Objectives

After completing this chapter, you will be able to:

■ Explain the purpose of compressors in the process industries.
■ Identify common compressor types and describe the operating principle of each.
■ Identify compressor components and explain the purpose of each.
■ Describe the theory of operation for a compressor.
■ Identify potential problems associated with compressors.
■ Describe safety and environmental concerns associated with compressors.
■ Identify typical procedures associated with compressors.
■ Describe the process technician’s role in compressor operation and maintenance.
■ Explain the purpose of a compressor performance curve and demonstrate its use.
Key Terms

Antisurge — automatic control instrumentation designed to prevent compressors from operating at or near pressure and flow conditions that result in surge.

Antisurge protection — protection that prevents damage to the compressor. Antisurge protection is calculated and designed by engineers to ensure proper and safe compressor operation.

Axial compressor — a dynamic compressor that contains a rotor with contoured blades followed by a stationary set of blades (stator). In this type of compressor, the flow of gas is axial (in a straight line along the shaft).

Centrifugal compressor — a dynamic compressor in which the gas flows from the inlet located near the suction eye to the outer tip of the impeller blade.

Cylinder — a cylindrical chamber in a positive displacement compressor in which a piston compresses gas and then expels the gas.

Demister — a device that promotes separation of liquids from gases.

Dry carbon ring — an easy-to-replace, low-leakage type of seal consisting of a series of carbon rings that can be arranged with a buffer gas to prevent the process gas from escaping.

Dynamic compressor — nonpositive displacement compressor that uses centrifugal or axial force to accelerate and convert the velocity of the gas to pressure. Dynamic compressors are classified as either centrifugal or axial.

Interlock — a type of hardware or software that does not allow an action to occur unless certain conditions are met.

Labyrinth seal — a shaft seal designed to restrict flow by requiring the fluid to pass through a series of ridges and intricate paths.

Liquid buffered seal — a close fitting bushing in which oil and water are injected in order to seal the process from the atmosphere.

Liquid ring compressor — a rotary compressor that uses an impeller with vanes to transmit centrifugal force into a sealing fluid, such as water, driving it against the wall of a cylindrical casing.

Lubrication system — a system that circulates and cools sealing and lubricating oils.

Multistage compressor — device designed to compress the gas multiple times by delivering the discharge from one stage to the suction inlet of another stage.

Positive displacement compressor — device that may use screws, sliding vanes, lobes, gears, or a piston to deliver a set volume of gas with each stroke.

Reciprocating compressor — a positive displacement compressor that uses the inward stroke of a piston to draw (intake) gas into a chamber and then uses an outward stroke to positively displace (discharge) the gas.

Rotary compressor — a positive displacement compressor that uses a rotating motion to pressurize and move the gas through the device.

Seal system — devices designed to prevent the process gas from leaking from the compressor shaft.

Separator — a device used to physically separate two or more components from a mixture.

Single-stage compressor — device designed to compress the gas a single time before discharging the gas.

Surging — the intermittent flow of pressure through a compressor that occurs when the discharge pressure is too high, resulting in flow reversal within a compressor.

Introduction

Compressors are an important part of the process industries. Compressors increase the pressure of gases and vapors so they can be used in applications that require higher pressures. For example, they can be used in a wide variety of applications like compressing gases such as carbon dioxide, nitrogen, and light hydrocarbons, or providing the compressed air required to operate instruments or equipment.
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The two most common compressor types are positive displacement and dynamic. Positive displacement compressors use pistons, lobes, screws, or vanes to reduce a fixed volume of gas through compression and deliver a constant volume. Dynamic compressors use impellers or blades to accelerate a gas and then convert that velocity into pressure. Dynamic compressors are more commonly used than positive displacement compressors because they are less expensive, more efficient, have a larger capacity, and require less maintenance.

All compressors require a drive mechanism such as an electric motor or turbine to operate, and all are rated according to their discharge capacity and flow rate. Most compressors require auxiliary components for cooling, lubrication, filtering, instrumentation, and control. Some compressors require a gearbox between the driver and compressor to increase the speed of the compressor.

