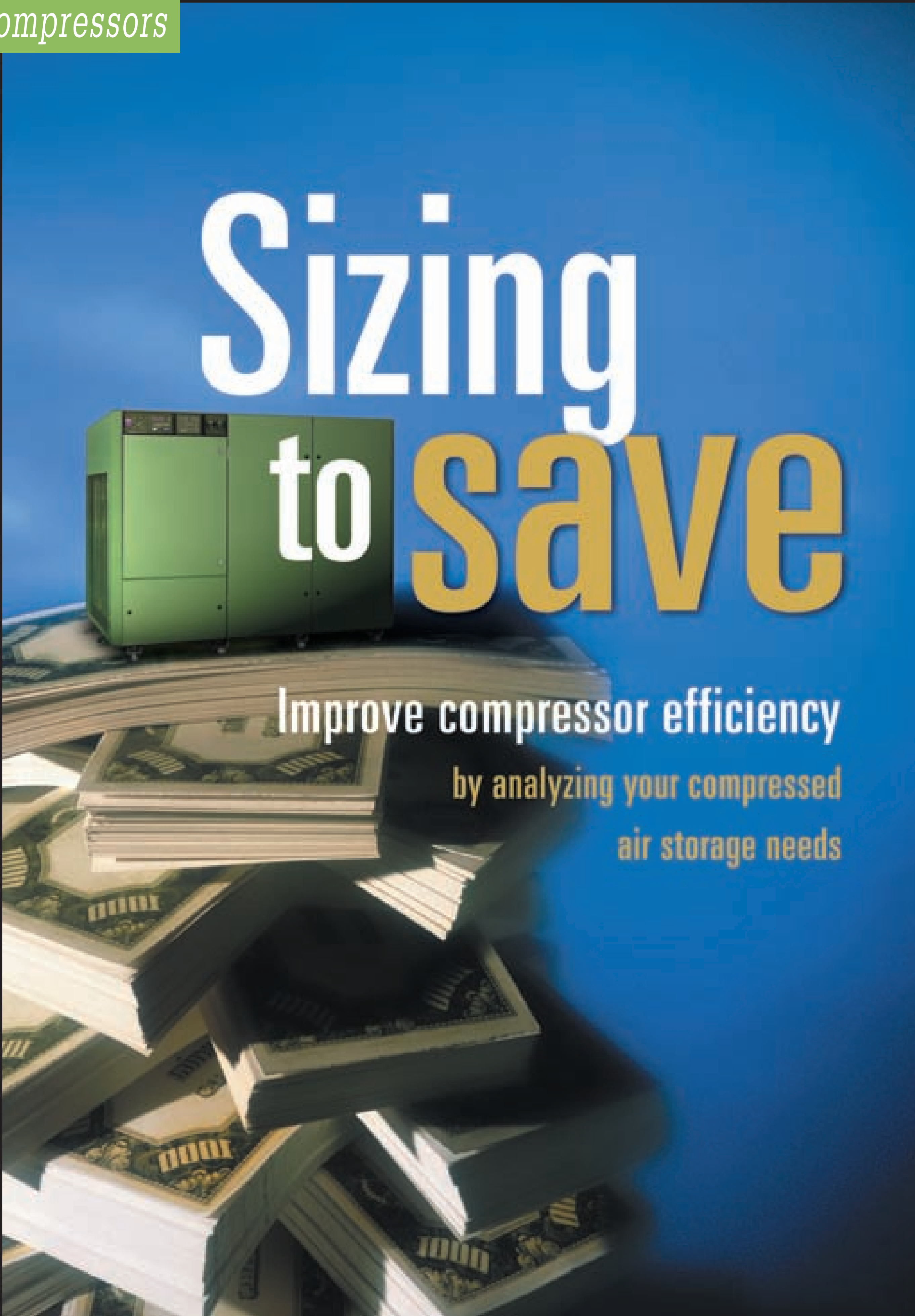


Sizing to save

Improve compressor efficiency

by analyzing your compressed air storage needs

Compressed air systems hold one of the keys to greater productivity, efficiency and profitability. This is the sixth in a series of articles that introduces some key points of Compressed Air Challenge training

