

Helpful Engineering Information

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How To Determine Water Content in Compressed Air Systems

The more sophisticated pneumatic equipment and instrumentation being used throughout the industry today requires greater attention to the purity of the compressed air which supplies this equipment. Compressed air, free of condensate, has become increasingly important for many industrial applications.

The question, "How much water or condensate must be removed from the system?" today, more frequently requires an answer.

The data presented in Figure 1 permits simple determination of the amount of condensate to be found in a compressed air system under a variety of operating conditions—pressure, temperature, and humidity.

Figure 1 gives this information in pounds of water per 1,000 cubic feet of air at different operating temperatures (°F) and pressures (psig). The data presented, water vapor content of saturated air at various temperatures and pressures, represent the worst possible condition. There is no guarantee that the water vapor content of compressed air will be any less than saturation at any given operating pressure and temperature; therefore, the saturated content should be used in all calculations.

The Following Examples Illustrate the Use of Figure 1

Example 1:

How much condensate will there be in a compressed air system operating at 100 scfm and 100 psig if the air at the compressor intake is at a temperature of 80°F and 75% saturation (relative humidity)?

The water vapor content of air at 80°F, 75% saturation, and 0 psig (atmospheric pressure) is 1.12 pounds of water per 1,000 cubic feet of air (intersection of the 75% saturation line and the 80°F line — see Figure 1).

If this air is compressed to 100 psig and then cooled to 70°F, either in an after cooler or as it flows through the distribution piping, the maximum water vapor content that this air can carry is 0.15 pounds of water per 1,000 cubic feet of air (intersection of the 100 psig operating pressure line and the 70°F line).

The difference, $1.12 - 0.15 = 0.97$ pounds of water per 1,000 cubic feet of air. This quantity of water appears in the system as condensate.

At an air consumption of 100 scfm, 6,000 cubic feet of air will be compressed each hour. $6 \times 0.97 = 5.82$ pounds of water or 0.698 gallons of water must be removed from the system each hour.

In an eight-hour operating day, $8 \times 0.698 = 5.584$ gallons of water must be removed from the system.

Example 2:

Assume, as in Example 1, that air is compressed at the rate of 100 scfm to an operating pressure of 100 psig and cooled to 70°F. The water vapor content equals 0.15 pounds of water per 1,000 cubic

feet of air (intersection of the 100 psig line and the 70°F line - see Figure 1).

If this air is then used in an environment at 0°F, or if it is desired to maintain a 0°F dewpoint to protect delicate pneumatic equipment or instruments, additional condensate or ice will form.

At 100 psig and 0°F, the saturated water vapor content of air is 0.0085 pounds of water per 1,000 cubic feet of air (intersection of the 100 psig line and the 0°F line). The difference, $0.1500 - 0.0085 = 0.1415$ pounds of water per 1,000 cubic feet of air, must be removed from the system.

Each hour of operation, $6 \times 0.1415 = .849$ pounds or 0.1018 gallons of water will appear as condensate.

In an eight-hour operating day, $8 \times 0.1018 = 0.814$ gallons of condensate.

Adding the results of Example 1 and 2, the total condensate to be removed from the system when air is compressed to 100 psig at the rate of 100 scfm and cooled to 0°F from a source at 80°F and 75% saturation is 5.584 plus 0.814 = 6.40 gallons per eight-hour day. If the air at the compressor intake was more than 75% saturation, the amount of condensate forming in the system would be even greater and could be as high as 8.86 gallons of water per eight-hour day.

Example 3:

If compressed air at 100 psig is saturated at 70°F (70°F dewpoint): What is the dewpoint at 40 psig? What is the dewpoint at 0 psig?

The water vapor content at 100 psig and 70°F is 0.15 pounds of water per 1,000 cubic feet of air (intersection of 100 psig line and 70°F line - see Figure 1). Move horizontally along the 0.15 vapor content line to the intersection with the 40 psig line - read temperature: 50°F. The dewpoint at 40 psig is 50°F.

Continue along the 0.15 vapor content line to the intersection with the 0 psig line - read temperature: 17°F. The dewpoint at 0 psig (atmospheric pressure) is 17°F.

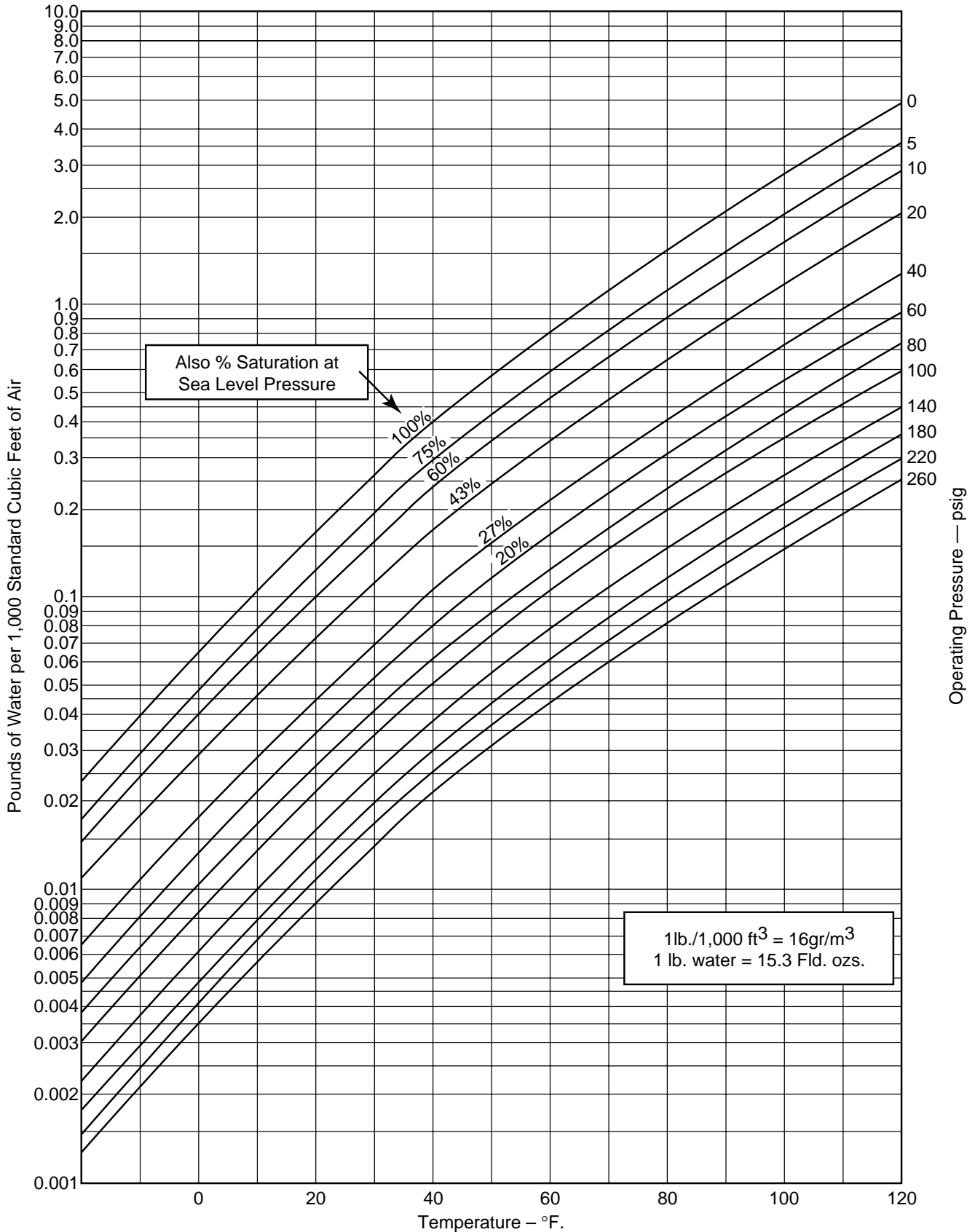


Figure 1. Water Vapor Content of Saturated Air



How To Determine Pressure Drop in Compressed Air Systems

Distribution Piping, Fittings, and Filters

The method used in this section represents a simplified approach to the determination of pressure drop in compressed air systems. It permits easy determination of the pressure-drop across any component installed in the system as well as determination of the pressure drop for the complete system or any segment of the system.

This method is based upon the recognized Darcy formula presented here in a somewhat different form:

$$\Delta P = \frac{KQ^2}{1000} \left[\begin{array}{c} 14.71 \\ 14.7=P \end{array} \right] \left[\begin{array}{c} 460+t \\ 520 \end{array} \right]$$

- ΔP = Pressure drop (psig)
- K = Constant for pipe or unit
- Q = Constant for flow (scfm)
- P = Working pressure (psig)
- t = Compressed air temperature (°F)

Figure 2 presents the relationship between air flow (scfm) and pressure drop (psig) for K = 1. Figure 2, when used in conjunction with the values of K presented in Tables 1, 2 and 3, readily permits the determination of pressure drop (ΔP) across any component installed in a compressed air system, the pressure drop of the entire system, or any segment of the system.

Example 1:

Determine the pressure drop (ΔP) in 150 feet of 3/4" schedule 40 pipe, at a flow of 80 scfm and an operating pressure of 100 psig:

1. Refer to Figure 2: Follow vertically the 80 scfm line to its intersection with the 100 psig operating pressure line.
2. Read the pressure drop (ΔP) at left corresponding to this intersection: P = 0.8.
3. Select from Table 1 the K value for 3/4" pipe: K = 5.93.
4. Multiply 5.93 x 0.8 = 4.74 psig per 100 feet of pipe.
5. ΔP for 150 feet of pipe equals $\frac{4.74 \times 150}{100} = 7.11$ psig since pressure drop is proportional to length.

Example 2:

Determine the pressure drop in a system containing 100 feet of 3/4" schedule 40 pipe, two 90° standard elbows, one globe valve and one 3/4" 40-micron filter (F74). The system pressure is 100 psig, and the flow requirement is 80 scfm:

1. Refer to Figure 2: Follow vertically the 80 scfm line to its intersection with the 100 psig operating pressure line.
2. Read the pressure drop (ΔP) at the left of the graph, corresponding to this intersection: $\Delta P = 0.8$ psig.
3. From Table 1, select the K value for 3/4" pipe: K = 5.93
4. From Table 2, select the K value for 3/4" standard 90° elbow: K=0.119. There are two elbows; therefore, multiply by 2: 0.119 x 2 = 0.238.
5. From Table 2, select the K value for a fully open globe valve: K = 1.36.
6. From Table 3, select the K value for a 3/4" 40-micron filter (F74); K = 1.78.
7. Add the K values from steps 3, 4, 5 and 6 (5.930 + 0.238 + 1.360 + 1.78 = 9.308=Kt).

8. Multiply the ΔP value determined from step 2 by Kt: 0.8 x 9.308 = 7.446. The pressure drop under the foregoing conditions will be approximately 7.5 psig.

9. If a higher pressure drop is permissible, make a similar computation for 1/2" pipe and fittings; if a lower pressure drop is desirable, consider 1" pipe and fittings.

Distribution Piping

Figures 3, 4, 5 and 6 present the relationship between air flow (scfm) and pressure drop (ΔP = psig) for pipe sizes 1/8" through 3" inclusive at operating pressures of 5 to 250 psig. Lines "A", "B", "C" and "D" represent the maximum flow for pressure drops equal to 5%, 10%, 20% and 40% of the supply pressure respectively over the operating range of 5 to 250 psig.