Selection of Compressors

A compressor is a mechanical device used to increase the pressure of a gas or vapor. The type of compressor that is used for a particular application depends on several factors. The factors include the type of gas being compressed, flow rates which are expressed as cubic feet per minute (cfm) or meters cubed/second (m³/s), and discharge pressure which is expressed as pounds per square inch (psi) or Kilopascals (kPa).

Types of Compressors

Several types of compressors are used in the process industries (see Figure 7-1). The most common, however, are positive displacement and dynamic. Both of these types of compressors can be single- or multistage.

DYNAMIC COMPRESSORS

Dynamic compressors are nonpositive displacement compressors that use centrifugal or axial force to accelerate and convert the velocity of the gas to pressure (as opposed to positive displacement compressors, which use a piston, lobe, or screw to compress gas).

CENTRIFUGAL COMPRESSORS

Centrifugal compressors are a dynamic type compressor in which the gas flows from the inlet located near the suction eye to the outer tip of the impeller blade. In a centrifugal compressor, the gas enters at the low pressure end and is forced through the impellers by the rotation of the shaft. As the gas moves from the center of the impeller toward the outer tip, the velocity is greatly increased. When the gas leaves the impeller and enters the volute, the velocity is converted to pressure due to the slowing down of the molecules.

Centrifugal compressors are used throughout industry because they have few moving parts, are very energy efficient, and provide higher flows than similarly sized reciprocating compressors. Centrifugal compressors are also popular because their seals allow them to operate nearly oil-free, and they have a very high reliability. They are also effective in toxic gas service when the proper seals are used, and they can compress high
volumes at low pressures. The primary drawback is that centrifugal compressors cannot achieve the high compression ratio of reciprocating compressors without multiple stages. Figure 7-2 shows an example of a centrifugal compressor.

Centrifugal compressors are more suited for continuous-duty applications such as ventilation fans, air movers, cooling units, and other uses that require high volume but relatively low pressures.

![Process Variable Relationships](image)

In a centrifugal compressor, there is a direct relationship between impeller speed, velocity, pressure, and flow. As the impeller speed increases, velocity increases. As velocity increases, pressure increases. As pressure increases, flow increases.

Centrifugal compressors may be single-stage or multistage, and the stages may be contained in one casing or several different casings. (Note: Multistage compressors are discussed in more detail later on in this chapter.) Figure 7-3 shows a cutaway of a single-stage centrifugal compressor.

![FIGURE 7-3 Cutaway of a Single-Stage Centrifugal Compressor](image)

The main components of a centrifugal compressor include bearings, a housing (casing), an impeller, an inlet and outlet, a shaft, shaft couplings, and shaft seals. Figure 7-4 shows another example of a centrifugal compressor and its components.
AXIAL COMPRESSORS

Axial compressors are dynamic-type compressors in which the flow of gas is axial (in a straight line along the shaft). A typical axial compressor has a rotor that looks like a fan with contoured blades followed by a stationary set of blades, called a stator.

Rotor blades attached to the shaft spin and send the gas over stator blades, which are attached to the internal walls of the compressor casing. These blades decrease in size as the casing size decreases. Rotation of the shaft and its attached rotor blades causes flow to be directed axially along the shaft, building higher pressure toward the discharge of the unit.

Each pair of rotors and stators is referred to as a stage. Most axial compressors have a number of such stages placed in a row along a common power shaft in the center. Figure 7-5 shows an example of an axial compressor with rotor and stator blades.

The stator blades are required to ensure efficiency. Without these stator blades, the gas would rotate with the rotor blades, resulting in a large drop in efficiency. Each stage is smaller than the last because the volume of air is reduced by the compression of the preceding stage. Axial compressors therefore generally have a conical shape, widest at the inlet. Compressors typically have between nine and fifteen stages. The main components of an axial compressor include the housing (casing), inlet and outlet, rotor and stator blades, shaft, and inlet guide vanes.

