
Compressed Air Systems

Course No: M02-012

Credit: 2 PDH

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Energy Tips – Compressed Air

Compressed Air Tip Sheet #1 • August 2004

Industrial Technologies Program



Suggested Actions

- Determine the cost of compressed air for your plant by periodically monitoring the compressor operating hours and load duty cycle.
- Use a systems approach while operating and maintaining a compressed air system.
- Adopt a plant-wide compressed air management policy to cut costs and reduce waste by eliminating inappropriate uses, fixing leaks, and matching system supply with demand.

References

From Compressed Air Challenge® (CAC):

The Compressed Air System Best Practices Manual, Guidelines for Selecting a Compressed Air System Service Provider

From DOE's Industrial Technologies Program and CAC:

Improving Compressed Air System Performance: A Sourcebook for Industry

Training

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Determine the Cost of Compressed Air for Your Plant

Most industrial facilities need some form of compressed air, whether for running a simple air tool or for more complicated tasks such as the operation of pneumatic controls. A recent survey by the U.S. Department of Energy showed that for a typical industrial facility, approximately 10% of the electricity consumed is for generating compressed air. For some facilities, compressed air generation may account for 30% or more of the electricity consumed. Compressed air is an on-site generated utility. Very often, the cost of generation is not known; however, some companies use a value of 18-30 cents per 1,000 cubic feet of air.

Compressed air is one of the most expensive sources of energy in a plant. The overall efficiency of a typical compressed air system can be as low as 10%-15%. For example, to operate a 1-horsepower (hp) air motor at 100 pounds per square inch gauge (psig), approximately 7-8 hp of electrical power is supplied to the air compressor. To calculate the cost of compressed air in your facility, use the formula shown below:

$$\text{Cost (\$)} = \frac{(\text{bhp}) \times (0.746) \times (\text{\# of operating hours}) \times (\$/\text{kWh}) \times (\% \text{ time}) \times (\% \text{ full-load bhp})}{\text{Motor Efficiency}}$$

Where:

bhp—Motor full-load horsepower (frequently higher than the motor nameplate horsepower—check equipment specification)

0.746—conversion between hp and kW

Percent time—percentage of time running at this operating level

Percent full-load bhp—bhp as percentage of full-load bhp at this operating level

Motor efficiency—motor efficiency at this operating level

Example

A typical manufacturing facility has a 200-hp compressor (which requires 215 bhp) that operates for 6800 hours annually. It is fully loaded 85% of the time (motor efficiency = .95) and unloaded the rest of the time (25% full-load bhp and motor efficiency = .90). The aggregate electric rate is \$0.05/kWh.

Cost when fully loaded =

$$\frac{(215 \text{ bhp}) \times (0.746) \times (6800 \text{ hrs}) \times (\$0.05/\text{kWh}) \times (0.85) \times (1.0)}{.95} = \$48,792$$

Cost when unloaded =

$$\frac{(215 \text{ bhp}) \times (0.746) \times (6800 \text{ hrs}) \times (\$0.05/\text{kWh}) \times (0.15) \times (0.25)}{.90} = \$2,272$$

$$\text{Annual energy cost} = \$48,792 + \$2,272 = \$51,064$$



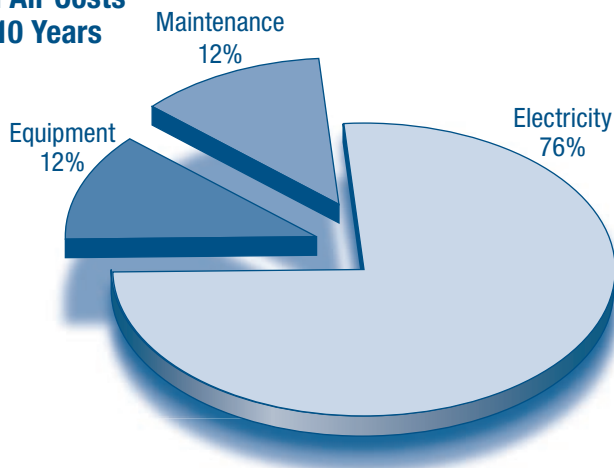
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Typical Lifetime Compressed Air Costs in Perspective—Costs Over 10 Years

Assumptions in this example include a 75-hp compressor operated two shifts a day, 5 days a week at an aggregate electric rate of \$0.05/kWh over 10 years of equipment life.



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BestPractices emphasizes plant systems, where significant efficiency improvements and savings can be achieved. Industry gains easy access to near-term and long-term solutions for improving the performance of motor, steam, compressed air, and process heating systems. In addition, the Industrial Assessment Centers provide comprehensive industrial energy evaluations to small- and medium-size manufacturers.

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The Industrial Technologies Program encourages industry-wide efforts to boost resource productivity through a strategy called Industries of the Future (IOF). IOF focuses on the following eight energy and resource intensive industries:

- Aluminum
- Forest Products
- Metal Casting
- Petroleum
- Chemicals
- Glass
- Mining
- Steel

The Industrial Technologies Program and its BestPractices activities offer a wide variety of resources to industrial partners that cover motor, steam, compressed air, and process heating systems. For example, BestPractices software can help you decide whether to replace or rewind motors (MotorMaster+), assess the efficiency of pumping systems (PSAT), compressed air systems (AirMaster+), steam systems (Steam Scoping Tool), or determine optimal insulation thickness for pipes and pressure vessels (3E Plus). Training is available to help you or your staff learn how to use these software programs and learn more about industrial systems. Workshops are held around the country on topics such as "Capturing the Value of Steam Efficiency," "Fundamentals and Advanced Management of Compressed Air Systems," and "Motor System Management." Available technical publications range from case studies and tip sheets to sourcebooks and market assessments. The Energy Matters newsletter, for example, provides timely articles and information on comprehensive energy systems for industry. You can access these resources and more by visiting the BestPractices Web site at www.eere.energy.gov/industry/bestpractices or by contacting the EERE Information Center at 877-337-3463 or via the Web at www.eere.energy.gov/informationcenter/.

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Energy Tips – Compressed Air

Compressed Air Tip Sheet #2 • August 2004

Industrial Technologies Program



Suggested Actions

- Walk through your plant and identify all compressed air uses and, if possible, the flow and pressure requirements of each use.
- Take steps to eliminate any inappropriate uses. Consult with a compressed air systems specialist to see if other equipment (blowers, mechanical or hydraulic devices) will be more cost-effective for those applications.