These figures are a convenience in that they permit direct reading of the pressure drop through 100 feet of schedule 40 pipe. The pressure drop read from these charts will not always agree exactly with the pressure drop calculated from the information contained on Figure 2. The differences, however, are minor and result primarily from limiting the computations to three significant figures. The results obtained using either method are well within the accuracy capabilities of the flow computations.

Example 1:

Determine the pressure drop in 100 feet of 3/4" schedule 40 pipe at a flow rate of 150 scfm and an operating pressure of 100 psig:

1. Refer to Figure 4—follow the vertical 150 scfm line until it intersects the diagonal 100 psig applied pressure line.
2. Read the pressure drop on the scale at the left: 17 psig.
3. At an applied pressure of 100 psig, this represents a pressure drop of 17%. You will note that this point falls between lines "B" and "C" representing 10% and 20% pressure drop.
4. If the operating pressure was 80 psig, a flow of 150 scfm would produce a pressure drop of 20 psig or 25% of the applied pressure. You will note that this point falls between the lines "C" and "D" indicating pressure drops of 20% and 40% respectively.



The information on the following tables and figures is based on a compressed air temperature of 60°F. For temperatures other than 60°F, multiply the final result, ΔP by $\frac{460 + °F}{520}$

Fitting	Pipe Size								
	1/8"	1/4"	3/8"	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"
90° Standard Elbow	15.4	4.09	1.09	0.422	0.119	.0432	.01400	.00711	.00219
45° Standard Elbow	8.3	2.20	0.53	0.216	0.059	.0216	.00720	.00382	.00131
90° Street Elbow	25.8	6.80	1.91	0.686	0.196	.0714	.02320	.01180	.00406
-45° Street Elbow	13.3	3.56	0.91	0.343	0.107	0.365	.01200	.00607	.00205
90° Long Radius Elbow	10.4	2.74	0.80	0.264	0.083	.0282	.00920	.00468	.00163
Standard Tee – Run	10.4	2.74	0.80	0.264	0.083	.0282	.00920	.00468	.00163
Standard Tee – Side	31.0	8.14	2.37	0.818	0.243	.0845	.02760	.01390	.00490
Globe Valve – Full Open	175.3	46.40	12.70	4.750	1.360	.4820	.15600	.08150	.02750
Gate Valve – Full Open	6.7	1.76	0.47	0.180	0.053	.0183	.00600	.00295	.00107
Angle Valve – Full Open	74.8	19.80	5.46	1.800	0.593	.1990	.06800	.03470	.01210

Table 2. Values of K for Commonly Used Fittings

Pipe Size	K
1/8"	2300.
1/4"	450.0
3/8"	91.0
1/2"	26.4
3/4"	5.93
1"	1.66
1-1/4"	0.400
1-1/2"	0.174
2"	0.0467
2-1/2"	0.0186
3"	0.0060

Table 1. Values of K for 100 Feet of Schedule 40 pipe

Filter Type	Micron Size	Pipe Size								
		1/8"	1/4"	3/8"	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"
F07	5	115	55.0							
	25	112	49.0							
	100	92	41.0							
F72	5		22.62	18.18						
	25		29.99	23.95						
	40		15.71	11.03						
F73	5		14.93	10.83	9.75					
	25		14.93	11.48	10.54					
	40		12.86	8.99	8.02					
F74	5			5.15	3.72	2.92				
	25			4.17	3.01	2.25				
	40			3.67	2.52	1.78				
F17	5					.47	.34	.34	.340	
	25					.34	.23	.20	.200	
	50					.32	.20	.19	.190	
	75					.32	.20	.19	.190	
F18	25								.050	.028
	50								.036	.020
	75								.032	.018

Table 3. Values of K for Norgren Filters

Applied Pressure PSIG	Nominal Standard Pipe Size										
	1/8"	1/4"	3/8"	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	2-1/2"	3"
5	0.5	1.2	2.7	4.9	6.6	13	27	40	80	135	240
10	0.8	1.7	3.9	7.7	11.0	21	44	64	125	200	370
20	1.3	3.0	6.6	13.0	18.5	35	75	110	215	350	600
40	2.5	5.5	12.0	23.0	34.0	62	135	200	385	640	1100
60	3.5	8.0	18.0	34.0	50.0	93	195	290	560	900	1600
80	4.7	10.5	23.0	44.0	65.0	120	255	380	720	1200	2100
100	5.8	13.0	29.0	54.0	80.0	150	315	470	900	1450	2600
150	8.6	20.0	41.0	80.0	115.0	220	460	680	1350	2200	3900
200	11.5	26.0	58.0	108.0	155.0	290	620	910	1750	2800	5000
250	14.5	33.0	73.0	135.0	200.0	370	770	1150	2200	3500	6100

Table 4. Maximum Recommended Air Flow (scfm) thru A.N.S.I. Standard Weight Schedule 40 Pipe

Use Table 4 as a guide in sizing piping and equipment in compressed air systems.

The flow values in Table 4 are based on a pressure drop as shown below.

Pressure Drop per 100 ft of Pipe	Pipe Size (Inches)
10% of Applied Pressure	1/8, 1/4, 3/8, 1/2
5% of Applied Pressure	3/4, 1, 1-1/4, 1-1/2, 2, 2-1/2, 3

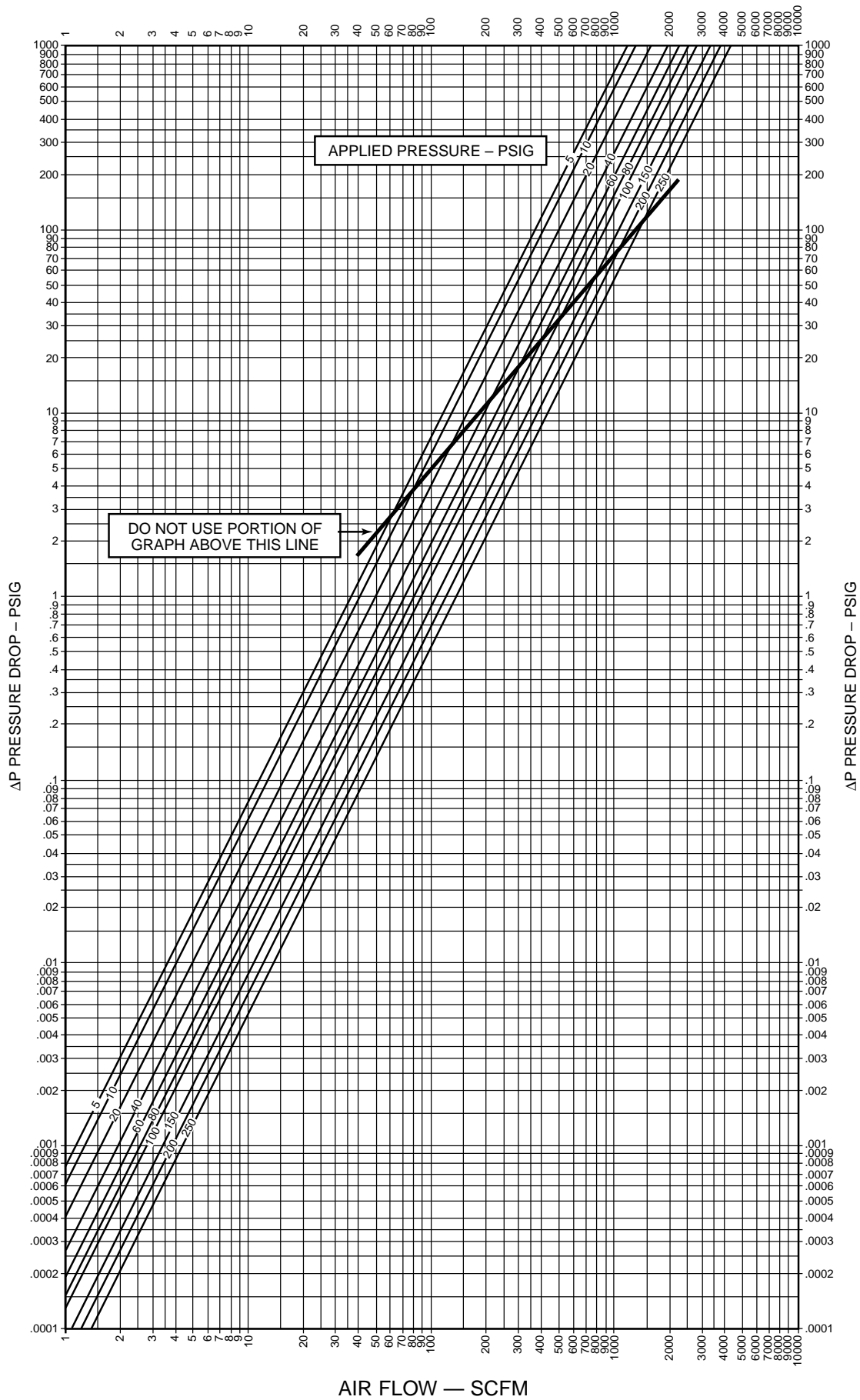


FIGURE 2. Air Flow - Pressure Drop Graph For $K = 1$ In Equation $\Delta P = \frac{KC^2}{1000} \left[\frac{14.7}{14.7 + P} \right] \left[\frac{460 + T}{520} \right]$