Axial compressors are very efficient compressors; however, they are not as frequently used in industry as reciprocating and centrifugal compressors because of the high initial and maintenance costs. Regardless of the type, all compressors are rated by dividing the discharge pressure by the suction pressure. This is called the compression ratio.

Calculating Compression Ratio

\[ \text{Discharge Pressure} / \text{Suction Pressure} = \text{Compression Ratio} \]

Example: A compressor with a suction pressure of 400 PSIG and a discharge pressure of 2000 PSIG has a compression ratio of 5.0.

\[ 2000 \text{ PSIG} / 400 \text{ PSIG} = 5.0 \text{ Compression Ratio} \]
Positive Displacement Compressors

Positive displacement compressors (see Figure 7-6) are devices that may use screws, sliding vanes, lobes, gears, or a piston to deliver a set volume of gas with each stroke. Positive displacement compressors work by trapping a set amount of gas and forcing it into a smaller volume. The two main types of displacement compressors are reciprocating and rotary, with reciprocating being the most commonly used.

RECIPROCATING COMPRESSORS

The term reciprocating refers to the back-and-forth movement of the compression device (a piston or other device is positioned in a cylinder). Reciprocating compressors use the inward stroke of a piston to draw (intake) gas into a chamber and then use an outward stroke to positively displace (discharge) the gas. A common application for the reciprocating compressor is in an instrument air system.

In a reciprocating compressor, a piston receives force from a power medium (e.g., a drive shaft) and then transfers that power to the gas being compressed. In a piston-type reciprocating compressor, the gas is trapped between the piston and the cylinder head and then compressed. The cylinder is the cylindrical chamber in which a piston...
Compresses gas and from which gas is expelled. Figure 7-7 displays a cutaway picture of a reciprocating compressor.

In theory, reciprocating compressors are more efficient than centrifugal compressors. They are also cheaper to purchase and install than a centrifugal compressor. However, problems with pulsation and mechanical reliability cause these compressors to be less desirable than centrifugal compressors for most industrial applications. More potential problems associated with compressors are discussed later in this chapter.

Another type of reciprocating compressor is the diaphragm compressor. Diaphragm compressors can be used for a wide range of pressures and flows (very low to very high). In a diaphragm compressor, a fluid is forced against one side of the diaphragm, which flexes the diaphragm into the free space above it, thereby compressing and pressurizing the gas on the other side of the diaphragm. Figure 7-8 displays the basic design of a diaphragm compressor with labels.

Because the process gas in a diaphragm compressor does not come in contact with the fluid, process purity is assured. This is useful in laboratory or medical applications.
Piston Compressors

In piston-type reciprocating compressors, the pistons connect to a crankshaft that converts the rotational motion of a driver to the reciprocating motion of the piston. The piston’s motion pulls gas into a cylinder from the suction line, and then displaces it from the cylinder through the discharge line. Check valves (compression valves) on the suction and discharge allow the flow of the gas in one direction only. Figure 7-9 displays an actual cutaway of a piston-type reciprocating compressor. Figure 7-10 displays the major components of the compressor, which include a cylinder, inlet, outlet, inlet and outlet valves, housing, piston, piston rings, and shaft.

Piston-type compressors can be single- or double-acting. Double-acting compressors trap the gas during the suction stroke on one side of the piston, while compressing the gas on the discharge side of the piston at the same time. Figure 7-11 shows an example of both double- and single-acting compressors.

Rotary Compressors

Rotary compressors (shown in Figure 7-12) move gases by rotating a set of screws, lobes, or vanes. As these screws, lobes, or vanes rotate, gas is drawn into the compressor by negative pressure on one side and forced out of the compressor (discharged) through positive pressure on the other. Rotary compressors do not require a constant suction pressure to produce discharge pressure.
In other positive displacement compressors, lobes or gears displace the gas from a cavity created between the rotors and the compressor body. If the suction pressure is lower than the original compressor design capacity, the compressor will still work, but with lower-than-design capacity results. Because of this, these compressors are appropriate for processes in which the inlet pressures change over a wider range than centrifugal compressors can operate. Figure 7-13 shows three diagrams of rotary compressors. Figure 7-14 is an example of a screw compressor, and Figure 7-15 shows a lobe compressor.
Another kind of rotary compressor is a liquid ring compressor. A liquid ring compressor uses an eccentric impeller with vanes to transmit centrifugal force to a sealing fluid (e.g., water), driving it against the wall of a cylindrical casing. The liquid moves in and out of the vanes as the rotor turns. The liquid is used in place of a piston that compresses the gas without friction. Gas is drawn into the vane cavities and is expelled against the discharge pressure. Figure 7-16 shows an example of a liquid ring compressor.

