National Appliance and Equipment Energy Efficiency Program

Analysis of Potential for Minimum Energy Performance Standards

for

Packaged Air Compressors

Prepared for the Australian Greenhouse Office

by

Mark Ellis & Associates

Final Report

March 1st, 2001

MARK ELLIS & Associates
44 Albert Street
Wagstaffe, NSW 2257, Australia
Tel: 02 4360 2931
Fax: 02 4360 2714
email: ellism@ozemail.com.au

This study was funded by the Energy Management Task Force, organised through the National Appliance and Equipment Energy Efficiency Committee and managed by the Australian Greenhouse Office.

The study was undertaken by Martin Poole of Mark Ellis & Associates with the aid of Mark Ellis and Zoe Pilven. We would also like to acknowledge the assistance provided by Lloyd Harrington of Energy Efficient Strategies. In addition, we thank members of the air compressor industry for their co-operation.

Mark Ellis & Associates is a consultancy service specialising in the design, management and evaluation of sustainable energy policies and programs. MEA brings over 17 years experience in Europe and Australasia to the following areas of expertise:

- energy and greenhouse policy
- greenhouse modelling
- design of energy efficiency strategies
- implementation and management of energy efficiency programs
- energy information and advisory services
- green pricing schemes
- energy sector micro-economic reform
- low energy planning and building design
- environmental impacts of energy generation technologies and fuels

CONTENTS

GLOSSARY

For convenience and clarity the following short descriptive terms are used. For precise definitions, please refer to the literature.

Absolute Pressure - Total pressure measured from zero (ie total vacuum).

Absolute Temperature - See Temperature, Absolute.

Absorption - The chemical process by which a hygroscopic desiccant, having a high affinity with water, melts and becomes a liquid by absorbing the condensed moisture.

Adsorption - The process by which a desiccant with a highly porous surface attracts and removes the moisture from compressed air. The desiccant is usually capable of being regenerated.

Actual Capacity - Quantity of gas actually compressed and delivered to the discharge system at rated speed and under rated conditions. Also called Free Air Delivered (FAD).

Air Receiver - See Receiver.

Aftercooler - A heat exchanger used for cooling air discharged from a compressor. Resulting condensate may be removed by a moisture separator following the aftercooler.

Atmospheric Pressure - The measured ambient pressure for a specific location and altitude.

Automatic Sequencer - A device which operates compressors in sequence according to a programmed schedule.

Brake Horsepower (bhp) - Horsepower delivered to the output shaft of a motor or engine, or the horsepower required at the compressor shaft to perform work.

Capacity - The amount of air flow delivered under specific conditions, usually expressed in cubic feet per minute (cfm).

Capacity, Actual - The actual volume flow rate of air or gas compressed and delivered from a compressor running at its rated operating conditions of speed, pressures, and temperatures. Actual capacity is generally expressed in actual cubic feet per minute (acfm) at conditions prevailing at the compressor inlet.

Capacity Gauge - A gauge that measures air flow as a percentage of capacity, used in rotary screw compressors as an estimator during modulation controls.

Compression, Adiabatic - Compression in which no heat is transferred to or from the gas during the compression process.

Compression, Isothermal - Compression is which the temperature of the gas remains constant**.**

Compression Ratio - The ratio of the absolute discharge pressure to the absolute inlet pressure.

Constant Speed Control - A system in which the compressor is run continuously and matches air supply to air demand by varying compressor load.

Cubic Feet Per Minute (cfm) - Volumetric air flow rate.

Cfm, Free Air – Volume flowrate of air delivered to a certain point at a certain condition, converted back to ambient conditions.

Actual Cfm (acfm) - Flow rate of air at a certain point at a certain condition at that point.

Inlet Cfm - Cfm flowing through the compressor inlet filter or inlet valve under rated conditions.

Standard Cfm - Flow of free air measured and converted to a standard set of reference conditions (14.5 psia, 68^{o}F, and 0% relative humidity).

Cut In/Cut Out Pressure - Respectively, the minimum and maximum discharge pressures at which the compressor will switch from unload to load operation (cut in) or from load to unload (cut out).

Cycle - The series of steps that a compressor with unloading performs; 1) fully loaded, 2) modulating (for compressors with modulating control), 3) unloaded, 4) idle.

Cycle Time - Amount of time for a compressor to complete one cycle.

Degree of Intercooling - Difference in air or gas temperature between the outlet of the intercooler and the inlet of the compressor.

Desiccant - A material having a large proportion of surface pores, capable of attracting and removing water vapour from the air.

Dew Point - The temperature at which moisture in the air will begin to condense if the air is cooled at constant pressure. At this point the relative humidity is 100%.

Demand - Flow of air at specific conditions required at a point or by the overall facility.

Discharge Pressure - Air pressure produced at a particular point in the system under specific conditions.

Discharge Temperature - The temperature at the discharge flange of the compressor.

Efficiency, Compression - Ratio of theoretical power to power actually imparted to the air or gas delivered by the compressor.

Efficiency, Isothermal - Ratio of the theoretical work (as calculated on a isothermal basis) to the actual work transferred to a gas during compression.

Efficiency, Mechanical - Ratio of power imparted to the air or gas to brake horsepower (bhp).

Efficiency, Volumetric - Ratio of actual capacity to piston displacement**.**

FAD or **Free Air Delivered -** Air at atmospheric conditions at any specified location, unaffected by the compressor.

Full-Load - Air compressor operation at full speed with a fully open inlet and discharge delivering maximum air flow.

Gauge Pressure - The pressure determined by most instruments and gauges, usually expressed in psig. Barometric pressure must be considered to obtain true or absolute pressure.

Horsepower, Brake - See Brake Horsepower.

Horsepower, Theoretical or Ideal. - The horsepower required to isothermally compress the air or gas delivered by the compressor at specified conditions.

Humidity, Relative -The relative humidity of a gas (or air) vapour mixture is the ratio of the partial pressure of the vapour to the vapour saturation pressure at the dry bulb temperature of the mixture.

Humidity, Specific -The weight of water vapour in an air vapour mixture per pound of dry air.

Indicated Power - Power as calculated from compressor-indicator diagrams.

Inlet Pressure - The actual pressure at the inlet flange of the compressor.

Intercooling - The removal of heat from air between compressor stages.

Leak - An unintended loss of compressed air to ambient conditions.

Litres per second (L/m) – Volumetric air flow rate

Load Factor - Ratio of average compressor load to the maximum rated compressor load over a given period of time.

Load Time - Time period from when a compressor loads until it unloads.

Load-Unload Control - Control method that allows the compressor to run at full-load or at no load while the driver remains at a constant speed.

Modulating Control - System which adapts to varying demand by throttling the compressor inlet proportionally to the demand.

Perfect Intercooling - The condition when the temperature of air leaving the intercooler equals the temperature of air at the compressor intake.

Piston Displacement - The volume swept by the piston; for multistage compressors, the piston displacement of the first stage is the overall piston displacement of the entire unit.

Pneumatic Tools - Tools that operate by air pressure.

Pressure - Force per unit area, measured in Newton per square metre (Nm^{-2}).

Pressure Dew Point - For a given pressure, the temperature at which water will begin to condense out of air.

Pressure Drop - Loss of pressure in a compressed air system or component due to friction or restriction.

Pressure Range - Difference between minimum and maximum pressures for an air compressor. Also called cut in-cut out or load-no load pressure range.

Rated Capacity - Volume rate of air flow at rated pressure at a specific point.

Rated Pressure - The operating pressure at which compressor performance is measured.

Required Capacity - Cubic feet per minute (cfm) of air required at the inlet to the distribution system.

Receiver - A vessel or tank used for storage of gas under pressure. In a large compressed air system there may be primary and secondary receivers.

Relative Humidity - The ratio of the partial pressure of a vapour to the vapour saturation pressure at the dry bulb temperature of a mixture**.**

Sequence - The order in which compressors are brought online.

Specific Humidity - The weight of water vapour in an air-vapour mixture per pound of dry air.

Specific Power - A measure of air compressor efficiency, usually in the form of kW/(L/s) or bhp/100 acfm or acfm/bhp.

Specific Weight - Weight of air or gas per unit volume.

Standard Air - The Compressed Air & Gas Institute and PNEUROP have adopted the definition used in ISO standards. This is air at 101.3kPa (14.5 psia or 1 bar); 20^{o}C (68F) and dry (0% relative humidity).

Start/Stop Control - A system in which air supply is matched to demand by the starting and stopping of the unit.

Surge - A phenomenon in centrifugal compressors where a reduced flow rate results in a flow reversal and unstable operation.

Temperature, Absolute - The temperature of air or gas measured from absolute zero - the Centigrade temperature plus 273.2, in units of Kelvin. It is also the Fahrenheit temperature plus 459.6, with the unit being the Rankine.

Temperature, Discharge - The total temperature at the discharge connection of the compressor.

Temperature, Inlet - The total temperature at the inlet connection of the compressor.

Temperature Rise Ratio - The ratio of the computed isentropic temperature rise to the measured total temperature rise during compression. For a perfect gas, this is equal to the ratio of the isentropic enthalpy rise to the actual enthalpy rise.

Temperature, Static - The actual temperature of a moving gas stream. It is the temperature indicated by a thermometer moving in the stream and at the same velocity.

Temperature, Total - The temperature which would be measured at the stagnation point if a gas stream were stopped, with adiabatic compression from the flow condition to the stagnation pressure.

Theoretical Power - The power required to compress a gas isothermally through a specified range of pressures.