By Paul Shaw

Proper compressed air storage is one of the most important components of a well designed compressed air system, but it's usually the most overlooked. Call them what you want—tanks, air receivers, storage receivers, bottles or vessels—they do the same thing: store compressed air for future use. Storage can help minimize system pressure loss, keep unneeded compressors from starting, enhance compressor part-load performance, separate moisture, reduce pulsations from reciprocating compressors, and stabilize and balance air pressure. When re-engineering a compressed air system or buying a new air receiver, size generously.

For example, a beverage producer was losing pressure at different times during the day, which disrupted production and caused another compressor to come online. The initial response to this problem was to investigate purchasing a larger air compressor.

While working with its compressed air system specialist, the company decided to monitor the system to determine exactly what was happening. This revealed a demand event of approximately 150 cfm that occurred several times a day and lasted for only a few minutes. The study also determined that without these intermittent demands, the current air compressor was sufficiently sized and operated the system efficiently. The final solution was to install additional storage. This was cost effective, and thanks to energy savings, provided a payback of less than two years.

Proper air receiver design

Air receivers should be built to the American Society of Mechanical Engineers (ASME) code, which governs design, material, fabrication and quality control. An ASME coded tank has a "U" stamp on it, is registered with the National Board of Boiler Pressure Vessel Inspectors, and should comply with state and local codes. An air receiver should never be operated beyond its maximum allowable working pressure or without a properly sized and installed safety valve.

Primary storage volume requirements

Traditionally, air receivers were sized for reciprocating air compressors. The general guideline was that for every cfm of air produced required one gallon of storage. Today, the suggested minimum size is between three and five gallons of storage per cfm produced. Size requirements can also vary by the type of compressor, compressor capacity control, the quantity and duration of transient demand events and the interval between them. When determining the volume of system storage per cfm required for multiple compressor systems, only the capacity of the trim compressor needs to be considered for reducing part-load energy requirements. Further consideration must be given to ample storage to prevent another compressor from coming online to meet intermittent requirements, as well as the time required to bring an additional compressor on line should the size and duration of a demand event require it.

Collaborative effort

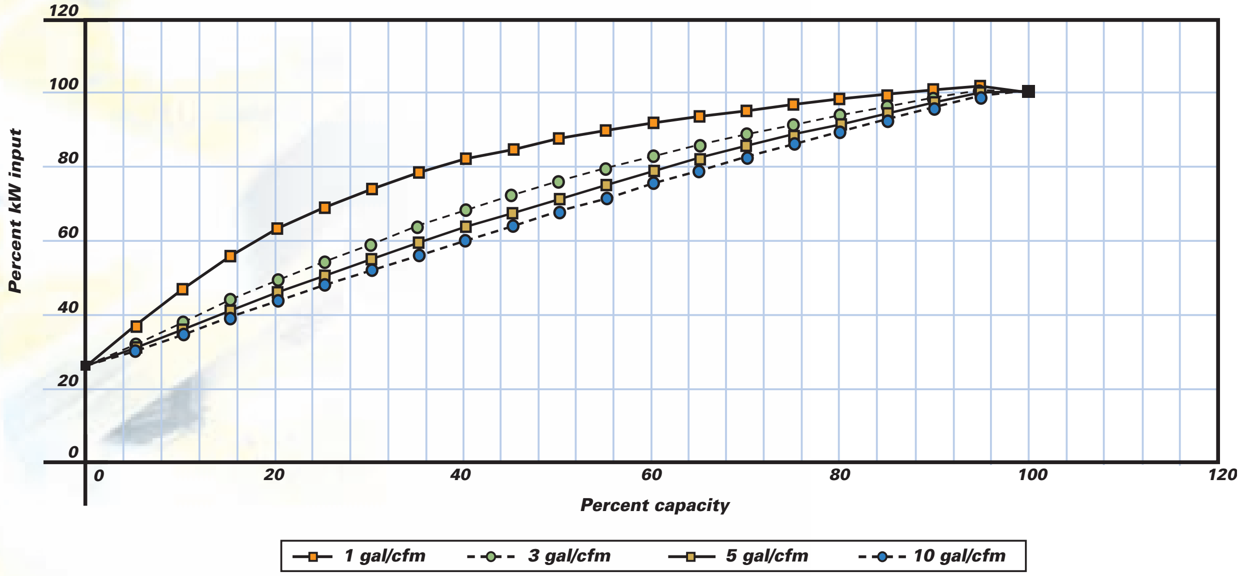
The Compressed Air Challenge (CAC), a non-profit corporation, began in 1997 as a collaboration of public, non-profit and private organizations dedicated to increasing the understanding and improving the efficiency of compressed air systems within the U.S. industry.

