Air and Gas Compressors

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Air and Gas Compressors

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Introduction

Compressors are widely used in construction, power plants, process industry, assembly plant, refineries, air conditioning, and refrigeration, to mention some of the applications. Compressors are power conversion machines, like pumps and electric motors. Compressed air systems are alternatives to hydraulic systems and electric operators in many applications. For these reasons, engineers, operations, and maintenance personnel should be aware of the applications and limitations of various types of compressors.

The same basic principles apply to all gas and vapor compressors, as well as air compressors.

Diagrams and illustrations are taken from the following sources:
Various issues of *Power* magazine, Mark's Standard handbook for Mechanical Engineers, sales brochures from Ingersol- Rand and Gardener-Denver, and *Process Engineer's guide to centrifugal compressors,* by Igor Karassik.

Air Compressors

Compressed air is free air that has been forced into a smaller volume and is at a pressure higher than atmospheric. Some of the terms and definitions used when discussing air compressors are as follows:

Absolute Pressure

The existing gage pressure plus the atmospheric pressure measured from absolute zero

Aftercooler

Device that dissipates heat caused by compression. This also effectively removes moisture down to the saturation temperature

Air Receiver

Tank into which compressed air is delivered and stored

Atmospheric pressure

Pressure at a specific altitude. At sea level this is 14.7 psia.

Brake Horsepower

Total power input required to compress and deliver a given quantity of air, including losses due to friction and other mechanical losses.

Capacity

SCFM - Standard cubic feet per minute. Delivered capacity in cubic feet of air measured at 68 deg F and 14.7 psia. (per ASME Power Test Code, but this standard may vary).

ICFM - Inlet cubic feet per minute. The capacity entering the inlet filter in CFM at actual inlet conditions.

ACFM - Actual cubic feet per minute. Delivered CFM as measured at actual conditions at the compressor suction downstream of the inlet filter. ACFM differs from ICFM primary by seal losses and to a much lesser extent by the lower pressure condition at the compressor suction due to pressure drop through the inlet filter. Since ACFM most realistically expresses the user's intent, it is recommended that compressors be specified in that unit.

Compression

The reduction of a specified volume, resulting in an increase in pressure

Compression Efficiency

Ratio of the theoretical to the actual required to compress air.

Compression Ratio

The ratio of the absolute discharge pressure to the absolute inlet pressure.

Compressor

A machine designed for compressing a gas or vapor from an initial pressure to a higher discharge pressure.

Design Pressure

Maximum continuous operating pressure. Also referred to as maximum working pressure.

Design Speed

Maximum continuous operating speed of a compressor.

Discharge Pressure

Total pressure at the discharge flange of the aftercooler.

Free Air

Air at atmospheric conditions. This may vary with altitude, barometric pressure and temperature.

Inlet Pressure

Total pressure at the inlet flange of the compressor or inlet filter

Inlet Temperature

Temperature at the inlet flange of the compressor or the inlet filter.

Load Factor

The ratio of the average actual compressor output to the maximum rated output for a defined period of time.

Moisture Separator

A devise designed to collect and remove moisture from the air during the cooling process

Pressure - Force per unit area

PSIG -	Pressure above local atmospheric pressure
PSIA -	Equal to gage pressure plus atmospheric pressure.
Pressure Drop -	Loss of pressure commonly due to friction.
Rated Discharge Pressure -	The highest continuous operating pressure to meet the specified conditions. It is lower than design pressure by 10% or 15 psig.

Slip

The internal leakage due to clearance.

Speed

The number of revolutions per minute

Unloaded Horsepower

The power that is consumed to overcome frictional losses when operated in an unloaded condition.

Vacuum

Pressure below atmospheric

Volumetric Efficiency

The ratio of the actual quantity of air delivered to the displacement of the compressor. (For reciprocating compressors).

Types of Compression

A brief review of the thermodynamics of gas compression is in order at this point. The perfect gas law expresses the equation of state for gases:

144pv = RT,

where p is the absolute pressure in psia,
v is the specific volume in cubic feet per pound,
R is a constant which depends on the nature of the gas, and T is the absolute temperature in deg F.

Specific heat is the amount of heat required to raise the temperature of one pound of gas 1 deg F. The specific heat of a gas has two distinct values, depending on whether the volume or the pressure remain constant during the addition of heat:

Cp = specific heat at constant pressure Cv = specific heat at constant volume

The factor or exponent k is the ratio between the specific heat at constant pressure to the specific heat at constant volume.

k=Cp/cv

The value of k for air is commonly taken as 1.4.

Adiabatic compression takes place when no heat is transferred into or out of the gas during compression. For adiabatic compression,

$$pv^k = \text{constant}$$

Adiabatic compression is further characterized by an *increase* in temperature during compression.

Isothermal compression occurs when the heat of compression is removed during compression, so that the temperature of the gas remains constant. The equation for isothermal compression is:

$$pv = \text{constant}$$

Polytropic compression is characterized by the equation:

$$pv^n = \text{constant}$$

When n=1, the polytropic compression is isothermal. When n=k, it is adiabatic. The slope of a pressure-volume curve is dependent on the value of n.

