The secret *is i*n the p*i*pe – there's no such thing as too large a compressed air line

By Hank van Ormer, Don van Ormer & Scott van Ormer (AirPower USA)

A common error we see in compressed air systems, in addition to poor piping practice, is line sizes too small for the desired air flow.

This isn't limited to the interconnecting piping from compressor discharge to dryer to header. It also applies to the distribution lines conveying air to production areas and within the equipment found there. Undersized piping restricts the flow and reduces the discharge pressure, thereby robbing the user of expensive compressed air power. Small piping exacerbates poor piping practices by increasing velocity- and turbulence-induced backpressure.

Pipe size and layout design are the most important variables in moving air from the compressor to the point of use. Poor systems not only consume significant energy dollars, but also degrade productivity and quality. How does one properly size compressed air piping for the job at hand? You could ask the pipefitter, but the answer probably will be, "What we always do," and often that's way off base. Another approach is matching the discharge connection of the upstream piece of equipment (filter, dryer, regulator or *compressor). Well, a 150-hp, two-stage, reciprocating, double*-acting, water-cooled compressor delivers about 750 cfm at 100 psig through a 6-in. port. But most 150-hp rotary-screw compressors, on the other hand, deliver the same volume and pressure through a 2-in.or 3-in. connection. So, which one is right? It's obvious which is cheaper, but port size isn't a good guide to pipe size.

Charts and graphs

Many people use charts that show the so-called standard pressure drop as a function of pipe size and fittings, which sizes the line for the what is referred to as an acceptable pressure drop. This practice, too, can be misleading because the charts can't accommodate velocity- and flow-induced turbulence. Think about it. According to the charts, a short run of small bore pipe exhibits a low total frictional pressure drop, but the high velocity causes an extremely large, turbulence-driven pressure drop. Then there's the question of the meaning of acceptable pressure drop. The answer to this question often isn't supported by data, such as the plant's electric power cost to produce an additional psig.

We've audited many plants during the past 20 years and found the unit cost of air for positive-displacement compressors runs from several hundred dollars per psig per year to several thousand dollars per psig per year. At current energy costs, you don't want the pipe to be a source of pressure drop.

Table 1. Compression ratios at gauge pressures

psig	Compression ratio
60	5.05
70	5.76
80	6.44
90	7.12
100	7.8
110	8.48
120	9.16
130	9.84
140	10.52
150	11.20
200	14.5

Shooting blind

Not knowing the energy cost of lost pressure as a function of line size can lead to a blind decision. Unfortunately, this is what we find in most of the air piping systems installed during the past 30 years. Older systems that were designed with care are often right on the mark, except if they've been modified after the original installation. Some might call pipe sizing a lost art, but we see the issue as a lack of attention to detail, basic piping principles and guidelines. Read on to learn how to size air piping using velocity, which, when combined with appropriate piping practice, ensures an efficient compressed-air distribution system. As compressed-air system consultants and troubleshooters, we use these guidelines to design new piping systems and to analyze existing system performance and opportunities for improvement.

Interconnects and headers

The interconnecting piping is a critical element that must deliver air to the distribution headers with little pressure loss, if any. This isn't only an energy question. It also ensures the capacity controls will have sufficient effective storage to allow them to react to real demand and translate less air usage to a comparable reduction in input electrical energy. The main distribution headers not only move air throughout the plant, they also supply the appropriate local storage that ensures the process feeds have adequate entry pressure and flow. The main header system represents storage that supports the operating pressure band for capacity control. <u>You want the pressure drop between compressor discharge and point of use to be significantly less than the normal operating control band (10 psig maximum).</u>

The targets

The objective in sizing interconnecting piping is to transport the maximum expected volumetric flow from the compressor discharge through the dryers, filters and receivers to the main distribution header with minimum pressure drop. Contemporary designs that consider the true cost of compressed air target a total pressure drop of less than 3 psi. Beyond this point, the objective for the main header is to transport the maximum anticipated flow to the production area and provide an acceptable supply volume for drops or feeder lines. Again, modern designs consider an acceptable header pressure drop to be 0 psi. Finally, for the drops or feeder lines, the objective is to deliver the maximum anticipated flow to the work station or process with minimum or no pressure loss. Again, the line size should be sized for near-zero loss. Of course, the controls, regulators, actuators and air motors at the work station or process have requirements for minimum inlet pressure to be able to perform their functions. In many plants, the size of the line feeding a work station often is selected by people who don't know the flow demand and aren't aware of how to size piping. In our opinion, new air-system piping should be sized according to these guidelines. For a system that doesn't meet the criteria, the cost of modification must be weighed against the energy savings and any improvements in productivity and quality. Obviously, <u>the lower the pressure drop in transporting air, the lower the system's energy input. Lower header pressure also reduces unregulated air flow (including leaks) by about 1% per psi of pressure reduction.</u>