The purpose of the CAC is to provide a solutions-neutral environment for educating both suppliers and users of industrial compressed air systems on the benefits of taking a "systems approach."

The CAC has developed two levels of training for plant engineers: "Fundamentals of Compressed Air Systems" and "Advanced Management of Compressed Air Systems." Other educational products include publications, such as the Sourcebook. Other materials are under development. For more information, call 800-862-2086 or visit *www.compressedairchallenge.org*.

Figure 1.

Average kW versus average capacity with load/unload capacity control



The following graph illustrates the effect of receiver size on a lubricated rotary screw compressor with load/unload controls (Figure 1).

Pressure differential and the effects on storage

For storage to work there must be a pressure differential and an allowable pressure band. Without an allowable pressure differential, there is no storage. The usable pressure differential and the air receiver size determine the available storage.

A receiver has a given volume, normally measured in gallons, except in large sizes, where they are measured in cubic feet. There are 7.48 gallons in a cubic foot.

The amount of free air in the receiver depends upon the pressure. At sea level, the atmospheric pressure is 14.7 psia (0 psig). If air in the receiver has been compressed to 100 psig, the absolute pressure is 114.7 psia (100 + 14.7). A 1,000 gallon receiver at 100 psig will hold the equivalent of: (1,000 * 114.7)/(7.48 * 14.7) = 1,043 cu.ft. of free air.

The amount of <u>usable</u> compressed air would depend on the pressure differential. For example: with the 1000 gallon air receiver and an allowable pressure differential of 10 psi (100 to 90 psig) the available compressed air in storage would be: 1000 gal. x (100 – 90)/(7.48 * 14.7) = 91 cu. ft.

The time required for the pressure to fall from 100 to 90 psig is proportional to the rate of demand (presuming no supply during the demand event):

$T = V * (p_1 - p_2) / (C * p_a)$

Where T = time in minutes

V = receiver volume in ft.^{3}
(in this case 1000/7.48 = 134 ft.^{3})

p_1 = Initial pressure – psig (in this case 100)

p_2 = Final pressure – psig (in this case 90)

C = air demand - cfm of free air
p_a = atmospheric pressure - psia
(in this case 14.7)

For a demand rate of 200 cfm of free air, the time would be:
134 * (100-90)/(200 *14.7) = 0.456 minutes
Similarly, the pressure would take one minute to fall from 100 psig to 78 psig.

Be careful not to raise compressor operating pressure to increase storage. Every 2 psi increase in operating pressure consumes one percent more in energy, and may also overload the motor. For example, the increase in energy cost for raising a 100-hp (110 bhp) air compressor's operating pressure 10 psi is five percent or 5.5 bhp. For a 24/7 operation having a $0.05 per kWh energy rate, this is $1,900 per year in additional energy costs. As you can see, purchasing additional storage is cost effective and can provide a rapid payback.

Pressure/flow controllers or pressure regulators help capture available storage and run the system more efficiently by providing a normal pressure band at the compressors and primary receivers, and by maintaining a stable, reduced system pressure.

Primary storage location

A constant source of debate is whether to locate the primary air receiver before or after the dryer. For a reciprocating compressor, a receiver placed after the compressor provides a pulsation dampening that benefits both the compressor and the system.