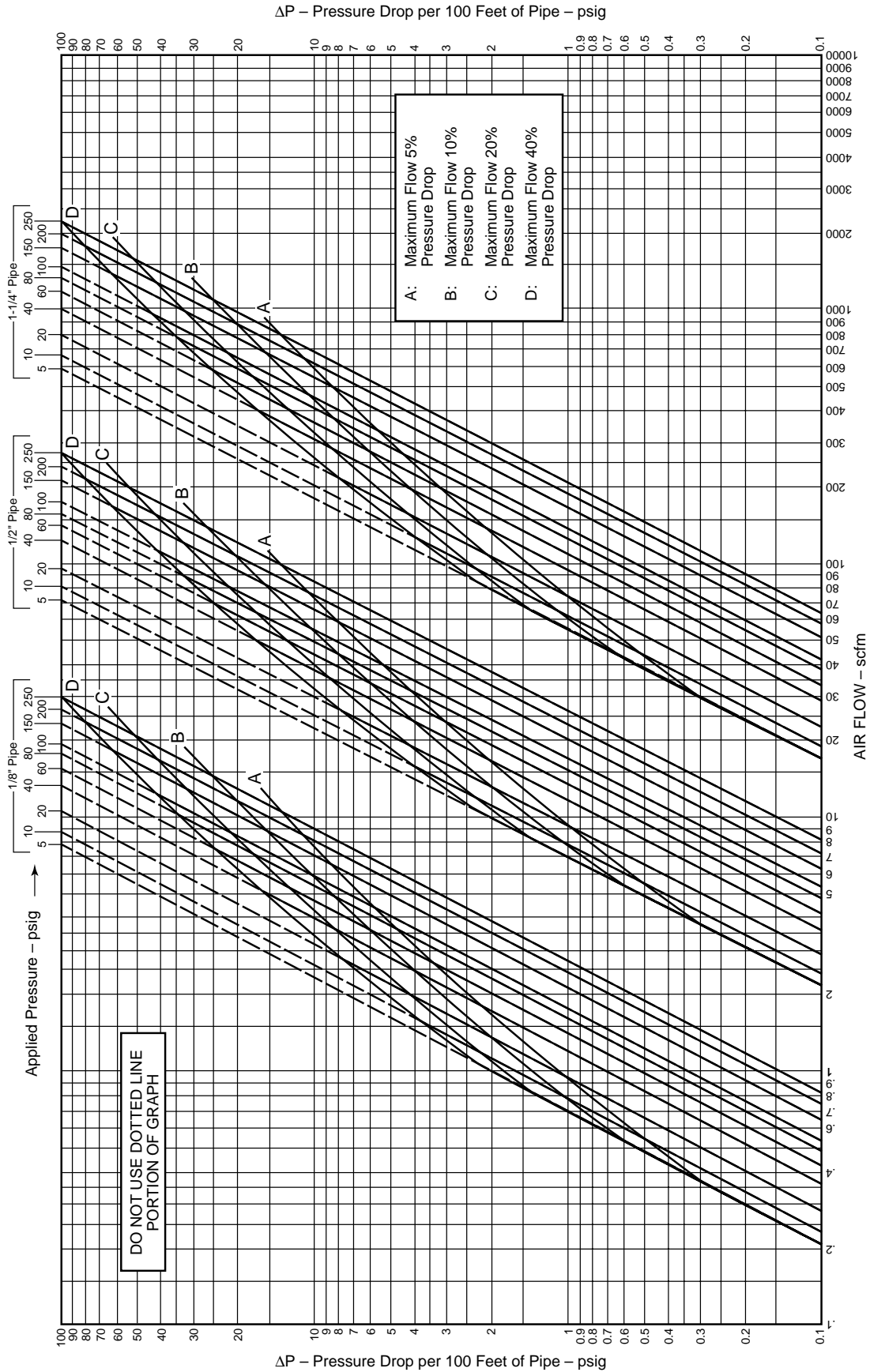


Figure 3. Air Flow – Pressure Drop Graph (1/8", 1/2", 1-1/4" Pipe)

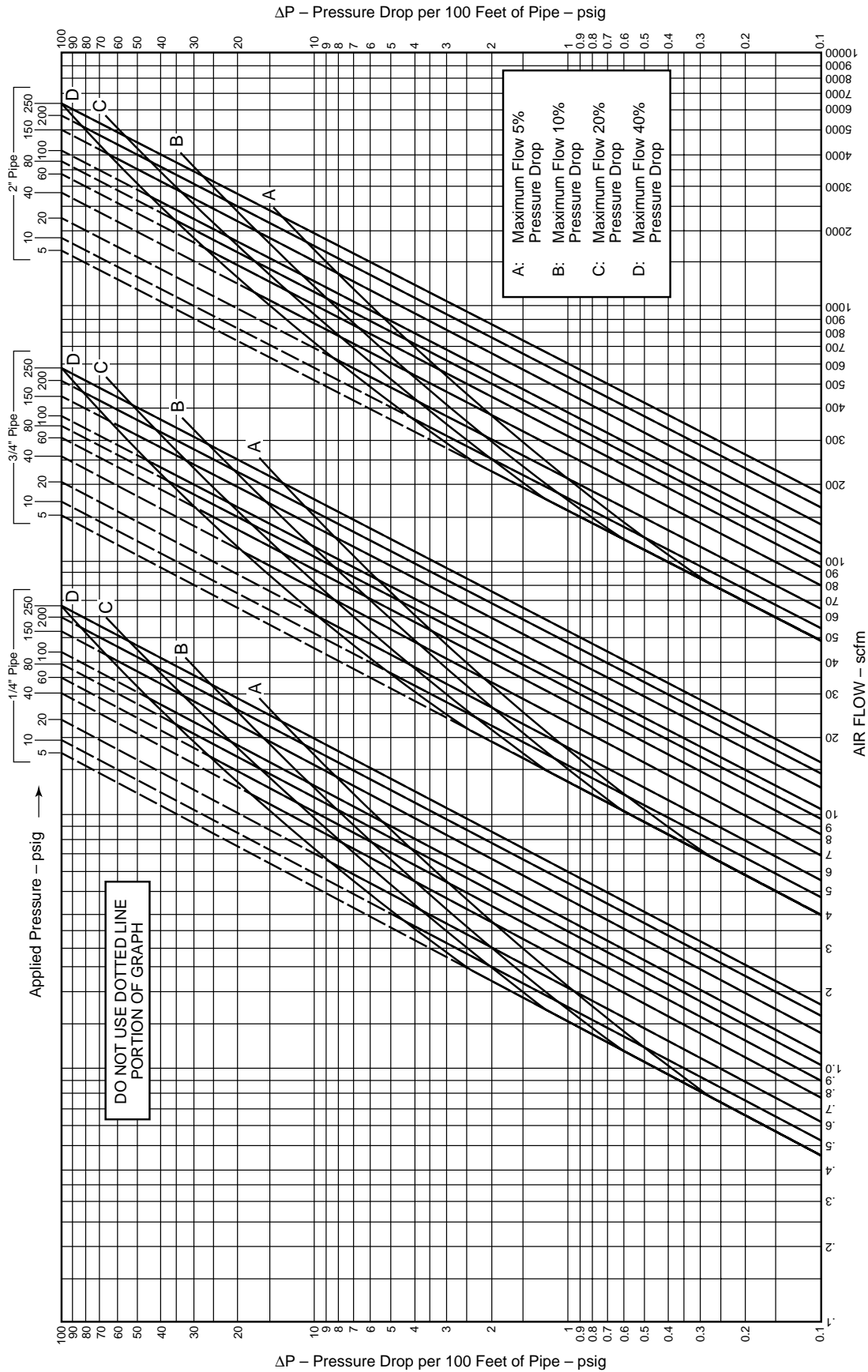


Figure 4. Air Flow – Pressure Drop Graph (1/4", 3/4", 2" Pipe)

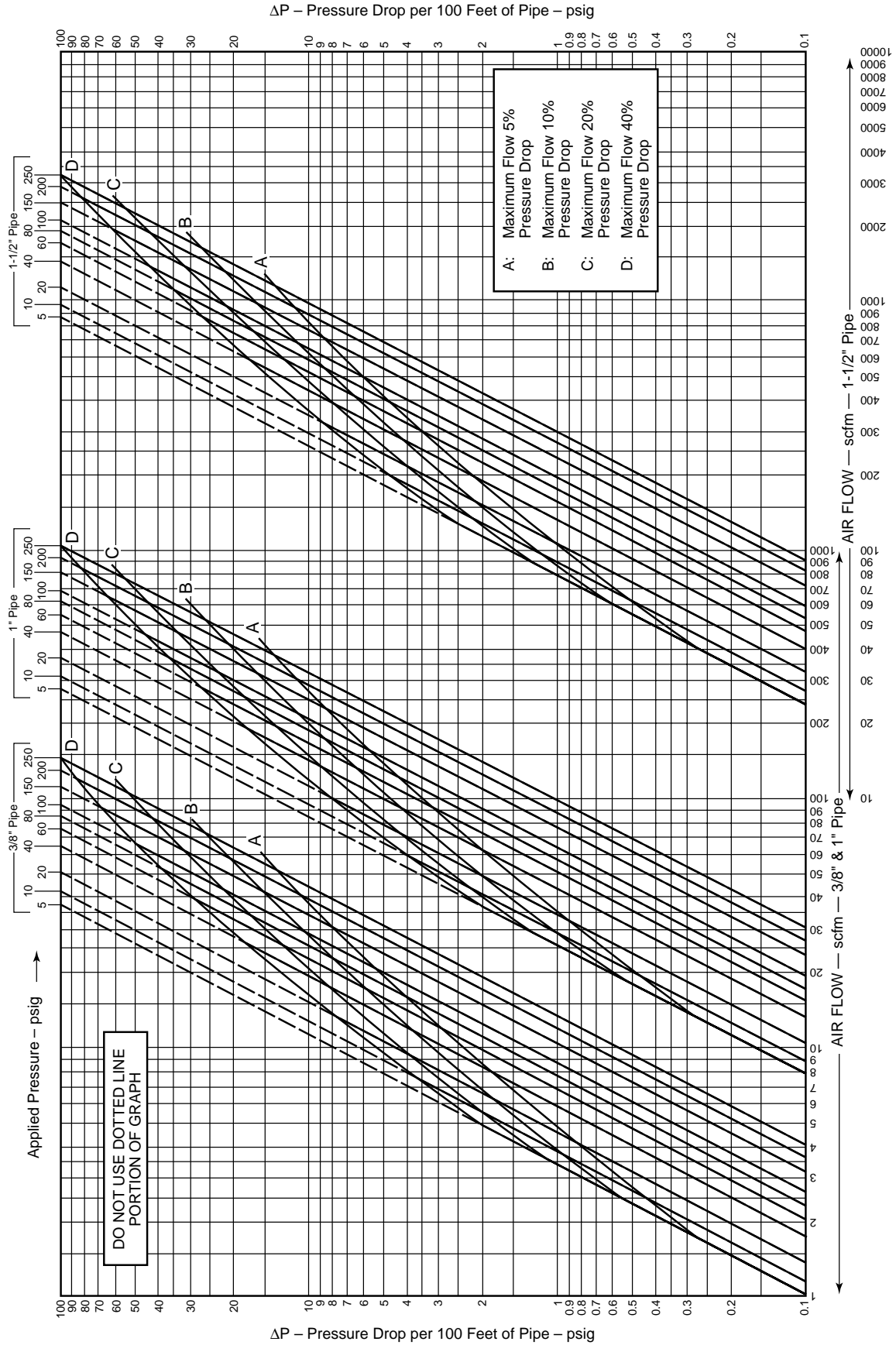


Figure 5. Air Flow – Pressure Drop Graph (3/8", 1", 1-1/2" Pipe)

