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MARK THROWER MANAGING EDITOR

SERIES **13** | MODULE **04** | **COMPRESSED AIR**

Identifying savings in compressed air systems

Compressed air article by Eric C Harding, managing director, Air Technology Ltd

Compressed air - often known as the fourth utility - is a vital asset to over 97 per cent of industry with applications ranging from dentistry, through all manner of manufacturing plants to nuclear power generation. Approximately 10 per cent of industry's electrical power spend is used to generate compressed air.

It is a very popular method of transmitting energy from the input power source to point of use. If the system is designed and correctly operated compressed air is very safe but it can be very dangerous if improperly applied.

Compressed air is generated at many pressure levels ranging from a 0.2 barg to over 400 barg by specialised machines.

Low pressure air at 0.2 to 1 barg is used for aeration of effluent treatment plants, medium pressure at 3 barg for glass bottle blowing. General purpose, process and instrument air at 7 to 10 barg accounts for over 90 per cent of applications with the higher pressures being used for aerosol filling, tyre manufacturing, breathing air bottle filling and many other specialist uses.

The diagram opposite **(Fig 1.)** shows the components of a typical industrial compressed air system.

The quality of the air used ranges from quite low for tools to extremely high for microelectronics paint finishing, food and pharmaceuticals where the air can be in contact with the product.

At 7 barg the cost of air to drive tools is around 10 times more than an equivalent electric tool. This is due to the fact that around 90 per cent of the input energy is rejected by the compressor in the form of waste heat in the cooling streams as shown in the following diagram opposite **(Fig 2.)** that applies to a single stage oil injected air compressor.

Compressors are only needed because the customer has a use for compressed air but as they are the beginning of the process it is logical to start with air generation.

There are many configurations of compressors such as reciprocating, vane, diaphragm, toothed rotor, scroll, roots blowers, rotary screw and centrifugal machines with lots of subsets around cooling, pressure and air quality requirements.

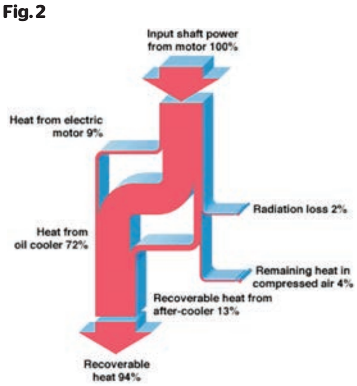
There are several ways of expressing the efficiency of compressors such volumetric, isentropic and polytropic but the only important measure of efficiency is the power input versus the air output at the specified pressure. This is known as the specific power consumption (SPC).

The SPC depends on the size and configuration of the machines. At 7 barg it should be around 11 to 13kW/100m3/h with the compressor on full load.

It is important to know the off load and part load power consumptions as well as the full load as very few compressors will be running at full load.

In spite of the apparently overwhelming choice of configurations there are actually only two types of compressors. One is the positive displacement (PD) machine the other the dynamic machine as shown on page 30. **(Fig 3.)**.

Fig. 2



Fixed volume of air

The performance of positive displacement types can best be described with a pressure volume diagram as shown below. This type of machine inhales and compresses a fixed volume of air.

Here (below) **(Fig 4.)** it can be seen the inhaled or swept volume is compressed to the terminal pressure according to the equation PVn = C where n is the gas constant (that for air is around 1.39). As the air is compressed its volume decreases with the amount being delivered into the system being in relationship with the absolute compression ratio which in the case shown will be 1/8th.

Once the piston or open screw or vane flute completes its air delivery

Fig. 4

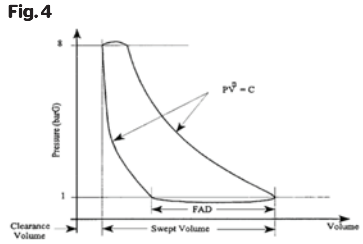
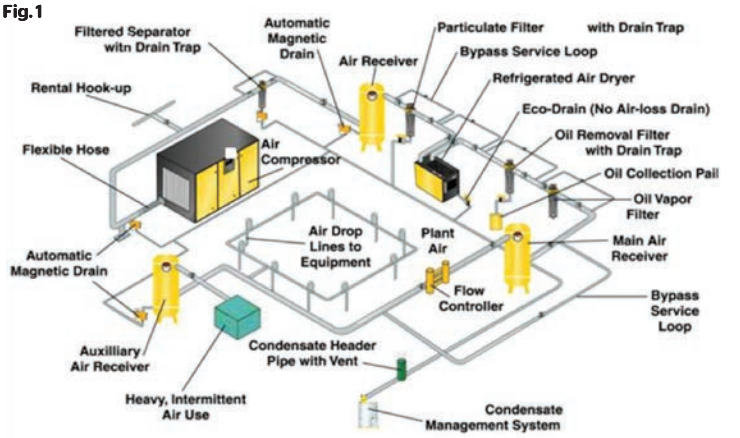


