



AIR SYSTEM PIPING GUIDE

CONSIDERATIONS AND INSTALLATION TIPS FOR COMPRESSED
AIR DISTRIBUTION SYSTEMS





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INTRODUCTION

If compressed air is the lifeblood of a plant, then the piping is the veins and arteries that carry it to each point of use. While it is absolutely essential for a compressed air system to function, piping is often overlooked during optimization projects and it's also one of the first project costs cut when an installation budget needs trimming. Truth be told, piping material selection greatly impacts pressure drop, air quality, and leak load. Whether you are installing a brand new system or are considering upgrades to an existing one, this e-book will assist you in identifying the best piping materials for your application and also give you installation and maintenance tips to give you the best performance possible.

For the purposes of this e-book, it's assumed you have already identified the pressure, flow and air quality requirements of your system. If you are unsure, we strongly recommend you contact a compressed air system expert for help determining these system parameters.

This e-book should be used as a supplement to any service manuals with your compressed air equipment or piping materials.

Diagrams in this e-book are presented only as examples. They are not necessarily the best way of installing your particular system.

If you need assistance, consult your local authorized Kaeser representative for expertise in installing your piping system.

Throughout the e-book, there are boxes with efficiency tips and additional resources. The links included in those will take you directly to more information that our engineers and piping experts have selected specifically to further assist with your piping system.



PRESSURE DROP

CONSIDERATIONS FOR REDUCING PRESSURE DROP

Pressure drop is the reduction in pressure from the compressor discharge to points-of-use. While it is best practice to reduce pressure drop as much as possible, it is not possible to eliminate it completely. A well-designed system should not have a pressure drop of more than 10% from the compressor discharge to the farthest point in the distribution piping.

Pressure drop occurs as the compressed air travels to the point-of-use through compressors, filters, dryers, piping, and all fittings and valves in between. Any kind of obstruction will result in a loss of pressure.

While pressure drop is to be expected, having excessive pressure drop can lead to poor system performance and higher energy consumption. Flow restrictions require higher system pressure to overcome the restriction, causing higher than necessary energy consumption. As a matter of fact, every 2-psi increase causes approximately a 1% increase in compressor power. Since a compressed air system is quite often the highest electrical consumer in a plant, properly controlling pressure drop can offer significant savings opportunities.

When pressure drops at the point-of-use, the common reaction is to increase the pressure at the compressor. Unfortunately, this does nothing to address the root cause of the pressure drop.

At higher pressures, leaks will leak more and other forms of artificial demand (e.g. blow-off, sweeping) will waste more compressed air. Instead of turning up the pressure, take a look at your system and see why there is an issue.

For example, if you notice there are periods of time with intermittent demand—meaning periods of time when you need more air for a specific part of your process—look at adding storage to your system so you'll have extra air to supply that demand event.

If tools are under-pressurized, check the size of the line. Many times plants will add on tools as their process demand increases, but they never increase the size of the line. It is also possible that instead of piping, point-of-use distribution is completely hose. These are common causes of pressure drop that can easily be fixed.

Finally, if you have multiple compressors that are short cycling—ramping up and down—this can be because they are not properly controlled. In this case, add a master controller that can monitor your system demand and select the most efficient combination to meet it. However, if the short cycling is due to insufficient piping or excessive pressure drop in the compressor room, addressing these issues first can provide significant operational benefits.

Fix the problem instead of raising the pressure.

PIPING MATERIALS

CHEMISTRY AND COMPRESSED AIR PIPING

A large component of reducing compressed air system energy costs and increasing plant efficiency is choosing the right air distribution system. Here's an overview of common piping materials and some considerations to keep in mind when selecting pipe for your installation.



For those types of pipe subject to corrosion, over time rust and scale deposits can build up.

COMMON PIPING MATERIALS

Choose piping materials based on operating temperature and pressure of the compressed air. Keep in mind that compressed air can be contaminated with water, particulate, and oil. Therefore the piping must not deteriorate with the presence of these contaminants (as in the picture above).

The most common piping materials include stainless steel, aluminum, copper, galvanized iron, black iron, and PVC. The table on the next page lists the advantages and disadvantages of each. PVC is included in the chart because it's commonly used, but it's not a material we would recommend because of the safety concerns associated with installing it, as OSHA has stated that PVC is not safe for use in compressed air systems.

Generally speaking, aluminum and copper would be the best choices since they are not prone to build-up and will provide years of low pressure drop air delivery. Also, aluminum is available as a system—complete with perfectly matched connectors for leak-free design.

Copper is also a solid choice, however installation does require an open flame and quality brazing to prevent leaks. The material cost can also be high.

Stainless steel is not prone to build up or leaks, but it is very expensive and really only called for in specialty applications—if you need it, you'll know.

Material	Advantages	Disadvantages
Black iron	• Moderate material costs • Readily available in multiple sizes	• Labor-intensive installation • May rust and leak • Rough inside promotes contaminants to build up and creates pressure drop
Galvanized iron	• Moderate material costs • Readily available in multiple sizes • Some rust protection	• Often exterior is coated • Labor-intensive installation • May rust at joints and leak • Rough inside promotes contaminants to build up and creates pressure drop
Copper	• No rust, good air quality • Smooth interior - low pressure drop	• Requires quality brazing to prevent leaks • Susceptible to thermal cycling • Installation requires open flame
Stainless steel	• No rust, good air quality • Smooth interior - low pressure drop	• Labor intensive installation • Expensive materials
PVC	• Lightweight • Inexpensive	• Not recommended for compressed air • Lower safety • May not be code-compliant • Subject to bursting • Adhesives not compatible with compressor oils
Aluminum	• Corrosion resistant • Lightweight • Easy to install • Lower cost of ownership	• Limited pressure ratings • Material costs

GALVANIC CORROSION



Left: aluminum piping with rust and scale after one year of operation.

Right: pitting on the same aluminum pipe after cleaning.

Most compressed air systems are a hybrid of new and old. In these cases, piping connections can be made simply by putting two joints together, flanged or threaded. However, when it comes to chemical composition, connecting aluminum directly to brass or copper can cause a chemical reaction called galvanic corrosion. Over time any water present (such as condensate) will serve as a conductor, shedding electrons from one material to another. This can cause pitting corrosion, even in your new aluminum piping.

How to avoid galvanic corrosion in aluminum piping:

- Don't connect your aluminum directly to copper or brass; connect it to steel piping (but not stainless steel)
- Add a drip leg with a no-loss demand drain at the discharge of the compressor; get the condensate out of the system!
- Alternative to the drip leg, if your compressor does not have an internal centrifugal separator (with drain), add them at the discharge to the compressor.
- Slope the compressor discharge piping so that any condensate runs downhill and doesn't have an opportunity to pool in the piping.

To avoid pitting avoid angles and pockets in which water can accumulate. Use shapes that promote draining (i.e. sloping the pipe, don't install piping in a U).

