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Take a Closer Look at Compressed Air Systems

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Choose the Right Air Compressor

Consider centrifugal as well as screw units

By Amin Almasi, rotating equipment consultant

Compressed air is used extensively in process plants. It's a clean, safe and efficient utility that can be employed where other energy types (such as electricity) might pose a potential hazard. Compressed air is the motive force for many instruments, actuators, control valves and equipment. In addition, some processes require compressed air.

Most air compressors are electrically driven but engine-driven units also are used.

The "air" is naturally contaminated with solid particles such as dust, soot, salt, etc. It also contains water vapor, which if not removed can cause significant corrosive damage under the compression. Many applications require completely dry and oil-free air, to avoid risk of contaminating sensitive pneumatic equipment.

For a system to operate efficiently, the supply of air from the compressor has to match demand, which will rise and fall over different and complex patterns. In conventional air systems using screw compressors, the compressed air being generated but not used is the single largest cause of energy wastage. Sometimes, because of an inefficient air compression system, poor air-system energy management, improper capacity control and other reasons, more than 60% of the energy used in air compression is wasted. Generally, the issue of the energy efficiency is overlooked in air compressor packages.

Air compressor selection depends upon factors such as capacity, discharge pressure, required air quality and ambient conditions. Packages usually are tailor-made to customer specifications and local regulations.

COMPRESSOR OPTIONS

Single- or two-stage oil-free screw compressors or single-stage oil-flooded screw compressors commonly are used for air services. Figure 1 shows two examples of screw compressor packages as well as the air receiver (the vertical vessel).

Few manufacturers produce large (say, above 0.8 MW) oil-free (dry-type) screw compressors. For some large sizes, only two or three oil-free screw compressor manufacturers can provide successful references. Other limiting factors in oil-free (dry-type) screw compressors are the discharge temperature and the differential pressure.

In view of those limitations, plants often opt instead for oil-flooded screw compressors for medium and large applications (even for dry air ones such as instrument air or nitrogen packages). However, such compressors frequently suffer relatively high rate of wear and need complex sealing systems (whose seals are prone to abrasion and operational problems). Oil selection also presents a great challenge; highly sophisticated and expensive synthetic oil usually is necessary for successful operation.

SCREW COMPRESSORS
Figure 1. Such units are unrivalled for small applications.
Source: Accurate Air Engineering.

In oil-flooded screw compressors, air is mixed with a large quantity of oil; the oil then is extracted at discharge using very sophisticated multistage separation/filtration methods. Even the best oil-flooded screw compressor packages with the most effective and reliable oil separation systems still pass a certain level of oil. This amount of oil in a volume of compressed air may seem insignificant but for a compressor generating large air flow it can add up very

API CENTRIFUGAL COMPRESSOR
Figure 2. Highly engineered integrally geared unit can run for up to five years without a shutdown.

quickly. The oil can build up in actuators (and other systems) and lead to sluggish and interrupted response. On the other hand, malfunction of a component in the complex oil-separation system can cause contamination of the air system with a huge amount of oil, which could result in extensive damage and potential for highly dangerous catastrophic failures (explosions, serious injuries to personnel, etc.).

Vendors of oil-flooded screw compressors often offer "oil carryover" guarantees. However, they usually don't cover "oil carryover at any upset condition" and "oil carryover over the service life."

Oil-free turbocompressors generally are the best options for dry air services, e.g., for instrument air, dry process air, etc. They have fewer wear parts than screw compressors and many use advanced oil-free bearings, so their reliability is better. Turbocompressors generally are lighter and smaller than comparable screw compressors. The most common turbocompressor designs have two or three centrifugal stages for pressure in the 7–12 Barg range. Centrifugal turbocompressors with eight-to-ten stages (usually in a form of integrally geared machines) can reach pressures up to 100 Barg (or even more).

Units meeting the standards of the American Petroleum Institute (API), such as API 672 for integrally geared centrifugal turbocompressors, have been used for decades in critical air services. Complying with the standards' engineering, design, manufacturing, inspection and test requirements probably raises the cost of these highly engineered turbocompressors to two-to-four times that of conventional packages. However, they usually can provide three-to-five years' operation without any shutdown. Figure 2 shows an integrally geared API centrifugal compressor in a compact and well-arranged package.

