Energy Efficient Compressed Air Systems

Useful Practical Guide

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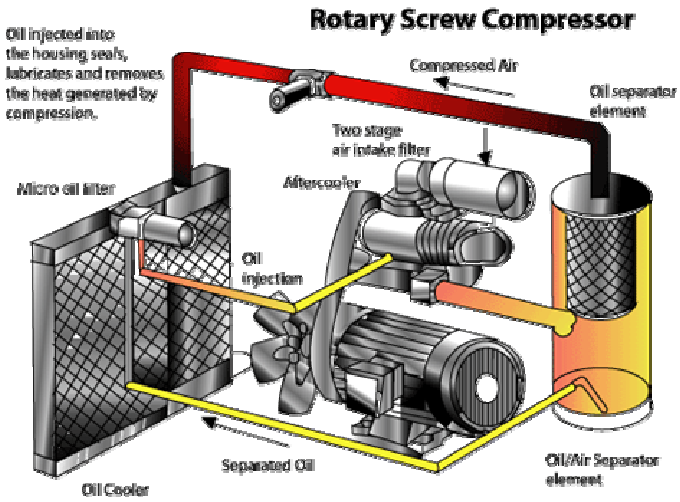

1 Introduction

Compressed air systems are safe, reliable and versatile, but they are usually taken for granted with scant regard to cost. An essential resource for industry, business and the public sector, compressed air is often referred to as the fourth utility after electricity, gas and water. However, unlike the other three, compressed air is generated on-site, and users therefore have much more control over usage and costs.

1.1 Why take action to control compressed air

There are three important reasons why it is worth investing time and effort in reducing compressed air costs:

- It will save energy and money by identifying and eliminating waste
- It will improve the reliability and performance of the compressed air system
- It will reduce environmental impact through reduced electricity consumption and consequent lower carbon emissions.

A properly designed and maintained compressed air system that is energy efficient could save the user thousands of pounds each year. It will also minimise the risk of lost production by increasing the reliability of supply and improve the health and safety aspect of operating a pressurized system. Every pound saved on energy goes straight to the bottom line and is a very effective way of increasing profits.

Of all utilities, compressed air represents one of the largest opportunities for immediate energy savings on any site. Furthermore, most of the energy and carbon savings are achievable with little or modest investment.

Table 1 *Energy saving opportunities for a typical industrial compressed air system*

	Potential Investment	savings
Management Actions		
Raise the awareness of all users to the proper use of compressed air	10-15%	Low
Develop and implement a maintenance programme for the whole system	5-8%	Low
Install metering and implement monitoring	5-10%	Medium
Use only trained and competent personnel for installation, servicing and system upgrades	5-10%	Low
Develop and implement a purchasing policy	3-5%	Low
Technical Actions		
Implement a leak reporting and repair programme	20-40%	Low
Do not pressurise the system during non-productive periods	2-10%	Low
Fit dryer controls (refrigerant and desiccant)	5-20%	Medium
Install compressor drive and system control measures	5-15%	Medium
Install heat recovery measures where appropriate	Up to 75%	Medium

1.3 Taking a system approach

An energy efficient compressed air system will be one that is:

- Well maintained throughout, with all equipment serviced regularly and performance tested
- Properly designed to minimise pressure drop with respect to all fittings, air treatment, piping and connections
- Monitored continuously or on a regular basis, with specific energy consumption calculated from the data obtained
- Used by staff who are aware of the cost of compressed air and properly trained in the effective use of equipment utilising it
- Subject to an ongoing leak reporting and repair programme.

1.4 Purchasing for energy efficiency

As a general rule, the more efficient equipment usually costs more to buy then the less efficient alternative. Suppliers of equipment are often unable to supply the expected lifetime operating cost, so purchase decisions are too frequently based on purchase price alone. The policy of lowest price is often detrimental to energy efficiency and any benefit derived from technology advances.