If a compressor is not cooled, and the compression takes place with 100% efficiency, it would be Adiabatic. However, the inefficiency of the compressor results in the addition of heat during compression. As a result, the actual compression of an uncooled compressor is polytropic, with a value of n greater than k.

Design Classifications

There are two broad classifications of compressors; positive displacement and dynamic.

Positive displacement compressors confine successive volumes of gas in an enclosed space where pressure increases as the volume of the enclosed space decreases. They can be thought of as constant volume-variable pressure machines; that is, they move a certain volume of gas with each stroke, and the pressure is that of the system into which they discharge.

With dynamic compressors, the mechanical action of rotating impellers impart pressure and velocity to the gas. They are constant pressure-variable volume machines.

Categories of Compressors

Compressors are generally categorized as: Reciprocating, Rotary, Centrifugal, and Axial. These are illustrated below in Figure 1. Figure 2 shows approximate ranges of capacity and pressure for each compressor category.

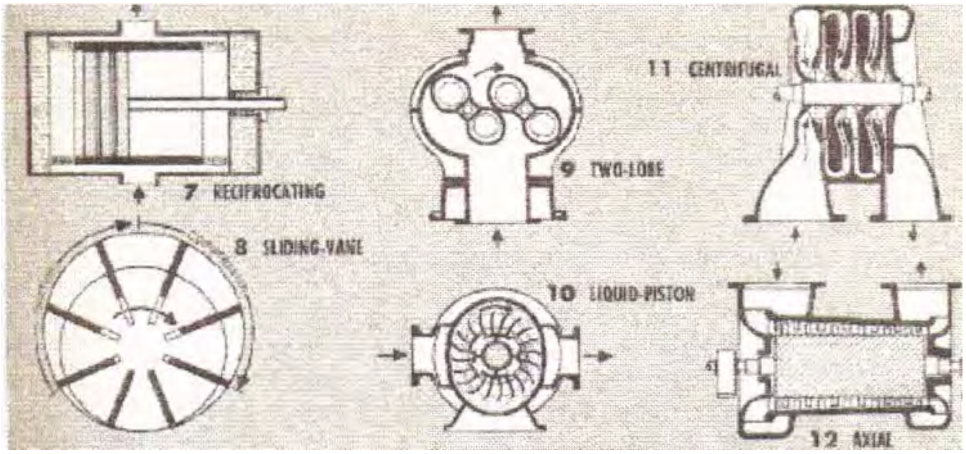

Figure 1 – Illustration of various types of compressors.

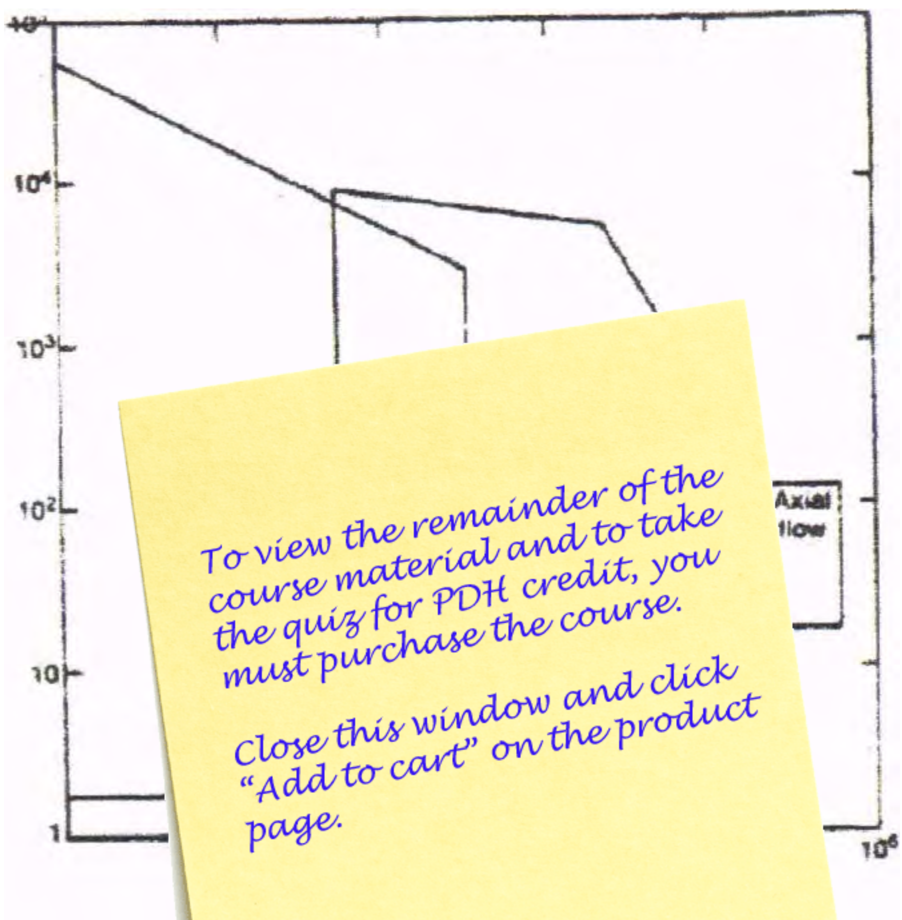

Figure 2 – Approximate ran… …ugal, and axial flow conditions.