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Pipe size calculation for compressed air supply

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Abstract

Pipe designers and engineers often encounter complex mathematical equations to determine the diameter required for adequate compressed air at specific flow velocities. This article aims to simplify the calculation of compressed air pipe sizes. The formulas and factors derived herein can be utilized for determining pipe diameters in compressed air applications. Ultimately, the findings provide engineers and designers with practical tools to enhance the reliability and efficiency of compressed air system.

Keywords: Handy formula for Compressed air pipe size calculation; Volumetric flow rate of compressed air; Compressed air Pipe diameter calculation; How to calculate the pipe size for compressed air flow; pipe design for compressed air. Compressed air velocity in industrial application

1. Introduction

In compressed air systems, proper pipe sizing is critical to ensure optimal performance, minimize pressure drops, and avoid energy losses. Incorrect pipe sizes can lead to inefficiencies, causing higher energy consumption or insufficient pressure at end-use points. In this article, we'll walk through the pipe size calculation using a formula that incorporates flow rate, velocity, and pressure, along with an example calculation. We'll also cover essential precautions, considerations, and limitations to help you design an effective compressed air system. Our handy formula significantly streamlines the compressed air pipe sizing process, enabling designers to achieve accurate results in a fraction of the time required by conventional methods. Traditional calculations often involve complex equations and lengthy analyses, requiring frequent reference other resources, which can be cumbersome and time-consuming. By simplifying these calculations, our formula reduces the workload for engineers while maintaining accuracy.

2. Key Factors in Compressed Air Pipe Sizing

Before diving into calculations, understanding the variables affecting pipe size is essential:

- ***Flow Rate (Q):*** The volume of air flowing through the pipe, typically measured in cubic feet per minute (CFM) or Liters per second (L/s).
- ***FAD & SCFM:*** Free air delivery (FAD) is a measurement of the volume of air drawn into a compressor and delivered at a specific pressure. When FAD is normalized to standard conditions, it's expressed as standard cubic feet per minute (SCFM)
- ***Operating Pressure (P):*** The pressure at which the system operates, often expressed in pounds per square inch (PSI) or bar.
- ***Pipe Length (L):*** The distance the air needs to travel, which includes the total length of the pipe run.

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- ***Pressure Drop (ΔP):*** The allowable pressure loss from friction over the length of the pipe, generally kept within 10% of the operating pressure.
- ***Pipe Material:*** The friction factor of the material, as different materials (steel, aluminium, copper) have varying smoothness affecting pressure loss.
- ***Absolute Pressure (Pa):*** The total pressure at sea level, which is usually taken as 14.7 PSI.
- ***Compressor Gauge Pressure (Pd):*** The pressure of the air supplied by the compressor, measured in PSI (pounds per square inch).

3. Compressed Air Pipe Size Calculation Formula

The continuity equation, written as Q = AV, is essential in fluid dynamics as it demonstrates the relationship among volumetric flow rate, cross-sectional area, and fluid velocity. In this equation, Q denotes the volumetric flow rate, A signifies the cross-sectional area of the pipe or channel, and V indicates the fluid's velocity. Comprehending this equation is vital for engineers and designers when selecting pipe sizes and optimizing fluid transport across different applications.

Derivation of formula for Compressed air pipe size calculation:

$$Q = AV$$

$$A = \frac{Q}{V} \ldots\ldots\ldots\ldots (i)$$

The compressed air flow is generally referred to as CFM (cubic feet per minute) and its velocity in FPS (feet per second).

$$A = \frac{144 * Q}{60 * V} \ldots\ldots\ldots\ldots (ii)$$

Where:

- A : Cross-sectional area of the pipe bore (square inches)
- D : Pipe diameter (Inch)
- V : Average velocity in the pipe (FPS – feet per second)
- Q : Volumetric flow rate of Compressed air (CFM – cubic feet per minute)

Here, Q represents the volume of airflow per minute. However, this airflow is measured in SCFM (Standard Cubic Feet per Minute) at sea level atmospheric pressure. We need to calculate the pipe size for compressed air at a specific pressure, which we will refer to as Pd.