Torque - A torsional moment or couple. This term typically refers to the driving couple of a machine or motor.

Total Package Input Power - The total electrical power input to a compressor, including drive motor, cooling fan, motors, controls, etc.

Unload - (No load) Compressor operation in which no air is delivered due to the intake being closed or modified not to allow inlet air to be trapped.

EXECUTIVE SUMMARY

This report describes the types of packaged air compressor currently used in Australia and their characteristics. Technologies covered by the report include reciprocating single-acting air compressors, up to 20kW input power; and rotary screw compressors, up to 20kW input power.

Domestic uses include inflating tyres, boats and pool toys, spray painting and power tools. Domestic uses are intermittent and may total less than a few hundred hours per year.

Commercial applications include spray painting, cleaning and air driven tools. Commercial applications range from intermittent use (for example pneumatic tools) to seasonal (recreation services) to continuous (medical uses).

The industrial sector uses compressed air for a multitude of operations. Most industrial facilities have at least two compressors, and in a medium-sized plant there may be hundreds of different uses of compressed air. Uses include powering pneumatic tools, packaging and automation equipment, and conveyors. Many manufacturing industries also use compressed air and gas for combustion and process operations such as oxidation, fractionation, cryogenics, refrigeration, filtration, dehydration, and aeration.

Market profile

Total annual sales for air compressors (< 20kW) are estimated to be approximately 100,000 units. Based on a 10 year average lifetime, the total stock is estimated at 1,000,000 units. There is no industry consensus on growth patterns for the industry.

Table E1: Estimated annual sales and stock

Air compressor size range	Approx annual sales	Approx installed stock
Less than 2.25kW	23,000	230,000
More than 2.25kW but less than 20kW	77,000	770,000
Total	**100,000**	**1,000,000**

It is estimated that 90% of all these units are electrically driven. Petrol engine units make up about 9% of the market and diesel 1%. Of the electric units an estimated 63% are single phase and 37% three phase.

There are at least 17 suppliers of commercial air compressors in Australia, some of which companies manufacture components or complete compressors, while others import packaged units. In 1999, just over 6,000 air compressors were imported, and it is estimated that most of these units were petrol or diesel driven.

Compressor efficiency

There are several contributors to the efficiency of a positive displacement air compressor:

- The efficiency of the drive unit, usually an electric motor but may be a petrol or diesel internal combustion engine
- The mechanical design of the “air end”
- The mechanical design of other aspects of the package (for example, inlet and outlet valves, piping)
- Use patterns (for example, continuous or intermittent)
- Control (for example, is the drive unit switched off when there is no demand); and

- Whether the unit is lubricated or dry.

Although standards exist for the measurement of compressor efficiency, they are not always accurately and consistently applied. As a result, when comparing compressor efficiency, users should make sure that tests have been performed to the same standards and at the same conditions.

To enable the accurate calculation of compressor efficiency, Pneurop in Europe and the Compressed Air and Gas Institute (CAGI) in the US have jointly developed 'simplified performance testing standards' (Compressed Air Challenge, 2000). These standards have been incorporated as an Annex to ISO1217: 1996 – Displacement Compressors Acceptance Tests. The relevant standard to the compressors covered in this report is "CAGI/PNEUROP PN2CPT C2, Acceptance Test Code for Electrically Driven Packaged Displacement Air Compressor (1st edition)".

Standards

Australian Standard AS4297, 1995 covers safety aspects of the installation and operation of air compressors used in underground mining, however energy consumption is not covered.

Of the estimated population of 1,000,000 air compressors, an estimated 37% have three phase motors, which will be affected by the proposed Minimum Energy Performance Standard for electric motors for three phase induction motors that is likely to come into force in July 2001.

The potential increase in average motor efficiency in the range 3 to 7.5kW resulting from this program is about 1%, estimated to lead to greenhouse emissions reductions of 14 kt CO_2-e per year.

Overseas there are no known standards related to minimum energy performance.

Other Programs

Overseas programs aimed at improving the efficiency of compressed air systems include The Compressed Air Challenge (United States) and the Energy Efficiency Best Practice Program (United Kingdom). These programs are aimed at large, centralised industrial compressed air systems, but some aspects are relevant to the smaller units covered by this report.

In addition, the NSW Sustainable Energy Development Authority provides a simple program to enable users to calculate the potential savings available from compressed air system changes.

Greenhouse Emissions

In the absence of data on average utilisation of packaged air compressors, emissions have been estimated on the basis of the following assumptions:

- Compressors with a capacity < 2.25 kW are assumed to have a capacity of 1.5 kW and operate for 750 hours/year;
- Compressors with a capacity > 2.25 kW < 20 kW are assumed to have a capacity of 10 kW and operate for 1,000 hours/year.

Total greenhouse emissions are estimated to be:

- Units < 2.25 kW = 259 kt CO_2-e per year
- Units > 2.25 kW < 20 kW = 3850 kt CO_2-e per year

It is likely that the potential to reduce emissions is approximately 10% or 400kt CO_2-e per year. The reduction would be achieved through (approximately in order):

- Eliminating leaks
- Better system design
- Better system control
- Performance standards for electric motors that go into compressors
- Performance standards for compressors (i.e the non-prime mover parts).

It should be noted that the majority of the savings accrue from 'system' measures and control rather than from improvements to the efficiency of the prime movers (electric, petrol or diesel motors) or to the compressors themselves.

Recommendations

For the following reasons, MEPS are not recommended for packaged air compressors in the size range covered in this report:

- the majority of the potential savings accrue from the improvement in the design, operation and maintenance of the *whole compressed air system* and the associated downstream uses, rather than the efficiency of the compressor unit itself;
- there is no split-incentive to affect most air compressor purchase decisions and if users had improved information on the efficiency of compressors there's no reason they would not choose more efficient models;
- there are practical issues related to the difficulty in policing imports of large numbers of small, low value units;
- due to their small size and relatively low utilization, the savings available from small, electric driven packaged air compressors are relatively small.

There are potentially large greenhouse reductions available from compressors both in the size range covered in this report and in all larger units and their related systems, and consideration of one or more of the following programs is strongly recommended.

- Information programs for system design, operation and control – based on Compressed Air Challenge – possibly as part of the Best Practice Program;
- Efficiency labelling – in parallel with encouraging manufacturers to calculate figures to ISO1217 (in parallel with improved specification of the allowable tolerances under this test method);
- Promotion of case studies demonstrating cost savings from the implementation of compressed air system improvements;
- Underwriting of advice from industry experts, measuring of energy savings and development of payback models;
- Leak reduction programs – expand use of tools like SEDAs leak calculator (see Appendix G); possibly targeted at industries with widest air distribution systems;
- The AGO Australian Motor Systems Challenge Program (AGO, 2000b) is relevant for for compressors that are assembled in Australia.

Further investigation of the industrial market is recommended. Compressed air is a very substantial energy use and the majority of industrial compressed air systems would use compressors larger than the 20kW limit in this report.

1. PURPOSE

This report has been commissioned by the Australian Greenhouse Office as part of the National Appliance and Equipment Energy Efficiency Program (NAEEEP). Its purpose is to explore the potential for energy and greenhouse savings through the introduction in Australia of Minimum Energy Performance Standards (MEPS) for packaged air compressors.

2. SCOPE

This report describes the types of packaged air compressor currently used in Australia and their characteristics. Technologies covered by the report include:

- Reciprocating single-acting air compressors, up to 20kW input power; and
- Rotary screw compressors, up to 20kW input power.

Other types of air compressor that are not within this scope are described, including reciprocating double acting, centrifugal and sliding vane types.

The report examines the current market for these technologies and identifies developments that may have a significant influence on energy consumption and greenhouse emissions.

It describes methodologies for measuring the efficiency of air compressors and issues related to their application.

The report assesses the potential for MEPS and other programs aimed at increasing the energy efficiency of packaged air compressors.

3. PRODUCT DESCRIPTION

3.1 Reciprocating compressors

3.1.1 Reciprocating, single acting

Overview

These compressors are an example of positive displacement machines, where air pressure is increased by reducing the size of the space that contains the air. Reciprocating compressors resemble small automotive engines and have a crankshaft, a connecting rod and piston, a cylinder and a valve head. In operation, air flows into the cylinder where the piston compresses and discharges it. While there are some models that consist of just the cylinder and a motor, most compressors also have an air tank to hold a quantity of air within a preset pressure range. As compressed air from the tank is drawn off by the end user, the motor cycles on and off automatically to maintain tank pressure.

At the top of the piston are the inlet and discharge valves. Both are usually thin metal flaps, one mounted above and one below a metal plate. As the piston moves down it creates a partial vacuum in the cylinder which allows atmospheric pressure to push open the inlet valve and flow into the cylinder. As the piston then moves up, the air above it is compressed, holding the inlet valve shut and pushing the discharge valve open. The air moves out through the discharge valve and into the tank. With each stroke of the piston, more air enters the tank and the pressure rises.

Single and two cylinder

Typical small compressors are one or two cylinder versions. At the smaller end of the size range, most of the two cylinder versions operate in the same way as single cylinder models except that there are two strokes per revolution instead of one. Some larger, commercial, two cylinder compressors are two-stage machines – one piston pumps air into a second cylinder that further increases pressure.

Control

Compressors use a pressure switch to stop the motor when the tank pressure reaches a pre-set limit – 800 to 1,000kPa for many single stage models. The air line coming from the tank may contain a regulator that can be set by the user to provide lower pressure air for a specific requirement. Gauges before and after the regulator may monitor pressure in the tank and in the air line. The tank has a safety valve that will open if the pressure switch malfunctions. The pressure switch may also incorporate an unloader valve that reduces the tank pressure when the compressor is switched off.