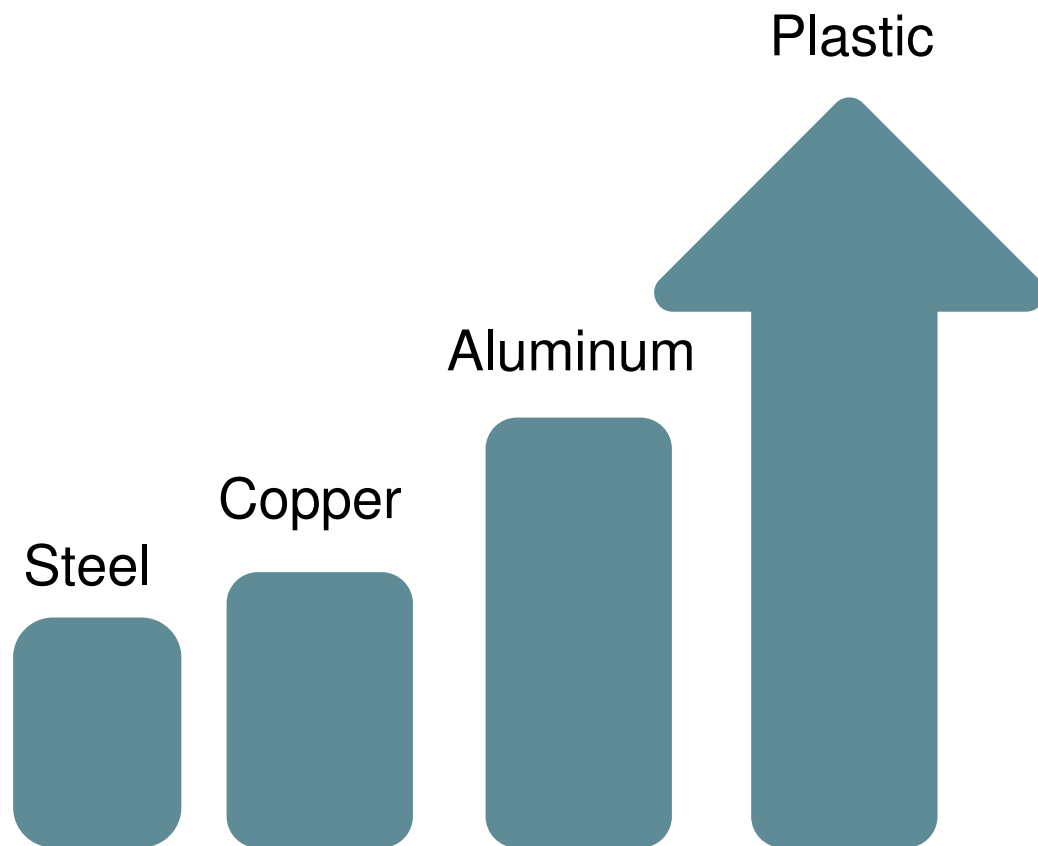
Read our blog post for more on galvanic corrosion.



THERMAL EXPANSION

All piping materials experience thermal expansion—some materials more than others. If thermal expansion and contraction is not compensated for in the system design, it can have long-term, damaging effects. Leaks from stressing threads and soldered points and compromised couplings are just a few examples.

Expansion hoses and anti-whiplash straps can be installed to help compensate. Any time temperature changes from area to area consider adding an expansion hose, as well as at the compressor discharge. For specific guidance, contact your piping manufacturer or supplier.



PVC IS NOT RECOMMENDED FOR USE WITH COMPRESSED AIR.

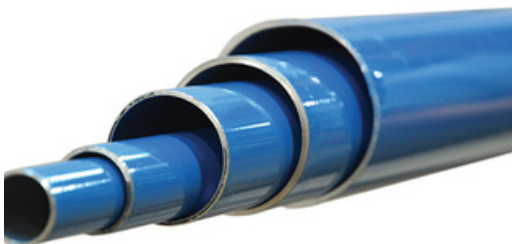
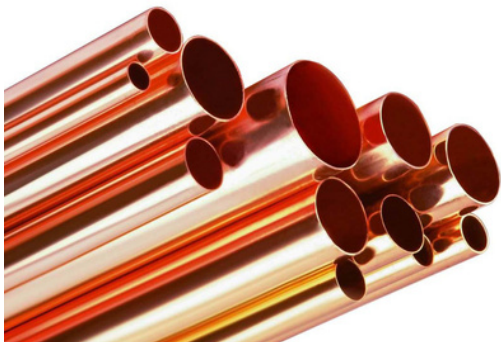
INSTALLATION CONSIDERATIONS

BEST PRACTICES FOR AN EFFICIENT SYSTEM



When selecting piping for an installation, consider the following:

- Material cost: Will you need to purchase special tools to install or maintain the pipe?
- Installation: Will you need to outsource? Also, do you anticipate growth or making changes to your piping? (Aluminum pipe can be disassembled easily and adding in drops to accommodate growth is fast. Copper is not as quick to install as aluminum, but it is still faster than threaded pipe).
- Air quality: Can your process tolerate contamination from rust or other build-up flaking off from the pipe? (Black iron and galvanized iron are notorious for this).
- Maintenance: Do you have the time and manpower to continually monitor and fix leaks that can occur with materials that are more susceptible to rusting at joints and leaking? (A concern for black iron and galvanized iron. Also, the brazing on copper should be inspected regularly).
- Safety: We recommend that when our technicians find a system with PVC or other piping not rated for compressed air that they complete a safety observation form and instruct the customer and then perform the service (or start-up) once they have addressed the safety issue.



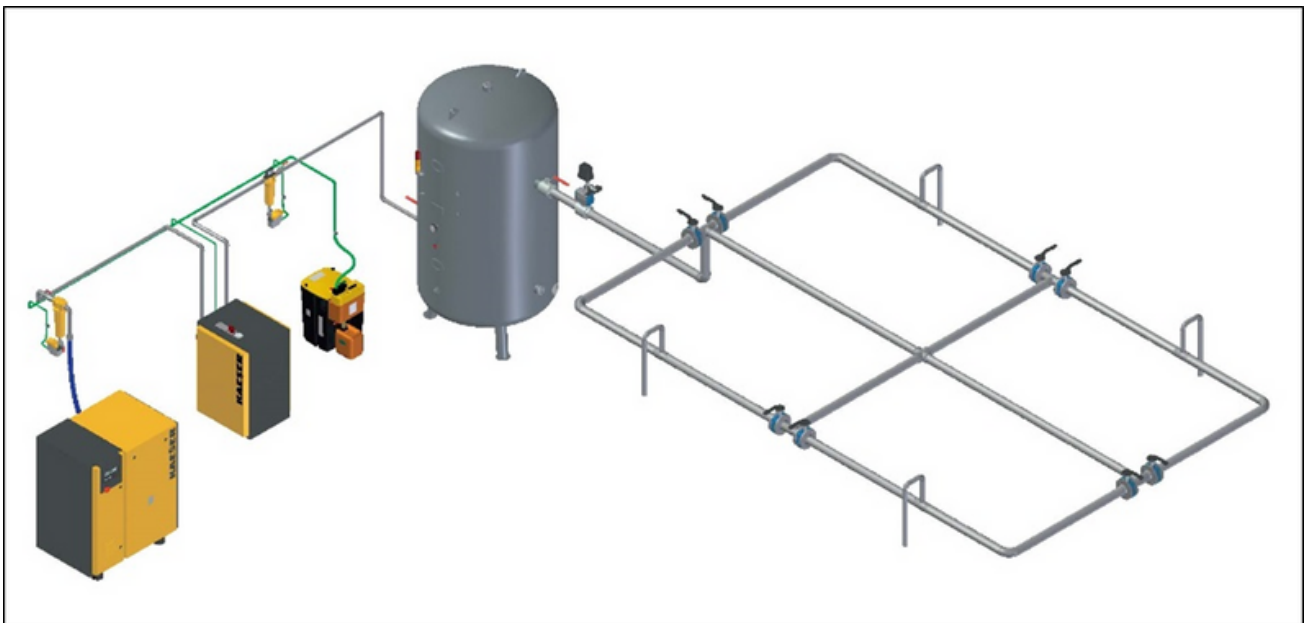
When it's time to choose piping materials, look at more than the cost of the pipe. Think about your system needs today and long term. Looking ahead can help you make the right investment at the right time.