Let’s calculate the air volume at Pd pressure (it is gauge pressure)

Boyle's Law states that for a given amount of gas, at constant temperature, the pressure and volume are inversely proportional. In other words, as pressure increases, volume decreases, and vice versa, as long as the temperature and the amount of gas remain constant. The equation can be expressed as:

$$V2 = \frac{P1V1}{P2}$$

Where:

- P1, V1 : are the initial pressure and volume.
- P1, V2 : are the final pressure and volume.

Initial pressure is (Pa) and the final pressure is (Pd).

$$V2 = \frac{V1 * Pa}{(Pd + Pa)} \ldots\ldots\ldots\ldots (iii)$$

V1 is the initial volume of the air at the Pa pressure. And Q is the initial volumetric flow of air at Pa pressure. To calculate the pipe size for compressed air at Pd pressure we have to put the final volumetric flow of air at Pd pressure. Hence from equation (ii) and (iii).

$$A = \frac{144 * Q * Pa}{60 * V * (Pd + Pa)}$$

Where:

- Pa : Prevailing absolute pressure (typically 14.7 PSI at sea level).
- Pd : The pressure of the air supplied by the compressor, measured in PSI (pounds per square inch)

Once you have cross-sectional area A, you can calculate the pipe diameter (D) using the formula:

$$D = \sqrt{\frac{4A}{\pi}}$$

Where:

- D : Pipe diameter (inches)
- A : Cross-sectional area of the pipe (square inches)

This formula ensures that the pipe size accommodates the flow rate and pressure in the system.

4. Step By Step Calculation – Examples

Let's work through an example where we need to size a header for a system delivering 500 SCFM at a pressure of 100 PSI at sea level, with a design velocity of 30 ft/s.

4.1. Step 1: Define the Parameters

- Flow rate, Q = 500 SCFM
- Absolute pressure, Pa = 14.7 PSI
- Compressor gauge pressure, Pd = 100 PSI
- Design velocity, V = 30 ft/s

4.2. Step 2: Calculate the Cross-Sectional Area

$$A = \frac{144 * Q * Pa}{60 * V * (Pd + Pa)}$$

$$A = \frac{144 * 500 * 14.7}{60 * 30 * (100 + 14.7)}$$

First, calculate the denominator:

$$60 * 30 * (100 + 14.7) = 60 * 30 * 114.7 = 206460$$

Now, calculate the numerator:

$$114 + 500 + 14.7 = 1058400$$

Now, divide the numerator by the denominator to find the cross-sectional area:

$$A = \frac{1058400}{206460} = 5.13 \; square \; inches$$

4.3. Step 3: Calculate the Pipe Diameter

Once we have the cross-sectional area, we can calculate the pipe diameter using:

$$D = \sqrt{\frac{4A}{\pi}}$$

$$D = \sqrt{\frac{4 * 5.13}{3.14}} = \sqrt{\frac{20.52}{3.14}} = \sqrt{6.54} = 2.56\ inches$$

Thus, the pipe diameter required for this system is approximately **2.56 inches = 2.56 x 25.4 mm = 65.02 mm**

5. Simplification of calculation and generation of Handy formula

In Indian industries, compressed air is commonly referred to in terms of CFM (cubic feet per minute), pressure is expressed in bars, and the velocity of compressed air is measured in meters per second. To create a handy formula, we will incorporate these values as they are, without converting them to other units

Let's make a handy formula for pipe size calculation for compressed air at specific velocity and pressure.

$$A = \frac{144 * Q * Pa}{60 * V * (Pd + Pa)}$$

$$D = \sqrt{\frac{4A}{\pi}}$$

$$D = \sqrt{\frac{4 * 144 * Q * Pa}{\pi * 60 * V * (Pd + Pa)}}$$

$$D = \sqrt{Q} * \sqrt{\frac{4 * 144 * Pa}{\pi * 60 * V * (Pd + Pa)}} \dots\dots\dots\dots (iv)$$

