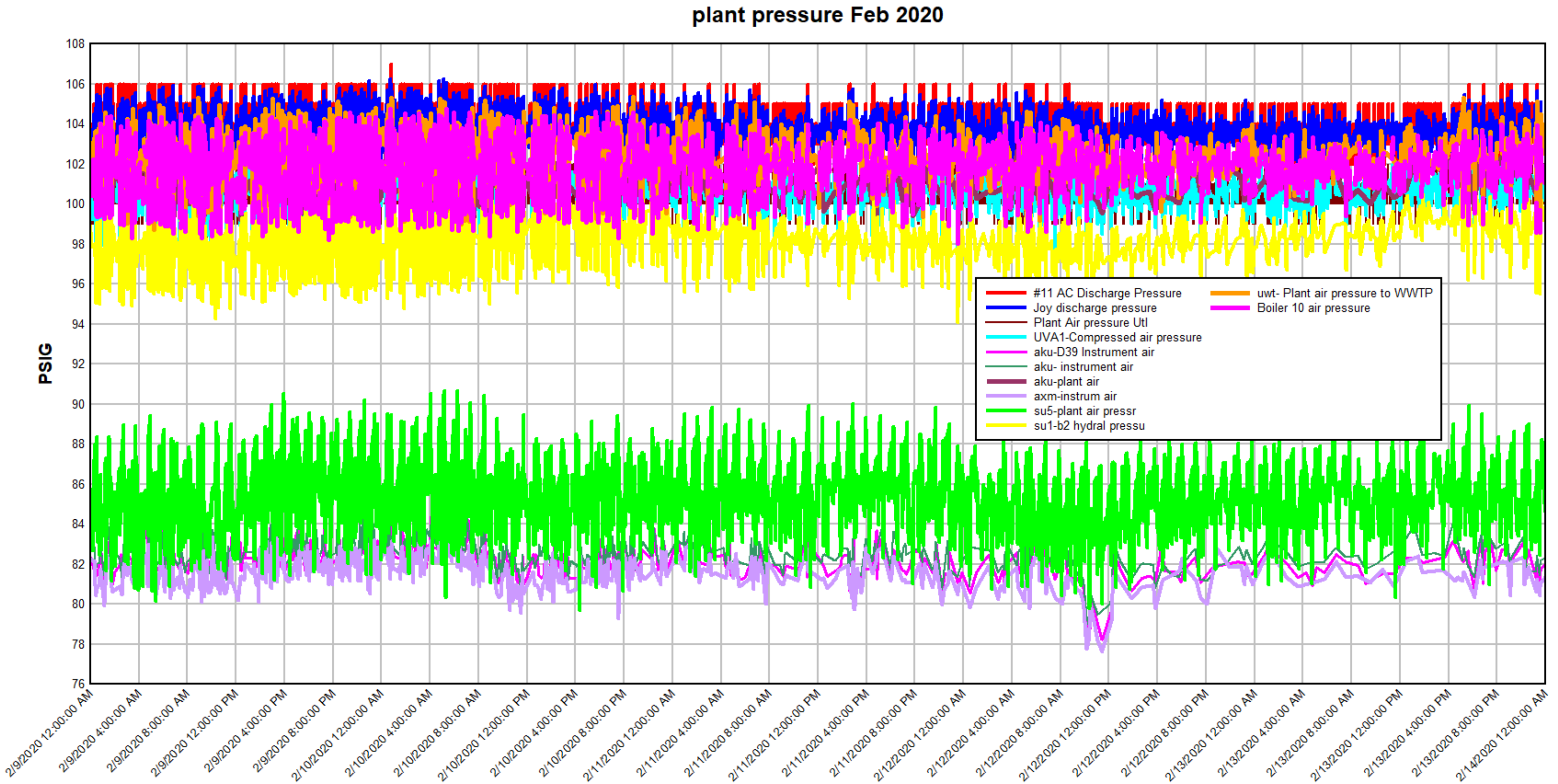
No High Pressure Activity
Compressors Reacting