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Eliminate Inappropriate Uses of Compressed Air

Compressed air generation is one of the most expensive utilities in an industrial facility. When used wisely, compressed air can provide a safe and reliable source of power to key industrial processes. Users should always consider other cost-effective forms of power to accomplish the required tasks and eliminate unproductive demands. Inappropriate uses of compressed air include any application that can be done more effectively or more efficiently by a method other than compressed air. The table below provides some uses of compressed air that may be inappropriate and suggests alternative ways to perform these tasks.

Potentially Inappropriate Uses	Suggested Alternatives/Actions
Clean-up, Drying, Process cooling	Low-pressure blowers, electric fans, brooms, nozzles
Sparging	Low-pressure blowers and mixers
Aspirating, Atomizing	Low-pressure blowers
Padding	Low to medium-pressure blowers
Vacuum generator	Dedicated vacuum pump or central vacuum system
Personnel cooling	Electric fans
Open-tube, compressed air-operated vortex coolers without thermostats	Air-to-air heat exchanger or air conditioner, add thermostats to vortex cooler
Air motor-driven mixer	Electric motor-driven mixer
Air-operated diaphragm pumps	Proper regulator and speed control; electric pump
Idle equipment*	Put an air-stop valve at the compressed air inlet
Abandoned equipment**	Disconnect air supply to equipment

*Equipment that is temporarily not in use during the production cycle.

**Equipment that is no longer in use either due to a process change or malfunction.

Example

The table below shows inappropriate uses of compressed air in an automobile assembly plant. The plant took several action steps identified in the table to eliminate or reduce these inappropriate uses. Peak flow is identified in cubic feet per minute (cfm).

Operation	Original Peak Flow (cfm)	Number of Hours	Action Taken	Revised Peak Flow (cfm)	Peak Flow Reduction (cfm)
Open hand-held blow guns	200	6,500	Installed nozzles	50	150
Vacuum generator	1,000	5,000	Motor-driven vacuum pump	0	1,000
Personnel cooling	800	3,500	Used fans	0	800
Pneumatic actuators	750	3,500	Replaced with electric actuators	0	750
Total CFM reduction:					2,700



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The plant audit showed that the energy used to generate the compressed air averages 18 kW/100 cfm. The aggregate electric rate at the plant is \$0.05 per kWh.

$$\begin{aligned}\text{Annual savings} &= [\text{kW per cfm}] \times [\text{cfm savings}] \times [\# \text{ of hours}] \times [\$ \text{ per kWh}] \\ &= 18/100 \times [(150 \times 6,500) + (1,000 \times 5,000) + (800 \times 3,500) \\ &\quad + (750 \times 3,500)] \times \$0.05 \\ &= \mathbf{\$102,600}\end{aligned}$$

Net savings:

Calculate electric energy costs for the motor-driven vacuum pump, fans, and actuators, and subtract these costs from the annual savings calculated to determine the net savings. Note that there will be a one-time cost of installation for the added equipment.

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Energy Tips – Compressed Air

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Suggested Actions

- Fixing leaks once is not enough. Incorporate a leak prevention program into operations at your facility. It should include identification and tagging, tracking, repair, verification, and employee involvement. Set a reasonable target for cost-effective leak reduction—5%-10% of total system flow is typical for industrial facilities.
- Once leaks are repaired, re-evaluate your compressed air system supply. Work with a compressed air systems specialist to adjust compressor controls. To maximize energy savings, compressor run time must be reduced to match the reduced demand.

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Minimize Compressed Air Leaks

Leaks are a significant source of wasted energy in a compressed air system, often wasting as much as 20%-30% of the compressor's output. Compressed air leaks can also contribute to problems with system operations, including:

- Fluctuating system pressure, which can cause air tools and other air-operated equipment to function less efficiently, possibly affecting production
- Excess compressor capacity, resulting in higher than necessary costs
- Decreased service life and increased maintenance of supply equipment (including the compressor package) due to unnecessary cycling and increased run time.

Although leaks can occur in any part of the system, the most common problem areas are couplings, hoses, tubes, fittings, pipe joints, quick disconnects, FRLs (filter, regulator, and lubricator), condensate traps, valves, flanges, packings, thread sealants, and point-of-use devices. Leakage rates are a function of the supply pressure in an uncontrolled system and increase with higher system pressures. Leakage rates identified in cubic feet per minute (cfm) are also proportional to the square of the orifice diameter. See table below.

Leakage rates ^a (cfm) for different supply pressures and approximately equivalent orifice sizes ^b						
Pressure (psig)	Orifice Diameter (inches)					
	1/64	1/32	1/16	1/8	1/4	3/8
70	0.29	1.16	4.66	18.62	74.4	167.8
80	0.32	1.26	5.24	20.76	83.1	187.2
90	0.36	1.46	5.72	23.1	92	206.6
100	0.40	1.55	6.31	25.22	100.9	227
125	0.48	1.94	7.66	30.65	122.2	275.5

^a For well-rounded orifices, values should be multiplied by 0.97 and by 0.61 for sharp ones.

^b Used with permission from Fundamentals of Compressed Air Systems Training offered by the Compressed Air Challenge®.

Leak Detection

The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize high frequency hissing sounds associated with air leaks. These portable units are very easy to use. Costs and sensitivities vary, so test before you buy. A simpler method is to apply soapy water with a paintbrush to suspect areas. Although reliable, this method can be time consuming and messy.

Example

A chemical plant undertook a leak-prevention program following a compressed air audit at their facility. Leaks, approximately equivalent to different orifice sizes, were found as follows: 100 leaks of 1/32" at 90 pounds per square inch gauge (psig), 50 leaks of 1/16" at 90 psig, and 10 leaks of 1/4" at 100 psig. Calculate the annual cost



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savings if these leaks were eliminated. Assume 7,000 annual operating hours, an aggregate electric rate of \$0.05 kilowatt-hour (kWh), and compressed air generation requirement of approximately 18 kilowatts (kW)/100 cfm.