The sealing fluid in a recycling system is replenished and cooled in an external reservoir. In a once-through cooling system, the sealing fluid is removed and replaced with fresh fluid.

A sliding vane compressor employs a rotor filled with blades that move freely in and out of the longitudinal slots in the rotor. The blades are forced out against the housing wall by centrifugal force, creating individual cells of gas that are compressed as the eccentrically mounted rotor turns. As the vanes approach the discharge port, they have reduced the chamber volume and compressed the gas, which is discharged at a pressure much higher than when it entered the compressor. Figure 7-17 shows an example of a sliding vane compressor.
Operating Principles

Compressors are used in a variety of industries and have many uses. They are designed and selected based on inlet pressure, gas flow, and final discharge pressure. Inside a compressor, mechanical components compress gases and vapors for use in a process system.

When selecting compressors, unit designers must take into consideration the capability of the compressor and the process conditions. The difference between the operations of compressors and the operation of pumps is the physical properties of gases and liquids. While they operate similarly, compressors cannot move liquids, and pumps cannot move gases. Positive displacement compressors are called displacement compressors because they trap a volume of gas into a chamber, compress it with a device such as a piston or rotor, and then force (displace) it through the discharge valve and into the discharge piping.

SINGLE-STAGE VERSUS MULTISTAGE COMPRESSORS

Single-stage compressors, which compress the entering gas one time, are generally designed for high gas flow rates and low discharge pressures.

Multistage compressors compress the gas multiple times by delivering the discharge from one stage to the suction inlet of another stage. Figure 7-18 shows an example of a multistage compressor. Figure 7-19 is an example of a multistage compressor with parts labeled.

Multistage compressors raise the gas to the desired pressure in steps or stages (chambers), cooling the gas between each stage. Between stages, the gas from a multistage compressor is cooled. During this cooling phase, liquids are frequently condensed.

FIGURE 7-18 Functional Diagram of a Multi-Stage Compressor

FIGURE 7-19 Multi-Stage Compressor with Labels
These liquids must be removed and not allowed to enter the compressor because liquids are noncompressible and could cause severe damage to the compressor.

Frequently in the process industries, the desired discharge pressure is more than ten times that of the inlet pressure. In cases such as these, a single-stage compressor cannot be used because of the high temperature generated, so a multistage reciprocating compressor with cooling after each stage is required.

In all compressors, the temperature of a gas increases as it is compressed. The amount of temperature increase is a function of the gas and the compression ratio (the ratio of the discharge pressure to inlet pressure in absolute pressure units). To avoid extremely high discharge temperatures, the compression ratio in compressors is usually limited to around 3:1 or 5:1.

Multistage compressors can be centrifugal, axial, or reciprocating piston compressors. Large, multistage compressors can be extremely complex, with many subsystems including bearing oil systems, seal oil systems, and extensive vibration detection systems.

**Centrifugal Compressor Performance Curve**

The design and selection of compressors involve several factors, including physical property data and a description of the process gas. When a compressor is selected, a performance curve is provided with the compressor so engineers can track the operational performance of the equipment.

Centrifugal compressors must operate on a performance curve just like centrifugal pumps. A typical curve is shown in Figure 7-20. The vertical axis is feet of head (\(H_p\)), which means feet of head for a gas being compressed. The horizontal axis is actual cubic feet per minute (cfm) of gas compressed. The compressor operates on its specified curve unless a problem occurs (e.g., it malfunctions, is mechanically defective, or is compressing dirty gas).