Fig. 1



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the compressed air left trapped within the machine has to re-expand until atmospheric pressure is reached at which time the machine can inhale more air.

The compressor can only deliver the amount of air that it inhales. This is known as the Free Air Delivered (FAD). The volumetric efficiency is the FAD divided by the swept volume.

The area contained within the curves is proportionate to the work being done to compress the air. The most efficient theoretical compression cycle is isothermal during which the temperature is constant. Compressor designers attempt to approach isothermal by such methods as intercooling and oil or water injection.

In practice, when optimising air generation systems engineers should ensure that compressor intake air and cooling stream temperatures are as low as possible, suction filter pressure drop is minimised, and the delivery pressure is set as low as possible to keep the compression ratio down and reduce the work being done.

Compressors are normally sized with some spare capacity to allow for peak demands so pressure drops are avoided and some growth for the future. This means that efficient control is important both of individual and groups of machines.

The most popular method of individual control of fixed speed machines can be by inlet valve opening when air is required or shut when there is no air demand known as two-step or all on-line off line control. Inlet valves can also be modulated over the higher ranges of demand from around 60 to 100 per cent. Inlet valve operation is controlled by a the system air pressure that when rising to its top limit the machine will unload and when the pressure falls to its pre-set low limit the machine will load.

Two-step control of fixed speed machines is the most frequently seen. Long periods of no-load running should be avoided as the power consumption will be around 20 to 25 per cent of the full load power.

Variable speed drive is available for positive displacement machines this can be more efficient than two step or modulation control as long as the machine is correctly sized and does not run for long periods above 80 per cent of capacity where inverter and other losses make the machine less efficient.

The diagram opposite **(Fig 5.)** shows the relative power consumption of typical individual controls.

Centrifugal machine

The most common form of dynamic machine found in industry is the centrifugal machine. This type of machine inhales a volume of air at the atmospheric conditions prevailing then accelerates it in high speed impellors thus imparting kinetic energy that is transformed into pressure energy by reducing the air speed in diffusers.

This machine has a characteristic curve as shown right **(Fig 6.)**.

Control by inlet valve

These machines can be controlled efficiently by inlet valve, inlet guide and diffuser guide vanes over the stable operating range before natural surge pressure becomes close to the design pressure.

Group control systems should always be aimed at ensuring that the most efficient machines in the installation are used at all times at the minimum sensible generation pressure. Electronic panels are available that the right mix of machines is on line at any one time.

Great care must be taken when designing generation systems with a mix of fixed speed and variable speed machines.