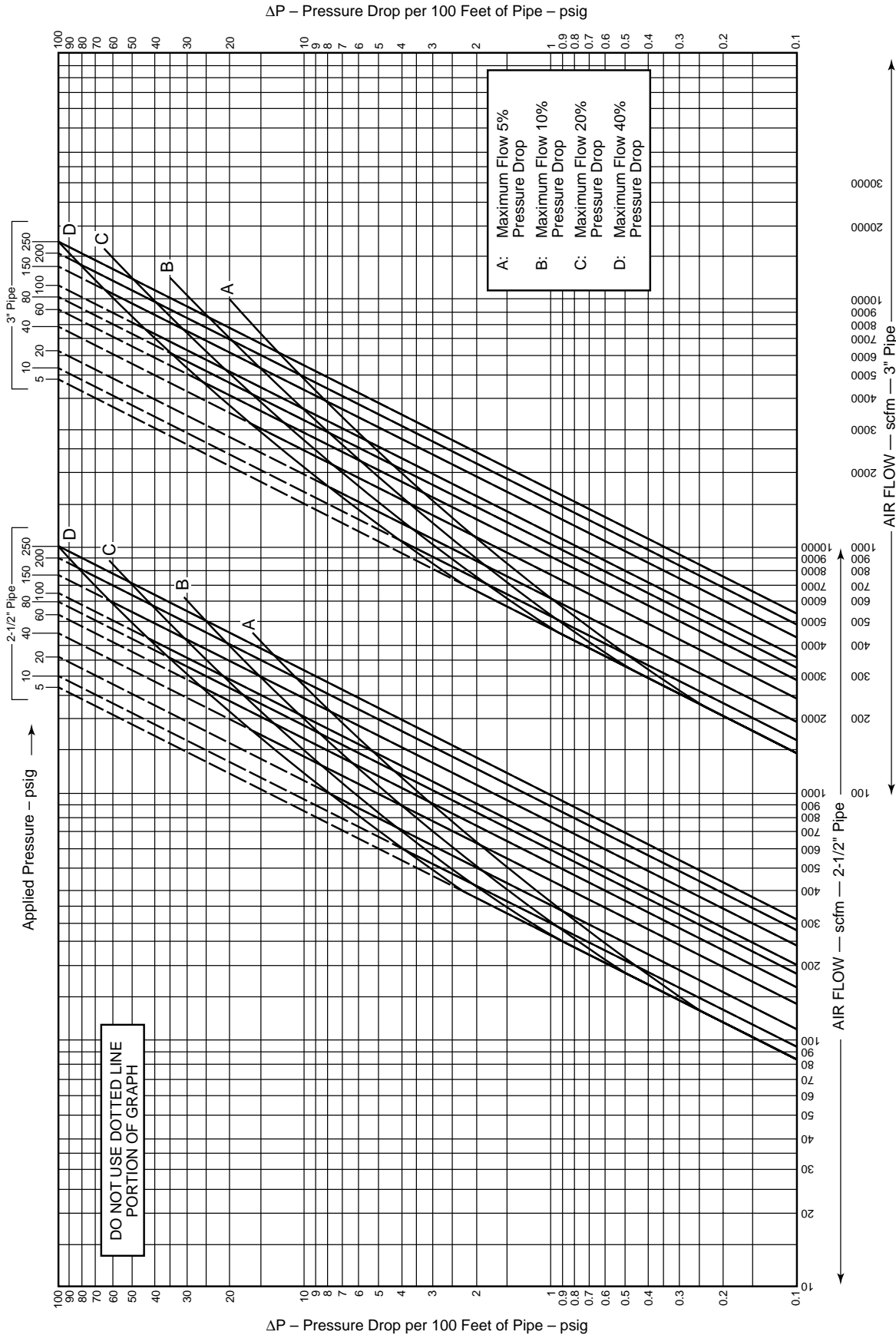


Figure 6. Air Flow – Pressure Drop Graph (2-1/2" & 3" Pipe)



How To Determine Flow and Pressure Drop in Water Systems

Table 5 is self-explanatory. For the conditions given, flow values can be read directly from the chart

Figure 7 is more versatile - it provides the means for determining pressure drop (ΔP) or flow (gpm) for a variety of operating conditions.

Figure 7 gives the relationship between pressure drop (ΔP) and flow (gpm) for pipe sizes 1/8" to 3". Two auxiliary scales on Figure 7 provide the applied pressure corresponding to a (ΔP) of 5% and 10%.

The Following Examples Illustrate the Use of Table 5 and Figure 7

Example 1:

Determine the flow in 1/2" pipe (gpm) that will produce a pressure drop (ΔP) of 10 psig per 100 feet of pipe when operating at an applied pressure of 100 psig:

From Table 5, the flow can be read directly = 4.6 gpm or from Figure 7, locate the intersection of the diagonal line for 1/2" pipe and the 10 psig ΔP line: Read flow = 4.6 gpm.

Example 2:

Determine the flow in 1/2" pipe (gpm) that will produce a pressure drop (ΔP) of 12 psig in 150 feet of pipe when operating at an applied pressure of 100 psig:

First—Determine the ΔP for 100 feet of pipe:

$$\Delta P = \frac{12 \times 100}{150} = 8 \text{ psig}$$

Second—From Figure 7, locate the intersection of the diagonal line for 1/2" pipe and the 8 psig ΔP line: Read flow = 4.2 gpm.

Example 3:

Determine the pressure drop (ΔP) in 75 feet of 3/4" pipe when operating at a flow of 10 gpm and an applied pressure of 150 psig:

First—From Figure 7, determine the ΔP for 100 feet of 3/4" pipe by locating the intersection of the diagonal line for 3/4" pipe and the 10 gpm line: Read ΔP = 10 psig.

Second—For 75 feet of pipe: $\Delta P = \frac{75 \times 10}{100} = 7.5 \text{ psig}$

Applied Pressure PSIG	Nominal Standard Pipe Size										
	1/8"	1/4"	3/8"	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	2-1/2"	3"
5	0.10	0.24	0.50	0.92	1.4	2.6	5.3	8.0	16	25	47
10	0.14	0.34	0.73	1.3	2.0	3.7	7.8	12	23	37	68
20	0.21	0.50	1.1	1.9	2.9	5.4	11	17	33	53	100
40	0.30	0.73	1.5	2.8	4.2	8.0	16	25	48	78	145
60	0.37	0.90	1.9	3.5	5.2	10	21	31	60	96	180
80	0.43	1.1	2.2	4.1	6.1	12	24	36	70	112	210
100	0.48	1.2	2.5	4.6	6.8	13	27	41	80	128	240
150	0.60	1.5	3.1	5.8	8.5	16	33	51	99	155	290
200	0.71	1.7	3.7	6.8	10	19	39	60	115	185	350
250	0.80	2.0	4.2	7.6	11	21	44	67	130	210	390

Table 5. Maximum Recommended Water Flow (gpm) Through A.N.S.I. Standard Weight Schedule 40 Pipe.

Use Table 5 as a guide in sizing piping in water systems.

The flow values in Table 5 are based on a pressure drop as shown below.

Pressure Drop per 100 ft of Pipe	Pipe Size (Inches)
10% of Applied Pressure	1/8, 1/4, 3/8, 1/2
5% of Applied Pressure	3/4, 1, 1-1/4, 1-1/2, 2, 2-1/2, 3

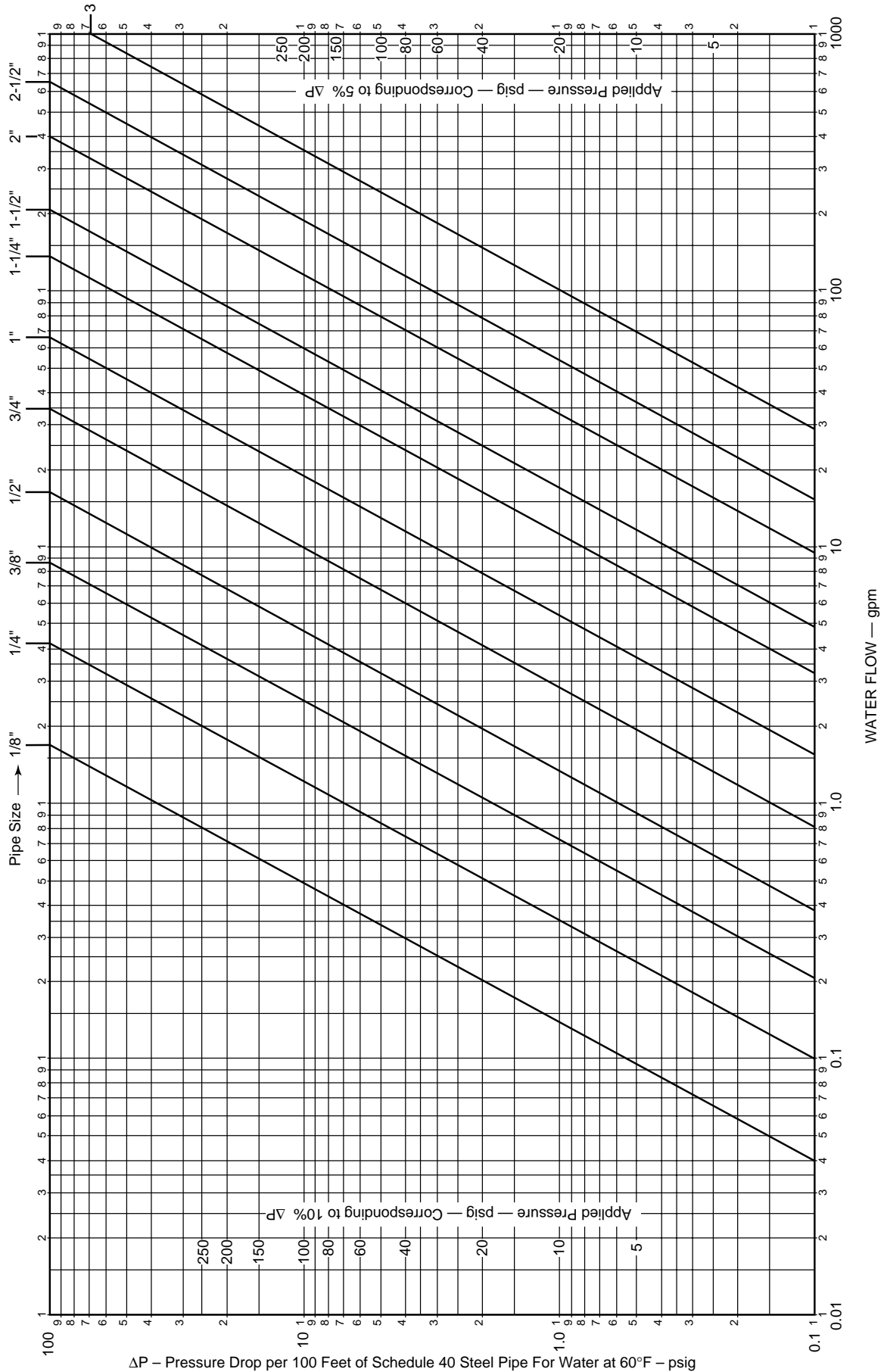


Figure 7. Water Flow — Pressure Drop Graph



How To Determine Proper Air Valve Size

Most manufacturers catalogs give flow rating Cv for the valve, which was established using proposed National Fluid Power Association (NFPA) standard T3.21.3. The following tables and formulas will enable you to quickly size a valve properly. The traditional, often used, approach of using the valve size equivalent to the port in the cylinder can be very costly. Cylinder speed, not port size, should be the determining factor.

The following Cv calculations are based upon simplified formulas which yield results with acceptable accuracy under the following standard conditions: **Air at a temperature of 68°F (20°C)**

Absolute downstream or secondary pressure must be 53% of absolute inlet or primary pressure or greater. Below 53%, the air velocity may become sonic and the Cv formula does not apply. To calculate air flow to atmosphere, enter outlet pressure p₂ as 53% of absolute p₁. Pressure drop ΔP would be 47% of absolute inlet pressure. These valves have been calculated for a Cv = 1 in Table 3.

Nomenclature

- B Pressure Drop Factor
- C Compression Factor
- Cv Flow Factor
- D Cylinder Diameter (IN)
- F Cylinder Area (SQ IN)
- L Cylinder Stroke (IN)
- p₁ Inlet or Primary Pressure (PSIG)
- p₂ Outlet or Secondary Pressure (PSIG)
- ΔP Pressure Differential (p₁ - p₂) (PSID)
- q Air Flow at Actual Condition (CFM)
- Q Air Flow of Free Air (SCFM)
- t Time to Complete One Cylinder Stroke (SEC)
- T Absolute Temperature at Operating Pressure. Deg R = Deg F + 460 (°R)

Valve Sizing For Cylinder Actuation — Direct Formula

$$Cv = \frac{\text{cylinder area (SQ IN)} \times \text{cylinder stroke (IN)} \times \text{compression factor (See Table 2)}}{\text{pressure drop factor (See Table 2)} \times \text{time to complete (SEC)} \times \text{cylinder stroke (SEC)}} \times B$$

Example:

Cylinder size 4" Dia. x 10" stroke. Time to extend: 2 seconds. Inlet pressure 90 PSIG. Allowable pressure drop 5 PSID. Determine Cv.