![Surge point](figure720.png)

For all compressor performance curves, as the compressor discharge pressure increases, the \(H_p\) increases and the volume of gas compressed (ACFM) decreases. When the volume of gas compressed drops below a critical flow, then the compressor is backed up to its surge point.

Data such as flow rate, temperature, and pressure conditions are collected on compressors. These data are provided to engineers, who analyze the data on a daily basis to ensure that the compressor is operating at the designed output. If the data begins to show abnormalities, the compressor may be assigned to maintenance for repair. It is important to keep compressors properly maintained to prevent compressor failure, reduce maintenance costs, increase equipment life, and prevent process upset.

**Associated Utilities and Auxiliary Equipment**

Compressors are part of process systems. As a result, a wide variety of auxiliary equipment is needed to enhance equipment productivity. Auxiliary equipment associated with compressors includes lubrication systems, seal systems, antisurge protection, intercooler, after-cooler, heat exchangers, separators, and surge bottles.
LUBRICATION SYSTEM

Normally, when gases are compressed, the bearings and seals become hotter. Some of the heat is transmitted to the seals and bearings. This heat is removed by cooling the lubricants.

Lubrication systems circulate and cool sealing and lubricating oils. In some applications, the sealing and lubricating oils are the same. Figure 7-21 shows an example of a lubricant cooling system.

SEAL SYSTEM

Seal systems (shown in Figure 7-22) prevent process gases from leaking to the atmosphere where the compressor shaft exits the casing. Compressor shaft seals can include labyrinth seals, liquid buffered seals, and dry carbon rings.

A labyrinth seal (shown in Figure 7-23) is designed to restrict flow by requiring the fluid to pass through a series of ridges and intricate paths. A purge of an inert gas (barrier gas) is provided at an intermediate injection point on the seal to prevent external leakage of process gas.

A liquid buffered seal is a close-fitting bushing in which a liquid is injected in order to seal the process from the atmosphere.

Dry carbon rings (see Figure 7-24) are a low-leakage type of seal that can be arranged with a buffer gas that separates the process gas from the atmosphere.
Packing is used in reciprocating compressors to prevent leakage where the piston rod passes through the crank-end of the cylinder. Typical packing consists of rings of fibrous material fitted around the piston rod (contained in a stuffing box) and compressed by an adjustable gland. Friction between the packing and piston rod is reduced by the injection of lubricating oil into the stuffing box.

**ANTISURGE DEVICES**

When the flow rate on a compressor is low enough to match the minimum critical flow rate of the maximum flow stage, a recycle valve located downstream of the discharge opens and spills flow back into the suction. This avoids reverse flow through the compressor.

Some compressor installations use variable speed motors to control the discharge pressure. Steam turbine drives use steam flow to control the compressor speed. Larger machines have antisurge instruments that prevent surging because surging can cause bearing and shaft failures and the destruction of the machinery. **Surging** is the intermittent flow of pressure through a compressor that occurs when a stage fails to pump. Surging results when the compressor falls into an unstable condition. Antisurge devices are used to prevent surging.

In antisurge devices (shown in Figure 7-25), the pressure differential across the machine increases when flow is reduced by throttling in either the suction or discharge. When this differential pressure reaches the point where the machine can no longer maintain it, the compressor loses suction. When this happens, the check valve on the discharge quickly closes as discharge flow stops and the discharge pressure before the discharge check valve flows backward inside the compressor toward the suction. This causes the pressure differential between the suction and discharge to equalize, so the compressor once again begins moving the gas. The discharge pressure again reaches the critical value, and the process repeats. This is called surging. Surging is discussed later in this chapter. If allowed to continue surging, the compressor can experience severe damage.

Because surging is so detrimental to equipment, centrifugal compressors are equipped with antisurge protection to prevent damage. This antisurge protection is
designed by engineers to ensure proper and safe compressor operation. Compressors are also designed with automatic shutdown initiators (emergency shutdown switches) to prevent damage to the compressor during abnormal conditions.

