

# *Improving air system efficiency*

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## *Part 7: A closer look at the demand side of compressed-air systems*

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It often seems that compressed-air system performance is evaluated only from the perspective of the supply equipment. If pressure anywhere in the system is below whatever is believed to be the minimum acceptable level, the common diagnosis is "insufficient supply." Little more is done to evaluate what is going on in the system. In existing systems, demand usually is calculated by adding up the rated capacity of all the compressors that are on, regardless of how much power they are pulling. Users do not realize that an on compressor is only an indication of cost -- not an indication of need!

Without demand, there is no requirement for supply. Most compressed-air systems have little or no storage and an uncontrolled approach towards expanding the air to the various pressures at which it will be used. Compressor manufacturers have developed formulas and perceptions based on the assumption that all of the demand is managed. In reality, less than half of the air (by volume), which is consumed is regulated, and half of the regulators in use are adjusted to their wide-open position. Typically, 80% of total demand is unregulated. As real demand increases, supply pressure drops and 80% of the total use volume diminishes proportionally to the reduced density of the supply air. The inverse is also true.

Demand in compressed-air systems can be viewed as many holes through which air flows and expands to do work. The number of holes, whether they are open or closed, how fast they open and close, the coincidence of these occurrences, and the various operating pressures determine the demand in the system. Following are the categories of usage:

**Appropriate production usage --** This term can be applied to usage for which the compressed-air system was installed in the first place. Some examples of appropriate usage would be valves, cylinders, instruments, air motors, pneumatic hand tools, and, in some cases, blowing applications. A portion of the total appropriate uses necessary to production will be regulated, while the balance will be unregulated. These applications are appropriate for compressed-air usage even if not properly controlled.

**Inappropriate production usage --** These are applications that could be accomplished better with electricity, hydraulics, or mechanical power instead of compressed air. Examples include use of plant air for aspiration of a flue gas, agitation or oxygenation of liquids, or aeration. These applications should be serviced with a single-stage, low pressure blower. When plant air is used instead, there is seldom an understanding of cost or consequences. Sometimes it is simply an effort to avoid the purchase of alternative non-air-using equipment to produce the same functional result. Certainly one would not install a 3/8-in. air hose to blow air with an annual operating cost of \$18,000 when a 1-hp blower could do the same thing with an installed cost of \$400 and an operating cost of \$850 per year.

**Leaks** -- Leaks represent waste, which is internal to the production equipment as well as in the general piping system from the compressors to the points of use. Leakage noise can range from inaudible to extremely irritating.

Remember that most leaks start small and then grow. It is not unusual for the sum of all leaks to equal up to one-third of the total air usage if they are not brought under control. The best way to evaluate leakage problems is to monitor the demand flow, corrected for pressure and temperature. **Artificial demand** -- This is the excess volume of air that is created on unregulated users as a result of supplying higher line pressure than necessary for the applications. It includes leaks, drain valves, and blowoff. When the supply pressure fluctuates, artificial demand increases and decreases from a minimum to a maximum waste level. As real production demand decreases and the pressure rises, artificial demand increases. Repairing leaks in the system causes pressure to rise and all unregulated demand (including the balance of the leaks) increases proportionately to the pressure rise.

Because little care is used in selecting regulators and filters, they frequently have high pressure drops. Operators will increase the pilot pressure to improve the workability of their equipment to solve application problems. When operators no longer can elevate the pressure, they run into the supply pressure of the system. At this point the application will track the supply pressure. The increased volume created is artificial demand, which can represent between 10 and 25% of the total air used.

**Expander offers solution** -- A demand expander can correct this problem when adjusted to the system's minimum required pressure. An expander is a main line control valve (or valves) that controls the maximum pressure at which demand air can be removed from the system. Unlike a regulator, which restricts flow to control pressure, an expander increases the volume from the higher upstream pressure to the control pressure. Because expanders are sized for the expanded flow at the lowest operating pressure, they impose an almost immeasurable resistance to flow on the system. They require very little supply energy to function properly. Compare this to a regulator which can require 5 to 10% of the system's input energy to overcome resistance to flow.