Solution: Table 1 F = 12.57 SQ IN
 Table 2 C = 7.1
 B = 21.6

$$Cv = \frac{12.57 \times 10 \times 7.1}{21.6 \times 2 \times 29} = .7$$

Select a valve that has a Cv factor of .7 or higher. In most cases a 1/4" valve would be sufficient

It is considered good engineering practice to limit the pressure drop ΔP to approximately 10% of primary pressure p₁. The smaller the allowable pressure drop, the larger the required valve will become.

After the minimum required Cv has been calculated, the proper size valve can be selected from the catalog.

Bore Size D (in.)	Push Bore F (sq. in.)	Bore Size D (in.)	Push Bore F (sq. in.)
3/4"	.44	4"	12.57
1"	.79	4-1/2"	15.90
1-1/8"	.99	5"	19.64
1-1/4"	1.23	6"	28.27
1-1/2"	1.77	7"	34.48
1-3/4"	2.41	8"	50.27
2"	3.14	10"	78.54
2-1/2"	4.91	12"	113.10
3-1/4"	8.30	14"	153.94

Table 1: Cylinder Push Bore Area F for Standard Size Cylinders

Inlet Pressure (psig)	Compression Factor C	Pressure Drop Factor B For Various Pressure Drops ΔP				
		2 PSID	5 PSID	10 PSID	15 PSID	20 PSID
10	1.7	6.5				
20	2.4	7.8	11.8			
30	3.0	8.9	13.6	18.0		
40	3.7	9.9	15.3	20.5	23.6	
50	4.4	10.8	16.7	22.6	26.4	29.0
60	5.1	11.7	18.1	24.6	29.0	32.0
70	5.8	12.5	19.3	26.5	31.3	34.8
80	6.4	13.2	20.5	28.2	33.5	37.4
90	7.1	13.9	21.6	29.8	35.5	39.9
100	7.8	14.5	22.7	31.3	37.4	42.1
110	8.5	15.2	23.7	32.8	39.3	44.3
120	9.2	15.8	24.7	34.2	41.0	46.4
130	9.8	16.4	25.6	35.5	42.7	48.4
140	10.5	16.9	26.5	36.8	44.3	50.3
150	11.2	17.5	27.4	38.1	45.9	52.1
160	11.9	18.0	28.2	39.3	47.4	53.9
170	12.6	18.5	29.0	40.5	48.9	55.6
180	13.2	19.0	29.8	41.6	50.3	57.2
190	13.9	19.5	30.6	42.7	51.7	58.9
200	14.6	20.0	31.4	43.8	53.0	60.4
210	15.3	20.4	32.1	44.9	54.3	62.0
220	16.0	20.9	32.8	45.9	55.6	63.5
230	16.7	21.3	33.5	46.9	56.8	64.9
240	17.3	21.8	34.2	47.9	58.1	66.3
250	18.0	22.2	34.9	48.9	59.3	67.7

Table 2: Compression Factor C and Pressure Drop Factor B.



Valve Sizing with Cv = 1 Table

(For nomenclature see previous page)

This method can be used if the required are flow is known or has been calculated with the formulas as shown below:

$$1. \quad Q = .0273 \frac{D^2 L}{t} \times \frac{p_2 + 14.7}{14.7} \quad (\text{SCFM})$$

Conversion of CFM to SCFM

$$2. \quad Q = q \times \frac{p_2 + 14.7}{14.7} \times \frac{528}{T} \quad (\text{SCFM})$$

Flow Factor Cv (standard conditions)

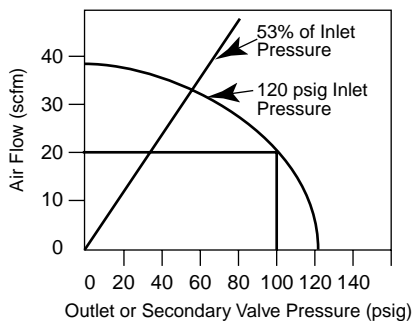
$$3. \quad C_v = \frac{1.024 \times Q}{\sqrt{\Delta P \times (p_2 + 14.7)}} \quad \text{Proposed NFPA Standard T3.21.3}$$

Maximum pressure drop Δp across the valve should be less than 10% of inlet pressure p_1 .

Inlet Pressure (psig)	Air Flow Q (SCFM) for Various Pressure Drops ΔP at Cv = 1					Air Flow Q (SCFM) to Atmosphere
	2 PSID	5 PSID	10 PSID	15 PSID	20 PSID	
10	6.7					12.0
20	7.9	11.9				16.9
30	9.0	13.8	18.2			21.8
40	9.9	15.4	20.6	23.8		26.6
50	10.8	16.9	22.8	26.7	29.2	31.5
60	11.6	18.2	24.8	29.2	32.3	36.4
70	12.3	19.5	26.7	31.6	35.1	41.2
80	13.0	20.7	28.4	33.8	37.7	46.1
90	13.7	21.8	30.0	35.8	40.2	51.0
100	14.4	22.9	31.6	37.8	42.5	55.9
110	15.0	23.9	33.1	39.6	44.7	60.7
120	15.6	24.9	34.5	41.4	46.8	65.6
130	16.1	25.8	35.8	43.1	48.8	70.5
140	16.7	26.7	37.1	44.7	50.7	75.3
150	17.2	27.6	38.4	46.3	52.5	80.2
160	17.7	28.4	39.6	47.8	54.3	85.1
170	18.2	29.3	40.8	49.3	56.0	90.0
180	18.7	30.1	42.0	50.7	57.7	94.8
190	19.2	30.9	43.1	52.1	59.4	99.7
200	19.6	31.6	44.2	53.4	60.9	104.6
210	20.1	32.4	45.2	54.8	62.5	109.4
220	20.5	33.1	46.3	56.1	64.0	114.3
230	21.0	33.8	47.3	57.3	65.5	119.2
240	21.4	34.5	48.3	58.6	66.9	124.0
250	21.8	35.2	49.3	59.8	68.3	128.9

Table 3: Air Flow Q (SCFM) For Cv = 1

Flow Curves — How to Read Them



Area where the Cv formula is a valid and close approximation

Example 1: Find air flow Q (SCFM) if Cv is known. Cv (from valve catalog) = 1.8

Primary pressure $p_1 = 90$ PSIG

Pressure drop across valve $\Delta P = 5$ PSID

Flow through valve from Table 3 for Cv = 1: 21.8 SCFM

$$Q = C_v \text{ of valve} \times \text{air flow at } C_v = 1 \text{ (SCFM)}$$

$$Q = 1.8 \times 21.8 = 39.2 \text{ SCFM}$$

Example 2: Find Cv if air flow Q (SCFM) is given.

Primary pressure $p_1 = 90$ PSIG

Pressure drop $\Delta P = 10$ PSID

Air Flow-Q = 60 SCFM

Flow through valve from Table 3 for Cv = 1: 30 SCFM

$$C_v = \frac{\text{Air Flow Q (SCFM)}}{\text{Air Flow at } C_v = 1 \text{ (SCFM)}}$$

$$C_v = \frac{60 \text{ SCFM}}{30} = 2.0$$

A valve with a Cv of minimum 2 should be selected.

Example 3: Find Cv if air flow Q (SCFM) to atmosphere is given (from catalog).

Primary pressure $p_1 = 90$ PSIG

Air flow to atmosphere Q = 100 SCFM

Flow to atmosphere through valve from Table 3 for Cv = 1: 51 SCFM

$$C_v = \frac{\text{Air Flow to atmosphere Q (SCFM)}}{\text{Air Flow to atmosphere at } C_v = 1 \text{ (SCFM)}}$$

$$C_v = \frac{100}{51} = 2.0$$

Flow given in catalog is equivalent to a valve with Cv = 2. This conversion is often necessary to size a valve properly, since some manufacturers do not show the standard Cv to allow a comparison.

Example 4: Find Cv if cylinder size and stroke speed is known, using the formulas 1 and 3

Primary pressure = 90 PSIG

Pressure drop across valve 5 PSID

Cylinder size 4" dia. x 10" stroke

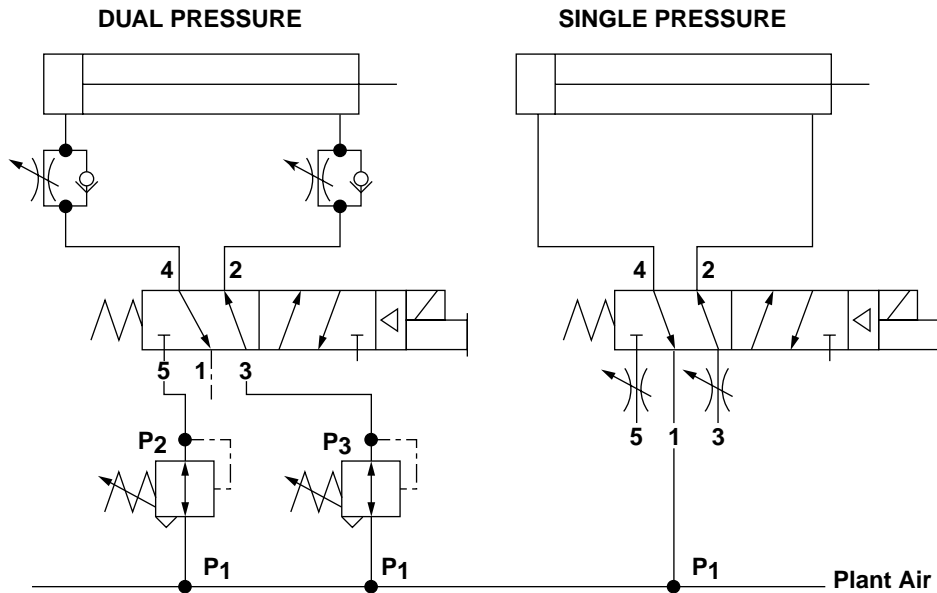
Time to complete stroke 2 sec.

$$Q = .0273 \frac{4^2 \times 10}{2} \times \frac{85 + 14.7}{14.7} = 14.81 \text{ SCFM}$$

$$C_v = \frac{1.024 \times 14.81}{\sqrt{5 \times (85 + 14.7)}} = .7$$



Savings with Dual Pressures Valves



“Dual pressure” means using two different supply pressures to the valve. One supply acts to extend the cylinder, and the other supply acts to retract the cylinder when the valve is shifted.