2 Managing a compressed air system

Making energy savings to reduce the cost of providing compressed air at a site is not just about the compressor. It involves looking at the efficiency and performance of all parts of the overall system. The different components (e.g. air distribution, compressors, storage, air treatment, condensate management) are considered. This section explains how to manage a compressed air system effectively.

2.1 Compiling and implementing a compressed air policy

Most compressed air systems evolve instead of going through a structured design process.
A number of departments are normally involved, including:

- Production
- Maintenance/facilities management
- Accounts/purchasing
- Energy/environment.

Such structures, with no overall responsibility assigned to one person, frequently lead to an uncoordinated approach to changes to the system — some of which may conflict with the needs of another department.

Formulating a compressed air policy is a key step towards improving the energy efficiency of a system.

The guidelines within the compressed air policy will also help to improve air supply reliability and to comply with legislation.

A compressed air policy should:

- Appoint a manager with responsibility to ensure overall coordination of the management of the system
- Set objectives with regard to:
  - Each department's role and responsibility
  - Raising awareness of all those who use compressed air
  - Establishing compressed air costs
  - Setting targets for reducing avoidable waste
  - Implementing a maintenance programme
  - Defining servicing and installation guidelines using trained personnel
  - Defining a purchasing policy.

This overall management approach to compressed air systems has the same principles as general energy management. This approach is essential in achieving the maximum reduction in energy consumption by the system. A reduction of 30% in energy costs is typical and achievable.

2.2 Establishing current usage and costs

Before implementing any improvements to a compressed air system, an audit should be carried out to:

- Determine annual costs
- Establish a baseline against which improvements can be measured.

If permanent metering is already installed, this will provide a demand profile and a baseline to help identify areas of avoidable waste. If there is no metering, an estimate of the energy consumption of each compressor can be calculated from the size of the motor, its average utilization and the number of hours it operates.

A compressed air equipment supplier or a consultant may be able to assist in obtaining more accurate costs and a demand profile. The usual method is to install a data logging system over a period of at least seven days to determine the demand and pressure variation, and power consumed during a typical week. This will identify:

- Pattern of demand (demand profile)
- Off load running time
- Demand peaks (expected and exceptional)
- Specific energy consumption.

Typical methods used to achieve this are:

- Power metering
- Flow metering
- On/off load monitoring

2.3 Identifying opportunities for improvement

Having calculated annual costs and established a baseline against which to measure improvement, the approach described in this guide can be used to identify opportunities for improvement. Start by carrying out a survey. It is best to start by reviewing end uses, because any improvements here may well affect the demand for compressed air and the air distribution network (i.e. redundant pipework and reduced pressure losses).

2.4 Maintenance

Effective maintenance is essential to energy efficiency in compressed air systems. Any organisation that cuts back on maintenance will pay more in terms of energy consumed as well as decreased service life and reduced reliability of components and equipment.

3. Misuse and waste of compressed air

Waste and misuse often offer the greatest potential for no-cost and low-cost energy savings in a typical system. Start by looking at all the uses of compressed air on the site.

During the lifetime of an organisation, processes evolve and production methods change. Both affect the way a compressed air system is maintained, upgraded and the way in which compressed air is used. For these reasons, it is good practice to review the system and working practices regularly. However, there are many cases where compressed air is the preferred choice and, indeed, has unique advantages over other power sources. These include:

- Air-driven equipment in hospitals to avoid electrical interference
- Air supply for remote locations where air can also be stored in tanks
- Offshore or hazardous area uses where risk of explosion excludes the use of electricity
- Cleaning out areas of extreme temperatures (e.g. freezers and furnaces).

3.1 Misuse

Compressed air is used for a myriad of applications due to its safety, flexibility and convenience. However, it is also misused — and hence wasted — for the same reasons, incurring unnecessary energy costs. Compressed air is sometimes used for an application just because an air supply is readily available, not because it is the most cost-effective or appropriate method. Table 2 gives examples of duties that do not warrant the use of treated compressed air, together with alternatives.

3.2 Waste

The main areas of waste that merit attention are:

- Leaks
- Pressure drop
- Running the compressor when there is no demand for air.