Screw Machine # 26
1 Second Sample Rate
PSIG
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
88
86
11/18/2020 10:35:54 AM
11/18/2020 10:35:59 AM
11/18/2020 10:36:04 AM
11/18/2020 10:36:09 AM
11/18/2020 10:36:14 AM
11/18/2020 10:36:19 AM
11/18/2020 10:36:24 AM
11/18/2020 10:36:29 AM
11/18/2020 10:36:34 AM
11/18/2020 10:36:39 AM
11/18/2020 10:36:44 AM
11/18/2020 10:36:49 AM
11/18/2020 10:36:54 AM
11/18/2020 10:36:59 AM
11/18/2020 10:37:04 AM
11/18/2020 10:37:09 AM
11/18/2020 10:37:14 AM
11/18/2020 10:37:19 AM
11/18/2020 10:37:24 AM
11/18/2020 10:37:29 AM
11/18/2020 10:37:34 AM
11/18/2020 10:37:39 AM
11/18/2020 10:37:44 AM
11/18/2020 10:37:49 AM
11/18/2020 10:37:54 AM
11/18/2020 10:37:59 AM
11/18/2020 10:38:04 AM
11/18/2020 10:38:09 AM
11/18/2020 10:38:12 AM
Date Time, GMT-08:00


Interval data (4 seconds) for System (Not Assigned) and Periods (Not Assigned)
1/27/2021 11:15:31 AM to 1/27/2021 12:09:35 PM
Pressure Test Car Affect on Plant Pressure
1 minute time stamp
Bld 1 System Pressure (psig)
Bld 2 Discharge Pressure (psig)
Bld 3 West Side Pressure (psig)
Bld 1 Discharge Pressure (psig)
Bld 1 East Side Pressure (psig)
Bld 1 Comp 1 kW (kW)
Bld 1 Sullair 900 (kW)
Bld 2 Comp 3 kW (kW)
Bld 2 Comp 4 kW (kW)
psig
kW
Bld 1 Comp #1 only comes up to 75% output
Bld 2 Comp #3 only comes up to 75% output
Bld 1 Comp #1 only comes up to 75% output
Bld 1 rental 900 stays fully loaded
Bld 2 Comp #4 stays off


plant pressure Feb 2020
PSIG
108
106
104
102
100
98
96
94
92
90
88
86
84
82
80
78
76
#11 AC Discharge Pressure
Joy discharge pressure
Plant Air pressure Utl
UVA1-Compressed air pressure
aku-D39 Instrument air
aku- instrument air
aku-plant air
axm-instrum air
su5-plant air pressr
su1-b2 hydral pressu
uwt- Plant air pressure to WWTP
Boiler 10 air pressure
2/9/2020 12:00:00 AM
2/9/2020 4:00:00 AM
2/9/2020 8:00:00 AM
2/9/2020 12:00:00 PM
2/9/2020 4:00:00 PM
2/9/2020 8:00:00 PM
2/10/2020 12:00:00 AM
2/10/2020 4:00:00 AM
2/10/2020 8:00:00 AM
2/10/2020 12:00:00 PM
2/10/2020 4:00:00 PM
2/10/2020 8:00:00 PM
2/11/2020 12:00:00 AM
2/11/2020 4:00:00 AM
2/11/2020 8:00:00 AM
2/11/2020 12:00:00 PM
2/11/2020 4:00:00 PM
2/11/2020 8:00:00 PM
2/12/2020 12:00:00 AM
2/12/2020 4:00:00 AM
2/12/2020 8:00:00 AM
2/12/2020 12:00:00 PM
2/12/2020 4:00:00 PM
2/12/2020 8:00:00 PM
2/13/2020 12:00:00 AM
2/13/2020 4:00:00 AM
2/13/2020 8:00:00 AM
2/13/2020 12:00:00 PM
2/13/2020 4:00:00 PM
2/13/2020 8:00:00 PM
2/14/2020 12:00:00 AM

Summary

- Use a loop piping system, if possible, both around the plant and within each area.
- Measure the pressure losses from supply to demand.
  - Create a Pressure Profile.
- Create the correct size storage by using proper size receivers
- Outlets must always be taken from the top of the pipeline to prevent carryover of condensed moisture to air using devices.
- Locate outlets from the main header as close as possible to the point of application.

Next Week Session 6 – System Volume vs Storage

Inadequately sized (or no) air receivers can cause real system problems.

When it comes to sizing of an air receiver, a good rule of thumb to remember is to allow 3-5 gallons for each CFM of compressed air depending on the type of an air compressor used and the application.

We will learn how to properly size a receiver tank in both Supply and Demand