Eliminate the drop

Most charts show frictional pressure drop for a given flow at constant pressure. Wall friction causes most of this loss, which is usually denominated as pressure drop per 100 ft. of pipe. Similar charts express the estimated pressure loss for fittings in terms of additional length of pipe. When added to the length of straight pipe, the sum is called total equivalent length. These charts reflect the basic calculations for pressure loss, which include:

- Air density at a given pressure and temperature.
- Flow rate.
- Velocity at pipeline conditions.
- The Reynolds number.
- Other factors, including a friction factor based on the size and type of pipe.

The calculations and chart data help to identify only the probable minimum pressure drop. Internal roughness and scaling dramatically affect the pipe's resistance to flow (friction loss). Resistance increases with time as the inner wall rusts, scales and collects more dirt. This is particularly true of black iron pipe. Pressure drop is proportional to the square of the velocity. Any high-volume, intermittent demand produces dramatic pressure drop during peak periods. Ignoring this fact affects every process connected to the header.

For a given size pipe:

- At constant pressure, the greater the flow, the greater the loss per foot of pipe.

• At constant flow rate, the lower the inlet pressure, the greater the loss per foot of pipe.
• At any condition, smooth-bore pipe (copper, stainless steel) exhibits lower friction losses.

Air velocity
The most overlooked idea in piping layout and design is air velocity. Excessive velocity can be a root cause of backpressure, erratic control signals, turbulence and turbulence-driven pressure drop.
The British Compressed Air Society suggests that a velocity of 20 fps or less prevents carrying moisture and debris past drain legs and into controls. A velocity greater than 30 fps is sufficient to transport any water and debris in the air stream. Thus, the recommended design pipeline velocity for interconnecting piping and main headers is 20 fps or less, and never to exceed 30 fps. Field testing reveals that, under these conditions, air stream turbulence is generally negligible. Line drops, feed lines or branch lines less than 50 ft. long work well at a velocity of 30 fps, but velocity here should not exceed 50 fps.

Crunching numbers
First, look at the velocity at maximum anticipated flow conditions using the following equation:

$$V = 3.056 * Q/D2 \qquad \text{(Eqn 1)}$$

Where V = air velocity (ft./sec.)
Q = volumetric flow rate (cfm)
D = conduit inside diameter (inches)

Although this method of determining the minimum pipe size on the basis of air velocity is easy, you also must consider that the compressed air volume is expressed in cubic feet per minute of free air, which is the air volume at ambient atmospheric conditions, not the compressed volume. To adjust the inlet air volumetric flow rate to actual pipeline conditions, you'll need to divide the volume of free air by the compression ratio using the following equation:

$$CR = (P+Pa)/Pa \qquad \text{(Eqn 2)}$$

Where P = line pressure (psig)
Pa = average atmospheric pressure at your elevation (psi)

Table 1 shows the compression ratio as a function of gauge pressure for a location at sea level, where the atmospheric pressure is 14.7 psi. At higher elevations, the average atmospheric pressure drops and the compression ratio rises. For example, Flagstaff, Ariz., at a 7,000-ft. elevation, has an average atmospheric pressure of about 11 psi. At 100 psig, the compression ratio is equal to 10 (i.e. 111/11). To determine the pipeline velocity at conditions, merely divide the velocity given in Equation 1 by the compression ratio given in Equation 2. After selecting the minimum pipe size on the basis of velocity, check any long runs for excessive pressure drop using an appropriate drop chart. For example, a velocity of 25 fps in black iron pipe represents about 0.25 psi loss per 100 ft. of run. Although this is a little above the recommended minimum of 20 fps and, depending on the layout, would probably be acceptable from a turbulence standpoint, a high total frictional loss might dictate using a larger pipe. This might seem to be somewhat complicated at first, but it's the most accurate way to avoid problems in sizing compressed air piping. Once you get the hang of it, it's easy to use.
After carefully selecting a conduit size that eliminates unnecessary loss, be sure to pay the same attention to downstream items such as quick disconnects, regulators, filters, controls, fittings, number of drops from a given header and number of connections per header, so as not to offset the gains made with the pipe.

Good piping performance is not an accident — it takes planning.

Hank van Ormer, Don van Ormer and Scott van Ormer are owners of
AirPower USA, Pickerington, Ohio. Contact them at
HankvanOrmer@aol.com and (740) 862-4112.
Figures: AirPower USA