For general-purpose air services, a standard turbocompressor (with several successful operating references) from a reputable manufacturer usually is a good choice. Leading-edge designs using direct drive (i.e., no gear box), which have only one moving part spinning at high speeds, may be the best option for many applications.

Relatively large applications (say, above 400 kW) call for use of oil-free magnetic bearings. For medium-size turbocompressors, simple and robust water-lubricated bearings or air-foil bearings suffice. Small-size units can get by with permanently lubricated and sealed bearings in special applications.

Turbocompressors lend themselves to modularization, which can reduce the number of components and consequently cut both capital and operating expenses. A modular design may require change of some turbocompressor parameters (usually minor and module-specific adjustments) for each application. Figure 3 shows modern air-compressor-package modules in a plant.

AIR COMPRESSOR MODULES
Figure 3. Modular approach for turbocompressors can cut both capital and operating expenses. ***Source: Accurate Air Engineering.***

A fully integrated design with a turbocompressor using a direct-drive high-speed driver, a vertical air tank and an integral refrigerated dryer (probably with filters) can be supplied in a compact one-piece package.

Today's high-speed, variable-speed direct-drive turbocompressors can provide energy savings of up to 30% compared to conventional machines (regular constant-speed turbocompressors or ordinary screw compressors).

OTHER FACTORS

Air services by their nature require a capacity control system that can cope with highly variable demand. This is another aspect where turbocompressors have an edge over screw compressors. Variable-speed drives (VSDs) usually are better matched to turbocompressors. For medium-range applications, where a VSD is too

Desiccant dryers are preferred when required air quality is extremely high.

expensive to use, a system with variable inlet guide vanes can provide turbocompressor capacity control. Turbocompressors can handle 20–100% turndown, with a higher efficiency and more reliable capacity control system than oil-free screw compressors in air systems.

An inherent characteristic of an air turbocompressor is that as system pressure decreases, capacity increases. This can be properly matched with the requirement of the air consumption patterns in many applications.

The turbocompressor air package produces the right volume of air required by an application. Using a highly responsive turbocompressor with the correct head/flow curve, a smaller air reservoir (usually two-to-three times smaller than that for screw compressor units) can be used at a relatively lower pressure, which could result in much less leakage in the air system.

Always consider local conditions, particularly the site level and ambient temperature, in air compressor design/selection. The dynamic nature of the turbocompressor can result in the head generated dropping as elevation rises because of lower air density. The turbocompressor mass flow and capacity at a given discharge pressure increase as the ambient temperature decreases. So, carefully choose rated point conditions (i.e., the worse-case scenario) when specifying air compressor requirements. Only a correct rated point can result in a sufficient and optimum package. Usually, a good selection for the worst case is a hot humid day and a realistic maximum temperature.

DRYERS AND FILTERS

Successful air-system performance depends upon selection of the right dryer, which can be either refrigerated or desiccant.

Refrigerated dryers commonly are used for dry air services. They employ a refrigeration system to lower the compressed air temperature to well below the ambient temperature. This condenses the moisture vapor into liquid that can be drained out of the system, and also decreases the dew point of the compressed air. As long as the compressed air doesn't cool below this new dew point, any remaining moisture will remain in the vapor phase. The dew point (at line pressure) should be at least 10°C below the minimum recorded temperature at the plant site or the consumption points (equipment, actuator, etc.). High-temperature refrigerated dryers precool the air before it enters the dryer.

Desiccant dryers operate by directing the compressed air across a bed of material that adsorbs moisture vapor. These dryers can produce dew points lower than those from refrigerated dryers and so are preferred when required air quality is extremely high.

Air filters come in a variety of types:

- *Moisture separator.* It mechanically separates water, oil, etc. from the air.
- *Particle filter.* Designed to capture dirt and dust, it may remove some water and oil mist.
- *Coalescing filter.* A fine filter for removing oil aerosols/mists and fine particles, it usually is placed after a dryer.
- *Vapor adsorber.* Such a unit, e.g., an activated-carbon filter, eliminates vapors (e.g., oil or water vapor). It should be installed after all other filters and dryers.