Fig. 6

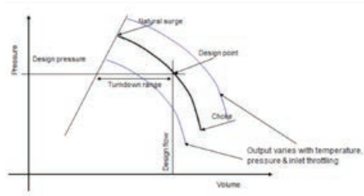


Fig. 3

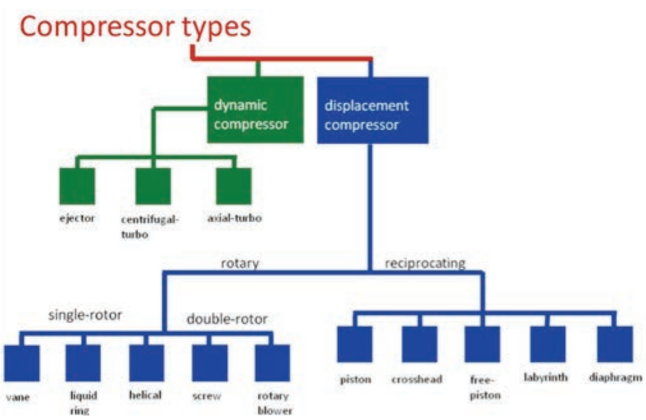


Fig. 5

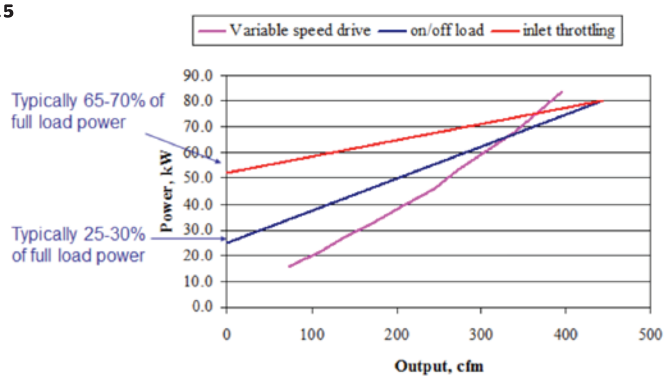
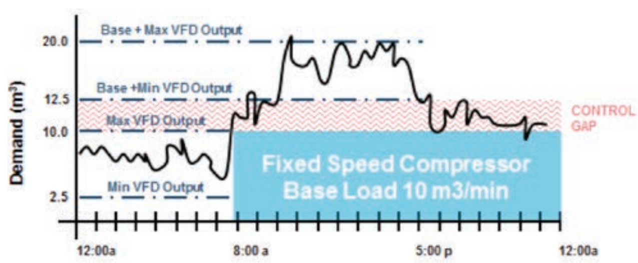


Fig. 7



The variable speed unit should always be used as the control machine. Correct sizing will avoid control gaps that can occur when running a fixed and variable speed control machine together.

An example of bad design with control gap issues is shown on the diagram below **(Fig 7.)**.

Treatment of the air

Following generation the air is treated to the standard required by the end using process by a variety of methods.

When the air leaves the final stage of the compressor at terminal pressure it is hot and fully saturated with water that has been inhaled from the atmosphere. As the air is cooled water condenses and if there is no treatment it will arrive at the usage points.

This cannot be tolerated and treatment to remove the water following air compression is required.

The first stage of treatment is the after-cooler that can be air or water cooled. This will reduce the air temperature from over 100°C to within 10° of the cooling medium's temperature and will remove around 80 per cent of the water. This good enough for some end users but most require that further treatment will be required.

There is usually a wet air receiver sized correctly for the delivered volume of the installed compressor capacity. This removes some of the entrained moisture and helps smooth out any pulsations.

There are many types of air dryer as shown in the following diagram. Selection of the correct dryer for the duty will depend on the required pressure dewpoint for the process.

Condensate removal from the aftercoolers, air receivers, filters, dryers and other drainage points should be by use of automatic drains the best type being of the zero loss electronic configuration. See chart opposite **(Fig 8.)**.

Removing oil contamination

Another contamination found in compressed air is oil. General purpose compressors are usually lubricated machines that have oil in the compression chambers. Some hydrocarbons are present in the atmosphere in industrial areas and these are inhaled and concentrated by the compressors.

For specialist end users such as pharmaceutical plants, microelectronic manufacturers, some food and beverage plants and motor vehicle paint shops oil free compressors are normally specified.

Oil can be removed from the compressed air by filters sometimes in several stages to arrive at the quality required. Odours from air that is used for breathing can be removed by carbon towers.

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Another contamination found in compressed air is particulate matter. This can come from compressor wear particles and from pipework. Again filtration is employed to remove particulate. For specialist duties the air system pipework is manufactured from welded polished bore stainless steel or copper to prevent particles.

The ISO8573.1 compressed air quality standard should be used when specifying air quality for the above contaminants. This will ensure that the correct levels of treatment are applied for the duties the air is to be used on saving both capital and energy costs.

Microbial contamination

The chart given right **(Fig 9.)** shows a summary of the standard and the classification of the contaminants and various levels.

Another contamination that occurs in compressed air systems is microbial. This must be avoided in pharmaceutical manufacturing and some beverages and food products for domestic use where shelf life can be reduced by microbes that live in the compressed air systems.

Treatment is by the use of steam sterilised filters and use of desiccant dryers as microbes cannot breed in air at pressure dewpoints below -30°C.

Following treatment there is often a dry air receiver then air is fed to the usage points by distribution networks. These should be sized with a maximum flowing velocity of 6 metres per second with the full output of the compressor station on line to avoid pressure losses.

