Mechanical Equipment - Course 230.1

COMPRESSORS

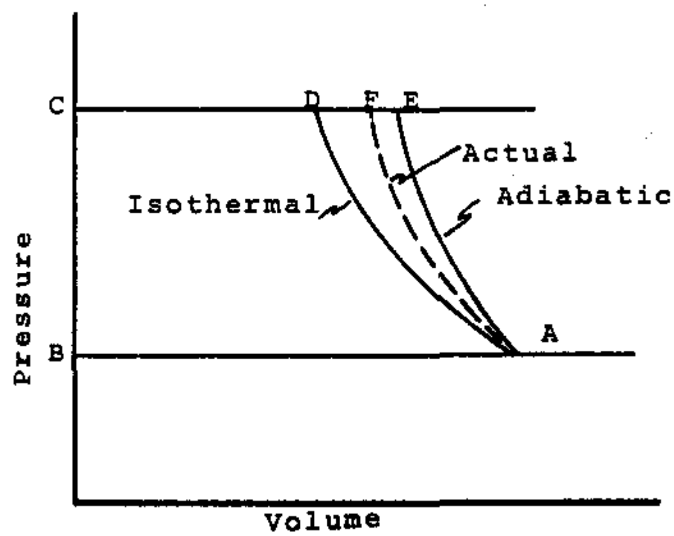
Various types of compressors were described in levels four and three mechanical equipment, the most important ones being reciprocating and rotary (liquid-ring) types.

Rather than discuss the physical characteristics of compressors in this lesson, the emphasis will be on the operational characteristics that operating people should be familiar with.

The Compression Process

In theory air may be compressed adiabatically (without the addition or removal of heat) or isothermally (at constant temperature). What this means is that the compression temperature of the air which has been adiabatically compressed will be much higher than the compression temperature of an isothermal compression. Since in most systems the compressed air is discharged into a receiver where it cools down to room temperature, that part of the compression energy which is subsequently lost by heat transfer through the receiver wall is wasted and represents increased power requirements at the compressor. The isothermal process which requires less work is therefore preferred and is approximated by cooling the air as it is compressed. Work is less because the air temperature is kept constant therefore the pressure is less as it is being compressed, therefore the piston doesn't have to do as much work. Keep in mind that this is an idealistic process.

Figure 1 illustrates a pressure volume diagram of the two compression processes. The dotted line AF is the actual compression curve, being closer to the adiabatic than to the isothermal. In a reciprocating machine it is not practical to have an isothermal process as it would have to occur over a long period of time. What is done however is that the cylinders are water jacketed, thus reducing the temperature somewhat. The area under each curve in Figure 1, isothermal (ADCBA), adiabatic (AECBA) and the actual (AFCBA) represents the work needed to compress the air. One can see that the adiabatic compression process requires more power. For example, an air system at 100 psig would result in 36 percent more power being required if it was an adiabatic compression process as opposed to an isothermal.