Lubrication

Many reciprocating compressors are oil lubricated and have an oil bath that splash-lubricates the bearings and cylinder walls as the crankshaft rotates. The pistons have rings that keep the compressed air above the piston and the lubricating oil away from the air. In practice, the rings are not completely effective and some oil will always enter the compressed air in aerosol form.

Having traces of oil in the compressed air is not necessarily a problem. Many pneumatic tools require in-line oiling and inline oilers may be added to provide a uniform oil supply to the tool. For applications where oil free air is required, oil separators or filters may be used. Alternatively, an oil free compressor design may be used. An oil free design uses permanently lubricated bearings in place of the oil bath.

Single-piece piston/connecting rod

A variation on the automotive-type reciprocating compressor is a model that uses a one-piece piston/connecting rod. The piston leans from side to side as an eccentric bearing on the shaft moves it up and down. A seal around the piston maintains contact with the cylinder walls and prevents air leakage.

In another variation is the diaphragm compressor where a membrane between the piston and the compressor chamber completely seals off the air and prevents leakage. This type of compressor supplies relatively small air volumes.

Single and two stage units

In a single stage unit, air is compressed to the final pressure in a single stroke. The design is generally used for pressures from 170 to 700kPa. Units are liquid or air-cooled.

The two-stage design compresses air to an intermediate pressure in the first stage. Most of the heat of compression is removed as the air passes through an intercooler, which is liquid or air cooled, to the second stage where it is compressed to the final pressure. Two-stage compressors are generally used for pressures from 700 to 1,700kPa.

Power source

A single or three-phase electric motor may be used, or a petrol or diesel internal combustion engine. In Australia, an estimated 90% of reciprocating compressors are electrically driven.

Other features

Smaller reciprocating compressors are generally mounted on a rigid portable frame ('skid mounted') or on wheels.

Larger reciprocating compressors, such as may be used in industrial applications, require heavy solid foundations to cope with the large vibrational forces they cause.

Reciprocating compressors are very popular because of their simplicity, efficiency, compactness, ease of maintenance and relatively low price.

3.1.2 Reciprocating, double acting

These designs compress air on both strokes of the piston and are normally used for heavy duty, continuous service. Discharge pressures range up to 10,000kPa and higher. The most common application is continuous duty supplying air at about 700kPa.

3.2 Rotary screw

These compressors are also positive displacement machines. They use one or two rotors (or screws) for compression and are constant volume, variable pressure machines. Oil or water injection is normally used to seal clearances and to remove the heat of compression. Oil-free designs have reduced clearances and do not require any other sealing medium.

In single screw designs, the rotor meshes with one or two pairs of gates. The screw and casing act like a cylinder and the gates act like the piston in a reciprocating compressor. The screw also acts as a rotary valve with the gates and screw working as a suction valve and a port in the casing acting as a discharge valve. Single stage sizes range from 5L/s to 500L/s with pressures up to 1,000kPa. Designs supplying 330L/s to 600L/s at 1,700kPa are available.

Dual rotor designs use two intermeshing rotors in a twin-bore housing.

Power consumption of rotary screw compressors during unloaded operation is normally higher than for reciprocating types. Recent developments have produced systems where the unloaded power is 15% to 25% of loaded power. These systems are normally used with electric motor, constant speed drives. Base load use is recommended to avoid excessive unloaded energy consumption.

Advantages of rotary screw compressors include smooth, pulse-free air output, compact size, high volume output, low vibration levels and long life.

3.3 Centrifugal

These compressors have rotating impellers that impart velocity and pressure to the air. Their design is simple and straightforward, consisting of one or more high-speed impellers with cooling sections. The only lubrication is in the drive system, which is sealed off from the air system.

Centrifugal air compressors are generally used in central plant air applications requiring volumes ranging from 500 to 14,000L/s. As such, they are outside the scope of this report and are not discussed further.

3.4 Sliding vane

A vane type rotor is mounted eccentrically in a housing. As the rotor turns, the vanes slide out against the stator or housing. Air compression occurs when the space between the sliding vanes is reduced as the rotor turns.

This type of compressor may or may not be lubricated. Non-lubricated designs are restricted to low pressure applications due to high operating temperatures and sealing difficulties. Higher pressures are obtained with lubricated designs.

Sliding vane compressor capacities range from 2L/s to 300L/s and pressures from 500kPa to 1,000kPa.

Advantages of sliding vane compressors include cool, clean, pulse-free air output, compact size, and low levels of noise and vibration.

3.5 Other types

Lobe compressors are a positive displacement type in which lobes have intermeshing profiles that form a decreasing volume while rotating. They are relatively vibration free. Lobe compressor capacities range from 90L/s to 700L/s at 800kPa.

Liquid ring compressors employ a rotor to drive a captive ring of liquid within a cylindrical housing. The inner surface of the liquid ring serves as the face of a liquid piston operating within each rotor chamber. The rotor chambers have openings at the inner diameter sealed by a central stationary plug. The plug has permanently open ports that permit air to be taken into and discharged from the revolving rotor chambers.

Liquid ring compressors provide a continuous air supply without pressure variations. Delivered air is oil free because the liquid ring is the piston and requires no lubrication. Liquid ring compressors are available in sizes ranging from 5L/s to 7,500L/s with maximum pressures from single stage units of about 240kPa and two-stage units of 900kPa.

3.6 Compressor selection

3.6.1 Typical compressor selection

The following table indicates typical compressor selection for various duties, within the size range of interest in this report (<20kW).

Table 1: Typical compressor selection, smaller units

Industry	Application of compressed air	Capacity requirement	Recommended compressor type
Workshop / auto garage	Tools, spray paint, cleaning	15L/s	Air cooled reciprocating
Construction, mines, boring	Rock drills,	50 to 600L/s	Portable screw compressor
Small engineering, small foundry	Tools, moulding m/c, spray painting and cleaning	50L/s	1. Single stage reciprocating 2. Screw compressor

3.6.2 Reciprocating vs rotary machines

In the size range of interest in this report, up to 20kW, reciprocating and rotary screw compressors dominate the market.

Larger compressors (above about 20kW)

Rotary screw compressors have taken over almost all of the market for commercial and industrial applications above about 20kW. Improvements in the performance and reliability of these machines coupled with reduced maintenance and lower capital cost are driving this trend.

Although a double acting reciprocating is still the most efficient compressor, rotary screw models are closing the efficiency gap. For example, a slow-speed direct-drive rotary screw compressor can be within 5-10% of the efficiency of a double-acting reciprocating.

Standard rotary compressor packages have a microprocessor-based or electro-pneumatic controller. These controllers allow the rotary machine to run at optimal efficiency at various loads.

Rotary compressors have advantages in terms of maintenance, due to the lack of valves, pistons and rings and other consumables. Rotary screw maintenance is mainly limited to oil, oil filter and air/oil separator changes.

Non-lubricated reciprocating units can cost 10% to 15% more than an equivalent lubricated unit and have similar power consumption and efficiency for a given duty. Maintenance costs can be much greater for non-lubricated models. Lubricated piston rings should last for several years whereas recent advances in the materials used in non-lubricated designs have only increased the lifetime to 8,000 hours.

Smaller systems (below about 20kW)

The small reciprocating compressor dominates the market below about 20kW. The purchase price in this size range is significantly less than a comparable rotary unit. Small reciprocating units are reliable, durable and a wide range is available.

Although more expensive in this size range, rotary units are starting to become more popular.

A comparison between the two types is shown in the following table.

Table 2: Comparison of features of reciprocating and rotary screw compressors

Reciprocating	Rotary screw
Cost advantage as a single-acting air-cooled unit below 20kW	Cost competitive above 20kW
Delivers higher pressures	Used more in 100kPa, lubricated air systems above 20kW
Needs an air tank to deliver pulse-free airflow	Delivers smooth, pulse-free output
High overall efficiency	More sophisticated control systems provide increased efficiency
Efficient at part-load and no-load conditions	Must vent air to reduce unloaded power consumption
Piston rings, valves require maintenance	Lower maintenance cost
Large sizes require heavy foundations due to vibration	Low vibration

4. APPLICATIONS

Compressed air is widely used in the domestic, commercial and industrial sectors.

Domestic uses include inflating tyres, boats and pool toys, spray painting and power tools. Domestic uses are intermittent and may total less than a few hundred hours per year.

Commercial applications include spray painting, cleaning and air driven tools. Pneumatic tools tend to be smaller, lighter, and easier to handle than electric motor-driven tools. They also deliver smooth power and are not damaged by overloading. Air-powered tools have the capability for infinitely variable speed and torque control, and can reach a desired speed and torque very quickly. In addition, they are often selected for safety reasons because they do not produce sparks and do not heat up in use. Although they have many advantages, pneumatic tools are generally much less energy-efficient than electric tools.

Commercial applications range from intermittent use (for example pneumatic tools) to seasonal (recreation services) to continuous (medical uses).

Some commercial sector uses for compressed air are given in the table below.