For all types of systems, locating the storage before the dryer reduces the moisture load by separating condensate, providing some temperature reduction from radiant cooling and reducing the likelihood of liquid slugging if the aftercooler moisture separator trap of the compressor should fail. However, the downside is that as the receiver fills with saturated air, a large demand event could overload the dryer and cause moisture to be carried downstream.

Locating the air receiver after the dryer provides the dry air needed to accommodate large demand events without creating overloading. However, other problems can arise, such as the loss of the pressure band because of pressure drops through the dryer and filters, and compressor signal reaction. What is the optimum? Place storage before and after the dryer, using the wet receiver as the control point. This allows you to reap the benefits of both locations.

Secondary storage

Secondary storage can provide a source of compressed air for a single operation, reduce pressure drops or help balance the system. In a stamping operation, for example, secondary storage provides for the sudden burst of air required for proper press operation. Without secondary storage, there may be a pressure drop at the clutch requiring larger line sizes or higher pressure, or sometimes both.

Storing air for a large pulse load may require needle and check valves. A check valve eliminates the possibility of storage being drawn off by events elsewhere in the system. Meanwhile, a needle valve controls the rate of refilling, so that a large demand event becomes a small, steady draw on the compressed air system.

Figure 2 (see pg. 50) shows a dust-collector system. In this case, the pulsing of the dust collector created a pressure drop and supply problems in the system header. Metering with a needle valve eliminated the pressure drop in the header. The needle valve is set so that the secondary air receiver re-fills at a slow rate, just in time before the next pulse. This turned a high intermittent demand into a steady, small demand.

The following formula is used to size a secondary receiver:

$V = (T * (C - R) * Pa)/p_1 - p_2$

Where:

V = receiver volume, ft^3

T = time allowed for pressure drop of 10 psi to occur (10 minutes)

C = intermittent demand, cfm (100 cfm)

R = rate of flow through the needle valve

P_a = absolute atmospheric pressure, psia (14.7 psia)

p_1 = initial receiver pressure, psig (100 psig)

p_2 = final receiver pressure, psig (90 psig)

Proper use of secondary storage can provide many advantages and benefits and should be considered in an overall compressed air system strategy.

High pressure off-line storage

In some compressed air systems, there can be a very large demand event that happens infrequently. In others, large air compressors can often take several minutes before going online. With both cases, sometimes an air compressor is left on to provide coverage. While both conditions would benefit from using a very large air receiver, the payback doesn't always make it economically viable.

A more cost-effective solution would be using high-pressure, off-line storage. Here a small, high-pressure air compressor, usually a reciprocating unit, supplies air at a higher pressure to a smaller air receiver.

For example, a plant had three 3,000 CFM centrifugal air compressors. Two supplied the plant; the third was left on standby. A few times a year, a compressor would shut down unexpectedly. This caused the operating pressure to fall below the required 80 psig, resulting in machine shutdowns that crippled plant processes for hours.

One solution was to install excess primary air storage to cover an unexpected loss of an air compressor. Another was building in a high-pressure, off-line storage and metering it into the system.

It takes approximately one minute for the 3,000 cfm standby centrifugal compressor to start producing air. For example, the start up time for a compressor with a 10 psi differential would require a 32,987 gallon air receiver (1 min.* 3,000 cfm * 14.7 psia/10 psid = 4410 cf * 7.48 = 32,987 gallons).