Use of multiple types of filters in the system can enhance effectiveness.

MAKE THE RIGHT CHOICE

For small- and medium-size applications, many packages now combine a rotary screw air compressor, storage tank and dryer in one durable and compact unit. Turbocompressors can't compete with oil-free screw compressors in small sizes. However, for medium- and large-size packages, compact high-speed turbocompressors using oil-free bearings can provide more and cleaner air with higher reliability and far less noise and vibration. ●

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Inflate Compressed Air Efficiency

Check for ten problems that often impair performance

By Ron Marshall, Marshall Compressed Air Consulting

Most people aren't aware that compressed air is one of the most costly utilities in a plant. Typical wire-to-work efficiency of a 100-psi system is only about 10%–15% at best. That is, if you put 10 hp into an air compressor, you only can get about 1 hp of work out of the other end when operating a compressed-air-powered device or tool.

Worse yet, this efficiency ratio is for a perfect system — for the compressor running at 100 psi and at full load, its most efficient operating point. However, many compressors don't operate in this way. Also, the ratio doesn't include leakage or waste in a system and doesn't consider pressure differentials across system components. This ratio is kind of like the gas mileage number that appears on the sticker of a new car, a value only attainable in the laboratory — not in real life.

There isn't a lot you can do about most of this loss — it's simple physics: when you compress air, the biggest product of the operation is heat. If you can use this heat, don't let it go to waste. Heat recovery is the most effective way of making a compressed air system more efficient. (For more on the topic, see "Recover Heat from Air Compression," http://goo.gl/oycLO2).

What's left for your attention is to ensure your system is as close to perfect as possible.

PERVASIVE PROBLEMS

So, let's look at ten issues, mostly related to screw compressors, that frequently reduce the efficiency of compressed air systems.

Inefficient control mode. This is one of the most common efficiency problems. Compressors must be controlled to maintain constant system pressure. If uncontrolled compressors put too much air into the system, the pressure goes too high; if they put in less than you use, the pressure goes too low. The onboard compressor controller in each unit is tasked to ensure that just enough compressed air is added to your system to maintain a more-or-less constant pressure between set limits.

When matching the compressor capacity to the load, normally at least one compressor is operating at partial load, that is, not putting out its full capacity. And this is where using an efficient compressor control mode is important. Common control modes in order of most efficient to least efficient are:

- Variable speed — An inverter drive or special motor changes the speed of the compressor. The power in this mode decreases in almost direct proportion to the flow.
- Variable displacement — Bypassing through controlled ports reduces the effective length of the compression element. Useful for the top 50% of flow, power turns down about 7% for each 10% reduction in flow.
- Load/unload — The compressor alternately produces full or zero flow between two pressure set points. The average power decreases about 5%–6% per 10% drop in flow but only if the system has large storage receiver capacity.
- Modulation — The inlet of the compressor is choked off to control the output flow. The power turns down about 3% for every 10% reduction. Thus, if a compressor with this type of control is putting out 40% of its capacity, it's consuming about 85% of full-load power.

What mode are your compressors operating in? Ask your service provider or someone in your plant who knows compressors. If your compressors are in modulation, you likely have some work to do to improve your efficiency. However, there usually are lots of potential opportunities to get compressors operating better with other modes of operation. Often in a system of multiple compressors, one or more may need replacement due to age. For a new unit, consider a more efficient mode.