Expanders also are very precise control devices, normally using a PLC platform-centered, PID control format. The expander has a control and response sensitivity within tenths of a psi. The use of an expander allows storage to be maintained in the upstream supply system to handle variations in demand rather than using "on board" power.

Another problem in the system provokes operating at elevated pressures. If the system is operating correctly, and demand is stable, a neutral (or 0 cfm) rate of change occurs. This implies that supply energy and demand energy are equal. When more air-using equipment comes online, this is referred to as a demand event. The excess demand over the supply energy is expressed as a negative rate of change. Until the supply system responds to the event, the air required is taken from the demand piping system, causing the pressure to drop. This pressure decay will be greater at the point of use and diminish closer to the supply. The decay will continue systemwide until supply adjusts; then the system will assume a positive rate of change until the air removed from the system is replaced, pressure is brought back to the original control point, and rate of change returns to neutral.

**Open blowing** -- Open blowing is plant air used for moving product, drying, wiping, cooling, and parts and scrap ejection. These applications typically are little more than copper tubes or pipe nipples attached to rubber hose or polyvinyl tubing. Although regulation should occur, these

applications seldom have regulators installed. Depending on the shape and configuration, a 1¼-in. copper tube can pass 48 to 108 cfm at 70 to 100 psig. This represents 13 to 30 bhp of supply energy. At \$0.06 per kW-hr, plus maintenance and depreciation, compressed air costs about \$2.00 per 100 cfm per hr of usage. That means the 1¼-in. copper tube used for open blowing could cost between \$4037 and \$18,922 per year on a 3- shift basis. The people who randomly apply these nozzles do not know the financial implications of their action, or what alternatives are available.

**Open Drainage** -- This occurs when plant air is released through open valves, notched ball valves, and motorized or solenoid-operated drain valves to dispose of compressed air effluent, such as water and/or lubricant. Although these seem like a positive means of effluent removal, the consequences can be expensive. The usage is not usually significant by volume, but the high rates of flow for short periods of time can depress the supply pressure enough to keep any compressor from unloading or turning off. Let's investigate the use of five timer-operated, motorized, 1½-in. ball valves to drain effluent from a small system. If left open, each valve will exhaust 477 ft<sup>3</sup> of air at 100 psig in one minute. If the timers are set for 5-sec drain cycles, each valve will consume:  $477 \times (5/60) = 39.75 \text{ ft}^3/\text{cycle}$ .

Assume that the supply system has 60 ft<sup>3</sup> of storage per psig, or 2169 gallons of capacity for all tanks and piping. This implies that for every 20 ft<sup>3</sup> of air removed from the system (above the amount that is being put into the system), the pressure will drop 1 psig. Every time one drain valve opens and dumps 39.75 ft<sup>3</sup> of air for five seconds, the system pressure drops 2 psig.

If all of the timers are set for 5 sec of draining every five minutes, the statistical probability of coincidental drain events would be quite high, at least for up to three valves. If three valves actuated simultaneously, the supply pressure would drop 6 psig. Because one or more drains are open at least 8.33% of the time, pressure could not be kept high enough to time out the motor on an off compressor before the pressure dropped to reload the compressor. If all five units function simultaneously, which will happen statistically, the 5-sec flow seen by the compressor room would be 198.75 ft<sup>3</sup>, which is a rate of flow of 2385 scfm. This would be more than enough to load the next available compressor, regardless of its size.

If you feel compelled to use solenoid or motorized valves for drainage, adjust the timer to the shortest possible duration and increase the frequency. This not only will reduce the air flow per cycle but also the potential for coincidental drainage events. The objective is to remove liquid, not air.

**Centrifugal compressor bleed bypass or blow-off** -- This is part of the normal control functions of a centrifugal compressor. A substantial portion of the cooling of the compressor is assigned to air being compressed. There is a minimum flow required to prevent overheating. When the demand for air in the system is below the minimum stable mass flow for the type of compressor, the control system will blow off the difference between the minimum stable flow and the actual demand requirement to atmosphere.

Blowing off compressed air to the atmosphere is an intentional waste of energy if the total minimum stable flow capacity of the on-line centrifugal compressors is more than the actual requirement. It is not uncommon for all or some of the centrifugal compressors, which are on, to be blowing off. This is not necessarily because the controls are not working properly. It is common to oversize compressors.