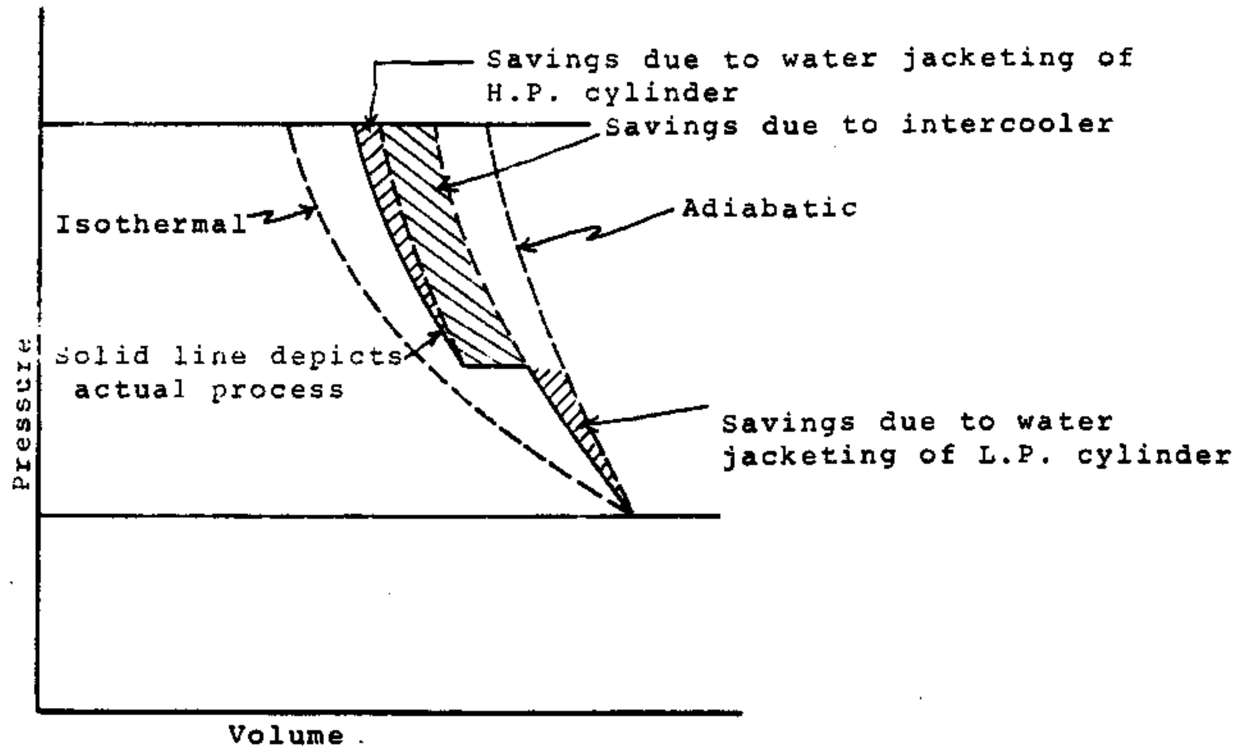
Compression Process

Figure 1

Multistage Compression

One practical method of minimizing the power losses arising from the heat of compression is to compress the air only part way to its final pressure, extract some of the heat then compress to the final pressure. This is done by compression in two or more stages. Cooling of the air between stages is then accomplished by passing it through an intercooler. The power caused by multistaging of positive displacement compressors depends upon several factors such as the ratio between the suction and discharge pressure, the cooling mediums used and the effectiveness of the intercooler.

Figure 2 illustrates the power savings effected by two-staging a water cooled reciprocating compressor and also indicates the saving due to water jacketting of the cylinders.



Multistage Compression Process

Figure 2

Compressor Capacity

Capacity of a compressor is the amount of air or gas measured at suction condition that is compressed and actually delivered through the discharge valves in one minute. The piston displacement is the volume swept by the piston in one minute.

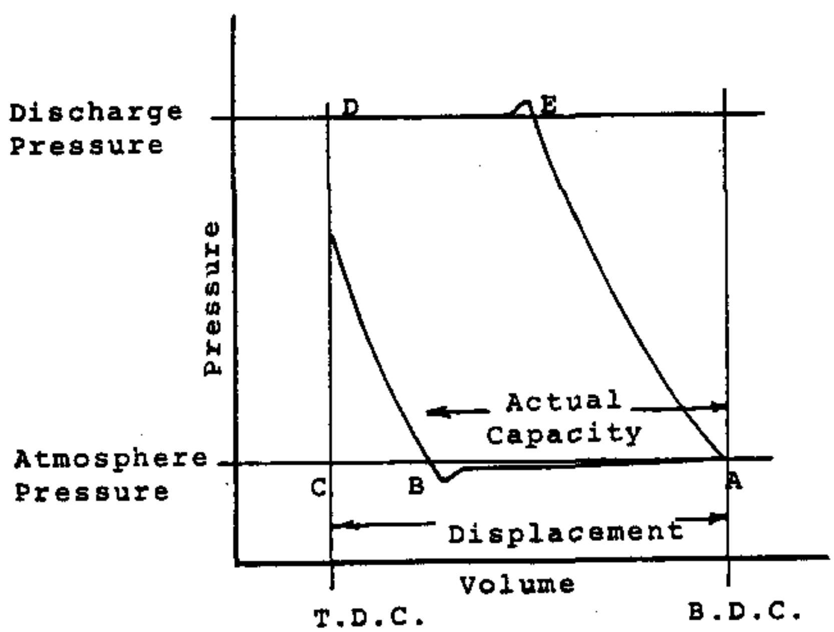
The actual delivered capacity divided by the piston displacement is referred to as the volumetric efficiency of the compressor and is expressed as a percentage. If air were an incompressible fluid, a compressor's capacity would be approximately equal to the piston displacement. However, since air expands and contracts with change in pressure and temperature, the actual capacity is always less than the piston displacement. This is also due to the necessary clearance between the piston and the cylinder head at the end of the stroke and to valve openings in the cylinder. At the end of the compression stroke, this clearance space is filled with air that has been compressed but not delivered through the discharge valve. On the return stroke this air will re-expand in the cylinder until the pressure is below the intake pressure which allows the intake valves to open.