[Read our blog post for more tips on material selection.](#)

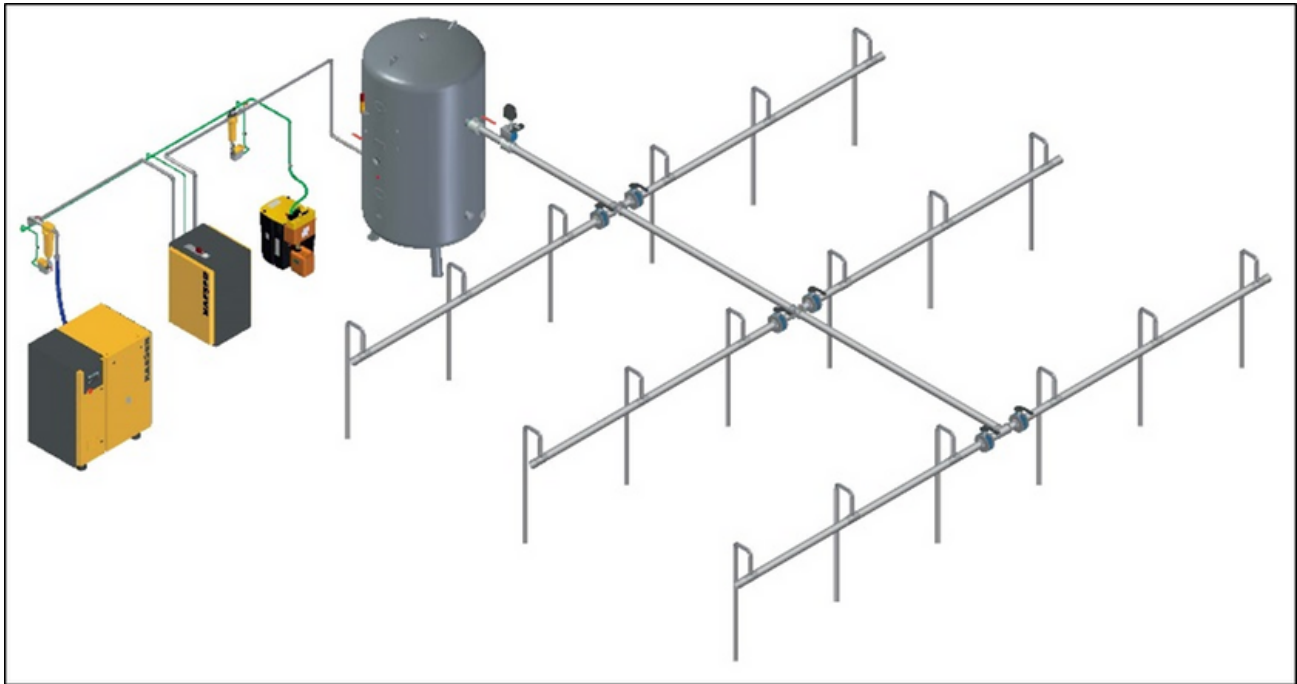


INSTALLATION BEST PRACTICES

There are three main types of piping network distribution design: ring (or looped), branch, and combination. With a ring pipe network, it's possible to use smaller diameter piping and the overall ring can be sized roughly for half of the flow volume and length. To address possible problems with pressure fluctuations we recommend using point-of-use storage and metered supply valves to ensure stable plant pressure throughout the network.



A branch pipe network require less pipework than a ring, but they need a larger piping diameter comparatively. If pressure drop becomes problematic, they can be expanded into a combination pipe network.



The combination pipe network offers the best of both piping network designs. The piping diameter can be smaller (thanks to the ring) and it's still easy to isolate sections of piping with strategically placed valves. In determining the size for the main header, look to the future and make sure it's sized adequately enough for future expansion. This will reduce the likelihood of future pressure drop issues and save you time, money, and headaches down the road.

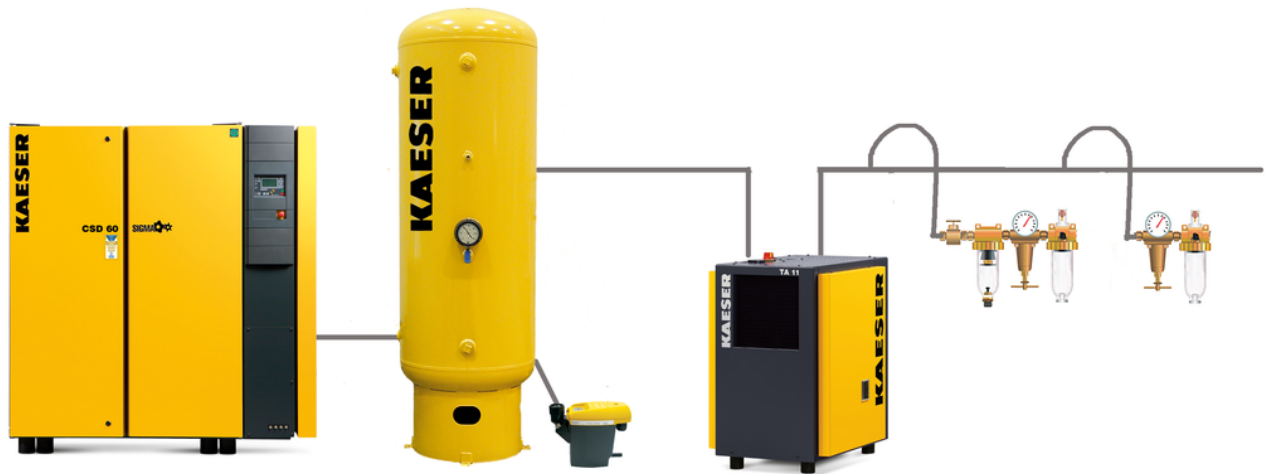


For systems without a dryer, most of the condensate occurs in the distribution network. To prevent condensate build-up, the line should slope downward at least 2° and include a condensate drain at the lowest point. Any point-of-use applications should be connected to the main line with a swan neck, to keep the condensate in the main line.

If you are connecting one or more compressors that don't include an integrated moisture separator, they should be connected with a swan neck as well to prevent condensate from back-flowing to the compressor.