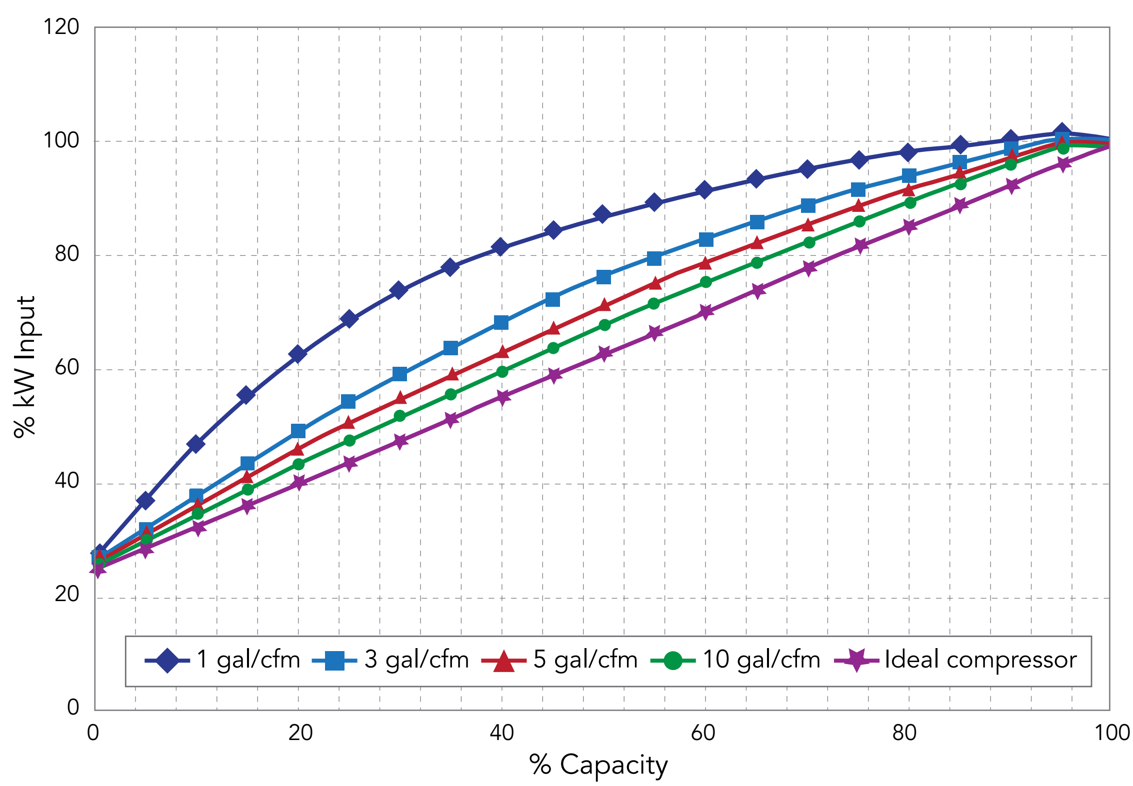
Lack of storage. Too often a system doesn't include enough storage receiver capacity. The presence of one or more large storage receivers near the compressor room helps the compressors maintain stable system pressure and run more efficiently. Receivers store a significant quantity of air that can prevent the system pressure from falling or rising too fast. This simplifies compressor control and could very well allow one or more compressors to turn off when not required instead of running unloaded, wasting power.

If a compressor is running in load/unload mode, the presence of large storage will make the compressor more efficient by reducing the frequency of load cycles. Figure 1 shows the effect of adding storage to lubricated screw compressors. As more storage is available, the power consumption at part loads decreases.

How large is "large?" Try to install 5–10 gal of capacity for each cfm of trim compressor capacity. (A trim compressor is one that operates at part load.) So, for a 100-hp compressor, put in between 2,000 and 4,000 gal. Yes, that's a large tank but it usually will pay for itself many times over.

Pressure too high. Very often some well-meaning person in operations will set the compressor discharge pressure higher than is required by the users. Perhaps someone is occasionally experiencing low pressure. Or perhaps the compressors simply are rated at a high pressure, so the operator thinks why not set the pressure to the highest possible value?

