# Dare to Compare Air Compressors

Knowing operating characteristics and physical limitations will help you select the best machine for your plant

**By Niff Ambrosino**

Most industrial air compressors are supplied as self-contained packages that include drive motor, inlet filter, mechanical and electrical controls and various optional accessories. Depending on the type and size of air compressor, the package might be mounted on an air receiver. Air compressors are classified either as positive-displacement or dynamic.

### Positive-displacement compressors

Air is drawn into an enclosed chamber where the volume is reduced by mechanical means, causing the pressure within to rise and forcing the air into the system. A simple example of a positive-displacement compressor is the hand pump for inflating tires. The operating principle for positive-displacement compressors is either reciprocating or rotary.

### Reciprocating type

A reciprocating compressor uses a moving piston in an enclosed cylinder. In a single-acting design, compression takes place on just one side of the piston and produces air on only one stroke per revolution. Double-acting compressors develop compression on both sides of the piston and produce air on two strokes per crankshaft revolution. This results in almost twice the capacity of a single-acting design of identical bore and stroke. In either case, the compressor might be air or water-cooled, lubricated or non-lubricated.

Single-stage reciprocating compressors have one or more cylinders connected in parallel to compress air from atmospheric pressure to the final discharge pressure in one step. Most single-stage compressors are designed for a maximum discharge pressure of 100 psig.

Multi-stage reciprocating compressors, on the other hand, have two or more cylinders connected in series. Each stage adds some degree of compression. For example, in a two-stage unit, air is compressed from atmospheric pressure to an intermediate pressure in the first stage, cooled by an intercooler and raised to the discharge pressure in the second cylinder. Multi-stage reciprocating compressors are more efficient, run cooler and have longer life than single- stage compressors, all because the intercooler(s) remove the heat of compression. While not typical for plant air, some special-application, two-stage compressors can deliver 250 psig or more.

Single-acting reciprocating compressors are commonly air-cooled, have one or two stages and available to 150 hp. However, in most industrial applications, the maximum size is generally 30 hp. A measure of operating efficiency is called specific power and is the kW input to produce 100 cfm, or kW/100 cfm. For a single-stage, single-acting compressor, the specific power is approximately 24 kW/100 cfm at 100 psig. Typical specific power for a two-stage, single-acting compressor at 100 psig is 19 kW/100 cfm to 21 kW/100 cfm.

Double-acting compressors are generally water-cooled and range in size from 25 hp (single-stage) to 500 hp. Common sizes for two-stage industrial applications range between 75 hp and 250 hp. A two-stage double-acting reciprocating compressor is the most energy-efficient air compressor. Typical specific power at 100 psig is approximately 15 kW/100 cfm to 16 kW/100 cfm. Double-acting compressors have a higher initial price, more expensive installation and higher maintenance costs than other types of compressors.

### Rotary compressors

The lubricated rotary-screw air compressor is the most widely used design for industrial applications. It's characterized by low vibration, a simple installation with minimal maintenance in broad ranges of capacity and pressure. A rotary-screw air end consists of two close-clearance helical rotors turning in synchronous mesh. The male rotor has four helical lobes and the female rotor has five or six mating grooves. In a lubricated rotary-screw compressor, the male rotor drives the female rotor.

Ambient air is drawn through a suction port into a space between the spinning rotors, which then force the air into the decreasing inter-lobe cavity until it reaches the discharge port at the opposite end of the rotor. Oil injected into the rotor housing lubricates the moving parts, removes heat and seals the clearances to prevent back slippage of the compressed air. The air/lubricant mixture discharges into the lubricant reservoir, which also serves as a separator that relies on directional and velocity changes. A coalescing-type filter reduces the final lubricant-to-air concentration to 3 ppm to 5 ppm.

**A two-stage double-acting type reciprocating compressor is the most energy efficient air compressor.**

Operating at too low a system pressure (65 psig to 75 psig) increases the velocity across the separator, which leads to greater lubricant carryover. To prevent carryover at startup and when system pressure is too low, a minimum-pressure device is used to maintain internal compressor pressure above the manufacturer's minimum.

The lubricant separated from the air stream circulates through a cooler and filter before being injected back into the air end. The temperature of the lubricant at the injection port needs to be high enough to prevent condensation from forming in the lubricant. Air-cooled units use a thermostatic valve to maintain an injection temperature of 150°F to 170°F. Water-cooled packages use a water-flow-regulating valve or thermostatic valve, or both.

**Variable-displacement or variable-speed capacity control can improve part-load efficiency.**

To remove condensate, rotary-screw packages use an aftercooler to reduce the discharge air temperature and a moisture separator with an automatic drain. Most industrial applications use air-cooled heat exchangers for the lubricant and compressed air. Water-cooled models use shell-and-tube exchangers.

Single-stage lubricated rotary-screw compressors are available in sizes from 5 hp to 600 hp and produce between 35 psig and 210 psig. Typical 100-psig specific power at full load is approximately 18 kW/100 cfm to 19 kW/100 cfm. Variable-displacement or variable-speed capacity control can improve part-load efficiency.

Two-stage compressors are available for operation up to 500 psig. They generally achieve better energy efficiency when used as base-load compressors. At 100 psig, specific power is approximately 16 kW/100 cfm to 18 kW/100 cfm. Variable-speed control can also make them suitable as trim compressors.

Non-lubricated rotary-screw air ends are similar to the lubricated variety, except for the lack of lubricant injection.