Ring mains are preferred to spur mains and local air receivers can be beneficial close to points of high demand.

Because compressed air is expensive its use should be carefully considered. As an example it may be possible to use an electric tool rather than an air tool, or a centralised vacuum system rather than local vacuum ejectors on a production machine.

Once it is established compressed air is to be used then the correct pressure for the duty should be applied. To avoid overpressure local regulators can be employed.

When there is no production on a line, in a department or a factory the air should be turned off to avoid waste. Any essential users can be supplied by small compressors.

Leakage is one of the main sources of waste in air systems and can often be easily rectified. The optimum leakage rate should be less than 5 per cent of the mean production air demand. This figure can usually be arrived at by taking timings of the loaded and off loaded times or by speeds of variable drive units or by flow metering during and in and out of production times.

There are several methods of leak detection such as by ear and soap and water solutions but the most effective method is by use of a good quality ultrasonic leak detector.

Leaks that occur in the hard piping before any system regulators will vary in air loss according the absolute system pressure ratio as the pressure rises and falls with compressors loading and unloading. This is known as artificial or unregulated demand. The leakage loss downstream of regulation is a constant amount.

The heat rejected by air and water cooled compressors in their cooling streams can be recovered and used if a suitable application can be found.

The diagram above **(Fig 10.)** shows potential uses for waste heat.

Energy savings over 30 per cent

Optimising compressed air systems can enable excellent energy savings of around 30 per cent over the original generation cost to be achieved some at little or no cost.

Achievable savings can be generalised with the first low cost 10 per cent coming from reducing leakage, wastage and generation pressure and condensate trap losses, the next medium cost 10 per cent that should provide a return on investment within one year from improving distribution networks, compressor control and air treatment and improved maintenance with the final higher cost 10 per cent coming from new compressors, variable speed drives, new efficient air treatment systems and point of use improvements where ROI can be much longer unless savings in maintenance costs are also taken into account.

Energy savings areas are air generation, air treatment, distribution networks, use and misuse, leakage and waste heat recovery.

With air generation the minimum pressure that is required at the usage points should be established then the potential saving by reducing the air generation pressure can be calculated based on a cost reduction of 6 per cent per bar of pressure reduction. To enable pressure reduction restrictions in the air system should be identified and eliminated.

With the air system on full load the pressure loss across the air treatment system should not exceed 0.5 bar and from the exit of the treatment system to the far end of the distribution system the loss should not be greater than 0.2bar.

Control systems that ensure only the minimum number of machines to meet the duty are on line. Variable speed driven machines can be very beneficial but should not be run for extended periods at over 80 per cent capacity due to inverter losses. Control systems should always be programmed to ensure that variable speed machines are always used as the control unit when there is a mix of variable and fixed speed units. Fixed speed machines should always be used as base load units.

Treatment should be to the minimum standard required as an example air at a pressure dewpoint of +3°C is perfectly suitable for most factories but there may be a small use of high quality air at -40°C for instrumentation that should be treated by a local dryer to save energy costs.

All desiccant dryers should be fitted with dewpoint sensing controls that will avoid over regeneration of the towers.

It is possible to obtain energy efficient zero air loss desiccant dryers that have external blowers or vacuum pumps with the regeneration heat source being waste heat from the compressors or steam.

Other simple optimisation opportunities exist from isolation of production machines when not in use, improvements to distribution networks and local machine connections and internal tubing and control devices and reduction in leakage.