Blow-off or bleed bypass is real demand that requires energy, whether it is productive or not. The objective in operating a centrifugal should be to keep each base load unit fully loaded and

operating on its natural curve on a year-round basis. You can configure an arrangement of centrifugal-only compressors that do not blow-off if the following occurs:

- demand is determined by correcting for mass flow at density to the anticipated operating pressure, including the full range from maximum to minimum and off production
- supply capabilities are determined from actual curves at various inlet conditions and operating control approaches to determine the best sizes and fits for the range of demand required
- actual limited throttle capabilities including field adjustments are evaluated based on performance curves for the range of inlet conditions at the anticipated operating pressure, and
- the back-up compressor to support a unit failure is properly designed and integrated into the configuration. This implies that the off compressor is evaluated for the permissive start requirements from a hot start. Control storage must be provided to limit the minimum acceptable pressure drop that occurs while the compressor motor is being turned on and the compressor goes through its permissives. It will then have to close the blow-off valves and open the inlet throttle valve allowing the capacity of the unit to stop the decay of pressure and replace the air lost in control storage.

**Attrition** -- This is the additional air consumption that occurs on applications that result from unmanaged wear. Attrition typically is a normal function of sand or grit blast nozzles, textile machinery nozzles, etc. Solid particulate in the air stream will cause nozzle wear.

Unattended attrition can increase a particular volumetric consumption by 50% and frequently provokes the increase of pressure at both the point of use and the supply. A 1½-in. nozzle with 1/16-in. wear, which has had supply pressure increased from 80 to 90 psig (to compensate for the wear), will increase the volume by 50%. Monitoring attrition is essential. Blast nozzle operators have calipers that can slide into the nozzle and indicate an acceptable or unacceptable level of wear. Blast operators know that excess wear spreads the pattern, reduces thrust or force per square inch, inhibits desired quality, and impedes labor efficiency. On stationary applications such as air jet looms or spinning machines, mass flow at pressure should be measured regularly to monitor wear. The need for a few more cubic feet of air on each of a few hundred production machines can indicate the need for another compressor.

The logic behind any attrition management program is benchmarking the mass flow at pressure or measuring the actual wear on the nozzle. The nozzle or insert should be changed when the cost of energy to maintain the wear exceeds the cost of changing the nozzle or insert.

**Purge air from desiccant dryers** -- This air is consumed in the process of stripping air dryers of moisture. The process can range from 3 to 14.7% of the total air systems capacity from one method of purging to another. There are specialty categories of air, such as CDA 100, which is used for the microelectronics industry where purge can approach 25% of total capacity for the system. This is primarily used where the desired pressure dew point can be as low as -100° F.

The purge rate of flow is a function of the capacity of the dryer and its purge pressure, which normally is adjustable. An air reactivated or heatless dryer rated at 3000 cfm at 100 psig has a purge flow of 441 cfm at 100 psig. If the air flow through the dryer is 1000 cfm, the purge rate of flow will not change. With dew point control, the total cycle time increases, but the rate of flow will remain at 441 cfm for the preset purge time duration. The time between purges will lengthen as the flow through the dryer drops.

The rate of flow, not the cycle time, affects the system and loads compressors. One might have been led to believe that if the length of the cycle is doubled, the amount of purge will be cut in half. The effect of loading or the peak compressor requirement will not change; the same purge cycle will just occur less frequently. This will reduce the kW/hr, but not the power of demand.

**Bleed air or control bypass** -- This a point-of-use consumption where air is bled off the system or bypasses an application as a means of improving the accuracy of pressure and/or flow control. Where accuracy of pressure is important, and there is considerably more power or higher pressure than needed on line, the pressure can fluctuate erratically or perturbate. There is normally a control or storage-associated problem that is compensated for, with bleed or bypass control.

## **Constituents of demand**

In general, the previously discussed issues represent the constituents of demand encountered in audited systems. The last four categories -- bleed air, purge air, attrition, and bleed bypass -- only represent 23% of all systems, while the others are typical constituents.