Use automatic condensate drains to prevent compressed air loss.





Systems with a dryer do not need to have a slope in the piping. It is important to pipe the points-of-use so the outlet is at the top (swan neck). This prevents condensate from damaging any air consumers should the refrigerated dryer fail.

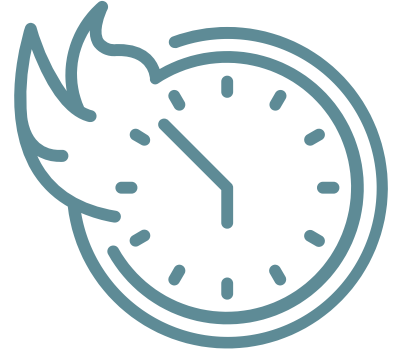
As with the previous example, if you are connecting one or more compressors that don't include an integrated moisture separator, they should be connected with a swan neck as well to prevent condensate from back-flowing to the compressor.

The after-filter and components, including piping, fittings, seals, etc. downstream of a heated desiccant dryer, must be rated for 400°F (204°C).

VELOCITY

Another key factor in pipe design is velocity. The velocity of compressed air in piping has a number of effects:

- Pressure drop. The higher the velocity, the greater the pressure drop. This is because air molecules are colliding with the pipe walls more often, creating friction and upsetting good laminar flow.
- Reduced air quality. High air velocity reduces contact time in dryers, and they may not dry the air to specification. The result is moisture in tools and equipment. Further, high velocities can tear filters and allow particulate through. In both cases, equipment may require more maintenance or have more downtime, and there is increased risk of product contamination.
- Loosening pipe rust and scale. In iron piping, rust and scale may be carried downstream, clogging compressed air filters at the point of use and impacting production equipment. Over time, this may erode the pipe walls, leading to leaks.
- Noise and vibration. Increased turbulence may cause piping and pneumatics to vibrate and chatter. This could even lead to loose fittings including at points of use.



The ideal velocity for compressed air piping depends on a number of factors, including the length of the piping, and the pressure requirements. We recommend minimizing the compressed air velocity in the compressor room to **15 feet per second**. In the main distribution header the velocity should be **30 feet per second**, and in the point-of-use piping the velocity should be a maximum of **45 feet per second**.

Here are some additional tips for minimizing the effects of velocity on compressed air piping:

1. Use the correct pipe size. The larger the pipe diameter, the lower the velocity will be. The CAGI Handbook has a good guide for pipe sizing based on pressure and flow.
2. Apply controls to multiple compressors. If multiple compressors feed the same pipe but don't have a common controller, they may unnecessarily come online at the same time and deliver excess flow, increasing velocity and wasting power.
3. Apply flow controls. Flow controls between the supply side and demand side can be used to pressurize the downstream piping more smoothly to prevent high velocities that overrun dryers and damage filters, especially during periods when the system is being pressurized after being off. Flow controls can also be used to isolate intermittent high flow uses from the rest of the system.
4. Find and eliminate leaks to reduce demand (and therefore flow). For the same reason, replace timed condensate drains with reliable no-loss demand drains on all moisture collection points to reduce air demand.

LEAKS

COST AND LEAK DETECTION

A single, small hole that is 1/4" in diameter costs you approximately \$1,246 every month (at 90 psig).



Compressed air systems have leaks. Some are present from the time of installation while others develop over time. Regardless of the source, they can greatly reduce operating effectiveness and cost a lot in energy. The U.S. Department of Energy estimates that as much as 25% of compressed air is lost to leaks - and it's higher in many plants.

Kaeser recommends a post-installation leak check as well as periodic leak detection checks. Upon commissioning, the system can be checked for leaks by simply charging the system with air and not using air. If the compressor cycles on to recharge the system or if the pressure drops at the storage tank, there are leaks.

We recommend annual leak audits to identify and fix leaks that develop over time.

The chart below shows how much even a single leak can cost you year after year. An annual leak detection plan can help you stay ahead of the game.

Leak Size	90 psig	100 psig
1/16"	\$933	\$1,112
1/4"	\$14,948	\$17,818
3/8"	\$33,586	\$40,051
1/2"	\$59,761	\$71,271

Annual leak cost based on 8,760 operating hours and \$0.10 kW/h. See Appendix B for more information.



LEAK DETECTION

There are three main methods for leak detection: listen and feel, soapy water, and ultrasonic. Listen and feel is exactly what it sounds like—walking the length of the piping, listening for hissing leaks, and then touching the pipe to help locate the leak. This approach is simple and straightforward for finding large leaks. As it does require direct physical contact with the piping, it may not be practical nor would it be the safest.

Using the soapy water method involves applying a soapy mixture to the areas suspected of leaking and waiting for bubbles to form. This is also simple and reliable, yet time consuming. Like the listen and feel method, it requires direct contact with the piping and neither can give any information on the volume of the leak.

The industry standard is ultrasonic leak detection. While this method requires special equipment and some training, it is fast and accurate. It can even detect leaks as small as a pinhole. Perhaps the biggest benefit for this method is that it can provide the volume of the leak and calculate how much money is being lost to each one. This can be helpful in prioritizing which leaks to fix first.

The chart on the next page compares each leak detection method.

Method	Advantages	Disadvantages
Listen and feel	• Simple • Quickly identifies large leaks • No special tools requireds	• Only effective for large leaks • Requires direct physical contact • Must be able to hear above the plant equipment • Will not work for most leaks • Give no information on leak volume
Soapy water	• Reliable • Simple • No special tools required	• Time consuming • Requires direct physical contact • Give no information on leak volume
Ultrasonic	• Versatile • Can detect leaks as smsall as a pinhole • Fast and accurate • Does not require plant downtime • Does not require physical contact	• Requires special equipment

Contact your local authorized Kaeser representative for assistance obtaining leak savings information for other pressures.



CALCULATORS

HOW TO MONETIZE AND PLAN

The following pages include formulas and instructions for common calculations associated with piping.

Use our Kaeser Toolbox, which includes online calculators and other helpful tips.



PRESSURE DROP

To calculate pressure drop, you'll need to know the pressure drop due to friction, pipe diameter, length of pipe, initial pressure, and flow rate of the system.

For the below example, we'll use the pressure drop due to friction at 100 psig chart (below).

Formula:

Piping Pressure Drop =

$$\frac{\text{Pressure drop due to friction} \times \text{System Pipe Length (ft.)} \times (\text{Pressure} + 14.5)}{\text{Pipe Length} \times (\text{Initial Pressure} + 14.5)}$$

Example:

What is the pressure drop in a 2-inch pipe, 350 feet in length, with an initial pressure of 85 psig, and a flow rate of 500 cfm of free air?

$$\frac{19.2 \times 350 \text{ (ft.)} \times (100 + 14.5)}{1,000 \text{ (ft.)} \times (85 + 14.5)} = 7.73 \text{ psi}$$

In this example, 7.73 psi is 10% of the generation pressure; we would recommend going up a size for your piping.