Cost savings = # of leaks x leakage rate (cfm) x kW/cfm x # of hours x \$/kWh

Using values of the leakage rates from the above table and assuming sharp-edged orifices:

Cost savings from 1/32” leaks = 100 x 1.46 x 0.61 x 0.18 x 7,000 x 0.05 = **\$5,611**

Cost savings from 1/16” leaks = 50 x 5.72 x 0.61 x 0.18 x 7,000 x 0.05 = **\$10,991**

Cost savings from 1/4” leaks = 10 x 100.9 x 0.61 x 0.18 x 7,000 x 0.05 = **\$38,776**

Total cost savings from eliminating these leaks = \$57,069

Note that the savings from the elimination of just 10 leaks of 1/4” account for almost 70% of the overall savings. As leaks are identified, it is important to prioritize them and fix the largest ones first.

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Compressed Air Tip Sheet #4 • August 2004

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Suggested Actions

- Take a training class on system optimization or seek the services of a compressed air system professional who understands these techniques.
- Follow the seven-step action plan.
- Consider implementing a leak-detection/repair program using an ultrasonic leak detector. An effective leak-repair program must include a review of system pressure and controls in order to realize energy savings.

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Analyzing Your Compressed Air System

The first step in analyzing a compressed air system is to determine your compressed air needs. Compressed air needs are defined by the air quality and quantity required by the end uses in your plant. Assessing these needs carefully and understanding the difference between air quality and air quantity will ensure that a compressed air system is configured properly. Determining your pressure and demand load requirements are also important steps in analyzing your compressed air system.

Air Quality

Air quality is determined by the air dryness and contaminant level required by end uses. Learn the actual dryness level needed and the maximum contaminant level allowed for reliable production. Overtreating air beyond the required dryness and allowable contaminant level wastes money and energy.

Air Quantity

The required compressed air system volume can be determined by summing the requirements of your compressed air applications and process operations (taking into account load factors) and the duration of such volumes by those applications. The total air requirement is not the sum of the maximum requirements for each tool and process, but the sum of the average air consumption of each.

Pressure Requirements

The minimum required discharge pressure level must take into account the different pressure ratings of compressed air applications and processes as well as the pressure drops from components in the system. Too often, low or fluctuating pressure at end uses is misdiagnosed as not enough discharge pressure.

Pressure drop is a term used to characterize the reduction in air pressure from the compressor discharge to the actual point of end use. Pressure drop occurs as compressed air travels through the treatment and distribution system. Excessive pressure drop will result in poor system performance and excessive energy consumption. A pressure profile is a series of measurements of compressed air pressure at different points in the system, and allows identification of system components that are causing excessive pressure drop.

Demand Load Requirements

Another key to properly designing and operating a compressed air system is analyzing a plant's compressed air requirements over time, or load profile. The variation of demand for air over time is a major consideration in system design. Plants with wide variations in air demand need a system that operates efficiently under part-load. In such a case, multiple compressors with sequencing controls may provide more economical operation. Plants with a flatter load profile can use simpler control strategies.

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Getting Started

The following is a seven-step action plan from CAC *Fundamentals of Compressed Air Systems* to analyze and improve your compressed air system:

1. Develop a basic block diagram of your compressed air system.
2. Measure your baseline (kW, pressure profile, demand profile, and leak load) and calculate energy use and costs.
3. Work with your compressed air system specialist to implement an appropriate compressor control strategy.
4. Once controls are adjusted, remeasure to get more accurate readings of kW and pressures, and to determine leak load. Recalculate energy use and costs.
5. Walk through to check for obvious preventive maintenance items and other opportunities to reduce costs and improve performance.
6. Identify and fix leaks and correct inappropriate uses – know costs, re-measure, and adjust controls as above.
7. Begin implementation of continuous improvement programs.

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Energy Tips – Compressed Air

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Suggested Actions

- Review compressed air applications and determine the appropriate level of air quality they require.
- Review compressed air treatment equipment to ensure that it is performing adequately.
- Inspect compressor inlet air intakes to make sure they are clear of potential contaminants.
- Consider a professional compressed air system evaluation to validate air quality needs.
- Refer to Tip Sheet #4 “Analyzing Your Compressed Air System”.

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Determining the Right Air Quality for Your Compressed Air System

Knowing the proper air quality level required for successful production is an important factor in containing compressed air energy and other operating costs, because higher quality air is more expensive to produce. Higher quality air requires additional air treatment equipment, which increases capital costs as well as energy consumption and maintenance needs. The quality of air produced should be guided by the degree of dryness and filtration needed and by the minimum acceptable contaminant level to the end uses.

Level of Air Quality	Applications
Plant Air	Air tools, general plant air
Instrument Air	Laboratories, paint spraying, powder coating, climate control
Process Air	Food and pharmaceutical process air, electronics
Breathing Air	Hospital air systems, diving tank refill stations, respirators for cleaning and/or grit blasting

Compressed Air Contaminants

Compressed air contaminants can be in the form of solids, liquids, or vapors. Contaminants can enter a compressed air system at the compressor intake, or can be introduced into the air stream by the system itself.

Air quality class is determined by the maximum particle size, pressure dewpoint, and maximum oil content allowed. For more information, see ISO 8573-1 Compressed Air Quality Classes in the Compressed Air System Best Practices Manual. (See references in sidebar).

One of the main factors in determining air quality is whether lubricant-free air is required. Lubricant-free air can be produced either by using lubricant-free compressors, or with lubricant-injected compressors and additional air treatment equipment. The following factors can help one decide whether lubricant-free or lubricant-injected air is appropriate:

- If only one end use requires lubricant-free air, only the air supply to it should be treated to obtain the necessary air quality. Alternatively, it may be supplied by its own lubricant-free compressor. If the end uses in a plant require different levels of air quality, it may be advisable to divide the plant into different sections so that air treatment equipment that produces higher quality air is dedicated to the end uses that require the higher level of compressed air purification.
- Lubricant-free rotary screw and reciprocating compressors usually have higher initial costs, lower efficiency, and higher maintenance costs than lubricant-injected compressors. However, the additional separation, filtration, and drying equipment required by lubricant-injected compressors will generally cause some reduction in system efficiency, particularly if the system is not properly maintained.



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Careful consideration should be given to the specific end use for the lubricant-free air, including the risks and costs associated with product contamination before selecting a lubricant-free or lubricant-injected compressor. Centrifugal compressors also offer an alternative for plants whose end uses require lubricant-free air.