In the equation (iv), If the velocity (V) and pressure (Pd) is fixed then the value of $\left(\sqrt{\frac{4*144*Pa}{\pi*60*V*(Pd+Pa)}}\right)$ will be a constant, Lets call it "C3".

$$\boldsymbol{D = \sqrt{Q} \times C3}$$

Where, C3 is the constant value at a fixed velocity and fixed pressure of compressed air flow in pipeline. Let's call it DC factor for "Compressed air pipe size calculation". The above formula provides a straightforward method for calculating pipe sizes based on a given velocity and pressure of compressed air.

DC factor for Compressed air pipe size calculation: The values of DC factor at different velocity are given in Table 1 for compressed air pipe size calculation.

Table 1 DC Factor for Compressed air pipe size calculation 'C3' at different velocity and pressure

PRESSURE BARG	DC Factor for Compressed air pipe size calculation 'C3'					
	Factor at 6 m/sec velocity	Factor at 8 m/sec velocity	Factor at 10 m/sec velocity	Factor at 12 m/sec velocity	Factor at 14 m/sec velocity	Factor at 15 m/sec velocity
3.0	5.03	4.35	3.90	3.56	3.29	3.18
3.5	4.74	4.11	3.67	3.35	3.10	3.00
4.0	4.50	3.90	3.48	3.18	2.95	2.85
4.5	4.29	3.72	3.32	3.03	2.81	2.71
5.0	4.11	3.56	3.18	2.90	2.69	2.60
5.5	3.95	3.42	3.06	2.79	2.58	2.50
6.0	3.80	3.29	2.95	2.69	2.49	2.41
6.5	3.68	3.18	2.85	2.60	2.41	2.32
7.0	3.56	3.08	2.76	2.52	2.33	2.25
7.5	3.45	2.99	2.67	2.44	2.26	2.18
8.0	3.36	2.91	2.60	2.37	2.20	2.12
8.5	3.27	2.83	2.53	2.31	2.14	2.07
9.0	3.18	2.76	2.47	2.25	2.08	2.01
10.0	3.04	2.63	2.35	2.15	1.99	1.92

How to use "Handy Formula" :

- To calculate the pipe diameter in millimetres, multiply the square root of the flow Q value in CFM (cubic feet per minutes) by the DC factor at the selected velocity from Table 1.
- Please note that the calculated pipe size refers to the inner diameter of the pipe.

5.1. Examples

Size a header for a system delivering 600 SCFM at a pressure of 7 barG with a design velocity of 6 mps.

5.2. Solution

- Flow rate, Q = 600 SCFM
- Compressor gauge pressure, P = 7.0 barG
- Design velocity, V = 6.0 mps

First find the "C3" / DC factor for compressed air pipe at 6.0 mps velocity and 8 bar gauge pressure. = 3.56

$$D = \sqrt{Q} \times C3$$

$$D = \sqrt{600} \times 3.56\, mm$$

$$D = 87.2\, mm$$

As we can see, the calculation of compressed air pipe size becomes significantly easier and quicker by utilizing the DC factor.

Continuity equation, written as Q

6. Velocity of compressed air flowing in the pipe

The recommended velocity for air flowing through compressed air pipes typically falls within the range of 20 to 40 feet per second (ft/s), or 6 to 12 meters per second (m/s).

However, the ideal velocity depends on the specific section of the compressed air system:

6.1. Main Header Pipe (Large Pipes)

- 20 to 30 ft/s (6 to 9 m/s) is recommended.
- A lower velocity here minimizes pressure losses over long distances, which is critical in maintaining system efficiency.

6.2. Branch Lines and Smaller Pipes

- 30 to 40 ft/s (9 to 12 m/s) can be acceptable.
- In smaller pipes or branch lines where the air is delivered to the equipment, slightly higher velocities are tolerable as they minimize the pipe diameter without causing excessive losses.