Therefore, additional air is not admitted to the cylinder until the piston has travelled part way through its return or intake stroke. It can be seen in Figure 3 that suction valves open at point B and discharge at point E. It also becomes apparent that for a given cylinder volume, the greater the clearance, the later the suction valves will open and the lower the volumetric efficiency will be.

The volumetric efficiency involves every factor that causes a compressor to deliver less air that its piston displacement, and includes reduction in capacity due to preheating of air, slippage of air past piston rings and reversal of air flow through valves before closing.

Compression efficiency is the ratio of the horsepower required for a reversible adiabatic compression (theoretical process) to the horsepower actually expended in the cylinders, known as indicated horsepower. Indicated horsepower is the brake horsepower at the compressor shaft minus mechanical horsepower losses in the compressor.

Compressor efficiency is the ratio of the theoretical horsepower for a reversible adiabatic compression to the shaft horsepower input. It is equal to the product of the compression efficiency times the mechanical efficiency.



Effect of Cylinder Clearance on Volumetric Efficiency

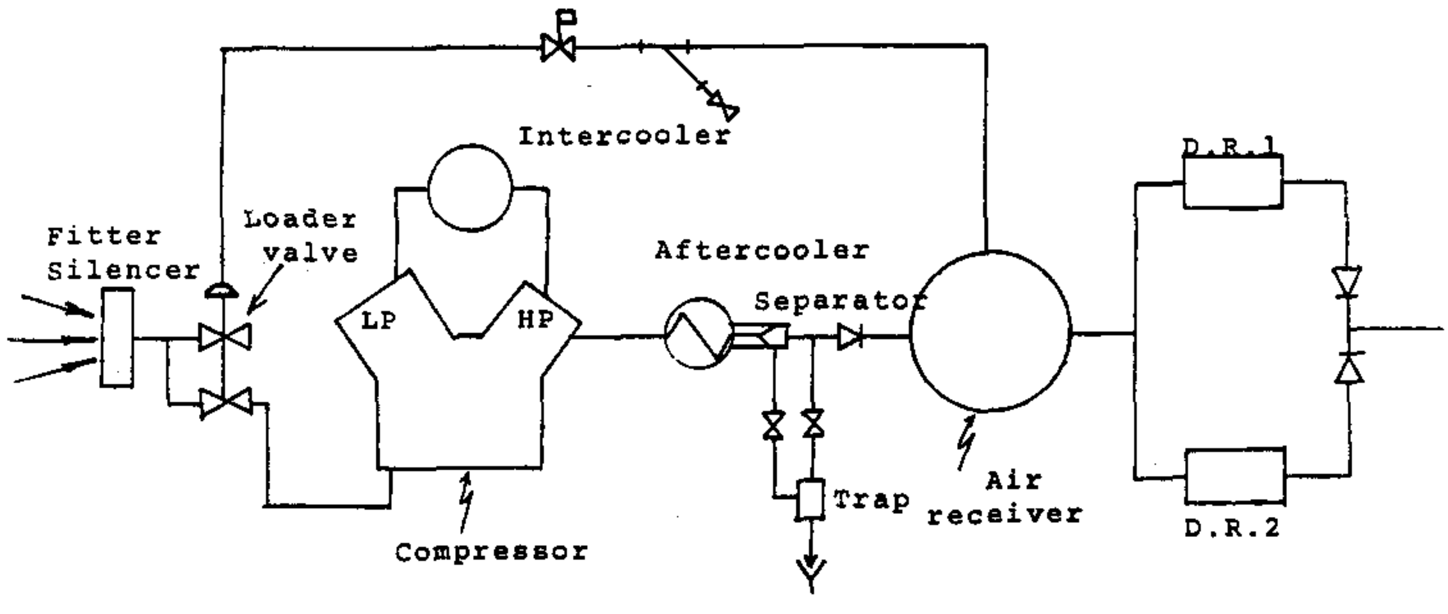
Figure 3

The Compressed Air System

In a simple air compressor system, air is drawn through a filter and the suction valves into the compressor where it is compressed. It is then forced through the discharge valves into an air receiver which acts as a storage tank or accumulator. This receiver assists in making regulation easier and aids the unloader in maintaining steady pressure. On most systems, compressor accessories such as intercoolers, aftercoolers, separators, traps, and dryers will be found. The functions of these accessories were discussed in Level 3 Mechanical Equipment so little more will be said here. However, it is worthwhile to look at typical systems one might find in the plants.

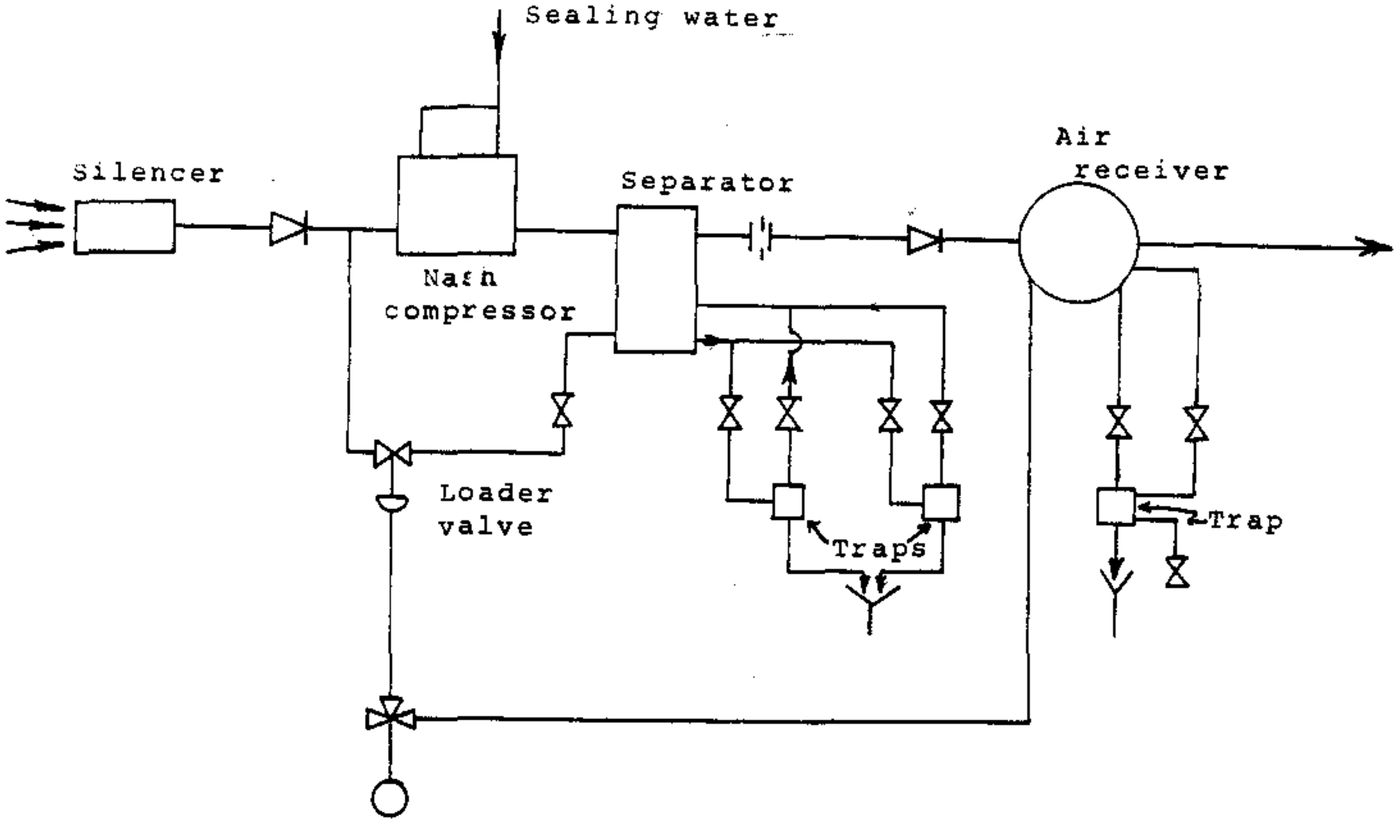
Figure 4 illustrates the high pressure instrument air system at Pickering G.S. This system consists of 6 Broomwade oil-free compressors of the two-stage double-acting type Vee apposed cylinders. The accessories as shown in Figure 4 consist of combination intake filter and silencer, intercooler, aftercooler, separators and dryers.