Because the manufacturer had neither the room nor the capital for this size air receiver, it elected to use high-pressure, off-line storage. A small, high-pressure air compressor capable of providing 300 psig was installed, as well as a 1,500 gallon air receiver and the required

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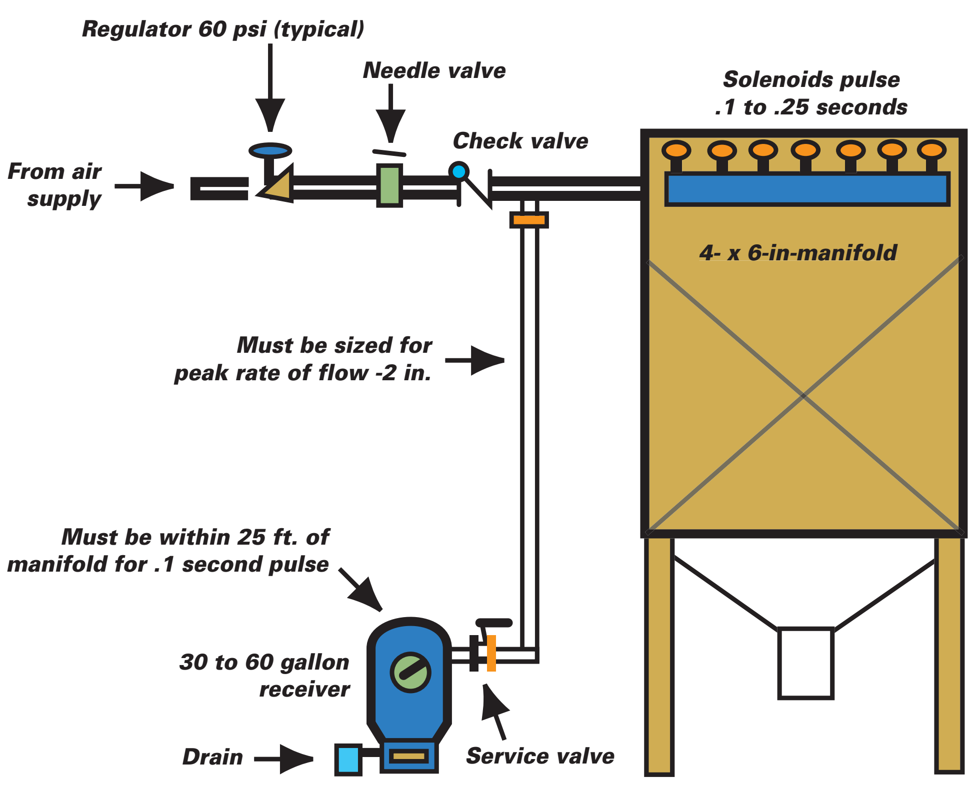
Figure 2. Local storage



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accessories to reduce the pressure to 80 psig:

1,500 gallon/7.48. * (300 psig – 80 psig) / 14.7 psia = 3,001 cu. ft.

So far, the system has worked as designed and shutdown problems have been eliminated. High-pressure, off-line storage can be another cost effective solution for a well-designed compressed air system.

A complete understanding of your compressed air system and its end uses is essential to implementing storage solutions. Adequate primary and secondary storage can make systems easier to control, reduce maintenance costs and help compressors operate more efficiently.

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Storage formulas

There are 7.48 gallons to the cubic foot.

Convert gallons to cubic feet: $\frac{\text{Gallons}}{7.48}$

Cubic feet of free air required to raise a receiver from some pressure greater than 0 gage to a final higher pressure:

$$\text{Receiver volume in cu. ft.} \times \frac{(\text{final psig} - \text{initial psig})}{\text{Atm. pressure}}$$

*Usable cubic feet of stored air:

$$\text{Receiver volume } (ft^3) \times \frac{(\text{final psig} - \text{required operating psig})}{\text{Atm. pressure}}$$

Fill time for an air receiver:

$$\frac{\text{Receiver volume in cu. ft.} \times (\text{final psig} - \text{initial psig})}{\text{Atm. pressure} \times \text{compressor cfm}}$$

If the demand in cfm is known, the size of an air receiver can be calculated as follows:

$$V = T \times \frac{C \times Pa}{P_1 - P_2}$$

WHERE:

V = Receiver volume, in cubic feet

T = Time allowed (minutes) for pressure drop to occur

C = Air demand, cfm of free air

Pa = Absolute atmospheric pressure, psia

P_1 = Initial receiver pressure, psig

P_2 = Final receiver pressure, psig