**TABLE 1: COMPARISON OF COMPRESSOR TYPES (100 HP TO 500 HP)**

| Category (**) | Two-stage double acting reciprocating | Lubricant-injected screw (single-stage) | Lubricant-injected screw (two-stage | Lubricant-free screw | Centrifugal |
|---|---|---|---|---|---|
| Size and weight | 3 | 1 | 2 | 2 | 2 |
| Complete package | 3 | 1 | 1 | 1-2 | 1-2 |
| Can be located close to points of use | 4 | 2-3 | 2-3 | 2-3 | 3 |
| Maintenance costs | 3 | 1 | 1 | 1 | 1 |
| Foundation requirements | 4 | 1 | 1 | 1 | 1-2 |
| Reduced capacity efficiency* | 1-2 | 1-4 | 1-4 | 1-3 | 1-3 |
| Lubricant free air – lube**/lube free | 4/1 | 2 | 2 | 1 | 1 |
| Lubricant carry-over - lube/lube free | 4/1 | 3 | 3 | 1 | 1 |
| Lubricant changes or make-up - lube/lube free | 4/1 | 3 | 3 | 1 | 1 |
| Equipment cost | 4 | 1 | 2 | 2 | 2 |
| Installation cost | 4 | 1 | 1 | 1 | 2 |
| Full Load Operating kW/100 cfm *** | 15-16 | 18-19 | 16-18 | 18-22 | 15-20 |

Key: 1 = Very good; 2 = Good; 3 = Fair; 4 = Poor.

These evaluations are very general and might not cover specific features of a given compressor type or manufacturer. They are intended to provide a general guide in how to compare compressors. It's important to evaluate each point in any comparison of quoted equipment. Other factors to be considered include Warranty and Service requirements.

* It's important to compare kW/100 cfm ratios at reduced capacity. Rotary compressors having variable displacement or variable-speed drive capacity controls might provide substantial energy savings when operating at reduced capacities.

** Any compressor requires appropriate downstream air quality treatment.

*** Specific power kW/100 cfm based upon full capacity at a discharge pressure of 100 psig and a full-load motor efficiency of 92%. Higher motor efficiencies are available.

Source: "Best Practices for Compressed Air Systems," a Compressed Air Challenge Publication (McCulloch and Scales 2007)

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Two types are available - dry and water-injected.

In the dry type, the male rotor doesn't drive the female rotor. Instead, timing gears, which are separated from the compression chamber by lubricant seals and air seals, maintain proper rotor clearances. The operating temperatures are around 350°F to 400°F because there's no fluid injection to help remove the heat of compression. Single-stage models can reach 50 psig. Most manufacturers use a two-stage design with an interstage cooler to produce pressures of 100 psig to 150 psig. Typical specific power at 100 psig is approximately 18 kW/100 cfm to 22 kW/100 cfm.

The water-injected, non-lubricated rotary-screw compressor can produce 100 psig, and more in a single stage because the water injected into the compression chamber seals clearances and removes the heat of compression. The water is removed by conventional means, cooled and recirculated. Automatic controls maintain the water level and quality.

## Other types

The sliding-vane rotary compressor uses a rotor with metallic or non-metallic vanes that slide in and out of the rotor in an offset housing. As the rotor spins, the vanes are forced outward against the cylinder walls. During part of the revolution, the contained volume between vanes decreases, and pressure rises as it nears the discharge port.

The rotary-scroll compressor is a relatively new design in sizes from fractional to 7.5 hp. Because of its small footprint, multiple compressors and drives can be mounted on a common base to provide higher capacities. One of two identical intermeshing spirals or scrolls is stationary and the other oscillates in relation to the stationary scroll. (Editor's note: go to www.airsquared.com/cd_overview.html to learn how the scrolls interact.) The spirals are mounted with 180° phase displacement to form air pockets with variable volumes. As the moving scroll orbits within the fixed scroll, the air pockets diminish in size as they scroll spirally towards the center. Most scroll manufacturers limit maximum discharge pressure to 115 psig.

## Dynamic compressors

A dynamic compressor uses high-speed impellers to impart velocity to the air. A centrifugal compressor is similar to a centrifugal pump, with ambient air entering at the center of a high-speed impeller that accelerates the air radially. This velocity head is translated to pressure head at the discharge volutes or diffusers.

The number of stages and impeller blade configuration determines the operating pressure and flow rate. Most industrial centrifugal air compressors use a multi-stage design. Backward-leaning impeller blades can achieve higher discharge pressures, but somewhat lower flow. Radial impeller blades might achieve greater flow, but at lower pressures. Your air demand and pressure variation limitations determine the best configuration.

Compressor manufacturers have controls to avoid the phenomenon of surge, where air flow reverses inside the compressor. As the compressor discharge pressure increases, flow decreases. Eventually, the discharge pressure can't overcome the system pressure and the air flow reverses, going from discharge to inlet. Most capacity controls automatically avoid this condition at low demand. Typically centrifugal compressor sizes start at approximately 150 hp and the specific power at 100 psig is approximately 15 kW/100 cfm to 20 kW/100 cfm.

## Which do you need?

When comparing compressor types for an application, it's important to consider the relevant factors and specific requirements (Table 1). For example, if the compressor is expected to operate fully loaded, efficiency at reduced capacity might be less important. However, if you anticipate wide swings in air demand, then reduced-capacity efficiency might be a more important factor.