Table 3: Commercial uses of compressed air

Sector	Example Compressed Air Uses
Transportation	Pneumatic tools, hoists, air brake systems
Agriculture	Farm equipment, materials handling, spraying of crops, dairy machines
Power Generation	Starting gas turbines, automatic control, emissions controls
Wastewater Treatment	Vacuum filters, conveying
Recreation	Ski resorts - snow making Hotels - elevators, sewage disposal Golf courses - seeding, fertilizing, sprinkler systems Cinemas - projector cleaning Amusement parks - air brakes Underwater exploration - air tanks
Service Industries	Pneumatic tools, hoists, air brake systems, garment pressing machines, hospital respiration systems, climate control

The industrial sector uses compressed air for a multitude of operations. Most industrial facilities have at least two compressors, and in a medium-sized plant there may be hundreds of different uses of compressed air.

Uses include powering pneumatic tools, packaging and automation equipment, and conveyors. Many manufacturing industries also use compressed air and gas for combustion and process operations such as oxidation, fractionation, cryogenics, refrigeration, filtration, dehydration, and aeration.

Many industrial applications require a continuous supply of air.

The table below lists some major manufacturing industries and the tools, conveying, and process operations requiring compressed air.

Table 4: Industrial uses of compressed air

Industry	Example Compressed Air Uses
Food	Dehydration, bottling, controls and actuators, conveying, spraying coatings, cleaning, vacuum packing
Textiles	Agitating liquids, clamping, conveying, automated equipment, controls and actuators, loom jet weaving, spinning, texturising
Mining	Pneumatic tools, hoists, pumps, controls and actuators
Apparel	Conveying, clamping, tool powering, controls and actuators, automated equipment
Lumber and Wood	Sawing, hoisting, clamping, pressure treatment, controls and actuators
Furniture	Air piston powering, tool powering, clamping, spraying, controls and actuators
Pulp and Paper	Conveying, controls and actuators
Chemicals	Conveying, controls and actuators

Petroleum	Process gas compressing, controls and actuators
Rubber and Plastics	Tool powering, clamping, controls and actuators, forming, mould press powering, injection moulding
Stone, Clay, and Glass	Conveying, blending, mixing, controls and actuators, glass blowing and moulding, cooling
Primary Metals	Vacuum melting, controls and actuators, hoisting
Metals Fabrication	Assembly station powering, tool powering, controls and actuators, injection moulding, spraying

5. COMPRESSOR EFFICIENCY

5.1 Introduction

There are several contributors to the efficiency of a positive displacement air compressor:

- The efficiency of the drive unit, usually an electric motor but may be a petrol or diesel internal combustion engine
- The mechanical design of the "air end"
- The mechanical design of other aspects of the package (for example, inlet and outlet valves, piping)
- Use patterns (for example, continuous or intermittent)
- Control (for example, is the drive unit switched off when there is no demand); and
- Whether the unit is lubricated or dry.

The rate at which a compressor can deliver air is measured in m^3/s or L/s, although even in Australia, cubic feet per minute (cfm) is very frequently quoted in sales literature. Because atmospheric pressure plays a role in how fast air moves into a cylinder, the flowrate will vary with atmospheric pressure. It also varies with the temperature and humidity of the air.

Since the density of air varies with temperature and pressure, the conditions at which the flowrate is measured must be stated.

5.2 Definition of efficiency

The principle behind the measurement of compressor efficiency is simple. The efficiency is volume of air delivered at a particular pressure divided by the power input.

Units are L/s/kW or m^3/s/kW. US units are cfm/hp.

Definition and measurement of compressor efficiency has many pitfalls. Although standards exist, they have not always been accurately and consistently applied.

Care needs to be taken when comparing published efficiency data since it is often specified for full load operation only (i.e full capacity and specified full-load discharge pressure). Since most systems operate at part-load for much of the time, it is important to compare part-load efficiencies when comparing the performance of different compressors.

When comparing compressor efficiency, users should make sure that tests have been performed to the same standards and at the same conditions. For example:

- Manufacturers may test their compressors at different 'standard' conditions. Standard conditions are 101.3kPa (14.5psia or 1 bar); 20^{o}C (68^{o}F) and dry (0% relative humidity)
- The actual full-load power required by a typical air compressor package will exceed the nominal nameplate rating of the main electric drive motor. Such motors have a continuous service factor, often 15%, which allows continuous operation above the nominal rating. Most compressor manufacturers use up to two thirds of the available service factor to that full power load will be say 10% above the nominal motor rating. It is therefore important to use the actual motor power rating not the nameplate rating when comparing efficiencies.

To include the motor efficiency and all package accessories and losses, a rating in total kW input should be used to provide more precise data.

- Manufacturers may use a flange-to-flange rating for air flow rate that does not include inlet, discharge and other package losses. This can cause overall efficiency to be overstated by 5% or more.
- Energy consumption for accessory components, such as cooling fan motors, may not be treated consistently.
- Manufacturers may apply different ranges or tolerances to performance data (see next section)
- Performance is usually based on perfect intercooling, which may not be realised under actual operating conditions. Perfect intercooling requires the air inlet temperature at each stage to be the same, requiring adequate cooling water. Poor intercooling will adversely affect compressor performance.

5.3 Measurement of efficiency

To address the issues identified in the previous section, Pneurop in Europe and the Compressed Air and Gas Institute (CAGI) in the US have jointly developed ‘simplified performance testing standards’ (Compressed Air Challenge, 2000). These standards have been incorporated as an Annex to ISO1217: 1996 – Displacement Compressors Acceptance Tests. The relevant standard to the compressors covered in this report is “CAGI/PNEUROP PN2CPT C2, Acceptance Test Code for Electrically Driven Packaged Displacement Air Compressor (1st edition)”.

While ISO1217: 1996 is a vital guide for efficiency testing, the tolerances set by PN2CPT C2 mean that a range of values for efficiency may be stated for a given machine (see next section). On the assumption that the high end of the range is likely to be stated on all sales information, the standard does provide a means of comparing the performance of different units. The tolerances allowed mean it is harder for the purchaser of the compressor to ensure that a unit has adequate capacity, and it therefore becomes more likely that an oversized unit will need to be purchased.

5.4 Performance calculations

The Pneurop/CAGI ‘Acceptance Code for Electrically Driven Packaged Displacement Air Compressor’ specifies tolerances that are permitted when carrying out performance tests on packaged air compressors.

These tolerances are illustrated in the following table.

Table 5: Tolerances for packaged air compressor performance tests

Compressor size	Volume flow rate	Energy Consumption On-load	Energy Consumption Off-load
Below 15 cfm	+/-7%	+/-8%	+/-20%
15 - 50 cfm	+/-6%	+/-7%	+/-20%
50 - 500 cfm	+/-5%	+/-6%	+/-20%
Over 500 cfm	+/-7%	+/-8%	+/-20%

In addition, the following tolerances apply for all sizes of machine:

Speed: +/- 4%

Inlet pressure (ambient): +/- 10%

Discharge pressure: +/- 3%

External coolant requirements: +/- 10%

Coolant injection temp: +/-10^{o}C

A sample calculation of the possible variation in measured efficiency of a theoretical 1,000cfm two-stage inter-cooled rotary air compressor illustrates a very wide range (Cashflo, 2000). The calculation demonstrates the use of the Pneurop/CAGI tolerances to give a range of efficiency.

In the example given, the range of efficiency for a 1000cfm is 3.81cfm/hp to 5.26cfm/hp, or about 30%.

This illustrates a difficulty in interpreting efficiency figures, even when an industry standard procedure is followed. However, since it would be reasonable to expect manufacturers to consistently state the higher end of the range, the standard does provide a means of comparing machines.

5.5 Examples of performance data

The following table shows performance data from two manufacturers for rotary screw compressors (all electric, 50Hz machines).

Table 6: Performance data, rotary screw compressors

Model	Test Pressure	FAD at normal working press	Installed power	Efficiency
	bar	L/s	kW	L/s/kW
GA5	7.5	13.7	5.5	2.49
	8	12	5.5	2.18
	10	10.6	5.5	1.93
	13	8	5.5	1.45
GA7	7.5	19.4	7.5	2.59
	8	17.7	7.5	2.36
	10	15.8	7.5	2.11
	13	12.5	7.5	1.67
GA10	7.5	26	11	2.36
	8	23.8	11	2.16
	10	20.9	11	1.90
	13	16.5	11	1.50
GA11	7.5	30.7	11	2.79
	8	28.6	11	2.60
	10	24.5	11	2.23
	13	19	11	1.73
GA15	7.5	41.5	15	2.77
	8	40.4	15	2.69
	10	35	15	2.33
	13	29.5	15	1.97
GA18	7.5	50	18.5	2.70
	8	48.3	18.5	2.61
	10	44.2	18.5	2.39
	13	36.5	18.5	1.97
GA22	7.5	60.3	22	2.74
	8	58	22	2.64
	10	52.2	22	2.37
	13	45.5	22	2.07
SSR series	7.5	9.0	4	2.25
	8.5	8.7	4	2.17
	10	6.7	4	1.67
	13	5.2	4	1.29
	7.5	13.8	5.5	2.52
	8.5	13.2	5.5	2.39

10	10.8	5.5	1.97
13	7.7	5.5	1.39
7.5	19.0	7.5	2.53
8.5	18.0	7.5	2.40
10	15.2	7.5	2.02
13	11.8	7.5	1.58
7.5	28.3	11	2.58
8.5	26.7	11	2.42
10	23.5	11	2.14
13	17.7	11	1.61

Note: 'GA' series is manufactured by Atlas Copco, 'SSR' series by Ingersoll Rand.

These air flow figures are measured in accordance with ISO1217: 1996. It is not clear whether the figure for 'installed power' is also measured in accordance with that standard. The figures indicate a range of efficiencies. As would be expected, the efficiency varies with the pressure of the delivered air, the size of the unit and also its design (for example compare GA10 and GA11 with the same motor power and at the same pressure).