Leaks

All compressed air systems have leaks. Reducing air leaks is the single most important energy saving measure that can be performed. The leak rate on an unmanaged compressed air system can be as much as 40% of the output. Compressed air leaks also lead to additional costs through:

- Fluctuating system pressure, which can cause air tools and other air-operated equipment to function less efficiently — potentially stalling and affecting production
- Reduced service life and increased maintenance of equipment due to unnecessary compressor cycling and running time
- Excess compressor capacity.

The sources of leakage are numerous, but the most frequent causes are:

- Manual condensate drain valves left open
- Shut-off valves left open
- Leaking hoses and couplings
- Leaking pipes and pipe joints
- Leaking pressure regulators
- Air-using equipment left in operation when not needed.

4 Air distribution network

The role of the distribution network is to deliver the compressed air from the compressor discharge to the points of use with minimal leakage, minimal loss of pressure and minimal effect on the quality of the air. Friction and leaks cause a pressure drop between the compressor output and the eventual point of use. This lost energy in the distribution network is largely due to its design and layout. This section describes how attention to pipe installation can reduce the pressure drop in distribution networks.

4.1 Pipe sizing

The cost of the air mains frequently represents a high proportion of the initial cost of a compressed air system. Therefore, smaller diameter pipe is often specified to save on capital cost. However, this is false economy since the restriction due to the smaller piping causes greater pressure drop across the system, resulting in higher energy consumption. These increased energy costs can soon exceed the price of larger diameter piping.

4.2 Pipe layout

All compressed air distribution pipelines should be designed with the following points in mind:

- Pipe diameters should be selected that minimize pressure drop and allow for possible expansion.
- Fittings and valves should be selected that create the minimum restriction to airflow. Large radius bends are preferred to elbows, for example. Full-throated valves such as ball valves should be used rather than gate valves.
- All piping must be well supported to minimize movement and sagging. This will help to minimize leaks, avoid build up of corrosion and fluids and lengthen the life of the pipeline.

4.3 Pipe materials

Most distribution piping is made of galvanized steel, although copper, aluminium and some specialized plastics are becoming more common. Different materials have different pressure and temperature ratings, which must be checked with the supplier's reference literature.

4.4 Zoning

In many cases, it is not necessary for all parts of a compressed air system to be pressurised either to the same pressure or for the same operating hours. Splitting the system into zones and pressurizing isolated zones as required will reduce leaks and save energy. This is particularly useful for 'out-of-hours' small applications. Redundant piping must be removed or isolated so that it is not pressurised.

4.5 Valves

Although valves are used primarily for isolating a branch or section of the distribution network, they are also used for flow or pressure control.

5 Compressors

The energy efficiency of any air compressor depends on its:

- Design
- Installation
- Use
- Maintenance.

Many compressors now incorporate higher efficiency motors (HEMs). The EFF1 class of HEMs saves energy in all situations compared with a standard motor. Compressors are at their most efficient when operating at full load. Even when off-load the power consumed can be 20-70% of the on-load power. For a compressor to operate at its most efficient, it is therefore necessary to match the supply from the compressor with the air demand.

5.1 Types of compressor

Categories of commonly used compressors, which, in most cases, are available in both lubricated and non-lubricated forms.

5.2 Improving existing compressor efficiency

Location and installation of the compressor

Compressors should be located in a dry, clean, cool and well ventilated area. Warm, moist air requires not only more energy to compress but also extra drying to ensure that the moisture does not cause pipe corrosion and other problems with equipment. Forced ventilation may be needed to dissipate the build-up of heat in the compressor room.

Compressor maintenance and upgrades

Compressor performance will deteriorate by over 10% of output if maintenance is neglected. The following steps should therefore be taken as part of the maintenance process:

- Make sure there is sufficient space around the compressor for maintenance access
- Replace the air inlet filter as required and check the air inlet duct regularly to make sure it is not obstructed
- Ensure coolers are kept clean
- Ensure that maintenance is carried out only by trained personnel as dictated by international standards for compressors
- Replace motors in older compressors with HEMs (EFF1 or EFF2) to gain significant energy savings.