6.3. Very Short Runs or Drops

- Slightly higher velocities may be tolerated, up to 50 ft/s (15 m/s), for short pipe runs or final drops to machinery.

6.4. Precautions, Considerations, and Limitations

6.4.1. Avoid Excessive Air Velocity

While increasing the velocity of air can reduce the pipe size, it can also result in higher friction losses. Excessive velocity (above 40 ft/s) can cause turbulence, vibration, and noise, leading to increased pressure drops. Always ensure that the design velocity is kept between 20 to 40 ft/s for optimal performance.

6.4.2. Pressure Drop Limitation

When designing a compressed air system, aim to limit the pressure drop to no more than 10% of the compressor's working pressure or as per design calculation and required residual pressure at consumption point. If the pressure drop exceeds this value, consider increasing the pipe diameter. Pressure drops lead to higher energy consumption as the compressor needs to work harder to compensate for the losses.

6.4.3. Long Pipe Runs

The length of the pipe affects the overall pressure drop in the system. Longer pipes result in greater friction, which causes significant pressure losses. For extended pipe runs, you may need to increase the pipe size to maintain proper pressure levels at the point of use.

6.4.4. Impact of Fittings and Bends

Elbows, valves, and other fittings introduce additional friction, which increases the overall pressure drop. When calculating the effective pipe length, consider the equivalent length of the fittings:

- A 90-degree elbow can add an equivalent length of 10-15 pipe diameters.
- A fully open gate valve can add an equivalent length of about 10 pipe diameters.

Always factor in these losses during the pipe size calculation, and consider using smoother, long-radius bends to reduce friction.

6.4.5. Material Considerations

Different materials used for piping (such as steel, copper, aluminium, or plastic) have different roughness levels, which affect the friction factor. For example:

- Steel pipes typically have higher friction due to their rough internal surfaces.

- Aluminum or copper pipes offer smoother surfaces, reducing friction and pressure losses.

Choosing a material with a lower friction factor can help maintain pressure and reduce energy consumption.

6.4.6. Altitude Adjustments

The formula used assumes sea level conditions (where absolute pressure Pa=14.7 PSI). If your system operates at higher altitudes, the atmospheric pressure will be lower, requiring an adjustment to the value of Pa. For example, at an elevation of 5,000 feet, Pa is closer to 12.2 PSI. This decrease in pressure means that larger pipes may be necessary to compensate for reduced air density.

6.4.7. Temperature Effects

Air density changes with temperature, and this can impact your calculations. For high-temperature applications, the air expands and becomes less dense, which can increase the required pipe diameter. Always factor in temperature variations, especially in systems where air is exposed to extreme heat or cold.

6.4.8. Future Expansion

It's essential to consider potential future expansions or increased demand. If there's a likelihood that your system's air demand will grow, it may be prudent to install larger pipes initially to avoid costly rework later. Oversizing the pipe by a small margin can save significant costs in the long run.

6.4.9. Maintenance Access

Larger diameter pipes can facilitate easier cleaning and maintenance. In systems where moisture, dust, or oil might accumulate, ensuring that maintenance access is easy can reduce downtime and improve system longevity.

Glossary

- CFM : Cubic feet per minute
- PSI : Pond per square inches
- FPS : Feet per second
- mps : Meter per sec
- C3 : Dinesh Chauhan's factor (DC Factor) for Compressed air pipe size calculation.

7. Conclusion

The DC factor is a multiplying factor at a particular velocity of compressed air at specific pressure to calculate the pipe diameter by multiplying it with the square root of volumetric flow (CFM). By using the DC factor, the calculation becomes very easy to calculate the compressed air pipe size.

Correct pipe sizing ensures optimal system performance and minimizes pressure losses. By using the formula provided, you can calculate the proper pipe size for your compressed air system based on the flow rate, pressure, and velocity.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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