Table 4.7 Loss of Air Pressure Due to Friction

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
1.28	6.50	.99	0.28								
2.56	25.9	3.90	1.11	0.25	0.11						
3.84	58.5	9.01	2.51	0.57	0.26						
5.12		16.0	4.45	1.03	0.46						
6.41		25.1	9.96	1.61	0.71	0.19					
7.68		36.2	10.0	2.32	1.02	0.28					
8.96		49.3	13.7	3.16	1.40	0.37					
10.24		64.5	17.8	4.14	1.83	0.49					
11.52		82.8	22.6	5.23	2.32	0.62					
12.81			27.9	6.47	2.86	0.77					
15.82			48.6	10.2	4.49	1.19					
19.23			62.8	14.6	6.43	1.72	0.21				
22.40				19.8	8.72	2.36	0.28				
25.62				25.9	11.4	3.06	0.37				
31.64				40.4	17.9	4.78	0.58				
38.44				58.2	25.8	6.85	0.84	0.20			
44.80					35.1	9.36	1.14	0.27			
51.24					45.8	12.1	1.50	0.35			
57.65					58.0	15.4	1.89	0.46			
63.28					71.6	19.2	2.34	0.55			
76.88						27.6	3.36	0.79			

Chart courtesy of Compressed Air and Gas Institute (CAGI).

LEAK LOAD

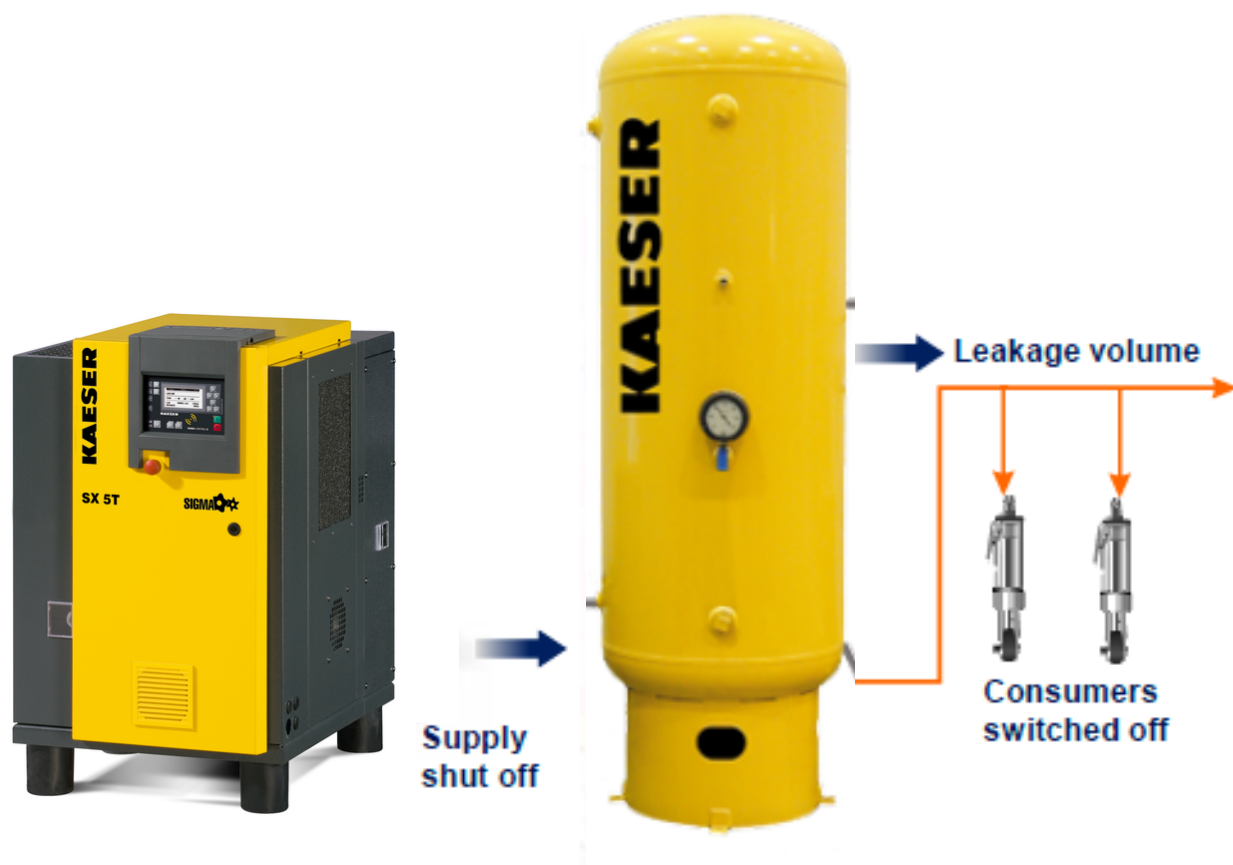
You can measure your system's total leak load using the pressure gauge on your air receiver. In order for this approach to be effective, you need to have an estimate of the total system volume (V) which would include all downstream air receivers, air mains, and piping (in cfm).

The system is started and brought up to operating pressure (P1). Then, you measure the time it takes (T) for the system to drop to a lower pressure (P2). This point should be approximately one-half of the operating pressure.

It's a good idea to take several time measurements and then average them.

$$\text{Leakage (cfm)} = [V \times (P1 - P2)] / [(T \times 14.7) \times 1.25]$$

The 1.25 multiplier is used to allow for reduced leakage with falling system pressure.



Compressor run times can also be used to measure leak load. This method can be applied for a complete compressed air system or a section of the distribution network, providing it can be isolated.

For this method, all compressed air users are off and the compressor is started. Then, the time it takes for the compressor to load and unload is measured. This is done several times to get a good average length of time.

$$\text{Leakage (\%)} = [(T \times 100) / (T + t)]$$

t = off-load time (minutes)

T = on-load time (minutes)

Note that many downstream users are constant users of compressed air, whether they are running or not. Therefore, it may be advantageous to add a solenoid valve to close the compressed air supply and only run compressed air to the equipment when it is required.



SAFETY ADVISORIES

HEALTH AND SAFETY CONSIDERATIONS

The piping installation should be conducted in a safe manner in accordance with OSHA and appropriate local regulations.

Before doing any work on a piping distribution system, the system should be de-pressurized. If working on a particular section of the system, that part of the system should be isolated from the main and de-pressurized.

When working in a lift, technicians should use a proper harness and rigging.

The piping distribution system must be installed so that normal operation poses no threat to work health or safety.

Follow OSHA recommendations for electrical lock-out/tag-out and compressed air blow-down precautions.

Follow all safety recommendations in the manufacturer's service manual.



Compressed air can provide significant forces. Always wear the proper PPE when working in a compressed air system.



ADDITIONAL RESOURCES

MORE TIPS AND RESOURCES

Looking for more information on piping and compressed air topics? Check out the following resources:

- us.kaeser.com/blog
Our company blog posts on a wide range of compressed air topics written by our subject matter experts and is updated regularly. You can also sign up to follow the blog to receive updates whenever there is a new blog post.
- us.kaeser.com/resources
This page has a collection of technical articles, safety data sheets (SDS), tools, and more.
- us.kaeser.com/whitepapers
Our collection of white papers provides in-depth technical information on challenges those in the compressed air industry are currently facing.

Don't forget about the Kaeser Toolbox, which includes online calculators and other helpful tips.