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- Aluminum
- Forest Products
- Metal Casting
- Petroleum
- Chemicals
- Glass
- Mining
- Steel

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Compressed Air Tip Sheet #5

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Compressed Air Tip Sheet #6 • August 2004

Industrial Technologies Program



Suggested Actions

- Establish a regular, well-organized maintenance program in accordance with manufacturer specifications.
- Appoint someone in the plant to have ultimate responsibility for ensuring that all compressed air system maintenance needs are performed properly, on schedule, and are adequately documented.

References

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Preventive Maintenance Strategies for Compressed Air System

A brewery neglected to perform routine maintenance on its compressed air system for years. As a result, two of its centrifugal compressors, whose impellers had been rubbing against their shrouds, were unable to deliver the volume of air they were rated for and one of those units had burned up several motors during its lifetime. In addition, plant personnel did not inspect the system's condensate traps regularly. These traps were of a type that clogged easily, which prevented the removal of moisture and affected product quality. Also, the condensate drains were set to operate under the highest humidity conditions, so they would actuate frequently, which increased the system's air demand. As a result, energy use was excessively high, equipment repair and replacement costs were incurred unnecessarily, and product quality suffered. All of this could have been avoided through regular maintenance.

Like all electro-mechanical equipment, industrial compressed air systems require periodic maintenance to operate at peak efficiency and minimize unscheduled downtime. Inadequate maintenance can increase energy consumption via lower compression efficiency, air leakage, or pressure variability. It also can lead to high operating temperatures, poor moisture control, excessive contamination, and unsafe working environments. Most issues are minor and can be corrected with simple adjustments, cleaning, part replacement, or elimination of adverse conditions. Compressed air system maintenance is similar to that performed on cars; filters and fluids are replaced, cooling water is inspected, belts are adjusted, and leaks are identified and repaired.

A good example of excess costs from inadequate maintenance can be seen with pipeline filter elements. Dirty filters increase pressure drop, which decreases the efficiency of a compressor. For example, a compressed air system that is served by a 100-horsepower (hp) compressor operating continuously at a cost of \$0.08/kilowatt-hour (kWh) has annual energy costs of \$63,232. With a dirty coalescing filter (not changed at regular intervals), the pressure drop across the filter could increase to as much as 6 pounds per square inch (psi), vs. 2 psi when clean, resulting in a need for increased system pressure. The pressure drop of 4 psi above the normal drop of 2 psi accounts for 2% of the system's annual compressed air energy costs, or \$1,265 per year. A pressure differential gauge is recommended to monitor the condition of compressor inlet filters. A rule of thumb is that a pressure drop of 2 psi will reduce the capacity by 1%.

All components in a compressed air system should be maintained in accordance with the manufacturers' specifications. Manufacturers provide inspection, maintenance, and service schedules that should be strictly followed. Because the manufacturer-specified intervals are intended primarily to protect the equipment rather than optimize system efficiency, in many cases, it is advisable to perform maintenance on compressed air equipment more frequently.



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One way to tell if a compressed air system is well maintained and operating efficiently is to periodically baseline its power consumption, pressure, airflow, and temperature. If power use for a given pressure and flow rate increases, the system's efficiency is declining. Baselineing the system will also indicate whether the compressor is operating at full capacity, and if that capacity is decreasing over time. On new systems, specifications should be recorded when the system is first installed and is operating properly.

Types of Maintenance

Maintaining an air compressor system requires caring for the equipment, paying attention to changes and trends, and responding promptly to maintain operating reliability and efficiency. To assure the maximum performance and service life of your compressor, a routine maintenance schedule should be developed. Time frames may need to be shortened in harsher environments. Proper maintenance requires daily, weekly, monthly, quarterly, semi-annual, and annual procedures. Please refer to the Compressed Air System Best Practices Manual for the types of procedures that are relevant to the compressors and components in your system.

Excellent maintenance is the key to good reliability of a compressed air system; reduced energy costs are an important and measurable by-product. The benefits of good maintenance far outweigh the costs and efforts involved. Good maintenance can save time, reduce operating costs, and improve plant manufacturing efficiency and product quality.

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Energy Tips – Compressed Air

Compressed Air Tip Sheet #7 • August 2004

Industrial Technologies Program



Suggested Actions

- Understand your system requirements by developing a pressure and a demand profile before investing in additional controls.
- Identify end uses that are affected by pressure problems.
- Check existing equipment to ensure that it is in good operating condition.
- Eliminate inappropriate uses, fix major leaks, and implement a leak management program.
- Once these actions have been taken, work with a compressed air specialist to match your control strategy to your actual system needs.

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Compressed Air System Control Strategies

Improving and maintaining compressed air system performance requires not only addressing individual components, but also analyzing both the supply and demand sides of the system and how they interact, especially during periods of peak demand. This practice is often referred to as taking a systems approach because the focus is shifted away from components to total system performance.

Matching Supply with Demand

With compressed air systems, system dynamics (changes in demand over time) are especially important. Using controls, storage, and demand management to effectively design a system that meets peak requirements but also operates efficiently at part-load is key to a high performance compressed air system. In many systems, compressor controls are not coordinated to meet the demand requirements, which can result in compressors operating in conflict with each other, short-cycling, or blowing off—all signs of inefficient system operation.

Individual Compressor Controls

Over the years, compressor manufacturers have developed a number of different types of control strategies. Controls such as start/stop and load/unload respond to reductions in air demand by turning the compressor off or unloading it so that it does not deliver air for periods of time. Modulating inlet and multi-step controls allow the compressor to operate at part-load and deliver a reduced amount of air during periods of reduced demand. Variable speed controls reduce the speed of the compressor in low demand periods. Compressors running at part-load are generally less efficient than when they are run at full-load.

Multiple Compressor Controls

Systems with multiple compressors should use more sophisticated controls to orchestrate compressor operation and air delivery to the system. Network controls use the on-board compressor controls' microprocessors linked together to form a chain of communication that makes decisions to stop/start, load/unload, modulate, and vary displacement and speed. Usually, one compressor assumes the lead role with the others being subordinate to the commands from this compressor. System master controls coordinate all of the functions necessary to optimize compressed air as a utility. System master controls have many functional capabilities, including the ability to monitor and control all components in the system, as well as trending data, to enhance maintenance functions and minimize costs of operation. Most multiple compressor controls operate the appropriate number of compressors at full-load and have one compressor trimming (running at part-load) to match supply with demand.