Justification of a dual pressure versus a single pressure valve can be done quickly, using this simple formula. Savings in air consumption is the most important consideration of the use of dual pressure valves.

$$K = \frac{D^2 \times S \times (2p_1 - p_2 - p_3) \times Z \times N}{560,000} \text{ (\$/HR)} \quad N = \frac{60 \text{ Sec}}{t_1 + t_2} \text{ (CPM)}$$

Nomenclature

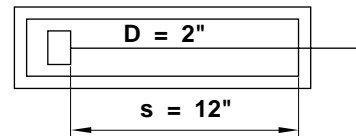
- D = Piston Diameter of Cylinder (IN)
- K = Cost Savings per Hour (\$/HR)
- p₁ = Plant Air Pressure (PSIG)
- p₂ = Work Stroke Pressure (Reduced) (PSIG)
- p₃ = Return Stroke Pressure (Reduced) (PSIG)
- t₁ = Work Stroke (SEC)
- t₂ = Return Stroke (SEC)
- S = Cylinder Stroke (IN)
- N = Cycles Per Minute (CPM)
- Z = Cost to compress 1,000 SCF of air to 150 psig (\$/1000 SCF)

(1976 estimate: \$.24/1000 SCF at 150 psig. Source: Assembly Engineering, page 50, May 1976)

Assumptions:

1. Rod diameter of cylinder is partially accounted for in the constant (560,000). Except for very small cylinders, where the use of dual pressure is questionable anyway, the formula is sufficiently accurate for most practical applications.
2. Atmospheric Pressure = 14.7 psia
3. Standard Temperature = 68°F

Example:



Work Stroke t₁ = 2 sec.
 Return Stroke t₂ = 2 sec.
 Plant Air Pressure p₁ = 150 psig
 Work Stroke Pressure p₂ = 100 psig
 Return Stroke Pressure p₃ = 30 psig
 Cost of 1000 SCF Compressed Air Z = \$.24
 $N = \frac{60}{2 + 2} = 15$

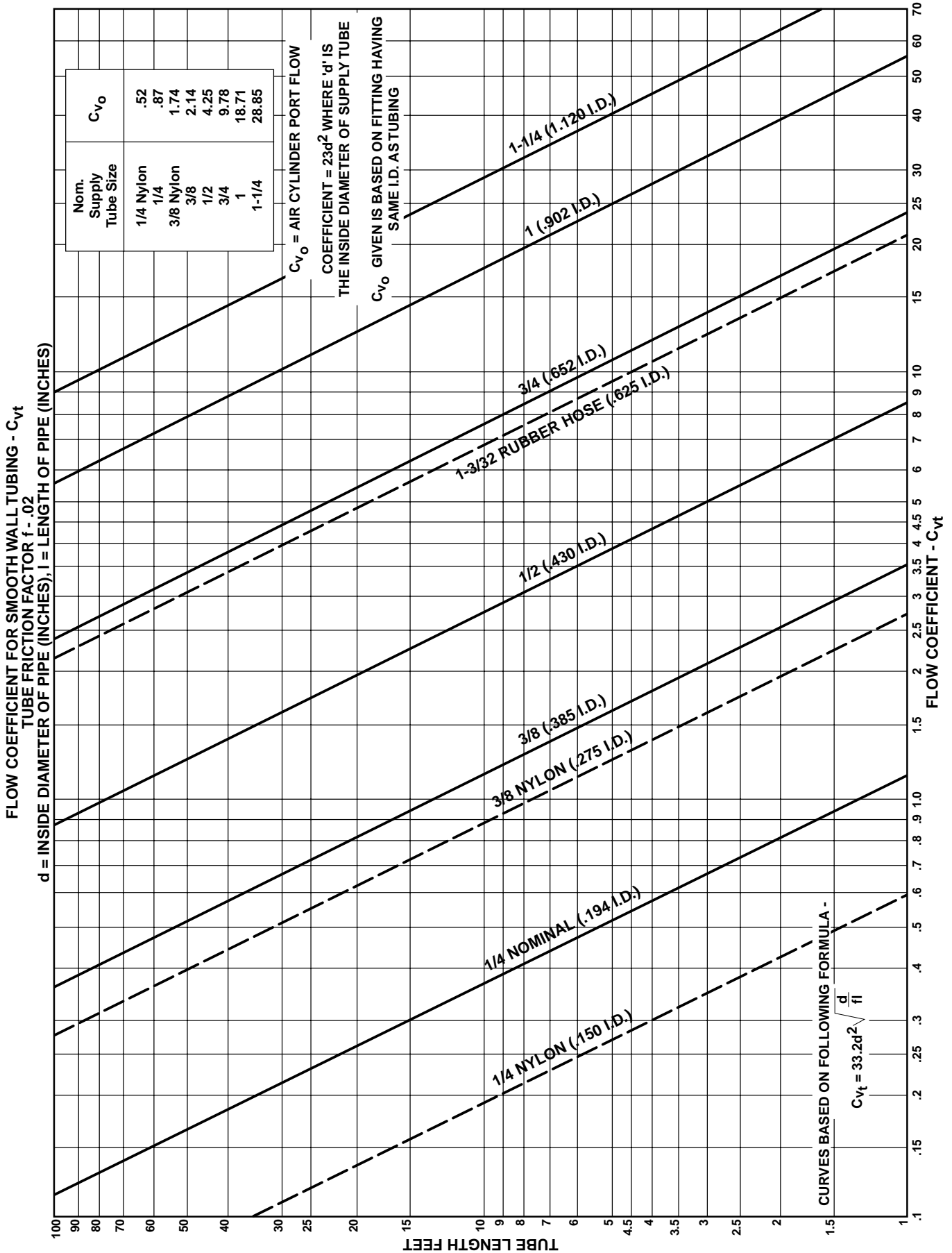
Calculate Savings per 8 Hour Shift

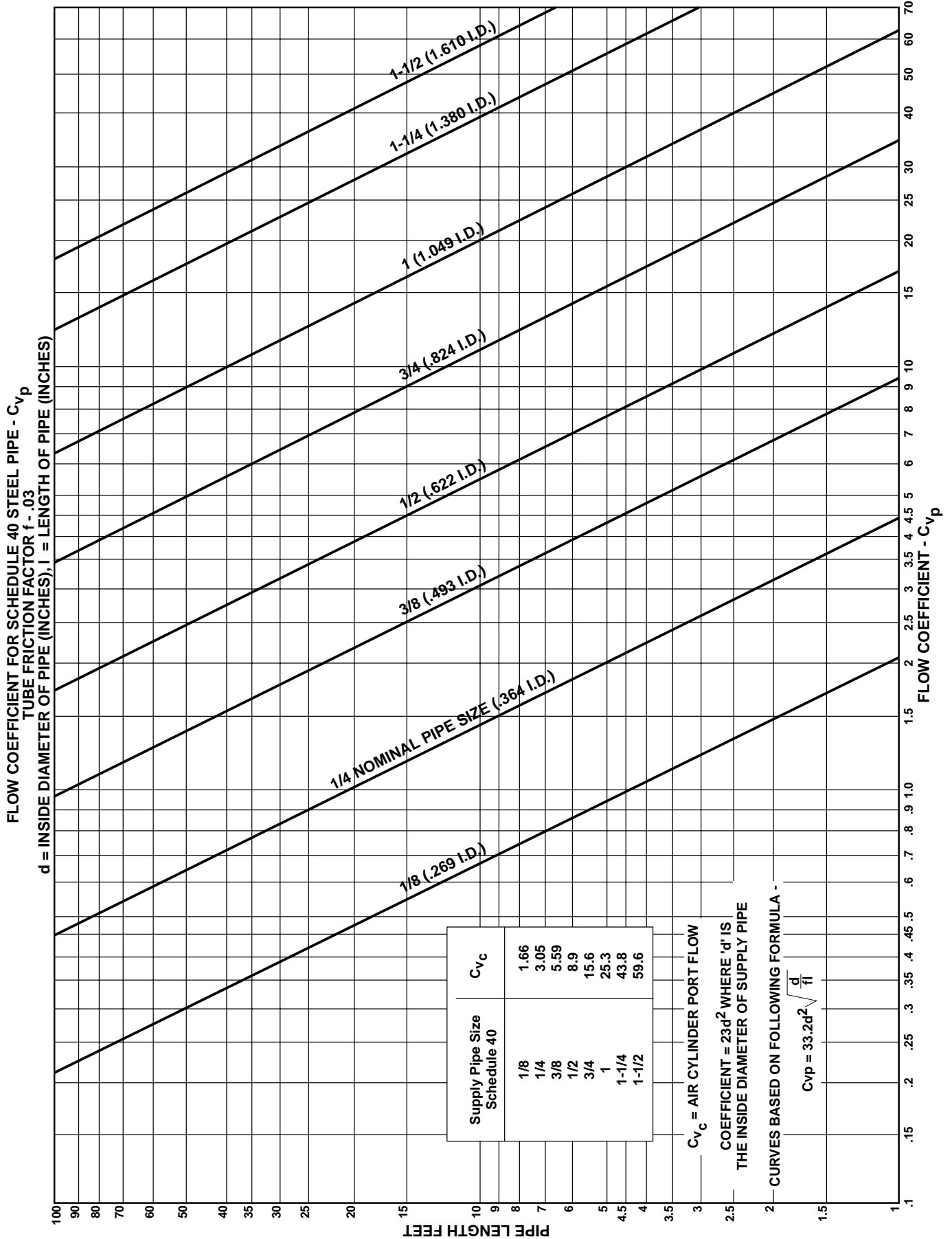
$$K = \frac{2^2 \times 12 \times (150 \times 2 - 100 - 30) \times .24 \times 15}{5.6 \times 10^5} = \$.053/\text{HR}$$

Savings are \$.42 for 8 hours

Conclusion:

As demonstrated in this example, savings for just one small cylinder result in a very short pay back period for the required additional one or two regulators. It should be kept in mind that a pressure reduction will result in a cylinder speed reduction. It is also important that relieving regulators be used.







Selected SI Units for Fluid Power Usage

Extracted from ISO 1000 with National Fluid Power Association permission.

Quantity	Symbol	Customary U.S. Unit		SI Units			Notes	
			Abbreviation	Preferred Unit				
Angular Velocity	ω	radian per second	rad/s	rad/s				
Area	A or S	square inch	in ²	cm ²	m ²	mm ²		
Bulk Modulus (Liquids)	K	pounds per square inch	psi	bar	N/m ²			
Capacity (Displacement)	V	cubic inches per revolution	ci/r	m ³ /r	l/r		1, 7	
Coefficient of Thermal Expansion (cubic)	α	°F-1	1/°F	1/K				
Dynamic Viscosity	μ	centipoise	cP	cP	P	Pa s	2	
Efficiency	η	percent		percent			3	
Force	F	pound (f)	(lb) f	N	kN			
Frequency	f	cycles per second	cps	Hz	kHz			
Kinematic Viscosity	ν	Saybolt Universal Seconds	SUS	cSt	m ² /s		4, 9	
Length	l	inch	in.	mm	m	μ m		
Linear Velocity	v	feet per second	ft/s	m/s				
Mass	m	pound (m)	lb (m)	kg	Mg	g		
Mass Density	ρ	pound (m) per cubic foot	lb (m)/ft ³	kg/m ³	kg/dm ³	kg/l	5	
Mass Flow	M	pound (m) per second	lb (m)/s	kg/s	g/s			
Power	P	horsepower	HP	kW	W			
Pressure (Above Atmospheric)	p	pounds per square inch	psi	bar	mbar	Pa	kPa	6
Pressure (Below Atmospheric)	p	inches of mercury, absolute	in. Hg	bar, abs	Pa	kPa		6
Quantity of Heat	Q _c	British Thermal Unit	BTU	J	kJ	MJ		
Rotational Frequency (Shaft Speed)	n	revolutions per minute	RPM	r/min	r/s			
Specific Heat Capacity	c	British Thermal Unit per pounds mass degree Fahrenheit	BTU/lb(m)°F	J/(kgK)				
Stress (Materials)	σ	pounds per square inch	psi	daN/mm ²	MPa			
Surface Roughness		microinch	μ in	grade N ₁	μ m		10	
Temperature (Customary)	θ	degree Fahrenheit	°F	°C				
Temperature (Interval)		degree Fahrenheit	°F	°C				
Temperature (Thermodynamic)	T	Rankine	°R	K				
Time	t	second	s	min	s	μ		
Torque (Moment of Force)	T	pounds (F) - inch	lb (f) - in.	Nm	kNm	mNm		
Volume	V	gallon	U.S. gal	l	m ³	cm ³	7	
Volumetric Flow (Gases)	Q (ANR)	standard cubic feet per minute	scfm	dm ³ /s _n	m ³ /s _n	cm ³ /s _n	8	
Volumetric Flow (Liquids)	Q	gallons per minute	USGPM	l/min	l/sec	ml/s	7	
Work	W	foot-pound (f)	ft-lb (f)	J				