Figure 5 illustrates the breathing air system at Pickering G.S. This system provides moist oil and particulate-free air to breathing air stations in the reactor buildings. Two compressor units serve the entire station (enough to support 30 men in plastic suits). The two compressors are of rotary water seal type (Nash). The accessories with this system are an intake silencer, separator and receiver.



High Pressure Instrument Air Compressor

Figure 4



Breathing Air Compressor

Figure 5

As discussed in Level 3 there are various methods of controlling compressors and that at one plant the common method was the single step, unloading method. In the case of the H.P. Instrument air compressors (Figure 4) a pressure switch connected to the air supply header of the particular system controls the compressor. When the compressor is on auto position (compressor will run on demand of the appropriate pressure switch) and the pressure switch sensing a lag in pressure is closed, a solenoid valve on the low pressure service water supply opens to provide cooling water to the jackets and intercoolers and the compressor motor breaker closes starting the compressor. After a 10-second delay, the solenoid valve on the air supply to the pneumatic loader closes which results in the loading valve on the intake line to open, loading the compressor. When the demand decreases the cycle is reversed, the loader valve closed to unload the compressor. The motor continues to run for 10 minutes before the breaker opens, at which time the solenoid valve at the cooling water supply closes.

The breathing air compressor starts on demand of the appropriate pressure switch. The bypass solenoid valve opens to admit bypass water to maintain minimum flow to the compressor, and following a one-second delay, the sealing water solenoid valve opens to admit sealing water and the solenoid valve between the air receiver and the compressor loader opens to load the compressor. Decrease in demand results in the compressor being unloaded, bypass opens, and sealing water valve closes, after 10 minutes compressor stops.

Running Unloaded

Compressors, be they reciprocating or rotary should always be started unloaded. The most obvious reason for starting unloaded is to reduce the starting torque of the machine. On large reciprocating machines, the starting torques needed to overcome the static friction in the bearing etc, can be quite high, therefore starting loaded would only compound the problem.

Another reason for starting unloaded is to allow the working parts to become thoroughly covered with a lubricant, and allowing time for adequate cooling water flow to be established.

Common Compressor Troubles

Compressor valves are a very common source of trouble. Because of the nature of their design, that they are free to move vertically within a certain clearance, they tend to wear and the clearance increases, thus greater travel which results in even greater wear and noise, eventually leading to leakage.

What are the symptoms of compressor valve problems? The quickest way to spot valve trouble in a two-stage compressor is to look at the intercooler pressure. This pressure varies with the size of the cylinder and the intake pressure; it is usually 26 to 30 psi for a machine with atmospheric intake and 100 psi discharge. High intercooler pressure means trouble in the high pressure cylinders resulting from leaky intake or discharge valves, leakage caused by rings in poor condition, or a badly worn cylinder bore. Most compressor valves have slight leakage, but if you hear a continuous blow, it indicates excessive leakage.