Pressure/Flow Controllers

Pressure/Flow Controllers (P/FC) are system pressure controls that can be used in conjunction with the individual and multiple compressor controls described above. A P/FC does not directly control a compressor and is generally not part of a



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compressor package. A P/FC is a device that serves to separate the supply side of a compressor system from the demand side, and requires the use of storage.

Controlled storage can be used to address intermittent loads, which can affect system pressure and reliability. The goal is to deliver compressed air at the lowest stable pressure to the main plant distribution system and to support transient events as much as possible with stored compressed air. In general, a highly variable demand load will require a more sophisticated control strategy to maintain stable system pressure than a consistent, steady demand load.

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Compressed Air Tip Sheet #7

Energy Tips – Compressed Air

Compressed Air Tip Sheet #8 • August 2004

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Suggested Actions

- Review compressed air applications and determine the required level of air pressure.
- Review your compressed air system's demand patterns to determine which method for stabilizing pressure is most appropriate.

References

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Stabilizing System Pressure

Stabilizing system pressure is an important way to lower energy costs and maintain reliable production and product quality. The need to stabilize system pressure should be guided by the compressed air demand patterns and the minimum acceptable pressure level required for reliable production. High-volume intermittent air demand events can cause air pressure to fluctuate, which is often misinterpreted as insufficient pressure. In some cases, improperly set compressor controls will cause another compressor to start, but because of the time required for the new compressor to ramp up, there will be a shortfall of air supply to the system. Such a delay can cause the system pressure to decay, resulting in lost production. Three methods can be used to stabilize system pressure: adequate primary and secondary storage, Pressure/Flow Controllers (P/FCs), and dedicated compressors.

Primary and Secondary Storage

One or more compressed air applications having large, intermittent air demands can cause severe, dynamic pressure fluctuations in the whole system, with some essential points of use experiencing inadequate pressure. Such demand is often of short duration; properly sized primary and secondary storage can supply the needs of the intermittent demand. The time interval between the demand events is adequate to restore the storage receiver pressure without adding compressor capacity. Primary storage receivers can:

- Prevent frequent loading and unloading of compressors
- Collect condensate, which may be carried over from the aftercooler and moisture separator
- Provide some radiant cooling to reduce moisture content and air dryer load if located in a cool location and installed upstream of the dryer
- Provide dampening of pressure pulsations from reciprocating compressors.

Secondary storage receivers can be used to:

- Supplement the primary receivers to stabilize system pressure and thus keep unneeded compressors from starting
- Supply adequate compressed air for a single intermittent event of a known duration.

The secondary receiver should be located as close to the end use as is practicable and its pressure rating must be at least equal to that of the primary receiver(s).

Pressure fluctuations may also occur due to inadequate storage or because the system pressure is at or near the lowest level of the compressor pressure control band. If a large, intermittent demand event occurs when the pressure is at or near the lowest level in the control band, the pressure in the distribution piping falls even further, affecting critical end-use applications. In such a case, the installation of a relatively small receiver with a check valve upstream of the application causing the demand event may address the problem.



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Pressure/Flow Controllers

A Pressure/Flow Controller (P/FC) is a device that serves to separate the supply side of a compressed air system from that system's demand side. P/FCs use the principle of operating compressors to fill and store air in receivers at higher pressures. P/FCs then reduce the pressure and supply it to the system at the pressure required by that system's compressed air applications. P/FCs work with pilot-operated regulators or electronic controls to sense and monitor the system's pressure downstream of the valves. Controlled pressure and adequate upstream storage are critical to satisfactory performance. P/FCs normally respond rapidly to demand fluctuations and maintain system pressure within a narrow band. For peak demand events, sufficient storage is necessary to release the stored air quickly into the system to maintain required downstream pressures within an acceptable tolerance. With proper design and system controls, storage can be used to meet air demand and reduce compressor run time.

Dedicated Compressors

Applications some distance from the main compressor supply or those with pressure requirements that differ from the main system requirements may be served by a dedicated compressor. Small or unit type compressors (generally up to 10 hp maximum) can be very suitable for an application whose pressure level is higher than that of the plant's other applications. Generally, such compressors can be located close to a point of use, avoiding lengthy piping runs and pressure drops; are adaptable to a wide range of conditions such as temperature, altitude, and humidity; and do not require separate cooling systems.

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Energy Tips – Compressed Air

Compressed Air Tip Sheet #9 • August 2004

Industrial Technologies Program

Suggested Actions

- Review the plant's compressed air demand patterns to determine whether storage would be beneficial.
- Examine the compressed air applications to determine if they can be supplied by a separate, smaller compressor with storage to reduce the system demand fluctuations caused by their intermittent demand.

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Compressed Air Storage Strategies

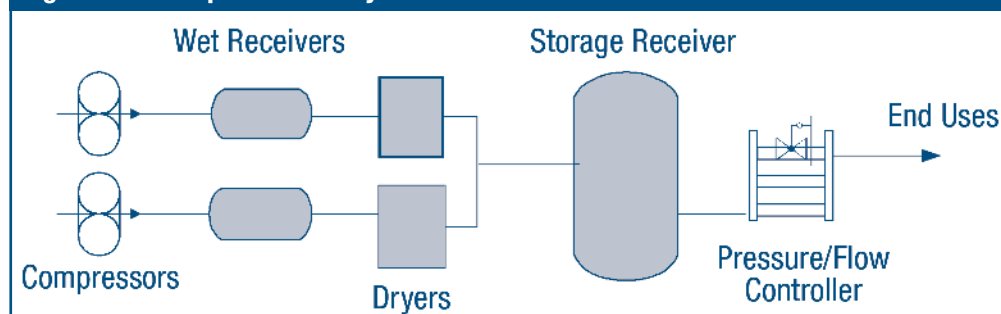
Compressed air storage can allow a compressed air system to meet its peak demand needs and help control system pressure without starting additional compressors. The appropriate type and quantity of air storage depends on air demand patterns, air quantity and quality required, and the compressor and type of controls being used. An optimal air storage strategy will enable a compressed air system to provide enough air to satisfy temporary air demand events while minimizing compressor use and pressure.

The use of air receivers is especially effective for systems with shifting air demand patterns. When air demand patterns are variable, a large air receiver can provide enough stored air so that a system can be served by a small compressor and can allow the capacity control system to operate more effectively. For systems having a compressor operating in modulation to support intermittent demand events, storage may allow such a compressor to be turned off. By preventing pressure decay due to demand events, storage can protect critical end-use applications and prevent additional units from coming online.