Always keep in mind that operating at a high pressure costs roughly 5% more

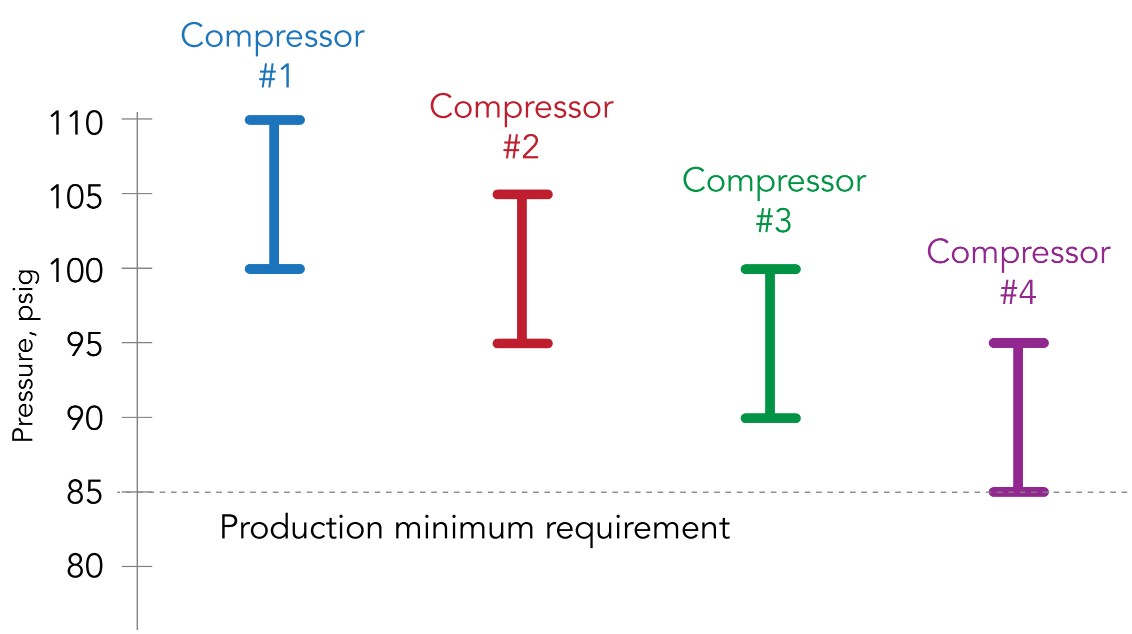


POWER CONSUMPTION VERSUS STORAGE CAPACITY
Figure 1. Using larger storage makes lubricated screw compressors run more efficiently in load/unload mode.

energy for every 10-psi increase in compressor discharge pressure. What's more, if any compressed air use is unregulated, the flow of air consumed by the equipment will rise by almost 1% for every 1 psi in higher pressure. This loads the compressors more, making them consume even more power. Carefully researching your end-user requirements and reducing the pressure may allow you to decrease your compressor power and save operating costs.

High pressure drop. Systems often contain less-than-optimal components like piping, filters, air dryers, regulators, lubricators, connectors and hoses that cause excessive pressure drop. This may stem from the desire to save money on the component purchase. Smaller components are cheaper — but sometimes they create major pressure restrictions. For example, undersized components may cause a 25-psi pressure differential between the compressors and an air-operated cylinder that needs 90 psi to function properly. This would force the compressor discharge pressure to at least 90 + 25 = 115 psi. The higher the discharge pressure, the more power the compressor consumes. Proper component selection can solve this problem and might lower the pressure drop to 5–10 psi or less.

Poor compressor coordination. In systems with multiple compressors, it's common to find that no defined control strategy is being employed to keep the compressors