Heat recovery

One of the key cost-reduction opportunities is to re-use the waste heat generated by the compressor in a suitable application. Only 10% of the electrical energy driving an air compressor is converted into compressed air energy. The remaining 90% is normally wasted as heat. A properly designed heat recovery unit can recover over 80% of this heat for heating air or water.

Lubricants

Synthetic oils can reduce friction levels up to 8%, extend service intervals and may produce a more environmentally friendly, biodegradable condensate discharge.

5.3 Compressor selection

Because every installation is unique in its design and purpose, there is no definitive compressor solution. Appendix C contains two sets of questions to be considered when selecting a compressor- those that users should ask themselves and those users should ask vendors.

The decision on which compressor is most suitable for a particular application will be based on a number of factors, but it will be primarily driven by:

- The level of air quality required by the application/process (e.g. is oil-free compressed air required?)
- The flow rate and pressure required
- The capital available and subsequent running costs.

5.4 Compressor control

Compressors can be fitted with their own individual control system to vary their output to meet demand. Such systems include:

Start/ stop control. This method is normally only used for very small machines (usually piston compressors) due to the limitations associated with starting and stopping larger motors.

Throttling (modulating) control. This is generally only applicable to single-stage screw and vane machines operating at greater than 70% load.

Load/off-load control. This is often called 'automatic' control and is widely used in single-stage screw and vane compressors. For larger piston machines (double acting, two-stage compressors), three-step control is used to give full load, half load and no load operation.

Variable speed control. This system varies the air output by varying the motor speed and is generally fitted to oil-injected screw and vane machines. It can be retrofitted to existing machines, but this is not recommended without consulting the manufacturer.

Centrifugal compressor control. The control of these machines is more complex as performance is affected by both inlet temperature and barometric pressure. Essentially, a form of throttling down to around 75% of output is used, below which flow is reduced by progressively blowing air to the atmosphere.

5.5 Control of multiple compressors

An individual air compressor is always supplied with some type of control. However, further savings can be achieved when two or more compressors are installed together.

6 Storage

Air storage is another function of proper system control. Determining the amount of air storage should be determined not in isolation but as part of an overall strategy to obtain the most efficient and effective operation of a compressed air system. In virtually all industrial applications, air demand varies. Air storage is therefore necessary to balance the demand from the system with the compressor plant capacity and the system control. The role of the air receiver (storage vessel) is to:

- Act as a reservoir that can be called upon to provide bursts of air to meet intermittent demands
- Create a more stable pressure in the system
- Prevent the compressor cycling too quickly.

In this way, a receiver acts like a flywheel or a water reservoir behind a hydroelectric dam.

6.1 Sizing the air receiver

The sizing of receivers is important as it has a direct impact on both the overall reliability and the energy efficiency of the compressed air system. The size of an air receiver will depend on the amount of fluctuation in air demand. In most cases an adequately sized receiver will be able to supply the extra air during a high demand period and then recharge when the demand drops off. This function allows the air compressor to be sized for the average demand, rather than for the maximum demand. In some cases when the fluctuation is too great, a solution can be to have a smaller compressor that can ‘kick in’ as required.

There are a number of formulae for calculating the storage volume required. However, the following empirical rule can provide an approximation for It is also worth considering the following:

- To provide optimum performance, the receiver should be sized for the largest expected air demand event.
- An undersized receiver will cause the compressor to cycle frequently in response to small changes in pressure.
- An oversized receiver will cost more and will store more air, but it will require the compressor to remain on load for longer periods to recharge the air receiver. This is balanced by the extra time the compressor will have to cool before it must come on load again.
- The volume of the pipework is often significant but is not included in the calculations.
- An effective control system will ensure that the receiver volume balances the demand from the system with the supply from the compressor.