Air entering a storage receiver needs to be at a higher pressure level than the system pressure. A good air storage strategy will allow the differential between these two pressure levels to be sustained. To accomplish such a pressure differential, two types of devices can be employed: Pressure/Flow Controllers (P/FC) and metering valves.

A P/FC is a device that serves to separate the supply side of a compressed air system from the demand side. In a system that employs P/FCs, the compressors generally operate at or near design discharge pressure to ensure that the P/FC receives air at a higher pressure level than it will discharge into the system. This allows the pressure in the demand side to be reduced to a stable level that minimizes actual compressed air consumption. P/FCs are added after the primary receiver to maintain a reduced and relatively constant system pressure at points of use, while allowing the compressor controls to function in the most efficient control mode and discharge pressure range. Properly applied, a P/FC can yield significant energy savings in a system with a variable demand load. See Figure 1.

Figure 1. A Compressed Air System with a Pressure/Flow Controller

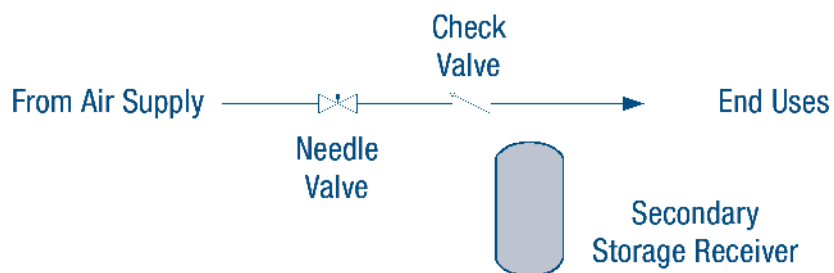


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For situations in which just one or a few applications have intermittent air demand, a correctly-sized storage receiver close to the point of the intermittent demand with a check valve and a metering valve can be an effective and lower cost alternative. For this type of storage strategy, a check valve and a tapered plug or needle valve are installed upstream of the receiver. The check valve will maintain receiver pressure at the maximum system pressure; the plug or needle valve will meter the flow of compressed air to “slow fill” the receiver during the interval between demand events. This will have the effect of reducing the large intermittent requirement into a much smaller average demand. See Figure 2.

Figure 2. A Compressed Air System with Check and Needle Valves



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Compressed Air Tip Sheet #9

Energy Tips – Compressed Air

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Industrial Technologies Program



Suggested Actions

- Review compressed air end uses and determine the required level of air pressure.
- Review the compressed air end uses' original configurations to determine whether manufacturing processes have evolved in such a way that those end uses are no longer necessary or can be reconfigured more efficiently.

References

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Engineer End Uses for Maximum Efficiency

Compressed air is one of the most important utility requirements of many industrial manufacturing plants because it directly serves processes and applications such as pneumatic tools, pneumatic controls, compressed air operated cylinders for machine actuation, product cleansing and blow-off applications. Ensuring an appropriate, stable pressure level at the end-use applications is critical to the performance of any industrial compressed air system. End uses that are engineered for maximum efficiency can help provide the consistent supply of compressed air that ensures reliable production.

To ensure the efficiency of compressed air end-use applications, a number of steps should be taken:

Step	Action
1	Review the pressure level requirements of the end-use applications. Those pressure level requirements should determine the system pressure level. Because there is often a substantial difference in air consumption and pressure levels required by similar tools available from different manufacturers, request exact figures from each manufacturer for the specific application. Do not confuse maximum allowable with required pressure.
2	Monitor the air pressure at the inlet to the tool. Improperly-sized hoses, fittings and quick disconnects often result in large pressure drops. These drops require higher system pressures to compensate, thus wasting energy. Reduced inlet pressure at the tool reduces the output from the tool and, in some cases, may require a larger tool for the specified speed and torque.
3	Avoid the operation of any air tool at "free speed" with no load. Operating a tool this way will consume more air than a tool that has the load applied.
4	Check the useful life of each end-use application. A worn tool will often require higher pressure, consume excess compressed air, and can affect other operations in the immediate area.
5	Air tools should be lubricated as specified by the manufacturer, and the air going to all end uses should be free of condensate to maximize tool life and effectiveness.
6	End uses having similar air requirements of pressure and air quality may be grouped in reasonably close proximity, allowing a minimum of distribution piping, air treatment, and controls.
7	Investigate and, if possible, reduce the highest point-of-use pressure requirements. Then, adjust the system pressure.
8	Investigate and replace inefficient end uses such as open blowing with efficient ones such as vortex nozzles.

Case Study: A New Compressed Air Application is Configured for Maximum Efficiency

A large, custom printing company installed a more technologically-advanced printing machine that could increase the output of its existing units. However, the initial configuration of the new printing machine more than doubled the compressed air demand of the entire site. After a thorough review, the plant personnel realized that it would be more cost-effective for the new machines to be redesigned to consume less air at lower pressures than to increase compressor capacity at all of the



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company's printing plants. Once the printing machines were reconfigured, the total air demand per printing machine was reduced from 27 standard cubic feet per minute (scfm) to 4.5 scfm and the need for 100 pounds per square inch gauge (psig) compressed air was eliminated, resulting in substantial avoided costs in energy and capital expenditures.

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Energy Tips – Compressed Air

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Industrial Technologies Program



Suggested Actions

- Review the compressed air applications to determine which ones are valid high-pressure and which ones can operate at lower pressures. The ones that can operate at low pressure could be supported with alternative methods.
- Consider a professional compressed air system evaluation. Such an exam could determine what applications could be served more efficiently and which appropriate alternative applications could replace them.

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Alternative Strategies for Low-Pressure End Uses

Compressed air is expensive to produce. Because compressed air is also clean, readily available, and simple to use, it is often chosen for applications in which other methods or sources of air are more economical. To reduce compressed air energy costs, alternative methods of supplying low-pressure end uses should be considered before using compressed air in such applications. Many alternative methods of supplying low-pressure end uses can allow a plant to achieve its production requirements effectively.

Before deciding to replace a low-pressure end use with an alternative source, it is important to determine the minimum practical pressure level required for the application.