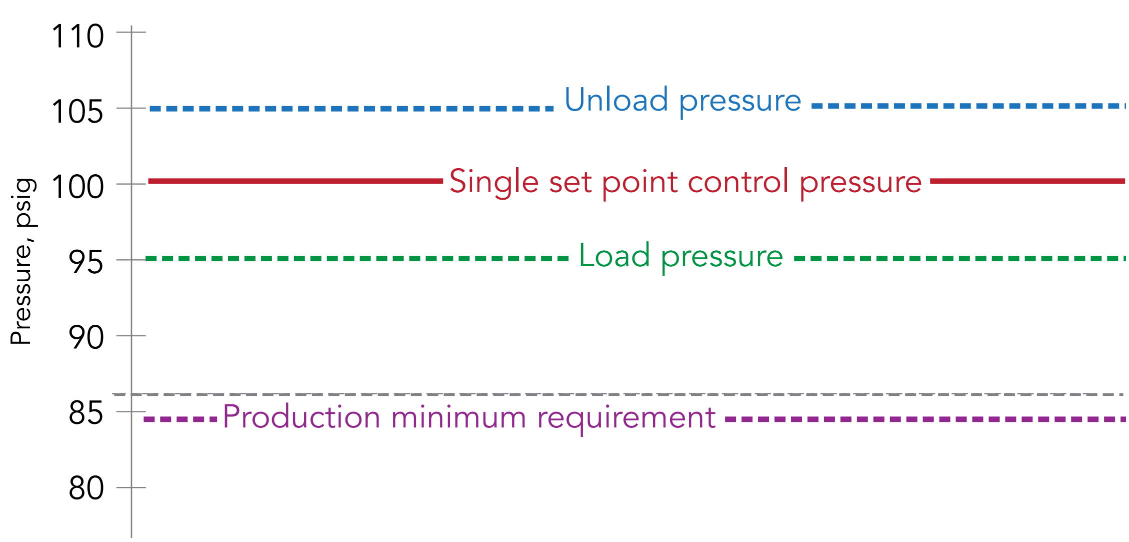
TRADITIONAL MULTIPLE-COMPRESSOR CONTROL SCHEME
Figure 2. Coordinating compressor pressure bands in a cascaded arrangement makes the system operate more efficiently.

playing together properly. Perhaps pressure settings were selected to be all the same for each compressor. Or perhaps the settings are the default set by the factory. The result might be that the compressors are all fighting with each other, causing very inefficient operation and poor pressure control. Very often you can improve system efficiency by examining the compressor pressure set points and ensuring they are set correctly.

The most common way to set load/unload compressors is in a cascaded arrangement (Figure 2). This operation is typical in systems with four or fewer compressors. For systems with more than four, the best way to run the compressors is with a single pressure band, coordinated with some sort of compressor control algorithm (Figure 3). Sometimes the onboard compressor controls have this type of control built in. Other times an external controller is required. The effect of these control strategies is to reduce the number of running compressors and decrease the average system pressure, saving power.

High levels of waste. The reality is that compressed air systems often are ignored until pressure problems occur. If you don't maintain your system, the normal wear and tear of plant operations will cause more and more compressed air leakage as time goes on. Typical plant leakage levels range between 20% and 30% of the average output. Really bad systems may exhibit levels of 50% or higher.

Do you have high levels of waste? Walk around your plant during non-production



BASIC SINGLE SET-POINT CONTROL SCHEME
Figure 3. Use of a compressor controller best coordinates multiple compressors in a single pressure band.

> If your plant sounds like a pit of angry vipers, it may be time to do some leakage detection and repair.

hours and listen. If your plant sounds like a pit of angry vipers, it may be time to do some leakage detection and repair.

Too many operating hours. Some plants run their compressors on evenings and weekends even when there's no production. For a plant that operates only two shifts and not on weekends, the non-production hours actually can exceed the production ones. During this time, the load often is very light and due only to leakage. This leakage costs energy; address the loss by simply turning off your compressors during these periods. Reducing the compressors' runtime also cuts required maintenance costs.

Sometimes critical loads such as boilers or fire systems need a small amount of compressed air during off hours, necessitating running the main compressors. In these cases, buy a small compressor to handle these loads, letting your main compressors rest.

No system monitoring. Many times there's no way to tell if your system is operating efficiently or not. There are pressure gauges galore and often many temperature readouts but instruments to measure flow and power rarely are present on an average system. In the past, these extra meters were expensive but now their cost has come way down. Time and time again experience has shown that monitoring your system efficiency enables achieving significant power savings. You can't manage what you don't measure.

Sometimes system monitoring will come built into a compressor controller. If it does, then installing good control also can open your eyes to the efficiency of your system.

Inefficient air drying. The air compressors consume most of the energy in a typical compressed-air system but you shouldn't ignore your air dryer efficiency. There are many efficiency choices when it comes to purchasing new units or upgrading your old ones.

For refrigerated dryers, energy often is wasted in running lightly loaded or with no load at all. Standard non-cycling dryers consume a constant power level even when little or no air is flowing through them. Choosing cycling dryers can reduce average power consumption. These units work like your refrigerator at home, turning the cooling circuit off and on with cooling demand.