Any proposed MEPS would have to set performance levels according to air delivery pressure (although this is often 7 or 8 bar in practice) as well as unit size.

6. IDENTIFICATION OF STAKEHOLDERS

6.1 Manufacturers and importers

There are at least 17 suppliers of commercial air compressors in Australia, 9 of which provided information for this profile - SIP, Trade Tools, Compair, Air and Power, Clisby, Forbes, Glenco, Ingersoll Rand and Champion.

These 9 suppliers employ between 6 and 135 staff with an average 55 emloyees. Some of these companies manufacture components or complete compressors (all but SIP and Compair) and others import packaged units.

There are many small retail and rental businesses listed in the Yellow Pages that distribute or hire products sourced from the larger suppliers.

6.2 Air and Mine Equipment Institute of Australia (AMEI)

Air compressor suppliers can choose to be represented by at least one industry association - the Air and Mine Equipment Institute of Australia (AMEI).

Contact details for this and other relevant industry associations are given in Appendix A.

7. MARKET PROFILE

7.1 Number in use and annual sales

There are no readily available figures on the number of air compressors in use. The estimates in this section draw on the following sources:

- Earlier estimates of the energy consumption of air compressors (Energetics and GWA, 1994)
- Discussions with air compressor suppliers
- ABS data for numbers of air compressors imported in 1999.

On the basis of these information sources, a total annual sales figure has been estimated. Industry sources indicate that a 10 year average lifetime is a reasonable expectation, and on that basis the estimated number of compressors in use is as shown in the following table.

Table 7: Estimated annual sales and stock

Air compressor size range	Approx annual sales	Approx installed stock
Less than 2.25kW	23,000	230,000
More than 2.25kW but less than 20kW	77,000	770,000
Total	**100,000**	**1,000,000**

It is estimated that 90% of all these units are electrically driven. Petrol engine units make up about 9% of the market and diesel 1%. Of the electric units an estimated 63% are single phase and 37% three phase.

The estimates in the above table are based on a variety of industry sources that showed a general lack of consensus. Further market research is required to obtain a better figure for both sales and stock and a breakdown between domestic, commercial and industrial use.

In the absence of better information, it is reasonable to assume that the smaller units are used for domestic and one-person business use. Larger units are likely to be used for longer hours in larger enterprises.

7.2 Market growth

As was the case with the figures for stock and for annual sales, industry views on the growth rate of the market were very varied.

The range of views was from 'diminishing' (four suppliers) to 'stable' (two suppliers) to 'growing' (three suppliers). Industry sources were unwilling to indicate quantitative growth rates.

8. INDUSTRY LINKS

Numbers of air compressors imported in 1999 are shown in the following table (ABS, 2000).

Table 8: Air compressor import data

Description	Number	Value
Reciprocating or rotary air compressor, mounted on a wheeled chassis for towing up to 50L/s capacity	4,010	$831,000
Reciprocating or rotary air compressor, mounted on a wheeled chassis for towing, capacity 50L/s to 420L/s	2,047	$4,914,000
Total	**6,057**	**$5,745,000**

It is likely that most of these units are petrol or diesel driven, not electric.

9. STANDARD DEVELOPMENT

9.1 Australia

There is an Australian Standard (AS4297, 1995) that covers safety aspects of the installation and operation of air compressors used in underground mining. Energy consumption is not covered. An abstract is given in Appendix B.

The proposed Minimum Energy Performance Standard for electric motors will affect air compressors.

Of the estimated population of 1,000,000 units, an estimated 90% of air compressors are driven by electric motors. Of the 900,000 electric compressors, an estimated 37% or 330,000 have three phase motors. These motors are covered by the proposed MEPS for three phase induction motors that is likely to come into force in July 2001 (AGO, 2000a).

9.2 Overseas

There are Standards detailing performance and efficiency measurement for various types of compressor. The tolerances specified in such standards have been discussed in section 5.

There are no known standards related to minimum energy performance.

Overseas standards are summarised in Appendix C.

Overseas (US and UK) programs aimed at improving the efficiency of compressed air systems are described in Appendix D and Appendix E. These programs are aimed at large, centralised industrial compressed air systems, but some aspects are relevant to the smaller units covered by this report.

10. GREENHOUSE EMISSIONS

10.1 Total greenhouse emissions

There are no figures available on average utilisation of packaged air compressors. In order to estimate greenhouse emissions, the following assumptions have been made:

- air compressors less than 2.25kW capacity are assumed to operate 3 hours per day and 5 days per week for 50 weeks per year, which is 750h per year;
- average capacity in the below 2.25kW capacity is assumed to be 1.5kW (many of these are likely to be driven by single phase motors);
- air compressors larger than 2.25kW but smaller than 20kW are assumed to have an average capacity of 10kW and to operate for 1,000h per year.

If more market research is carried out, data about average operating hours and average unit sizes should be collected (although suppliers may not have such information).

Further, it has been assumed that all air compressors in the size range of interest are electrically driven (in practice, around 90% are electric).

On the basis of these assumptions, and assuming an emissions factor of 1.0kgCO_2-e/kWh, total greenhouse emissions are estimated to be approximately 4,100 kt CO_2-e, as shown in the following chart:

Table 9: Estimated greenhouse emissions from air compressors, 2000

Compressor Size	kTCO2-e
Smaller units	258.75
Larger units	3850

10.2 Greenhouse reduction potential

10.2.1 Compressor and system potential

It is likely there is potential to reduce emissions by 10% (the same as the aim of the US Compressed Air Challenge Program), or 400kt CO_2-e per year. The majority of savings are through 'system' improvements on larger systems that have compressed air distribution.

The reduction would be achieved through (approximately in order):

- Eliminating leaks
- Better system design
- Better system control
- Performance standards for electric motors that go into compressors
- Performance standards for compressors (i.e the non-prime mover parts).

The majority of the savings accrue from 'system' measures and control rather than from improvements to the efficiency of the prime movers (electric, petrol or diesel motors) or to the compressors themselves.

10.2.1 Potential greenhouse reductions from motor MEPS

The proposed MEPS for three phase electric motors are likely to be introduced by July 2001.

The potential increase in average motor efficiency in the range 3 to 7.5kW is about 1% (AGO, 2000a).

The number of air compressors driven by three phase motors is estimated at 330,000, which consume a total of 1,400GWh per annum. If the efficiency of the motors in these units were increased by 1% over time, the energy saving would be 14GWh, or 14kt CO_2-e. This is less than 4% of the total estimated potential savings, underlining the importance of 'system' effects such as air distribution and controls.

11. APPROPRIATE MEPS LEVELS FOR AUSTRALIA

MEPS are not recommended for packaged air compressors in the size range covered in this report.

The reasons for this recommendation are as follows:

- the majority of the potential savings accrue from the improvement in the design, operation and maintenance of the *whole compressed air system* and the associated downstream uses, rather than the efficiency of the compressor unit itself;
- there is no split-incentive to affect most air compressor purchase decisions and if users had improved information on the efficiency of compressors there's no reason they would not choose more efficient models;
- there are practical issues related to the difficulty in policing imports of large numbers of small, low value units;
- due to their small size and relatively low utilization, the savings available from small, electric driven packaged air compressors are relatively small.

There are potentially large greenhouse reductions available from compressors both in the size range covered in this report and in all larger units and their related systems, and the consideration of one or more other programs, as outlined in the next section, is strongly recommended.

12. OTHER POTENTIAL PROGRAMS

Consideration should be given to strategies designed to promote efficiency in compressed air systems. These could include the following:

- Information programs for system design, operation and control – based on Compressed Air Challenge – possibly as part of the Best Practice Program;
- Efficiency labelling – in parallel with encouraging manufacturers to calculate figures to ISO1217 (in parallel with improved specification of the allowable tolerances under this test method);
- Promotion of case studies demonstrating cost savings from the implementation of compressed air system improvements;

- Underwriting of advice from industry experts, measuring of energy savings and development of payback models;
- Leak reduction programs – expand use of tools like SEDAs leak calculator (see Appendix G); possibly targeted at industries with widest air distribution systems;
- The AGO Australian Motor Systems Challenge Program (AGO, 2000b) is relevant for for compressors that are assembled in Australia.

Further investigation of the industrial market is recommended. Compressed air is a very substantial energy use and the majority of industrial compressed air systems would use compressors larger than the 20kW limit in this report.

13. IMPLEMENTATION

Since MEPS has not been recommended, we understand that the AGO will proceed with consultation with the industry in order to discuss and progress the other programs suggested in section 12.