Alternative Applications to Low-Pressure End Uses

Existing Low-Pressure End Use	Potential Alternatives	Reasoning
Open blowing, mixing	Fans, blower, mixers, nozzles	Open-blowing applications waste compressed air. For existing open-blowing applications, high efficiency nozzles could be applied, or if high-pressure air isn't needed, consider a blower or a fan. Mechanical methods of mixing typically use less energy than compressed air.
Personnel cooling	Fans, air conditioning	Using compressed air for personnel cooling is not only expensive, but can also be hazardous. Additional fans or an HVAC upgrade should be considered instead.
Parts cleaning	Brushes, blowers, vacuum pumps	Low-pressure blowers, electric fans, brooms, and high-efficiency nozzles are more efficient for parts cleaning than using compressed air to accomplish such tasks.
Air motors and air pumps	Electric motors, mechanical pumps	The tasks performed by air motors can usually be done more efficiently by an electric motor except in hazardous environments. Similarly, mechanical pumps are more efficient than air-operated double diaphragm pumps. However, in an explosive atmosphere and/or the pumping of abrasive slurries, the application of a double diaphragm pump with appropriate pressure regulating and air shut-off controls may be appropriate.

Case Study: Low-Pressure End Uses are Replaced with Alternative Applications

A bottling plant was using compressed air in some applications that could be better supported with less energy-intensive methods. The plant was cooling and hardening bottlenecks by blowing cool, compressed air on them. Also, some of the blow mold machines were continuously blowing compressed air through air jets onto the pre-form feed lines to prevent them from jamming. Lastly, the plant's stackers in the packaging area were using compressed air-operated venturi vacuum producers to pick up and position dividers between layers of bottles. To cool the bottlenecks, the application of a small blower that would blow cool air from chilled water was

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recommended. The installation of an electromechanical vibrator was identified as the best way to prevent the feed lines from jamming. Finally, a central vacuum system having energy costs that were 30% lower than that of the venturi devices was shown to be as effective as the existing system. The annual compressed air energy savings from implementing these simple modifications was \$80,000.

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Energy Tips – Compressed Air

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Industrial Technologies Program



Suggested Actions

- Review compressed air applications and determine the required level of air quality for each.
- Review the compressed air treatment equipment to determine whether it is operating satisfactorily. If it is not, consider improved maintenance or an upgrade.
- Check condensate traps for effectiveness. If stuck closed, they will not remove condensate, if stuck open, they will leak air. See Compressed Air Tip Sheet #13, *Remove Condensate With Minimal Air Loss*.

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Maintaining System Air Quality

Maintaining the proper air quality level is essential for keeping compressed air energy costs down and to ensure reliable production. Poor air quality can have a negative effect on production equipment and can increase energy consumption and maintenance needs. The quality of air produced should be guided by the quality required by the end-use equipment. The air quality level is a function of the levels of particulate, moisture, and lubricant contaminants that the end uses can tolerate. Such air quality levels should be determined before deciding whether the air needs additional treatment. Compressed air should be treated appropriately but not more than is required for the end-use application. The higher the quality, the more the air usually costs to produce (in terms of initial capital investment in equipment, energy consumption and maintenance).

Once the true end-use air quality requirements have been determined, the proper air treatment equipment can be configured. Separators, filters, dryers and condensate drains are used to improve compressed air quality. Treatment equipment maintenance is critically important for sustaining the desired air quality levels.

Grouping Equipment with Similar Air Quality Requirements

One strategy to improve air quality is to group end uses having similar air quality requirements in reasonably close proximity and install the appropriate air treatment equipment to serve these end uses with a minimum of distribution piping. Sometimes, grouping similar requirements of best quality air together is not always practical; if the requirement for this class is sufficiently high (70% or more of total), consider supplying the entire plant with this air quality level. If practical, separation of groups of end uses requiring similar pressure and air quality also allows some compressors and air treatment equipment to be located close to the end uses.

Filtration

Through proper filtration, appropriate air quality levels can be achieved. Because some end uses may require a higher level of air quality than others, it may not be necessary to have the entire airflow filtered to the highest level of air quality. Filters cause pressure drop that increases as the elements become fouled. Filters should be rated for the maximum anticipated operating pressure, but should be sized for the maximum anticipated rate of flow at the anticipated minimum operating pressure. The three types of compressed air filters (particulate, coalescing, and adsorption) have different functions and must be selected for the appropriate application.

Dryers

Compressed air dryers can be very effective at removing condensate from compressed air. Dryers are of three types: deliquescent, refrigerated, and desiccant. Deliquescent dryers provide a Pressure Dew Point (PDP) of 20°F lower than the dew point of the air entering them. Refrigerated dryers provide a PDP of between 35°F and 38°F and desiccant dryers can provide a PDP as low as -100°F. Dryers



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should be sized for the maximum anticipated rate of flow and must be matched to the air quality requirements. Overdrying wastes energy.

Separators

Moisture separators and condensate traps are used to remove condensate from the air stream. Because the first step in condensate removal is to separate it from the air stream, moisture separators should follow each intercooler and aftercooler.

Condensate Traps

There are four main types of condensate drains: manual, level-operated mechanical (float) traps, electrically-operated solenoid valves and zero-loss traps with reservoirs. Traps should allow removal of condensate, but not compressed air, and should not be left open.

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Suggested Actions

- Inspect the condensate traps and determine if they are operating properly.
- Review your condensate removal method and, if possible, the load on compressors during non-production hours. If it releases too much air, consider upgrading to zero-loss drain traps.

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Remove Condensate with Minimal Air Loss

Removing condensate is important for maintaining the appropriate air quality level required by end uses. However, significant compressed air (and energy) losses can occur if condensate removal is done improperly.

Excess compressed air loss during condensate removal can occur due to several factors. The table below illustrates several condensate removal methods and the characteristics of each method.

Condensate Removal Method	Characteristics
Manual operation	• Operators manually open valves to discharge condensate. • Depends on people opening valves at the appropriate time for the necessary amount of time. • Often leads to excess loss because air escapes when the valves are left open to drain the condensate.
Level-operated mechanical float traps	• Use a float connected by linkage to a drain valve that opens when an upper setting is reached and closes when the drain is emptied. • Require considerable maintenance. • Are prone to blockage from sediment in condensate. • Are prone to getting stuck in open position (leak excess air) and in the closed position (does not allow condensate to be drained). • Inverted bucket traps may require less maintenance, but will waste air if the condensate rate is inadequate to maintain the liquid level in the trap. • Most suited for a fully-attended powerhouse operation with scheduled maintenance.
Solenoid-operated drain valves	• Have timing devices that can be set to open for specified amounts of time at pre-set adjustable intervals. • The period during which the valve is open may not be long enough for adequate drainage of accumulated condensate. • The valve will operate even if little or no condensate is present, resulting in air loss. • Require strainers to reduce contaminants, which can block the inlet and discharge ports of these devices.
Zero-loss traps	• Have a float or level sensor that operates an electric solenoid or ball valve to maintain the condensate level in the reservoir below the high level point, or a float activates a pneumatic signal to an air cylinder to open a ball valve through a linkage to expel the condensate in the reservoir to the low level point. • Wastes no air. • Considered very reliable. • Reservoir needs to be drained often to prevent the accumulation of contaminants.