Desiccant dryers, if uncontrolled, very often are found to be consuming the largest amount of compressed air in a plant. Heatless desiccant dryers require a flow of compressed air to regenerate the desiccant. This flow can be considerable if the dryer is oversized, lightly loaded and doesn't have dew point control.

Selecting more efficient desiccant dryers with controls that turn off the purge flow when not required, or heated styles that use less (or no) compressed air flow for regeneration can save significant operating costs and free up some extra peak compressor capacity.

Attend a compressed air seminar

Gain more insights about energy efficiency measures by attending compressed air training. Check out the Compressed Air Challenge training schedule at www.compressedairchallenge.org.

Lack of information. A great many compressed air problems are caused because the operators of the equipment simply do not know any better. The solution to this problem is awareness training.

INFLATE EFFICIENCY

Your plant's compressed air system likely suffers from at least some of the issues we've covered. Addressing them can lead to improved efficiency. ●

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Make the Right Choice

Choosing the correct compressor technology involves several factors

By Susan Benes, FS-Elliott

Deciding between rotary screw and centrifugal technology to produce compressed air can often be a daunting decision for manufacturers. The key to making this decision is matching the right technology to the application. This ensures you are selecting a machine that can provide the air required in the most efficient manner possible.

The right choice will increase productivity by assuring an adequate supply of air, and reduce downtime, maintenance requirements and power costs. However, to make this decision, there are many factors to consider.

COMPLETE LIFE CYCLE COSTS OF A COMPRESSOR

Life cycle costs including energy and maintenance are typically the most significant expenses, whereas the purchase price is only 10% to 12% of the total cost. By failing to consider this, purchasing departments may select the least expensive machine available and end up paying more in the long-term due to high power bills and other hidden operational costs.

Aside from the initial equipment cost, review the installation, interest rates, depreciation, operations, maintenance requirements, water and power when evaluating a rotary screw and a centrifugal compressor (Table 1). To understand some of the more hidden, yet controllable costs, we will cover some of these in more detail.

Installation requirements. Both compressor types have installation requirements. Rotary screw compressors have an advantage with fewer installation costs. Centrifugal compressor installation costs depend on the size or capacity of the machine — a lower capacity unit will have lower installation costs than a higher capacity machine. Centrifugal machines also require a water source at the point of installation, while many rotary screw compressors do not.

Operational factors. Such factors to consider include compressor sizing, air demand or capacity, and training personnel. When a compressor is too large for a given application, it operates at a reduced load, consuming more energy than necessary. Compressors that are too small for an application are not capable of delivering the proper air supply to fulfill the plant's needs, affecting production time and requiring the purchase of another compressor.

When comparing compressor flow ratings, there is no universally applied rating consistent across both technologies, which can introduce confusion. To ensure a true comparison, it's best to ask the compressor manufacturer to quote a weighted flow of air based on ambient temperature and pressure.

Keep in mind, though, that demand might change over time; therefore, consideration should also be given to normal and maximum air demand. For the highest system efficiency, normal demand should be approximately 65% to 95% of the peak output. If you expect the air demand to increase dramatically, find out if the compressor can be rerated or revamped, which is essentially upgrading a centrifugal compressor with new internal components to improve performance and efficiency.

FACTOR	DESCRIPTION
Initial Cost	Purchase price including shipping
Installation	Foundation, piping, wiring
Interest	Cost of capital
Depreciation	Amortization of the compressor
Operation	Operator training and inspection
Maintenance	Oil, filter elements, parts and repair
Water	Cooling water for intercoolers
Power	Cost of electricity to operate compressor

COMPRESSOR SELECTION FACTORS
Table 1. Several factors besides the initial equipment price impact the overall cost of a compressor.

Using cool air intake leads to a more efficient compression process.

As a rule of thumb, the larger the compressor, the more efficient it is. Two units operating at 50% capacity will be less efficient than one larger compressor running at full load. If air demand is likely to be less than 50% for extended periods, one of the smaller compressors could be shut down for long periods, making this combination more efficient.