14. REFERENCES

ABS, 2000	Import data
AGO, 2000a	*Regulatory Impact Statement, Minimum Energy Performance Standards and Alternative Strategies for Electric Motors*, September.
AGO, 2000b	*Australian Motor Systems Challenge Program*, described at www.greenhouse.gov.au/energyefficiency/appliances/market/challenge/index.html
Cashflo, 2000	Theoretical Energy Calculation available at www.cashflo.co.uk
Energetics and GWA, 1994	*Energy Performance Standards and Energy Labelling for Industrial and Commercial Equipment*, April
Compressed Air Challenge, 2000	*Improving Compressed Air Performance*, Sourcebook for Industry, April 1998, available at www.knowpressure.org

APPENDIX A: MAILING LIST OF INTERESTED PARTIES

A.1 Organizations

A1.1 Air and Mine Equipment Institute of Australia

Executive Director

PO Box 124, Avalon NSW 2107

Phone: (02) 9918 7491

Fax: (02) 9918 5168

A1.2 Air-conditioning and Refrigeration Equipment Manufacturers Association of Australia

National Secretary

PO Box 7622, St Kilda Road

Melbourne VIC 3004

Phone: (03) 9280 0111

Fax: (03) 9280 0199

A1.3 Institute of Plant Engineers of Australasia

WA President

PO Box 7303

Perth Cloisters Square WA 6850

Phone: (08) 9470 5144

Fax: (08) 9470 5436

A1.4 Institution of Mechanical Engineers

PO Box 61

Wembley WA 6014

A1.5 Institution of Engineers, Australia

Policy Analyst (Engineering)

Engineering House, 11 National Circuit

Barton ACT 2600

A1.6 Australian Industry Group

National Manager, Trade Policy

GPO Box 817

Canberra ACT 2601

A1.7 Refrigeration and Air Conditioning Contractors Association

The Secretary

485 Princes Highway

St Peters NSW 2044

A1.8 Australian Institute of Refrigeration, Air Conditioning and Heating

The Director

James Harrison House, 52 Rosslyn St.

West Melbourne Vic 3003

A.2 Manufacturers

Air Compressors are mainly fully imported, or parts imported and assembled in Australia. However, the following manufacturers can manufacture the full product or parts depending on the application.

A2.1 Pilot Air Compressors

6-10 Gifford St

Silverwater NSW 2128

Phone: (02) 9648 3099

Fax: (02) 9648 3362

A2.2 F R Pulford & Son Pty. Ltd.

5 Baker St.

Botany NSW 2019

Phone: (02) 9316 9735

A.3 Major Suppliers

A3.1 Advanced Air Compressors Pty. Ltd.

6 Metlers Place

Wetherill Park NSW 2164

Phone: (02) 9725 5213

Fax: (02) 9756 1731

A3.2 CompAir (Australasia) Ltd.

115-121 Ballandella Rd, Pendle Hill NSW 2145

Phone: 1800 634 077

Fax: 1800 638 854

Web: www.compair.com.au

A3.3 Atlas Copco Compressors Australia

Bessemer St.

Blacktown NSW 2148

Phone: (02) 9621 9999

A3.4 Kaeser Compressors Australia Pty. Ltd.

45 Zenith Road, Locked Bag 1406

Dandenong South, VIC 3175

Phone: (03) 9791 5999

Fax: (03) 9791 5733

Web: www.kaeser.com

A3.5 Ingersoll-Rand (Aust) Ltd.

70 Long St.

Smithfield NSW 2164

Phone: (02) 9725 1577

Fax: (02) 9725 2802

A3.6 Champion Compressors Ltd.

1 Sheridan Close

Milperra NSW 2214

Phone: (02) 9772 4488

Fax: (02) 9772 1940

A3.7 Sullair Compressors

1 Sheridan Cl

Milperra NSW 2214

Phone: (02) 9772 4488

A3.8 S&C Air Compressors

20 Byrne St

Auburn NSW 2144

Phone: (02) 9748 0755

A.4 Regulators

These regulators consider the health and safety aspects arising from plant and systems of work associated with plant. Although air compressors are not specifically addressed, they may be part of, or associated with plant.

A4.1 Occupational Health & Safety Inspectorate

WorkCover ACT

P.O. Box 224

Civic Square ACT 2608

A4.2 Workplace Health and Safety

Department of Employment, Training and Industrial Relations

GPO Box 4160

Brisbane Qld 4001

A4.3 Department of Industries and Business

GPO Box 4160

Darwin NT 0801

A4.4 Department of Infrastructure, Energy and Resources

P.O. Box 56

Rosny Park Tas 7018

A4.5 Occupational Safety and Health

Department of Labour New Zealand

P.O. Box 3705

Wellington 6015

NEW ZEALAND

A4.6 Victorian WorkCover Authority

(Engineering Unit)

GPO Box 4306

Melbourne VIC 3001

A4.7 WorkCover NSW

GPO Box 5364

Sydney NSW 2001

A4.8 WorkSafe Western Australia

Construction and Engineering

P.O. Box 294

West Perth WA 6872

APPENDIX B: AUSTRALIAN STANDARDS

AS 4297-1995, Underground mining - Stationary air compressors

Scope

This International Standard establishes standards for the safe design, construction, installation and operation of stationary and skid-mounted air compressors for general use. It specifies requirements to help minimise compressor accidents and defines general safety practices for the field. Potential hazards associated with compressors are listed and detailed under the following headings in Clause 6:

- Improper lubrication.
- Inadequate cooling.
- Mechanical failures.
- Personal injury.
- Exposure to noise.
- Fires and explosions in the pressure system.
- Crankcase explosion.
- Incorrect installation, operation or maintenance.

This International Standard does not cover the prime movers, which are dealt with in other International Standards.

This International Standard is based on the requirement that the compressor components be designed in accordance with recognised good practice and applicable national Standards.

This International Standard is intended to apply to stationary and skid-mounted air compressors for general use. However, the following types of compressor are specifically excluded:

- Compressors with a shaft input less than 2kW.
- Compressors with an effective discharge pressure less than 0.5bar (50kPa).
- Compressors with an effective discharge exposure exceeding 50bar (5MPa)
- Compressors specifically supplying air for breathing, diving or surgery.
- Compressors used for air brake systems.
- Ejectors.

Abstract

Specifies rules for the safe design, construction, installation and operation of air compressors located in underground mines to accommodate underground applications. The Standard is based on ISO5388:1981, the full text of which has been reproduced. Variations to ISO5388 have been given in an appendix.

Status: Current

Published: 4 August 1995
Pages: 26

APPENDIX C: INTERNATIONAL STANDARDS

C.1 ISO 5388:1981, Stationary air compressors - Safety rules and code of practice

Scope

This International Standard establishes standards for the safe design, construction, installation and operation of stationary and skid-mounted air compressors for general use. It specifies requirements to help minimise compressors accidents and defines general practices for the field. Potential hazards associated with compressors are listed and detailed under the following headings in Clause 6.

- Improper lubrication.
- Inadequate cooling.
- Mechanical failures.
- Personal injury.
- Exposure to noise.
- Fires and explosions in the pressure system.
- Crankcase explosion.
- Incorrect installation, operation or maintenance.

This International Standard does not cover the prime movers, which are dealt with in other International Standards.

This International Standard is based on the requirement that compressor components be designed in accordance with recognised good practice and applicable national Standards.

This International Standard is intended to apply to stationary and skid-mounted air compressors for general use. However, the following types of compressor are specifically excluded:

- Compressors with a shaft input less than 2kW.
- Compressors with an effective discharge pressure less than 0.5 bar (50kPa).
- Compressors with effective discharge pressure exceeding 50 bar (5Mpa).
- Compressors specifically supplying air for breathing, diving or surgery.
- Compressors used for air brake systems.
- Ejectors.

C.2 ISO 1217: 1996 Displacement compressors – Acceptance test

C.3 Other ISO publications

ISO 3857-1: 1977 Compressors, pneumatic tools and machines - Vocabulary - Part 1: General

ISO 3857-2: 1977 Compressors, pneumatic tools and machines - Vocabulary - Part 2: Compressors

ISO 3857-3: 1989 Compressors, pneumatic tools and machines - Vocabulary - Part 3: Pneumatic tools and machines

ISO 5390: 1977 Compressors - Classification

ISO 5011: 1988 Inlet air cleaning equipment for internal combustion engines and compressors - Performance testing.

ISO 5941: 1979 Compressors, pneumatic tools and machines - Preferred pressures

ISO 8010: 1988 Compressors for the process industry - Screw and related types - Specifications and data sheets for their design and construction

ISO 8011: 1988 Compressors for the process industry - Turbo types - Specifications and data sheets for their design and construction

ISO 8012: 1988 Compressors for the process industry - Reciprocating types - Specifications and data sheets for their design and construction

ISO 8573-1: 1991 Compressed air for general use - Part 1: Contaminants and quality classes

ISO 8573-2: 1996 Compressed air for general use - Part 2: Test methods for aerosol oil content

C.4 BS 6244—1982, Stationary air compressors

Abstract

Specifies rules for the safe design, construction, installation and operation of air compressors located in underground mines to accommodate underground application.

This Standard is identical with ISO5388: 1998, the full text has been reproduced.

C.5 ASME B19.1 - 1995, Safety standard for air compressor systems

Scope

This Standard addresses all aspects of air compressor systems from the entrance to the inlet device through the compressor and associated heat exchangers, dryers, and pulsation suppression devices to the point of entry to the distribution system.

The following types of air compressor systems are specifically excluded from this Standard:

- Those having ratings of 5psig (0.34barg) or less differential pressure. This eliminates fans and low pressure blowers, but includes mechanical air vacuum pumps.
- Those having drivers rated at less than 1.5hp (1.1kW).
- Those which operate as part of facilities for processing petroleum, petrochemicals, or chemicals, including air separation plants.
- Those functioning as part of automotive and transportation equipment. Examples are truck air brake systems, aircraft air conditioning systems, and automotive emission control compressors.
- Thermal compressors such as steam jet ejectors.
- Turbochargers and superchargers that are part of a prime mover.

Application

The provisions of this Standard apply to air compressor systems except as excluded below. Other exceptions may be necessary with regard to systems of unusual design, complexity, or function. In such cases, the system designer has the responsibility to develop equivalent safety features.