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Other Points to Consider

Drain the condensate often and in smaller quantities rather than less frequently and in larger quantities. Consider oversized condensate treatment equipment to handle unexpected lubricant loading and to reduce maintenance.

All drain traps should be inspected periodically, with parts repaired or replaced as required. If replacement is the decision, consider using zero loss drain traps.

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Suggested Actions

- Inspect the entry to the compressor air intake pipe and ensure that it is free of contaminants.
- Inspect the compressed air intake filter element to ensure that it is of the appropriate type, that it is properly installed, and that it is clean.
- Check the intake filter regularly for excess pressure drop.

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Effect of Intake on Compressor Performance

The effect of intake air on compressor performance should not be underestimated. Intake air that is contaminated or hot can impair compressor performance and result in excess energy and maintenance costs. If moisture, dust, or other contaminants are present in the intake air, such contaminants can build up on the internal components of the compressor, such as valves, impellers, rotors, and vanes. Such build-up can cause premature wear and reduce compressor capacity.

When inlet air is cooler, it is also denser. As a result, mass flow and pressure capability increase with decreasing intake air temperatures, particularly in centrifugal compressors. This mass flow increase effect is less pronounced for lubricant-injected, rotary-screw compressors because the incoming air mixes with the higher temperature lubricant. Conversely, as the temperature of intake air increases, the air density decreases and mass flow and pressure capability decrease. The resulting reduction in capacity is often addressed by operating additional compressors, thus increasing energy consumption.

To prevent adverse effects from intake air quality, it is important to ensure that the location of the entry to the inlet pipe is as free as possible from ambient contaminants, such as rain, dirt, and discharge from a cooling tower. If the air is drawn from a remote location, the inlet pipe size should be increased in accordance with the manufacturer's recommendation to prevent pressure drop and reduction of mass flow. All intake air should be adequately filtered. A pressure gauge indicating pressure drop in inches of water is essential to maintain optimum compressor performance.

When an intake air filter is located at the compressor, the ambient temperature should be kept to a minimum, to prevent reduction in mass flow. This can be accomplished by locating the inlet pipe outside the room or building. When the intake air filter is located outside the building, and particularly on a roof, ambient considerations are important, but may be less important than accessibility for maintenance in inclement or winter conditions.

How to Select an Intake Air Filter

A compressor intake air filter should be installed in, or have air brought to it from a clean, cool location. The compressor manufacturer normally supplies, or recommends, a specific grade of intake filter designed to protect the compressor. The better the filtration at the compressor inlet, the lower the maintenance at the compressor. However, the pressure drop across the intake air filter should be kept to a minimum (by size and by maintenance) to prevent a throttling effect and a reduction in compressor capacity. A pressure differential gauge is one of the best tools to monitor the condition of the inlet filter. The pressure drop across a new inlet filter should not exceed 3 pounds per square inch (psi).



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Inlet Filter Replacement

As a compressor intake air filter becomes dirty, the pressure drop across it increases, reducing the pressure at the air end inlet and increasing the compression ratios. The cost of this loss of air can be much greater than the cost of a replacement inlet filter, even over a short period of time. For a 200 horsepower (hp) compressor operating two shifts, 5 days a week (4,160 hours per year) with a \$0.05/kilowatt hour (kWh) electricity rate, a dirty intake filter can decrease compressor efficiency by 1%–3%, which can translate into higher compressed air energy costs of between \$327 and \$980 per year.

About DOE's Industrial Technologies Program

The Industrial Technologies Program, through partnerships with industry, government, and non-governmental organizations, develops and delivers advanced energy efficiency, renewable energy, and pollution prevention technologies for industrial applications. The Industrial Technologies Program is part of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

The Industrial Technologies Program encourages industry-wide efforts to boost resource productivity through a strategy called Industries of the Future (IOF). IOF focuses on the following eight energy and resource intensive industries:

- Aluminum
- Forest Products
- Metal Casting
- Petroleum
- Chemicals
- Glass
- Mining
- Steel

The Industrial Technologies Program and its BestPractices activities offer a wide variety of resources to industrial partners that cover motor, steam, compressed air, and process heating systems. For example, BestPractices software can help you decide whether to replace or rewind motors (MotorMaster+), assess the efficiency of pumping systems (PSAT), compressed air systems (AirMaster+), steam systems (Steam Scoping Tool), or determine optimal insulation thickness for pipes and pressure vessels (3E Plus). Training is available to help you or your staff learn how to use these software programs and learn more about industrial systems. Workshops are held around the country on topics such as "Capturing the Value of Steam Efficiency," "Fundamentals and Advanced Management of Compressed Air Systems," and "Motor System Management." Available technical publications range from case studies and tip sheets to sourcebooks and market assessments. The Energy Matters newsletter, for example, provides timely articles and information on comprehensive energy systems for industry. You can access these resources and more by visiting the BestPractices Web site at www.eere.energy.gov/industry/bestpractices or by contacting the EERE Information Center at 877-337-3463 or via the Web at www.eere.energy.gov/informationcenter/.

BestPractices is part of the Industrial Technologies Program Industries of the Future strategy, which helps the country's most energy-intensive industries improve their competitiveness. BestPractices brings together emerging technologies and best energy-management practices to help companies begin improving energy efficiency, environmental performance, and productivity right now.

BestPractices emphasizes plant systems, where significant efficiency improvements and savings can be achieved. Industry gains easy access to near-term and long-term solutions for improving the performance of motor, steam, compressed air, and process heating systems. In addition, the Industrial Assessment Centers provide comprehensive industrial energy evaluations to small- and medium-size manufacturers.

FOR ADDITIONAL INFORMATION, PLEASE CONTACT:

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