APPENDICES

CHARTS AND REFERENCES

APPENDIX A

LOSS OF PRESSURE DROP DUE TO FRICTION

Charts taken from the Compressed Air and Gas Handbook. Visit www.cagi.org for more information.

Table 4.5 Loss of Air Pressure Due to Friction													
Cu ft Free Air Per Min	Equivalent		Nominal Diameter, In.										
	Cu ft Compressed Air Per Min	1/2	3/4	1	1 1/4	1 1/2	2	3	4	6	8	10	12
10	1.96	10.0	1.53	0.43	0.10								
20	3.94	39.7	5.99	1.71	0.39	0.18							
30	5.89	....	13.85	3.86	0.88	0.40							
40	7.86	....	24.7	6.85	1.59	0.71	0.19						
50	9.84	....	38.6	10.7	2.48	1.10	0.30						
60	11.81	....	55.5	15.4	3.58	1.57	0.43						
70	13.75	....	....	21.0	4.87	2.15	0.57						
80	15.72	....	....	27.4	6.37	2.82	0.75						
90	17.65	....	....	34.7	8.05	3.57	0.57	0.37					
100	19.60	....	....	42.8	9.95	4.40	1.18						
125	19.4	....	....	46.2	12.4	6.90	1.83	0.14					
150	29.45	....	....	....	22.4	9.90	2.64	0.32					
175	34.44	....	....	....	30.8	13.40	3.64	0.43					
200	39.40	....	....	....	39.7	17.60	4.71	0.57					
250	49.20	....	....	....	....	27.5	7.37	0.89	0.21				
300	58.90	....	....	....	....	39.6	10.55	1.30	0.31				
350	68.8	....	....	....	....	54.0	14.4	1.76	0.42				
400	78.8	....	....	....	....	....	18.6	2.30	0.53				
450	88.4	....	....	....	....	....	23.7	2.90	0.70				
500	98.4	....	....	....	....	....	29.7	3.60	0.85				
600	118.1	....	....	....	....	....	42.3	5.17	1.22				
700	137.5	....	....	....	....	....	57.8	7.00	1.67				
800	157.2	....	....	....	....	....	....	9.16	2.18				
900	176.5	....	....	....	....	....	....	11.6	2.76				
1,000	196.0	....	....	....	....	....	....	14.3	3.40				
1,500	294.5	....	....	....	....	....	....	32.3	7.6	0.87	0.29		
2,000	394.0	....	....	....	....	....	....	57.5	13.6	1.53	0.36		
2,500	492	....	....	....	....	....	....	....	21.3	2.42	0.57	0.17	
3,000	589	....	....	....	....	....	....	....	30.7	3.48	0.81	0.24	
3,500	688	....	....	....	....	....	....	....	41.7	4.68	1.07	0.33	
4,000	788	....	....	....	....	....	....	....	54.5	6.17	1.44	0.44	
4,500	884	....	....	....	....	....	....	....	....	7.8	1.83	0.55	0.21
5,000	984	....	....	....	....	....	....	....	....	9.7	2.26	0.67	0.27
6,000	1,181	....	....	....	....	....	....	....	....	13.9	3.25	0.98	0.38
7,000	1,375	....	....	....	....	....	....	....	....	18.7	4.43	1.34	0.51
8,000	1,572	....	....	....	....	....	....	....	....	24.7	5.80	1.73	0.71
9,000	1,765	....	....	....	....	....	....	....	....	31.3	7.33	2.20	0.87
10,000	1,960	....	....	....	....	....	....	....	....	38.6	9.05	2.72	1.06
11,000	2,165	....	....	....	....	....	....	....	....	46.7	10.9	3.29	1.28
12,000	2,362	....	....	....	....	....	....	....	....	55.5	13.0	3.90	1.51
13,000	2,560	....	....	....	....	....	....	....	....	....	15.2	4.58	1.77
14,000	2,750	....	....	....	....	....	....	....	....	....	17.7	5.32	2.07
15,000	2,945	....	....	....	....	....	....	....	....	....	20.3	6.10	2.36
16,000	3,144	....	....	....	....	....	....	....	....	....	23.1	6.95	2.70
18,000	3,530	....	....	....	....	....	....	....	....	....	29.2	8.80	3.42
20,000	3,940	....	....	....	....	....	....	....	....	....	36.2	10.8	4.22
22,000	4,330	....	....	....	....	....	....	....	....	....	43.7	13.2	5.12
24,000	4,724	....	....	....	....	....	....	....	....	....	51.9	15.6	5.92
26,000	5,120	....	....	....	....	....	....	....	....	....	....	18.3	7.15
28,000	5,500	....	....	....	....	....	....	....	....	....	....	21.3	8.3
30,000	5,890	....	....	....	....	....	....	....	....	....	....	24.4	9.5

In psi in 1000 ft of pipe, 60 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.

Table 4.6 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	1.55	7.90	1.21	0.34										
20	3.10	31.4	4.72	1.35	0.31									
30	4.65	70.8	10.9	3.04	0.69	0.31								
40	6.20	....	19.5	5.40	1.25	0.56								
50	7.74	....	30.5	8.45	1.96	0.87								
60	9.29	....	43.8	12.16	2.82	1.24	0.34							
70	10.82	....	59.8	16.6	3.84	1.70	0.45							
80	12.40	....	78.2	21.6	5.03	2.22	0.59							
90	13.95	....	....	27.4	6.35	2.82	0.75							
100	15.5	....	....	33.8	7.85	3.74	0.93							
125	19.4	....	....	46.2	12.4	5.45	1.44							
150	23.2	....	....	76.2	17.7	7.82	2.08							
175	27.2	....	....	....	24.8	10.6	2.87							
200	31.0	....	....	....	31.4	13.9	3.72	0.45						
250	38.7	....	....	....	49.0	21.7	5.82	0.70						
300	46.5	....	....	....	70.6	31.2	8.35	1.03						
350	54.2	....	....	....	....	42.5	11.4	1.39	0.33					
400	62.0	....	....	....	....	55.5	14.7	1.82	0.42					
450	69.7	....	....	....	....	....	18.7	2.29	0.55					
500	77.4	....	....	....	....	....	23.3	2.84	0.67					
600	92.9	....	....	....	....	....	33.4	4.08	0.96					
700	108.2	....	....	....	....	....	45.7	5.52	1.32					
800	124.0	....	....	....	....	....	59.3	7.15	1.72					
900	139.5	....	....	....	....	....	....	9.17	2.18					
1,000	155	....	....	....	....	....	....	11.3	2.68					
1,500	232	....	....	....	....	....	....	25.5	6.0	0.69				
2,000	310	....	....	....	....	....	....	45.3	10.7	1.21	0.29			
2,500	387	....	....	....	....	....	....	70.9	16.8	1.91	0.45			
3,000	465	....	....	....	....	....	....	....	24.2	2.74	0.64	0.19		
3,500	542	....	....	....	....	....	....	....	32.8	3.70	0.85	0.26		
4,000	620	....	....	....	....	....	....	....	43.0	4.87	1.14	0.34		
4,500	697	....	....	....	....	....	....	....	54.8	6.15	1.44	0.43		
5,000	774	....	....	....	....	....	....	....	67.4	7.65	1.78	0.53	0.21	
6,000	929	....	....	....	....	....	....	....	....	11.0	2.57	0.77	0.29	
7,000	1,082	....	....	....	....	....	....	....	....	14.8	3.40	1.06	0.40	
8,000	1,240	....	....	....	....	....	....	....	....	19.5	4.57	1.36	0.54	
9,000	1,395	....	....	....	....	....	....	....	....	24.7	5.78	1.74	0.69	
10,000	1,550	....	....	....	....	....	....	....	....	30.5	7.15	2.14	0.84	
11,000	1,710	....	....	....	....	....	....	....	....	36.8	8.61	2.60	1.01	
12,000	1,860	....	....	....	....	....	....	....	....	43.8	10.3	3.08	1.19	
13,000	2,020	....	....	....	....	....	....	....	....	51.7	12.0	3.62	1.40	
14,000	2,170	....	....	....	....	....	....	....	....	60.2	14.0	4.20	1.63	
15,000	2,320	....	....	....	....	....	....	....	....	68.5	16.0	4.82	1.84	
16,000	2,480	....	....	....	....	....	....	....	....	78.2	18.2	5.48	2.13	
18,000	2,790	....	....	....	....	....	....	....	....	....	23.0	6.95	2.70	
20,000	3,100	....	....	....	....	....	....	....	....	....	28.6	8.55	3.33	
22,000	3,410	....	....	....	....	....	....	....	....	....	34.5	10.4	4.04	
24,000	3,720	....	....	....	....	....	....	....	....	....	41.0	12.3	4.69	
26,000	4,030	....	....	....	....	....	....	....	....	....	48.2	14.4	5.6	
28,000	4,350	....	....	....	....	....	....	....	....	....	55.9	16.8	6.3	
30,000	4,650	....	....	....	....	....	....	....	....	....	64.2	19.3	7.5	