## **Other influences on energy and operation**

The amount of energy required to operate the system not only is based on how much air is consumed in demand, but also how it is used. The relationship between the supply arrangement and the way demand is used, will also determine the energy consumed. In examining demand the question must be asked, "Why do we operate the system the way we do?" Breaking down the issue provides the information necessary to manage the system most efficiently.

Minimum load is the condition with the least amount of energy requirement, but it usually represents the most hours of operation per year in most systems. In manufacturing, a daylight or on-production mentality is often developed. From Friday night at 11 p.m. until Monday morning at 7 a.m. equals 56 hours of weekend compressed air service. With three shifts, eight hours per shift, five days per week, the weekend represents the longest shift or 31.8% of the total time (2812 hours per year). If this low load condition also includes the third shift, the condition of usage can represent as much as 4962 hours a year out of a possible 8760 hours. Low or minimum load is usually not evaluated and winds up being the stepchild when sizing the system and its equipment.

During the minimum load condition, there is usually a significant amount of partial load on a larger-than-necessary compressor or compressors that are on and were sized for the peak demand.

Low-load requirements should be evaluated on their own for the best operating mode. In many cases, this operating condition supports only auxiliary requirements, such as heating, ventilating, and air conditioning controls in the system; a dry sprinkler system; mixing motors that may be operating around the clock; diaphragm pumps; instrument air; etc. Although these may be legitimate usage, small isolated support might make more sense rather than supporting the entire system. In many cases, some users also could be better applied with electrical drive equipment.

Another poor use of air during the minimum load condition is abandoned production air usage. Operators turn off their electrical controls but do not close the air valve on the machines when they leave their work stations. Up to one-third of the low load condition has been found to be representative of this usage. There needs to be specific management direction regarding air usage shut off when a work station is abandoned. This can account for as much as 5% of the annual operating cost of compressed air in the plant.

If demand is managed with a demand expander, pressure could be reduced considerably during low load to control operating costs. The percentage of unregulated air consumers' volume, including leaks, usually increases as the demand diminishes and system pressure rises. This is particularly true when the supply is poorly controlled and sized much larger than the low load needs. If normal production is operated at 90 psig, the demand control pressure could be reduced to between 55 and 70 psig on the low load condition, depending on the equipment needs.

Even the most diligent maintenance professional can easily overlook the opportunities of minimum load. This is the place to begin auditing the air system. It represents the start of determining the constituents of demand as well as a significant opportunity for operating cost management.

### **Some facts about air leaks**

- they are insidious and will grow in time. Typical air line contaminants are water vapor and oxides, which make an excellent lapping compound. Passing these contaminants through normal leak annulars ensures wear. If the system is controlled by pressure only, leaks will grow at a faster rate than in a demand-limited or controlled system. If some leaks are fixed -- and the demand pressure rises as a result -- the remaining leakage volume will increase in direct proportion to the relative increase in pressure. With this elevated velocity, the leaks will increase in physical size until the increased volume causes the pressure to drop to the original level of waste
- if system waste is allowed to grow unattended, the demand will eventually accommodate the supply that is on line until all compressors that are on are fully loaded. As leaks rob work energy from the system, the mass flow lost must be replaced if the pressure is going to be managed. The replacement air brings in water vapor, acid gas, hydrocarbon vapor, and other industrial contaminants that must be processed and removed. Most systems with contamination problems can be fixed by controlling leaks and other waste in the system