This Standard does not apply to the following:

- Basic mechanical design. This Standard assumes as essential that the compressor and air compressor system components be designed by qualified engineers in accordance with recognised standards and specifications.
- Design and operation of the compressed air distribution system. Distribution system refers to the compressed air system beyond the compressor and associated heat exchangers, dryers, and pulsation suppression devices.

- Design and operation of the equipment or apparatus which uses the compressed air.
- Air compressor systems that are an integral part of facilities for processing petroleum, petrochemicals, or chemicals, including air separation plants. These are covered by ASME B19.3, Safety Standard for Compressors for Process Industries.

The principles promoting safe generation and use of compressed air are not restricted to new air compressor systems. It is recommended that all air compressor systems be reviewed to consider possible changes due to revision of this Standard.

C.6 ASME B19.3b - 1995, Safety Standard for compressors for process industries

Purpose

It is the purpose of this Standard to make available general information on safe practices and specific recommendations covering basic safety requirements for compressors used in the process industries. This information is intended to provide guidance to those who design, install, and operate compressors. Safety requirements described in this Standard for compressor auxiliary equipment, including drivers, shall not apply to such auxiliary equipment when used in applications other than compressor installations.

Scope

The specific recommendations in this Standard cover the requirements for safety devices and protective facilities to prevent compressor accidents as a result of excessive pressure, destructive mechanical failures, internal fires or explosions, and leakage of toxic or flammable fluids. General safety practices and hazards unique to compressors are also covered. This Standard applies to the compressor and its auxiliaries, including drivers, intercoolers, surge chambers, disengaging drums or scrubbers, interconnection piping and lubrication, seal oil, and jacket water systems. The requirements of this Standard apply to all types of compressors (centrifugal, axial, rotary, and reciprocating) which are an integral part of facilities for processing petroleum, petrochemicals, or chemicals, including air separation plants. This Standard does not apply to plant utility air compressors.

Although the provisions of this Standard will apply to the majority of typical compressors used in the process industries, exceptions to these recommendations with regard to certain facilities of unusual design or complexity may be necessary. In such cases, it is intended that designers capable of applying a complete and rigorous analysis to system requirements shall have latitude in the development of safety features. Provisions in this Standard are not intended to apply to (1) and (2) below:

(1) Basic mechanical design of compressor components. This Standard is based on the requirement that the compressor components be designed by qualified engineers in accordance with the recognised standards and specifications. Further, it is essential that these engineers have a thorough knowledge of the basic concepts of the design of such equipment components as cylinders, pistons, crankshafts, flywheels, bearings, pressure vessels, and piping.

(2) Design and operation of connected process facilities.

The principles promoting safe operation of compressors used for process industries are not restricted to new compressor systems. It is recommended that all compressor systems be reviewed to consider possible changes due to revision of this Standard.

C.7 BS1571: Amendment 3 1975, Testing of positive displacement compressors and exhausters

Part 2: Methods for simplified acceptance testing for air compressors and exhausters

Scope

This Standard specifies acceptance tests for positive displacement air compressors and exhausters, the absolute intake pressures of which exceed approximately 1 mbar* (*1 mbar = 10^2 N/m^2 = 0.1 kPa.) In establishing the scope of this Standard a positive displacement compressor is considered as a machine where a static pressure rise is obtained by allowing successive volumes of air to be aspired into and exhausted out of an enclosed space by means of the displacement of a moving member. The Standard applies to such machines as reciprocating and rotary compressors.

C.8 BS 1571:1975, Amendment 4, Testing of positive displacement and exhausters

Part 2: Methods for simplified acceptance testing for air compressors and exhausters

Guiding principles

Only those measurements necessary to verify any guarantee given by the manufacturer to the purchaser shall be taken, together with any other observations called for when placing the contract or as may be subsequently agreed between the purchaser and the manufacturer.

The test conditions shall be as close as is reasonably possible to the guarantee conditions, and deviations from these shall not exceed the limits specified below:

speed ± 5%,

absolute intake pressure ± 5%,

temperature of cooling water ± 8°C,

pressure ratio ± 1%.

Where it is not feasible to test a machine within the limitations specified above, special conditions of test or special corrections shall be agreed between the purchaser and the manufacturer.

The compressor on test will be deemed to be acceptable provided the results obtained do not differ from the type test results by more than the allowances given in the following table.

Table C1: Capacity and specific energy consumption: tolerances for simplified test

Compressor	100% capacity		50% capacity		No load power
	Capacity	Specific energy consumption	Capacity	Specific energy consumption	
	%	%	%	%	%
Below 10 kW	± 6	± 7	—	—	± 20
10 kW to 100 kW	± 5	± 6	± 7	± 7	± 20
Above 100 kW	± 4	± 5	± 5	± 6	± 20

The need for simplified tests at other than full capacity shall be the subject of agreement between the manufacturer and the purchaser.

C.9 API STD 617 1995, Centrifugal compressors for petroleum, chemical and gas service industries

Abstract

This Standard covers the minimum requirements for centrifugal compressors used in petroleum, chemical, and gas industries services that handle air or gas. This Standard does not apply to fans or blowers that develop less than 34kPa (5 pounds per square inch) pressure rise above atmospheric pressure; these are covered by API Standard 673.

This Standard also does not apply to packaged, integrally-geared centrifugal air compressors, which are covered by API Standard 672.

Organization: American Petroleum Institute

C.10 API STD 618—1995, Reciprocating compressors for petroleum, chemical, and gas industry services

Abstract

This Standard covers the minimum requirements for reciprocating compressors and their drivers used in petroleum, chemical, and gas industry services for handling process air or gas with either lubricated or non-lubricated cylinders. Compressors covered by this Standard are of moderate-to-low speed and in critical services. Also covered are related lubricating systems, controls, instrumentation, intercoolers, aftercoolers, pulsation suppression devices and other auxiliary equipment. Compressors not covered are—

- integral gas-engine-driven compressors with single-acting trunk-type (automotive-type) pistons that also serve as crossheads; and
- either plant or instrument-air compressors that discharge at a gauge pressure of 9 bar (125 pounds per square inch) or less. Also not covered are gas engine and steam engine rivers.

NOTE: Requirements for packaged high-speed reciprocating compressors for oil and gas production services are covered in API Specification 11P.

Requirements for packaged reciprocating plant and instrument-air compressors are covered in API Standard 680.

Organization: American Petroleum Institute

C.11 API STD 619—1997, Rotary type positive displacement compressors for petroleum, chemical, and gas industry services, third edition

Abstract

This Standard covers the minimum requirements for dry and flooded helical lobe rotary compressors used for vacuum or pressure or both in petroleum, chemical, and gas industry services. It is primarily intended for compressors that are in special purpose applications. It does not cover portable air compressors, liquid ring compressor, and vane-type compressors. Standard air compressors for light duty are covered in International Standard ISO 10 440:1995 – Rotary type positive displacement oil-free compressors for general refinery services, Part 2 – Packaged air compressors.

C.12 API STD 672—1996, Packaged, integrally geared centrifugal air compressors for petroleum, chemical, and gas industry services

Abstract

This Standard establishes the minimum requirements for constant-speed, packaged, integrally geared centrifugal air compressors, including their accessories. It may be applied for gas services other than air which are nonhazardous and nontoxic. This Standard is not applicable to machines that develop a pressure rise of less than 0.35 bar (5.0 psi) above atmospheric pressure, which are classed as fans or blowers.

Organization: American Petroleum Institute

C.13 ASHRAE 4056—1977, Energy-saving opportunities for positive displacement air compressors

Organization: American Society Of Heating, Refrigerating & Air-Conditioning Eng.

C.14 CAGI 1981, Recommendation for performance statements for packaged integrally geared multistage, intercooled centrifugal air compressor (1st edition)

Organization: Compressed Air & Gas Institute (U.S.)

C.15 CAGI 1992, CAGI/PNEUROP PN2CPT C1, Acceptance Test Code for Bare Displacement Air Compressors (1st edition)

Organization: Compressed Air & Gas Institute (U.S.)

C.16 CAGI 1992, CAGI/PNEUROP PN2CPT C2, Acceptance Test Code for Electrically Driven Packaged Displacement Air Compressor (1st edition)

Organization: Compressed Air & Gas Institute (U.S.)

C.17 CAGI 1992, CAGI/PNEUROP PN2CPT C3, Acceptance Test Code for I.C. Engine Driven Package Displacement Air Compressor (1st edition)

Organization: Compressed Air & Gas Institute (U.S.)

C.18 CIMA PAC 100, Portable Air Compressors

Organization: Construction Industry Manufacturers Association (U.S.)

C.19 DOD MIL-C-555L Notice 1, Compressors, air, reciprocating and rotary, diesel engine driven

Abstract

This specification covers skid-mounted, and trailer-mounted, diesel-engine-driven reciprocating and rotary air compressors.

Organization: Department of Defense (U.S.)

Published: 09-03-1998

APPENDIX D: US COMPRESSED AIR CHALLENGE

The Compressed Air Challenge (CAC) is generally aimed at larger commercial and industrial users of compressed air systems, who would usually have centralized compressors and a compressed air distribution system.

Some aspects of the CAC are relevant to the smaller air compressors covered by this report, and an overview of the Challenge is given for completeness.

A national collaborative effort, the Compressed Air Challenge (CAC), was formed in October 1997 to assemble state-of-the-art information on compressed air system design, performance, and assessment procedures. The project aims to: deliver best-practice compressed air system information to the plant floor, create a consistent national market message that supports the application of these best practices, provide a technically sound and professionally delivered training program for plant operating personnel, and through a certification program, recognize plant personnel's skills in operating compressed air systems.