Notes to the Table of Selected SI Units for Fluid Power Usage

- The capacity (displacement) of a rotary device is given as "per revolution" Non-rotary devices are expressed as "per cycle".
- The centipoise, cP, is a non-SI unit, use of which is permitted by ISO 1000. The centipoise is equal to 10⁻³ N s/m².
- Efficiencies are normally stated as "percent" but the use of a ratio is also permitted.
- The centistokes, cSt, is a non-SI unit, use of which is permitted by ISO 1000. the centistokes is equal to 10⁻⁶ m²/s.
- Subject to change to kg/_ to correspond to recent action by ISO/TC 28 (Petroleum Fluids).
- The bar is a non-SI unit, use of which is permitted by ISO 1000. The bar is a special name for a unit of pressure and is assumed to be "gage" unless otherwise specified. 1 bar = 100 kPa; 1 bar = 10⁵ N/m².
- The litre is a non-SI unit use of which is permitted by ISO 1000. The litre is a special name for a unit of liquid measure and is exactly equal to the cubic decimetre.
- The abbreviation "ANR" means that the result of the measurement has been referred to the Standard Reference Atmosphere (Atmosphere Normale de Reference) as defined in clause 2.2 of ISO/R 554, "Standard atmospheres for conditioning and/or testing - Standard reference atmosphere - Specifications." This abbreviation should immediately follow the unit used or the expression of the quantity.
- For conversion from U.S. to Si units, see ANSI/Z11.129-1972 (ASTM/D2161-1971).
- For conversion from U.S. to SI units. see ISO/R 1302-1971.



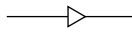
Conversion Tables

To Convert	Into	Multiply By	To Convert	Into	Multiply By
atmospheres	bar	1.0135	liters	cu dm	1.0
atmospheres	mm of mercury	760.0	liters	cu feet	0.0351
atmospheres	pounds/sq. in.	14.696	liters	cu inches	61.02
bars	atmospheres	0.9869	liters	cu meters	0.001
bars	kilopascal	100.0	liters	gallons (U.S.)	0.2642
bars	Newton/sq. meters	100,000.0	liters/min	gals/min	0.2642
bars	pounds/sq. in.	14.5	meters	feet	3.281
Btu	foot-lbs.	778.3	meters	inches	39.37
Btu	horsepower/hrs	3.927×10^{-4}	meters	yards	1.094
Btu	joules	1,054.8	millimeters	inches	0.03937
Btu	kilogram-calories	0.252	millimeters of mercury	psi	0.0194
Btu	kilowatts-hrs.	2.928×10^{-4}	Newton/sq. meter	pascal	1.0
Btu/pound °F	kilogram-calories/kg °C	1.0	Newton-meter	foot-pounds	0.7375
Centigrade	Fahrenheit	$9/5C^{\circ} + 32^{\circ}$	Newton-meter	joule	1.0
Centigrade	Kelvin	$C^{\circ} + 273^{\circ}$	Newtonmeter/sec.	foot-pounds/sec.	0.7375
centimeters	feet	0.0328	Newton-meter/sec.	watts	1.0
centimeters	inches	0.3937	ounces	grams	28.35
centipoise	gram/cm. sec.	0.01	pounds	kilograms	0.4536
centipoise	pound mass/ft. sec.	0.000672	pounds/cu ft.	grams/cu cm	0.01602
centistokes	sq. feet/sec.	1.076×10^{-6}	pounds/cu ft.	kgs/cu meter	16.02
cubic centimeters	cu inches	0.06102	pounds/cu in.	gms/cu in.	27.68
cubic feet	cu cms	28,317.0	pounds/hr.	kilograms/hr.	0.454
cubic feet	cu meters	0.028317	pounds/sec.	kilograms/hr.	1,633.0
cubic feet	liters	28.317	pounds-sec./sq. ft.	pounds mass/ft. sec.	32.2
cubic feet/min.	cu dms.sec.	0.472	pounds/sq. in.	atmospheres	0.06804
cubic feet/min.	pounds of air/hr.	4.5	pounds/sq. in.	bar	0.069
cubic feet/min.	cu Newton meters/hr.	1.7	pounds/sq. in.	inches of mercury	2.036
cubic inches	cu cms	16.39	pounds/sq. in.	inches of water	27.7
cubic inches	cu mm	16,387.0	pounds/sq. in.	kilopascal	6.895
cubic inches	liters	0.01639	pounds/sq. in.	mm of mercury	51.6
cubic meters	cu feet	35.31	square centimeters	sq. feet	0.001076
Fahrenheit	Centigrade	$5/9 (F^{\circ} - 32^{\circ})$	square centimeters	sq. inches	0.155
Fahrenheit	Rankine	$F^{\circ} + 460^{\circ}$	square centimeters	sq. cms	929.0
feet	centimeters	30.48	square feet	sq. meters	0.0929
feet	meters	0.3048	square feet	centistokes	92,903.0
feet	millimeters	304.8	square feet/sec.	sq. cms	6.452
foot-pounds	Newton-meters	1.356	square inches	sq. millimeters	645.2
foot-pounds/sec.	Newton meters/sec.	1.356	square meters	sq. feet	10.76
gallons (US)	liters	3.785	square meters	sq. yards	1.196
gallons/min.	cu in./min.	231.0	square meters	sq. inches	0.00155
gallons/min.	liters/min.	3.785	square millimeters	sq. meters	0.8361
gallons/min.	pounds of water/hr.	500.0	square yards	tons (metric)	1,000.0
grams	ounces (avdp)	0.3527	tons (metric)	pounds	2,205.0
grams/cu cm	pounds/cu ft	62.43	tons (short)	pounds	2,000.0
grams/cu cm	pounds/cu in.	0.03613	tons (short)	tons (metric)	0.9072
horsepower	foot-lbs/min.	33,000.00	yards	meter	0.9144
horsepower	foot-lbs/sec.	550.0			
horsepower (metric)	horsepower	0.9863			
horsepower	horsepower (metric)	1.014			
horsepower	watts	745.7			
inches	centimeters	2.54			
inches	meters	0.0254			
inches	millimeters	25.4			
inches of mercury	pounds/sq. in.	0.4912			
inches of water (4°C)	pounds/sq. in.	0.03613			
kilograms	pounds	2.205			
kilograms/cu meter	pounds/cu ft.	0.06243			
kilograms-calories	Btu	3.968			
kilopascal	bar	0.01			
kilopascal	psi	0.145			
kilowatt-hrs.	Btu	3,415.0			

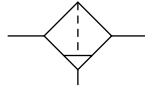


Circuit Symbols

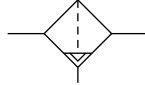
Direction of Flow in Pneumatic System



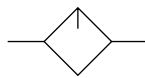
Manual Drain Filter



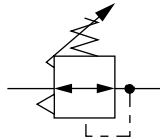
Automatic Drain Filter



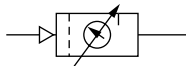
Lubricator



Airline Pressure Regulator (Adjustable, Relieving)



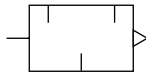
Airline Pressure Regulator & Lubricator With Gauge



Pressure Gauge



Muffler



Fixed Displacement Compressor



Unidirectional Motor



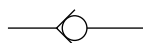
Bidirectional Motor



Adjustable Flow Control Valve



Check Valve



Valve Operations

Spring



Push Button



Manual Actuator



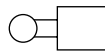
Push-Pull Lever



Pedal or Treadle



Mechanical Actuator



Pressure Compensated Actuator



Solenoid Actuator

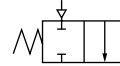


Solenoid and Pilot Actuator

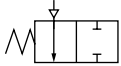


2-Way Valves

Normally Closed

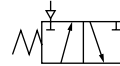


Normally Open

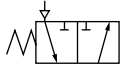


3-Way 2-Position Valves

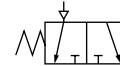
Normally Closed



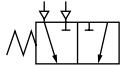
Normally Open



Distributor

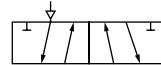


Selector

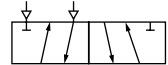


4-Way 2-Position Valves

Single Pressure



Dual Pressure

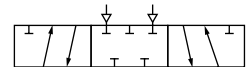
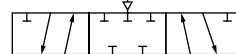


4-Way 3-Position Valves

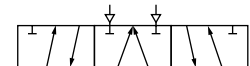
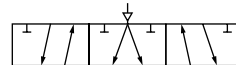
Single Pressure

Dual Pressure

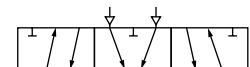
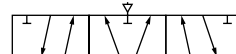
All Ports Blocked Center



Inlet To Cylinder Center



Cylinder To Exhaust Center



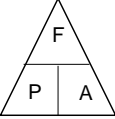


Useful Dimensional Data

Diameter	Internal Area Sq. In.			
	Circle Area	Hose	Std. Pipe	.032 Wall Copper Tubing
1/32 (.0312)	.00077			
1/16 (.0625)	.00307			
3/32 (.0938)	.0069			
1/8 (.1250)	.01227	.01227	.057	.0029
5/32 (.1562)	.01917			
3/16 (.1875)	.02761			.012
7/32 (.2188)	.03758			
1/4 (.2500)	.04909			.0271
9/32 (.2812)	.06213			
5/16 (.3125)	.0767			.0485
11/32 (.3438)	.09281			
3/8 (.3750)	.1104	.11	.191	.076
13/32 (.4062)	.1296			
7/16 (.4375)	.1503			.1095
15/32 (.4688)	.1726			
1/2 (.5000)	.1963	.196	.304	.149
17/32 (.5312)	.2217			
9/16 (.5625)	.2485			
19/32 (.5938)	.2769			
5/8 (.6250)	.3068	.307		.247
21/32 (.6562)	.3382			
11/16 (.6875)	.3712			
23/32 (.7188)	.4057			
3/4 (.7500)	.4418	.442	.533	.370
13/16 (.8125)	.5185			
7/8 (.8750)	.6013			
15/16 (.9375)	.6903			
1 (1.000)	.7854	.785	.864	.594
1-1/4 (1.250)	1.2272	1.227	1.496	.922
1-1/2 (1.500)	1.767		2.036	
2 (2.000)	3.1416	3.14	3.356	
2-1/2 (2.500)	4.9088		4.788	
3 (3.000)	7.07	7.07	7.39	
3-1/2 (3.500)	9.62			
4 (4.000)	12.57	12.57		
5 (5.000)	19.64			
6 (6.000)	28.27			
7 (7.000)	38.49			
8 (8.000)	50.27			
10 (10.000)	78.54			