Oil-free or oil-lubricated air. You must also consider if oil-free air is needed for your application. Lubricated rotary and reciprocating units can use oil to reduce friction and cool the air (remove the heat of compression). Residual oil can remain in the compressed air, so the oil must then be separated from the air prior to exiting the compressor. Some operators use separators to remove oil, but the issues here become filter maintenance, disposal of wastewater, additional capital expense, and power drop across the filters. For industries, such as pharmaceutical and food and beverage, that cannot afford contamination risks, air must be oil-free.

Replacement components repair. Most air compressors require regular replacement of various components. These costs should be calculated on a per year basis, including the rotary screw air end, which may have to be replaced every ten years. Centrifugal compressors use a closed loop cooling system that requires a water source at the point of installation, and additional maintenance attention.

ENSURE MAXIMUM COMPRESSOR EFFICIENCY

Power or energy costs are by far the largest cost of operating an air compressor, sometimes as much as 75% of life-cycle costs. One way to control efficiency is to provide a clean, dry location. As a rule of thumb, every 4°C rise in inlet air temperature, results in a 1% rise in energy consumption.

Using cool air intake leads to a more efficient compression process. This can be accomplished by drawing cool air from outside, as the temperature of the air inside the compressor room will be a few degrees higher than the ambient temperature from the exhaust.

Another common rule of thumb: every 2-psi increase in discharge pressure also increases required horsepower by 1%. The more horsepower you require, the more energy you consume.

Dust also can affect efficiency due to pressure drop from the filters, especially once they start to clog. Select air filters based on the compressor type and install as close to the compressor as possible. It is advisable to clean inlet air filters at regular intervals to minimize pressure drops.

Another factor impacting efficiency is the number of stages. Rotary and reciprocating compressors typically have one or two stages, while centrifugal compressors can have two or more. Smaller increments between stages result in higher efficiency since less energy is required to obtain the same air pressure. Because of this, centrifugal compressors typically operate at least 5% more efficiently than rotary or reciprocating compressors.

THE RIGHT COMPRESSOR

Choosing between a rotary screw compressor and a centrifugal compressor requires a proper evaluation of the individual application. In general, rotary screw compressors are best suited as a local point of use system in both low and fluctuating air supply conditions. Centrifugal compressors are more suited for applications that require higher flows and steady air supply.

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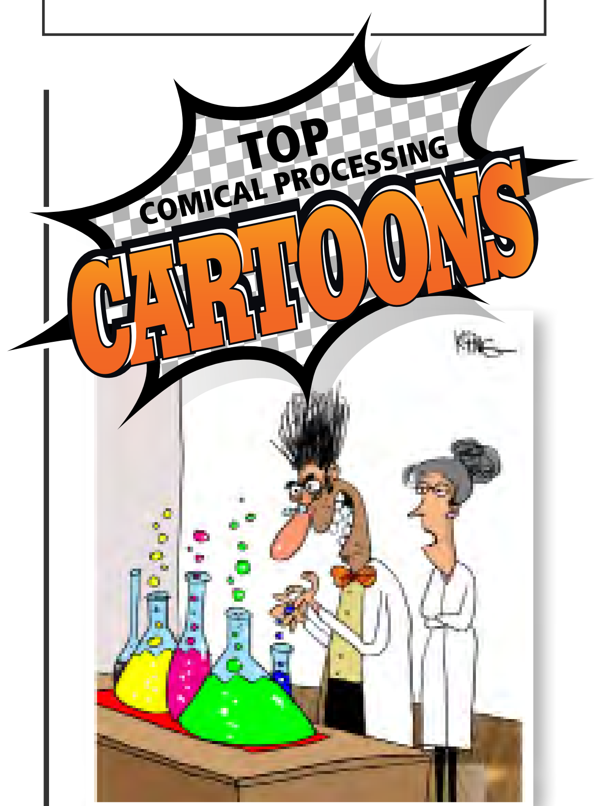

Visit the lighter side, featuring drawings by award-winning cartoonist Jerry King. Click on an image and you will arrive at a page with the winning caption and all submissions for that particular cartoon.