If intercooler pressure is below normal, the trouble is generally in the low pressure cylinder.

The chart in Table 1 identifies some of the troubles that occur with compressors and also points out the possible causes.

Explosions have been known to occur in compressed air systems. In some cases explosions have occurred because of inadequate lubrication. If the cylinder is oil lubricated, it is important to choose an oil with the right viscosity and flash point. If the oil is very sluggish, it collects and mixes with dirt and forms hard deposit, mostly carbon which clogs piston rings and valves.

These carbon deposits, in quantity, plus moisture and heat are gas producers. The principle gas being formed is CO_2 which ignites at 1204°F. Thus an explosive mixture needs only ignition to produce an explosion. A leaky discharge valve would allow some of the hot compressed air to re-enter the cylinder to be re-compressed and temperature increased. This in time could supply the ignition temperature. Therefore it is most important that:

(a) the correct oil is used (check manufacturer's specifications)

(b) that the valves are kept in good condition.

Explosions can occur when piping to the safety valve and unloader become frozen due to low temperatures and an accumulation of moisture in the lines.

Explosions can also occur due to dirty intercoolers, defective unloading and failure of cooling water supply.

Corrosion, cracks or erosion in an air receiver can cause ruptures. Metal wastage can be kept to a minimum by ensuring that moisture is never allowed to accumulate and by periodic inspection. Excessive water in the lines could also result in slugs of water travelling through the pipe which, on closure of a valve, could result in water hammer with possibility of a rupture occurring.

To ensure reliable operation of a compressor it should be inspected at definite intervals. Suction and discharge valves should be removed and examined periodically. Intercoolers should be cleaned and lines checked for leaks. Crankshaft, crossheads and main bearings should be inspected regularly. In other words preventive maintenance should be practiced.

SYMPTOMS	POSSIBLE CAUSE
Noise or knocking	Loose or burned out bearings, loose valve or unloader, loose flywheel, motor rotor shunting back and forth from unlevel mounting or belt misalignment.
Squeal	Motor or compressor bearings tight, belts slipping, lack of oil, leaking gasket or joint.
Intercooler safety valve blows while running unloaded	Broken or leaking hp discharge valve, or suction unloader, defective or stuck lp unloader, blown gasket.
Intercooler valve blows while running loaded	Broken or leaking hp discharge or suction valve, defective hp unloader held in unloaded position, blown gasket.
Sudden capacity drop	Bad leak in air operated equipment or air lines, discharge piping clogged, suction filters blocked, broken or badly leaking valves, blown gaskets, leak in intercooler.
Gradual capacity drop	Accumulation of small leaks in air lines, poorly seating valves, restricted suction filters, worn rings or cylinders.
Receiver safety valve blows	Defective pop valve, defective pressure switch or pilot valve, leak in control line, inoperative suction unloaders.
Unit blows fuses	Fuses too small, low voltage, pressure switch differential setting too close, unit starting against full load, electrical trouble, motor or compressor tight.
Unit will not start	Blown fuse or tripped overload relay, motor or electrical trouble, defective pressure switch, motor or compressor binding.
Roughness and vibration	Base too light, improper shimming under unit, foundation bolts loose, unbalance from one cylinder not pumping.
Excessive oil consumption	Oil level too high, oil viscosity too light, too high oil pressure (if forcefeed lubricated), worn rings and cylinders

Troubleshooting Chart

Table 1

ASSIGNMENT

1. Explain the difference between adiabatic and isothermal compression.

2. What compression process actually occurs in a compressor?

3. What is the advantage of having a two-stage compressor over a single stage compressor?

4. Define:

   (a) Volumetric efficiency
   (b) Compressor efficiency
   (c) Compressor capacity.

5. For what reasons are compressors started unloaded?

6. What are the symptoms of leaky compressor valves?

7. Give two reasons why explosions might occur in a compressed air system.