6.2 Additional local air receivers for intermittent demands

To provide optimal performance, receivers need to be sized to handle the largest demand for air in the system. However, this event may be a process or an item of equipment with a large intermittent air demand. In situations where the demand is not continuous, it is better to install an air receiver close to the process/equipment rather than to oversize the main air receiver or to install an additional compressor that would stand idle most of the time. To determine whether a local (auxiliary) air receiver is needed:

- Calculate the total maximum storage for the main receiver as described above
- Then calculate the storage required for the largest event. If this exceeds 10% of the total, then a local air receiver is recommended.

7 Air treatment

Although a lot of attention is given to the air compressor itself, the ancillary equipment for treating the air consumes energy and should, therefore, be viewed as a potential energy saving opportunity. This equipment includes dryers, filters and condensate drains.

7.1 Air purity (quality)

The international standard for compressed air purity, provides a system of classification for the three main contaminants (dirt, water and oil) present in any compressed air system. Dirt and oil are classified in term of size and concentration, and the water content as the pressure dew point (a measure of the humidity of the air).

7.2 Filtration

Filtration is required to remove contaminants from the compressed air. Filters may be fitted before and after dryers, and also at the point of use. In carrying out its function, the filter element will become increasingly blocked. Blocked filters:

- Can cause reliability problems
- Often compromise product quality
- Will increase energy consumption.

Filter elements should be regularly checked as part of a maintenance regime. Many filters have a diagnostic gauge fitted to their housing, which records the pressure drop across the filter element and indicates when the filter is due for replacement. The pressure drop across a new filter should be checked for comparison.

Dual filtration arrangement

Where high removal efficiency filters for either particulates or liquid are used, use of a dual stage filtration system is recommended.

7.3 Drying

As compressed air leaves the compressor and cools, the water vapour that was present in the inlet air condenses. This water must be removed from the compressed air system to avoid damage to components and product.

8 Condensate management

Water vapour is always present in the air entering a compressor. With a decrease in air temperature and/or an increase in pressure, this vapour will condense. This condensate is often contaminated with oil and solid particles.

8.1 Collecting condensate

Condensate is collected by installing drain traps (also known as drain valves). These are attached to components where water will condense, for example:

- Aftercoolers
- Air receivers
- Dryers
- Filters.

Maintenance and energy costs differ considerably between different drain traps. The main types are:

Level sensing drains. This type has an intelligent control system that detects and discharges condensate only when it is present and without the loss of valuable compressed air. Such drains are reliable and require very little maintenance.

Timed drains. These drains require frequent adjustment of timer settings to accommodate changes in ambient conditions and system load. When set incorrectly, they discharge significant amounts of valuable air or fail to remove all of the condensate, resulting in downstream contamination. The frequency and duration of discharge for timed drains varies from system to system.

Manual drains. Manual drains require frequent checking and emptying. As a result they are often left partially open to discharge the condensate — thus also discharging expensive system air.
These open valves also reduce the system pressure and may compromise the operation of downstream equipment.

Mechanical float drains. These drains are sensitive to dirt and may stick open, permanently discharging air, or stick closed, leading to downstream contamination from condensate carryover.

Disc and steam trap drains. In normal operation, these valves constantly discharge valuable, expensive air even if no condensate is present. They also emulsify condensate, preventing easy on-site separation. Inefficient condensate drains are a major cause of leaks and hence wasted energy. Although manual and timed drains are cheap to buy, they have high running costs. A Life Cycle Costing exercise should be applied.

8.2 Condensate disposal

It is illegal to pour contaminated condensate down foul sewers unless the oil content is reduced to a very low level. Otherwise, its oil content means it is classified as a hazardous waste. Efficient on-site disposal of compressed air condensate is best achieved with an oil/water separator — a simple, economical and more environmentally friendly solution. Oil/water separators can be installed as part of the compressed air system. They reduce the oil concentration in the collected condensate to the level allowed by the local sewerage provider and enable up to 99.9% of the total condensate volume to be disposed of safely to foul sewers (many oil/water separators are plumbed in directly to foul sewers). The small amount of concentrated oil is collected in drums for disposal by a specialist waste contractor.

Reference:

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