Participants include: large industrial users of compressed air, manufacturers and distributors of compressed air equipment and their associations, facility engineers and their associations, compressed air system consultants, state research and development agencies, energy efficiency organizations, and utilities.

The goals of the CAC are to:

- Increase the reliability and quality of industrial production processes,
- Reduce plant operating costs,
- Expand the market for high quality compressed air services, and
- Save energy; a 10% improvement over current usage, resulting in annual savings of approximately 3 billion kWh of electricity nationwide.

The purpose of the CAC is to initiate a national collaborative that develops materials, a training curriculum, a certification program, and other information that can be used by the project sponsors in cooperation with others to:

- Raise awareness of the importance of efficient, effective plant air systems,
- Train industrial plant operating personnel on best practices for plant air systems,
- Expand the market for expert plant air assessment services, and
- Help build the local market infrastructure to deliver these services.

The CAC had the following objectives for its first year:

- Inventory existing promotional and educational materials,
- Assess market opportunities,
- Package promotional materials drawn from existing information,
- Prepare a nationally-recognized professional development program to train plant operating personnel,
- Sponsor and evaluate five pilot training sessions for plant operating personnel,
- Develop a solutions-neutral training program for distributors, manufacturers' representatives, utility staff, and compressed air system consultants,
- Develop the basis for a plant engineer certification program, and
- Evaluate the effectiveness of its marketing materials, training, and process.

The CAC had the following objectives for its second year:

- Fully implement a training program for plant operating personnel,
- Refine curricula and training materials,
- Create a nationally recognized certification program in compressed air system proficiency for plant operating personnel, and
- Assess the technical and market viability of a nationally recognized certification program for compressed air system consultants.

The Compressed Air Challenge has developed a series of training sessions on the fundamentals of compressed air systems. A sourcebook and fact sheets are also available.

Two of the factsheets are particularly relevant to this report. These are summarized below.

Fact Sheet 8: Packaged Compressor Efficiency Ratings

This sheet discusses issues related to the measurement and reporting of packaged compressor efficiency. Standards for performance testing compressors exist but have not always been applied in a consistent manner and performance test results and efficiency ratings are not always published in consistent, standard formats.

The US-based Compressed Air and Gas Institute (CAGI), in conjunction with its European counterpart Pneurop, has developed simplified performance testing standards which have been incorporated as addenda in ISO 1217: 1996.

This sheet claims that "the revised ISO 1217 with Simplified Test Codes will likely be the most commonly used standard in future". CAGI has developed Data Sheets that outline a common format and style for reporting compressor performance, including efficiency. A sample data sheet is shown in Appendix E.

The industry norm for a comparison of compressor efficiency is given in terms of bhp/100 acfm (brake horsepower per actual cubic foot minute) at a compressor discharge pressure of 100psig. A typical single stage rotary screw compressor will have a rating of approximately 22bhp/100 acfm* (referenced to standard inlet conditions).

**Note:* In the units used in this paper, this is equivalent to 2.9L/s/kW

Even when accurate, consistent efficiency information is available, it may only be specified for full-load operation. Since many systems operate at part-load for much of the time, it is also important to compare part-load efficiencies when evaluating the performance of different compressors.

Fact Sheet 11: Proven Opportunities at the Component Level

Compressed air systems contain 5 major subsystems: (1) compressors (2) prime mover (3) controls (4) air treatment equipment and other accessories (5) the air distribution subsystem.

Performance aspects of each of these subsystems are discussed. The following comments and recommendations are relevant to this report:

Compressors:

- Users should select the most efficient model available
- Lubricant-free rotary screw and reciprocating compressors are generally less efficient than lubricated machines.

Prime movers:

- Standard, 3 phase induction motors are used in 90% of industrial compressor applications
- Since October 24, 1997, such motors are required to meet minimum federal efficiency levels
- The extra capital involved in buying the most efficient motor available for a particular application is typically paid back in less than a year from the resulting energy savings.

Controls:

- Controls are frequently configured poorly and proper control strategies can lead to substantial reductions in energy consumption.

Air treatment equipment and other accessories:

- Dryers can enhance the performance of compressed air systems, but the air should only be dried to the extent required
- Air filtration should only be to the level required
- Filter elements should be inspected and replaced regularly
- Air receivers should be correctly sized
- Consider heat recovery systems
- Ensure air/lubricant separators are regularly inspected and replaced.

Air distribution subsystem:

- It is through this subsystem that most leaks occur, energy is lost and maintenance is required
- Equipment should be selected to avoid excessive pressure drops and leakage
- The complete drying, filtration and distribution system should be sized and arranged so that the total pressure drop from the air compressor to the points of use is much less than 10% of the compressor discharge pressure
- Do not leave condensate traps open longer than necessary – ensure automatic traps are operating properly.

APPENDIX E: CAGI DATA SHEET

Source: Improving Compressed Air Performance, A Sourcebook for Industry, April 1998 (Compressed Air Challenge, 2000)

COMPRESSOR DATA SHEET

ROTARY SCREW COMPRESSOR

MODEL DATA			
1	Manufacturer		
2	Model Number_____________________ Air-cooled ______ Water-cooled ______ Oil-Injected ______ Oil-Free ______	# of Stages_________	
		VALUE	UNIT
3	Rated Capacity at Full Load Operating Pressure[1]		acfm[1]
4	Full Load Operating Pressure [2]		psig
5	Maximum Full Flow Operating Pressure[3]		psig
6	Drive Motor Nameplate Rating		hp
7	Drive Motor Nameplate Efficiency		percent
8	Fan Motor Nameplate Rating (if applicable)		hp
9	Fan Motor Nameplate Efficiency (if applicable)		percent
10	Total Package Power Input at Rated Capacity and Full Load Operating Pressure		kW
11	Specific Package Input Power at Rated Capacity and Full Load Operating Pressure		kW/100 cfm

1. Measured at the discharge terminal point of the compressor package in accordance with the CAGI/PNEUROP PN2CPTC2 Test Code (Annex C to ISO 1217). ACFM is actual cubic feet per minute at inlet conditions.

2. The operating pressure at which the Capacity (Item 3) and Electrical Consumption (Item 10) were measured for this data sheet.

3. Maximum pressure attainable at full flow, usually the unload pressure setting for load/no load control or the maximum pressure attainable before capacity control begins. May require additional power.

APPENDIX F: UK ENERGY EFFICIENCY BEST PRACTICE PROGRAMME

The UK Energy Efficiency Best Practice programme (EEBPP) is a Government programme designed to help organisations cut their energy bills by 10 - 20%. It provides independent, authoritative advice and assistance to UK private and public sector organisations.

The EEBPP publishes a range of information on industrial and commercial energy efficiency. One section of the 'Focus – Managers Guide to Saving Energy' covers compressed air, and contains a checklist of suggestions for reducing compressed air costs.

While the Guide is aimed at industrial users with central compressors and compressed air distribution systems, some of its recommendations are relevant to the small compressors covered by this report.

The checklist covers technology as well as operating practice, and the general areas covered are:

- Effective and regular identification and repair of leaks
- Permanent mechanical isolation of unused pipework; isolation valves can leak
- Regular checks of automatic drain traps; faulty drain traps can waste large quantities of air
- Check that compressed air is generated at the minimum pressure; more energy is needed to generate compressed air at higher pressure
- Avoid the use of blow-guns wherever possible; for example use an industrial vacuum cleaner instead
- If blow guns must be used, operate at recommended pressure; maximum recommended pressure is 2 bar, but blow-guns are often operated at system pressure of 7 bar
- Operate air knives at minimum pressure; excessive pressure wastes energy
- Switch off compressors when there is no demand for air
- Regularly inspect and clean air inlet filters
- Draw air directly from outside; compressors operate more efficiently using cool air and operating costs can be cut by up to 3% if air is drawn from outside
- Regularly inspect and maintain the air treatment plant; a poorly maintained air treatment plant can increase compressed air costs by as much as 30%
- Consider alternatives to compressed air driven tools; electrically driven tools are around 90% cheaper to operate than compressed air tools
- Introduce zoning to the compressed air system if different areas of the plant require compressed air for different periods or at different pressures
- Replace manually operated drain valves with automatically operated valves; manually operated valves can be left open for excessively long periods
- Operate all compressors on a 'demand-controlled' basis; compressors can use as much as 70% of on-load power while idling
- Sequence compressors to meet demand; aim to run the minimum number of compressors near full load rather than extra lightly loaded machines
- Install a dedicated localized compressor for equipment that needs a significantly different pressure or different operating hours to the rest of the system
- Review size of air receivers; an undersized receiver will result in frequent compressor loading and unloading
- Check pipework is correctly sized; undersized pipework results in higher pressure loss
- Consider fitting heat recovery system to the compressor; over 90% of the energy used by a compressor is turned into heat, which is often wasted
- Check the quality of air treatment; excessive levels of air treatment increase compressor operating costs
- Use local blowers [low pressure compressors] to operate equipment like air knives
- When choosing a new compressor, ensure energy efficiency is a key selection criterion and consider its efficiency over its entire operating range.

APPENDIX G: SEDA'S COMPRESSED AIR PROGRAM

This simple program appears on SEDA's website at www.seda.nsw.gov.au

It enables the user to carry out simple calculations on the potential savings available from compressed air system changes, including:

- Repairing leaks
- Reducing system pressure
- Cooling inlet air.