Terms used

Flow – m3/h
Pressure – barg
Power – kW
Specific power (SPC) – kW/100m3/h

Fig. 8

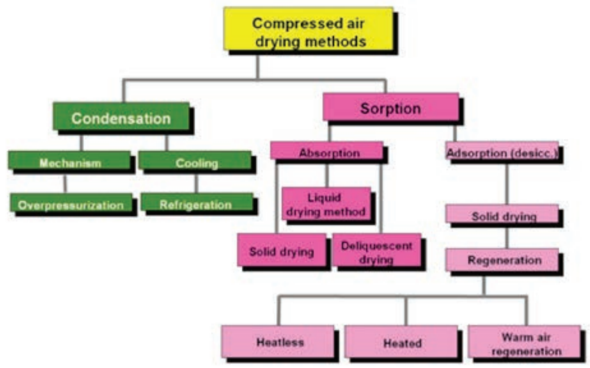


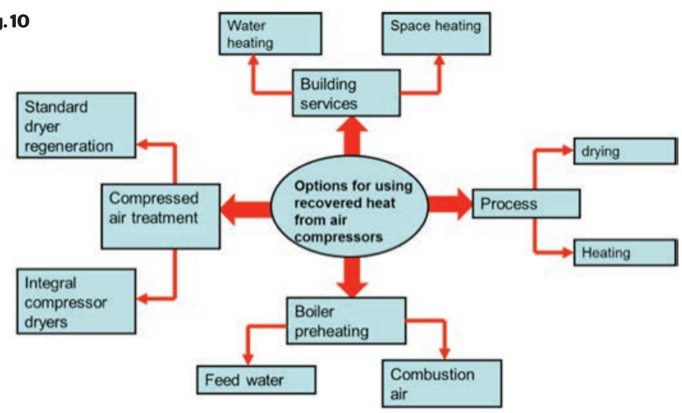
Fig. 9

Filtration — Drying — Filtration

Summary of ISO8573.1-2010

Class	Particulate - Maximum number of particles per m^3 – Particle size: ≤ 0.1	$0.1 < d \le 0.5\mu m$	$0.5 < d \le 1.0\mu m$	$1.0 < d \le 5.0\mu m$	Dewpoint °C	Oil carry over Mg/m^3
0	As specified by the equipment user or supplier and more stringent than class 1					
1	Not specified	20,000	400	10	$\le$-70	$\le$0.01
2	Not specified	400,000	6,000	100	$\le$-40	$\le$0.1
3	Not specified	Not specified	90,000	1,000	$\le$-20	$\le$1
4	Not specified	Not specified	Not specified	10,000	$\le$+3	$\le$5
5	Not specified	Not specified	Not specified	100,000	$\le$+7	
6	$\le 5\ Mg/m^3$				$\le$+10	
7	$5 > Cp \le 10\ Mg/m^3$				$Cw \le 0.5 g/m^3$	
8					$0.5 < Cw \le 5$	
9					$5 < Cw \le 0.5$	
X	$Cp > 10$				$Cw > 10$	> 5

Fig. 10



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COMPRESSED AIR

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. Approximately what percentage of industry's electricity bill is spent on generating compressed air?

☐ 10 per cent ☐ 12 per cent
☐ 5 per cent ☐ 25 per cent

2. Why does compressed air at 7 barg used for an air tool cost 10 times more than the electricity used for an equivalent electric tool.

☐ Because the air is supplied through a hose of too small a diameter
☐ Because the air tool bearings are too stiff
☐ Because the compressor rejects over 90 per cent of the input energy
☐ Because the air is on all the time

3. What is the best method of determining compressor full load efficiency?

Its power consumption
The temperature of the cooling medium
its specific power consumption
The unloaded power consumption

4. What is the typical off load power for a screw compressor running load/no load?

☐ 25 per cent ☐ 65 per cent
☐ 10 per cent ☐ 80 per cent

5. What is the difference between positive displacement and dynamic machines.

☐ The dynamic machine runs at a higher speed than the positive displacement machine.
☐ The positive displacement machine inhales a fixed volume then pressurises it to terminal pressure whereas the dynamic machine imparts kinetic energy on the inlet air stream.
☐ The dynamic machine is only available for oil free duties
☐ All of the above

6. What contaminants can occur in compressed air?

☐ Oil ☐ Water
☐ Particulate ☐ All of the above

7. To avoid pressure losses what should the flowing velocity in air mains be?

☐ 6 m/s ☐ 10 m/s
☐ 2 m/s ☐ 30 m/s

8. How would you use waste heat from a compressor?

☐ For space heating of a factory
☐ To heat domestic hot water
☐ To preheat boiler feed water
☐ All of the above

9. How much can the energy cost for generating 7 barg air be reduced if the pressure is lowered by 0.5 bar?

☐ 3 per cent ☐ 6 per cent
☐ 2 per cent ☐ 11 per cent

10. What is the best method of making a desiccant dryer efficient?

☐ Change the desiccant
☐ Bypass the dryer
☐ Fit dewpoint sensing control
☐ Buy a new dryer

Please complete your details below in block capitals

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