In psi in 1000 ft of pipe, 80 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.

Table 4.7 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				
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.

Table 4.8 Loss of Air Pressure Due to Friction

Cu ft Free Air Per Min	Equivalent Cu ft Compressed		Nominal Diameter, In.											
	Air Per Min		1/2	3/4	1	1 1/4	1 1/2	2	3	4	6	8	10	12
10	1.05	5.35	0.82	0.23										
20	2.11	21.3	3.21	0.92	0.21									
30	3.16	48.0	7.42	2.07	0.47	0.21								
40	4.21	.....	13.2	3.67	0.85	0.38								
50	5.26	.....	20.6	5.72	1.33	0.59								
60	6.32	.....	29.7	8.25	1.86	0.84	0.23							
70	7.38	.....	40.5	11.2	2.61	1.15	0.31							
80	8.42	.....	53.0	14.7	3.41	1.51	0.40							
90	9.47	.....	68.0	18.6	4.30	1.91	0.51							
100	10.50	.....	.....	22.9	5.32	2.36	0.63							
125	13.15	.....	.....	39.9	8.4	3.70	0.98							
150	15.79	.....	.....	51.6	12.0	5.30	1.41	0.17						
175	18.41	.....	.....	.....	16.3	7.2	1.95	0.24						
200	21.05	.....	.....	.....	21.3	9.4	2.52	0.31						
250	26.30	.....	.....	.....	33.2	14.7	3.94	0.48						
300	31.60	.....	.....	.....	47.3	21.2	5.62	0.70						
350	36.80	.....	.....	.....	.....	28.8	7.7	0.94	0.22					
400	42.10	.....	.....	.....	.....	37.6	10.0	1.23	0.28					
450	47.30	.....	.....	.....	.....	47.7	12.7	1.55	0.37					
500	52.60	.....	.....	.....	.....	58.8	15.7	1.93	0.46					
600	63.20	.....	.....	.....	.....	.....	22.6	2.76	0.65					
700	73.80	.....	.....	.....	.....	.....	30.0	3.74	0.89					
800	84.20	.....	.....	.....	.....	.....	40.2	4.85	1.17					
900	94.70	.....	.....	.....	.....	.....	51.2	6.2	1.48					
1,000	105.1	.....	.....	.....	.....	.....	63.2	7.7	1.82					
1,500	157.9	.....	.....	.....	.....	.....	.....	17.2	4.1	0.47				
2,000	210.5	.....	.....	.....	.....	.....	.....	30.7	7.3	0.82	0.19			
2,500	263.0	.....	.....	.....	.....	.....	.....	48.0	11.4	1.30	0.31			
3,000	316	.....	.....	.....	.....	.....	.....	69.2	16.4	1.86	0.43			
3,500	368	.....	.....	.....	.....	.....	.....	.....	22.3	2.51	0.57	0.18		
4,000	421	.....	.....	.....	.....	.....	.....	.....	29.2	3.30	0.77	0.23		
4,500	473	.....	.....	.....	.....	.....	.....	.....	37.0	4.2	0.98	0.24		
5,000	526	.....	.....	.....	.....	.....	.....	.....	45.7	5.2	1.21	0.36		
6,000	632	.....	.....	.....	.....	.....	.....	.....	65.7	7.5	1.74	0.52	0.20	
7,000	738	.....	.....	.....	.....	.....	.....	.....	.....	10.0	2.37	0.72	0.27	
8,000	842	.....	.....	.....	.....	.....	.....	.....	.....	13.2	3.10	0.93	0.38	
9,000	947	.....	.....	.....	.....	.....	.....	.....	.....	16.7	3.93	1.18	0.47	
10,000	1,051	.....	.....	.....	.....	.....	.....	.....	.....	20.6	4.85	1.46	0.57	
11,000	1,156	.....	.....	.....	.....	.....	.....	.....	.....	25.0	5.8	1.76	0.68	
12,000	1,262	.....	.....	.....	.....	.....	.....	.....	.....	29.7	7.0	2.09	0.81	
13,000	1,368	.....	.....	.....	.....	.....	.....	.....	.....	35.0	8.1	2.44	0.95	
14,000	1,473	.....	.....	.....	.....	.....	.....	.....	.....	40.3	9.7	2.85	1.11	
15,000	1,579	.....	.....	.....	.....	.....	.....	.....	.....	46.5	10.9	3.26	1.26	
16,000	1,683	.....	.....	.....	.....	.....	.....	.....	.....	53.0	12.4	3.72	1.45	
18,000	1,893	.....	.....	.....	.....	.....	.....	.....	.....	66.9	15.6	4.71	1.83	
20,000	2,150	.....	.....	.....	.....	.....	.....	.....	.....	.....	19.4	5.8	2.20	
22,000	2,315	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.4	7.1	2.74	
24,000	2,525	.....	.....	.....	.....	.....	.....	.....	.....	.....	27.8	8.4	3.17	
26,000	2,735	.....	.....	.....	.....	.....	.....	.....	.....	.....	32.8	9.8	3.83	
28,000	2,946	.....	.....	.....	.....	.....	.....	.....	.....	.....	37.9	16.4	4.4	
30,000	3,158	.....	.....	.....	.....	.....	.....	.....	.....	.....	43.5	13.1	5.1	

In psi in 1000 ft of pipe, 125 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.