- vapor seeks the lowest vapor pressure. This engineering anomaly can be helped along when we have a combination of a high percentage of leaks combined with desiccant or low-dew-point drying. If the ambient relative humidity is also high, water vapor will diffuse into the system from the atmosphere using the leaks as a vehicle. The higher the vapor pressure differential, the more effective the molecular diffusion or jet pump effect. Because leaks are neither planned nor managed, they increase flow through components in the system. The increase in flow causes an exponential increase in differential pressure across the components, resulting in a drop in downstream pressure. At the point of use, components are selected with little regard to differential. It is commonplace to elevate the regulated pressure to correct application workability. With this sloppy approach, leaks at the point of use have a most profound effect on the system. Imagine the capital and operating cost for installing another compressor at the supply end because of nagging complaints of continuously dropping pressure at one or more use-points. Sadly, leaks and plugged filters are usually the cause.
- leaks are the primary cause of problems with compressor control systems. Unfortunately, service providers neither use ultrasonics or regularly soap control lines to check for leaks. A few inaudible leaks can false-load a compressor as though there is large downstream demand. The result of this type of problem is severe cycling or hunting in the modulating control mode, and
- it is nearly impossible and impractical to eliminate all leaks from a system. Twenty percent of all leaks, by volume, are inaudible and very small. By unit count, 70-80% of leaks fall into this inaudible category. It is relatively easy to find and eliminate 75% of a system's total leak volume. Beyond this level, it is difficult to justify the return on labor invested even on a benchmarking basis. Most maintenance personnel only fix audible leaks. Keep in mind that a leak would have to be very large in order to be heard over typical industrial background noise.

## How compressors are oversized

When the initial sizing of a system is calculated, volumes at various pressures are added with no correction for mass density. There also are generous fudge factors for pressure and volume used at the various assessment stages of sizing. As an example, a manufacturer of equipment measures his demand at 100 cfm at 70 psig and then increases the pressure to 90 psig as a fudge factor. He expresses the demand as 100 cfm at 90 psig. This overstates the required mass flow at density. Percentages are arbitrarily added to volume. Pressures are elevated to accommodate the compressor specifications. Most of this is done to offset the unknowns or the fact that last time this exercise was done, mistakes were made. It is assumed generous oversizing will take care of the previous errors, whatever they were. If we had to pick a percentage relative to common oversizing, it would exceed one-third of the actual demand.

The turn-down or throttling capabilities of a centrifugal compressor can range from 20% to 40% of the total capabilities at the lowest operating inlet temperature. As the inlet temperature rises, the throttling capacity reduces, because the curve drops without the minimum stable flow changing. This may be evaluated on a unit-by-unit basis when the engineering evaluation occurs. Unfortunately, the effect on system operation is not evaluated considering the total number of compressors which will be operated versus the range of demand required. Most systems are

evaluated based on peak demand. They are seldom evaluated for minimum demand or turn-down requirements.

All centrifugal compressors have protective controls to ensure the compressor does not operate at or below its minimum stable flow point. These are either electrical minimum current (current limit low) or pneumatic blocks, which cause the compressor to blow off. The correct means of adjusting these limits or blocks is to perform a throttle surge test of the compressor at a specific inlet temperature and relative humidity, and operating pressure. By determining the input power at which the pressure begins to rise on the throttle surge curve or line, you can compare this to the rated performance of the compressor and interpolate what the minimum stable mass flow is at operating pressure.

Once you perform the test, you can adjust the blow-off controls to activate slightly before this point on the throttle line. Curves are seldom supplied (or requested) for compressors. The method that is used by the factory service technicians is to set the limits generously enough so that none of this needs to be done. The result is significant limits imposed on the throttling capacity of the compressor. We commonly find the compressor fields adjusted to blow off at 15-20% throttled off the full load capacity of the machine at the coldest condition and 5-10% of the full load capacity on the hottest summer day.

Because these units are very permissive, they are relatively slow to load up from a motor off and ready to start condition. The result is that most systems with centrifugal compressors have one extra compressor on all the time. When you evaluate the demand turndown and add another compressor to the online supply to protect the system against a unit failure, this forces all compressors to throttle. It is not uncommon to size a system to operate with two or three centrifugal compressors to support the demand in the system plus the extra on compressor to cover for a unit failure. If the demand requirement is less than 2/3 of the total capacity of the three compressors plus the extra unit online, you will have to blow off one or more compressors. Unfortunately most evaluations attempt to determine the type of compressor to acquire, when more than one type may be the prudent choice. Mixed types of compressors seldom are applied to any specific system. Other types of compressors, like positive-displacement units, have less limited turndown capabilities and can start from a cold off position within seconds. There is no need to operate another base load compressor in the event of a unit failure. Most evaluations begin by asking what type, size, and number of compressors are needed for the system. The question might be better asked: What types, sizes, and number of compressors will best suit the range of demand and ambient conditions that will be seen?

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