Summary of Formulas and Equivalents

Area & Volume	$A = D^2 \times 0.7854$ (or $A = \pi R^2$) $V = D^2 \times 0.7854 \times L$ $\sqrt{\text{Area} / 0.7854}$ <small>(A = area in sq. in., diameter in inches, V = volume in cu. in., L = length)</small>
Temperature	Absolute temperature °R = °F + 460
Pressure	Standard conditions = 14.7 psia @ sea level (68°F, 36% Relative Humidity) Compression Ratio (standard conditions) – $\frac{\text{psig} + 14.7}{14.7}$ Compression Ratio (corrected for elevation) – $\frac{\text{psig} + \text{psia}}{\text{psia}}$ Pascal's Law –  $F = P \times A$ $F = \text{Force in lbs./sq. in.}$ $P = F/A$ $P = \text{Pounds (lbs)}$ $A = F/P$ $A = \text{Area in sq. in.}$ psig (standard conditions) = psia -14.7 psia (standard conditions) = psig +14.7
Flow	$\text{scfm} = (\text{area in sq. inches} \times \text{stroke inches} \times \text{CPM}^*) / 1728$ $\text{cfm} = \frac{\text{area in sq. inches} \times \text{velocity in ft./min.}}{144 \text{ in.}^2/\text{ft.}^2}$ $\text{scfm} = \text{cfm} \times \text{compression ratio}$ *CPM = Cycles per minute
Pressure Drop (ΔP)	$\text{psid} = P1 - P2$ $\Delta P \text{ Averaged for distance} = \frac{\text{psig rcvr.} - \text{psig tool}}{\text{distance ft.}}$
Pressure / Volume	Boyles Law – $P1V1 = P2V2$ General Gas Law – $\frac{P1V1}{T1} = \frac{P2V2}{T2}$ Charles Law (variation) – $P1 \times V1 \times T1 = P2 \times V2 \times T2$
Coefficient of Flow	$Cv = \frac{Q \text{ (scfm)}}{22.67} \sqrt{\frac{^\circ\text{F} + 460}{\Delta P \times K}}$ $K = P2 \text{ absolute...if } \Delta P \text{ is less than } 10\%$ $K = (P1 \text{ abs.} + P2 \text{ abs.}) / 2 \text{...if } \Delta P \text{ is } 10\% \text{ to } 25\%$ $K = P1 \text{ absolute...if } \Delta P \text{ is greater than } 25\% \text{ (critical velocity)}$
Line Drop	$\text{drop/inches} = \text{run/ft} \times \% \text{ grade} \times 0.12$ $\% \text{ grade} = (\text{drop/inches}/0.12) / \text{run/ft}$ 1% to 2% grade recommended
Compressed Air Cost	$\text{Cost} = \text{cfm} \times 60 \times \# \text{ hrs.} \times \text{kWh/cfm} \times \$/\text{kWh}$



Summary of Formulas and Equivalents

Vacuum	negative psig = inches Hg x 0.49 inches Hg = psi/0.49 inches Hg x 1.133 = ft. H ₂ O inches H ₂ O x 0.036 = psi 1 foot H ₂ O x 0.8826 = 1 inch Hg Force = -P x A Lifting force = inches Hg x 0.4912 x sq. in.area
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Receiver Sizing	$\text{Volume (gallons)} = K \times \text{cfm} \times \frac{14.7}{\text{psig} + 14.7} \times 7.48$ $\text{Volume (gallons)} = K \times \text{cfm} \times \frac{14.7}{\text{psig} + 14.7} \times \frac{1728}{231}$ (V = volume/gal. K = 1 continuous, K = 3 intermittent) (7.48 converts cu. ft. to gal.)
	$\text{Time} = \frac{\text{cu. ft. volume} \times (\text{Pmax-Pmin.})}{\text{cfm rcvr. consumption} \times 14.7}$

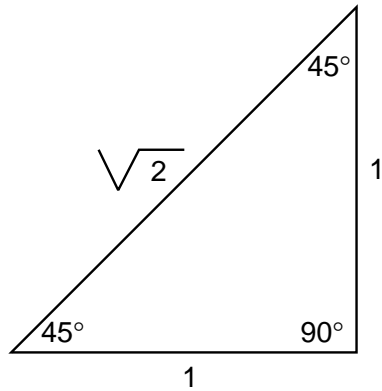
Cylinder Velocity	$\text{Velocity (ft./sec. extend)} = \frac{\text{inches stroke}}{\text{extend time seconds}} + \frac{\text{extended dwell sec.} \times 60}{12}$ $\text{Velocity (ft./sec. retract)} = \frac{\text{inches stroke}}{\text{extend time seconds}} + \frac{\text{extended dwell sec.} \times 60}{12}$
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Electrical	<div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> <p>("the eagle flies over the indian at the river")</p> </div> <div style="text-align: center;"> <p>("pie")</p> </div> </div> <div style="display: flex; justify-content: space-between;"> <div style="width: 30%;"> $E = I \times R$ $I = E / R$ $R = E / I$ </div> <div style="width: 30%;"> $P = I \times E$ $I = P / E$ $E = P / I$ </div> <div style="width: 30%;"> $P = I^2 R$ $P = E^2/R$ </div> </div> <p>(E = volts, I = amperes (current), R = Ohms (resistance), P = (Watts power))</p> <p>8 bit = 256 increments of resolution signal ratio (I/P) = amperes output / pressure input volts per inch = stroke / reference potential Kirchoffs Law – Rt = R1 + R2 + R3 (Rt = total resistance)</p>
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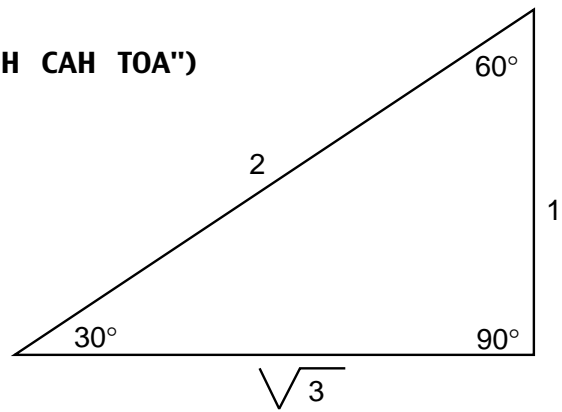
Moisture Content of Air	Dewpoint = Temperature at which moisture will condense Relative Humidity = (Absolute humidity / humidity at saturation x 100)
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Electrical



("SOH CAH TOA")



$\sin 30^\circ = .500$

$\cos 30^\circ = .866$

$\sin \theta = \text{opposite} / \text{hypotenuse}$

$\secant \theta = \text{hypotenuse} / \text{adjacent}$

$\tan \theta = \text{opposite} / \text{adjacent}$

$\text{hypotenuse} = \sqrt{(\text{adjacent squared} + \text{opposite squared})}$

$\sin 45^\circ = .707$

$\cos 45^\circ = .707$

$\cos \theta = \text{adjacent} / \text{hypotenuse}$

$\text{cosecant } \theta = \text{hypotenuse} / \text{opposite}$

$\text{cotan } \theta = \text{adjacent} / \text{opposite}$

$\sin 60^\circ = .866$

$\cos 60^\circ = .500$

Mechanical

$\text{Speed Ratio} = \frac{\text{driven shaft or gear}}{\text{drive shaft or gear}}$

$\text{Torque} = \text{force} \times \text{radius}$

$\text{Force} = \text{torque} / \text{radius}$

$\text{Motor Torque lb. - ft.} = 5252 \times \text{hp} / \text{rpm}$

$\text{Motor Torque lb.- in.} = 63025 \times \text{hp} / \text{rpm}$

$\text{Motor hp} = \text{lb. - in. torque} \times \text{rpm} / 5252$

$\text{Motor hp} = \text{lb. - in. torque} \times \text{rpm} / 63025$

$\text{Work} = \text{force} \times \text{distance}$

$\text{Power} = \text{force} \times \text{distance} / \text{time}$

$\text{Horsepower - hp} = \text{rpm} \times \text{ft. lb. torque} / 5252$

$\text{First class lever} = F_1 \times L_1 = F_2 \times L_2$ (F = force, L = Length)

$\text{Third class lever} = F_1 \times L_2 = F_2 \times L_1$ (F = force, L = length)



$\text{Mechanical advantage} = \text{total rod length} / \text{supported rod length}$

$\text{Bending moment} = \text{mechanical advantage} \times \text{side force}$

$\text{Total Force} = \text{coefficient of friction} \times \text{load}$

$\text{Up incline force} = \text{surface force} + \text{incline force}$

$\text{Down incline force} = \text{surface force} - \text{incline force}$

$\text{Surface force} = \text{coefficient of friction} \times \text{load} \times \cos \theta$

$\text{Incline force} = \text{load} \times \sin \theta$

$\text{Force along an incline} = F_1 \times D_1 = F_2 \times D_2$ (F = force, D = distance)

$\text{Rotary actuator torque - Torque} = \text{psig} \times \text{area} \times \text{pitch radius}$

**Mechanical Cont.**

Gripper – $F_1 \times L_1 = F_2 \times L_2$ or $F_2 = F_1 \times L_1 / L_2$ (F = force, L = load)
 Jib Crane force = $L \times (D_1 + D_2) / \sin \times D_1$
 Jib Crane load = $F \times \sin \times D_1 / (D_1 + D_2)$
 (L = load lbs., D1 = distance (in.) pivot to rod clevis. D2 = distance (in.) rod clevis to load)
 Feet per minute = $0.2618 \times \text{dia. inches} \times \text{rpm}$
 Inches Hg = inches H₂O / specific gravity Hg
 Intensifier sizing – Pressure air x area air = pressure oil x area oil
 Max. flow through an orifice (critical backpressure ratio) = > 53% P1 abs.
 GPM = Area in. x Stroke in. x cycles per mn. x 0.004329

Terminal Velocity = $2 \times \text{distance} / \text{time in seconds}$

Kinetic Energy (KE) = $\frac{\text{weight} \times \text{terminal velocity squared}}{2 \times \text{acceleration of gravity}}$
 (Acceleration of Gravity = 32.2 ft./sec./sec. OR 9.81 Meters/sec./sec.)

Conversions and Equivalents:

29.92 in. Hg = 14.7 psia
 760 mm Hg = 29.92 in. Hg = 33.899 ft-water = 10.34 Meters-water
 1 micron = 0.000001 meter = 0.000039 inch
 1 in. = 25,400 micron
 231 cu.in. = 1 gallon
 1728 cu. in. = 1 cu.ft.
 7.48 gallons = 1 cu. ft.
 1 micron Hg. = .0000193 psia
 Newton = 0.1022 Kilograms = .2248 lbs.
 Pounds = 4.448 Newtons
 Specific gravity of mercury (Hg) = 13.5951
 Specific gravity of water (H₂O) = 1
 1 mm Hg = 0.0446 ft. water
 Nm to Hp constant = 7124

Common Friction Factors

	<u>Valves</u>	<u>Friction Factors</u>
Gate Valves	full-open	0.19
	1/4 closed	1.15
	1/2 closed	5.60
	3/4 closed	24.00
	Globe valve	10.00
	Plug cock	0.26
	Swing check	2.50
	45° elbow	0.42
	90° elbow	0.90
	Close return bend	2.20
Standard tee	1.80	



Notes





Notes