Table 4.9 Loss of Air Pressure Due to Friction

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	611	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			

Table 4.9 Loss of Air Pressure Due to Friction (continued)

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
1,100							723	88.4	21.0	2.4			
1,200							850	105.2	25.0	2.8			
1,300								123.4	29.3	3.3			
1,400									33.9	3.8			
1,500									39.0	4.4			
1,600									44.3	5.1			
1,700									50.1	5.7			
1,800									56.1	6.4			
1,900									62.7	7.1	1.6		
2,000									69.3	7.8	1.8		
2,100									76.4	8.7	2.0		
2,200									83.6	9.5	2.2		
2,300									91.6	10.4	2.4		
2,400									99.8	11.3	2.6		
2,500									108.2	12.3	2.9		
2,600									117.2	13.3	3.1		
2,700									126	14.3	3.3		
2,800									136	15.4	3.6		
2,900									146	16.5	3.9		
3,000									156	17.7	4.1		
3,200									177	20.1	4.7		
3,400									200	22.7	5.3		
3,600									224	25.4	5.6	1.8	
3,800									250	28.4	6.6	2.0	
4,000									277	31.4	7.3	2.2	
4,200									305	34.6	8.1	2.4	
4,400									335	38.1	8.9	2.7	
4,600									366	41.5	9.7	2.9	
4,800									399	45.2	10.5	3.2	
5,000									433	49.1	11.5	3.4	
5,250									477	54.1	12.6	3.4	
5,500									524	59.4	13.9	4.2	1.6
5,750										64.9	15.2	4.6	1.8
6,000										70.7	16.5	5.0	1.9
6,500										82.9	19.8	5.9	2.3
7,000										96.2	22.5	6.8	2.6
7,500										110.5	25.8	7.8	3.0
8,000										125.7	29.4	8.8	3.6
9,000										159	37.2	10.2	4.4
10,000										196	45.9	13.8	5.4
11,000										237	55.5	16.7	6.5
12,000										282	66.1	19.8	7.7
13,000										332	77.5	23.3	9.0
14,000										387	89.9	27.0	10.5
15,000										442	103.2	31.0	12.0
16,000										503	117.7	35.3	13.7
18,000										636	148.7	44.6	17.4
20,000											184	55.0	21.4
22,000											222	66.9	26.0
24,000											264	79.3	30.1
26,000											310	93.3	36.3
28,000											360	108.0	42.1
30,000											413	123.9	48.2

*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.

APPENDIX B

DISCHARGE OF AIR THROUGH AN ORIFICE

Chart taken from the Compressed Air and Gas Handbook. Visit www.cagi.org for more information.

Table 4.11 Discharge of Air through an Orifice

Gage Pressure before Orifice, psi	Nominal Diameter, In.										
	1/64	1/32	1/16	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1
	Discharge, Cu. ft. Free Air Per Min.										
1	.028	0.112	0.450	1.80	7.18	16.2	28.7	45.0	64.7	88.1	115
2	.040	0.158	0.633	2.53	10.1	22.8	40.5	63.3	91.2	124	162
3	.048	0.194	0.775	3.10	12.4	27.8	49.5	77.5	111	152	198
4	.056	0.223	0.892	3.56	14.3	32.1	57.0	89.2	128	175	228
5	.062	0.248	0.993	3.97	15.9	35.7	63.5	99.3	143	195	254
6	.068	0.272	1.09	4.34	17.4	39.1	69.5	109	156	213	278
7	.073	0.293	1.17	4.68	18.7	42.2	75.0	117	168	230	300
9	.083	0.331	1.32	5.30	21.1	47.7	84.7	132	191	260	339
12	.095	0.379	1.52	6.07	24.3	54.6	97.0	152	218	297	388
15	.105	0.420	1.68	6.72	26.9	60.5	108	168	242	329	430
20	.123	0.491	1.96	7.86	31.4	70.7	126	196	283	385	503
25	.140	0.562	2.25	8.98	35.9	80.9	144	225	323	440	575
30	.158	0.633	2.53	10.1	40.5	91.1	162	253	365	496	648
35	.176	0.703	2.81	11.3	45.0	101	180	281	405	551	720
40	.194	0.774	3.10	12.4	49.6	112	198	310	446	607	793
45	.211	0.845	3.38	13.5	54.1	122	216	338	487	662	865
50	.229	0.916	3.66	14.7	58.6	132	235	366	528	718	938
60	.264	1.06	4.23	16.9	67.6	152	271	423	609	828	1,082
70	.300	1.20	4.79	19.2	76.7	173	307	479	690	939	1,227
80	.335	1.34	5.36	21.4	85.7	193	343	536	771	1,050	1,371
90	.370	1.48	5.92	23.7	94.8	213	379	592	853	1,161	1,516
100	.406	1.62	6.49	26.0	104	234	415	649	934	1,272	1,661
110	.441	1.76	7.05	28.2	113	254	452	705	1,016	1,383	1,806
120	.476	1.91	7.62	30.5	122	274	488	762	1,097	1,494	1,951
125	.494	1.98	7.90	31.6	126	284	506	790	1,138	1,549	2,023

Based on 100% coefficient of flow. For well-rounded entrance multiply values by 0.97. For sharp-edged orifices a multiplier of 0.65 may be used.

This table will give approximate results only. For accurate measurements see ASME Power Test Code, Velocity Volume Flow Measurement.

Values for pressures from 1 to 15 psig calculated by standard adiabatic formula.

Values for pressures above 15 psig calculated by approximate formula proposed by S. A. Moss: $w = 0.5303 a C P_1 \sqrt{T_1}$ where w = discharge in lb per sec, a = area of orifice in sq. in., C = coefficient of flow, P_1 = upstream total pressure in psia, and T_1 = upstream temperature in deg F abs.

Values used in calculating above table were $C = 1.0$, P_1 = gage pressure + 14.7 psi, $T_1 = 530$ F abs.

Weights (w) were converted to volumes using density factor of 0.07494 lb. per cu. ft. This is correct for dry air at 14.7 psia and 70°F.

Formula cannot be used where P_1 is less than two times the barometric pressure.

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MANAGER

At KAESER, we believe the more you know about proper system design and operation, the more you'll get out of it. That's why we are committed to offering you the most current information you need to wisely install, operate, and maintain yours. This e-book was written for you by Kaeser's piping and system design experts.

Your piping is a key part of your compressed air system and how it is installed and maintained will impact your overall system's efficiency for years to come. The goal of this e-book is to help you select the right materials, install them safely, and maintain them properly for a safe, efficient, and long-lasting compressed air distribution system.

We recognize that each system and application is unique, but applying the principles you read here is an excellent place to start. For the best in system optimization that is tailored to your needs, contact us for additional support.

[Learn more about our authors](#)





THE AIR SYSTEM SPECIALISTS

We earn our customers' business by supplying superior quality equipment and services. Our products are designed for reliable performance, easy maintenance, and energy efficiency. Prompt and dependable customer service, quality assurance, training, and engineering support contribute to the value our customers have come to expect from KAESER. Our employees are committed to implementing and maintaining the highest standards of quality to merit customer satisfaction. We aim for excellence in everything we do.

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