One form of antisurge device is a minimum-flow recycle. In this type of device, the compressor discharge flow is measured. When a flow rate is low enough to match the minimum critical flow rate of the maximum flow stage, a recycle valve located downstream of the discharge opens and spills flow back to the suction. This avoids surging of the compressor.

Another form of antisurge protection is a variable speed driver, which controls the discharge pressure. When steam turbine drives are used, steam flow to the turbine is used to control the compressor speed.

COOLERS

Coolers are used to cool gases at various stages in the process. Figure 7-26 shows a functional diagram of a multistage compressor with precooler, intercooler, and after-cooler.

Precoolers are used to cool the gas before it enters a compressor. Intercoolers are used in multistage compressors to cool gas between each stage of compression. In other words, intercoolers cool the discharge of the first stage before it enters the suction to the second stage. Interstage coolers prevent the overheating of the process gas and equipment. After-coolers cool the gas downstream from the last stage once the compression cycle is complete.

SEPARATORS

Separators physically separate two or more components from a mixture and collect excess moisture vapor from the compressor application. Examples of separators include demisters and desiccant dryers.

A demister (shown in Figure 7-27) is a device that promotes separation of liquids from gases. Demisters contain a storage area designed to collect liquid from gas and separate it from the gas in the system to prevent damage.

Desiccant dryers (shown in Figure 7-28) use chemicals (desiccants) to remove or absorb moisture. Desiccant dryers are usually used in tandem (one in service and one
out of service). When the desiccant in one dryer becomes saturated, the dryer is taken out of service and hot gas is sent through the dryer bed to dry it out. Because they are more efficient than demisters, desiccant dryers are often used for sensitive applications like instrument air.

**Potential Problems**

The role of the process technician is vital to the production and safety of any process unit. The responsibility of the process technician is to have a clear understanding of the process in which he or she is working and always maintain a keen awareness of the surroundings. Process technicians must have a basic understanding of troubleshooting techniques to prevent damage to a compressor in a time of malfunction.

To prevent potential problems, compressors are equipped with various safety protection devices. Problems that can arise include overpressurization, overheating, surging, leaks, loss of lubrication, vibration, interlock systems, loss of capacity, motor overload, and governor malfunction. Process technicians must be able to recognize these conditions and respond appropriately.

**OVERPRESSURIZATION**

Compressor overpressurization can occur if the valves associated with the compressor are incorrectly closed or blocked. Consider the example in Figure 7-29. In this example, valve A is open and valve B is closed. This means the gas is flowing through valve A, and then back into the tank. If a technician were to redirect the flow of the gas through valve B, he or she must open valve B before closing valve A. If both valves are closed at the same time, shown in Figure 7-30, the gas has no place to go. This is referred to as dead heading. The result is backflow pressure that can damage the compressor or cause serious personal injury.
OVERHEATING
Overheating is when excess heat is generated. Excessive amounts of overheating can be very detrimental to processes and equipment. Compressor overheating can be caused by a loss of cooling, improper lubrication, or valve malfunction. Compressor overheating is often caused by improper lubrication. Without lubrication, bearings fail and equipment surfaces rub together. As these surfaces rub against one another, friction is produced and heat is generated. Process technicians should always monitor compressors for unusual sounds and excessive heat because operating compressors under these conditions can lead to permanent equipment damage and/or personal injury (e.g., burns).

SURGING
Another operational hazard is surging (explained previously in the antisurge device section). Surging, which is typically associated with centrifugal compressors, is a temporary loss of flow to one or more impellers or stages of the compressor. This loss of flow causes the compressor speed to fluctuate wildly and vibration to increase dramatically. As discharge flow drops below acceptable levels, antisurge protection activates to ensure there is no reverse flow through the compressor.

Surging can result when the compressor throughput and head fall into an unstable region of the head/capacity curve. This can cause many problems, including bearing failures, shaft failures, and destruction of the machinery.

A compressor's surge point is a variable function of gas gravity, system pressure, machine speed, compressor differential pressure, and compressor rate. Surging can occur at a low gas gravity, system pressure, and compressor rate or at a high speed and high differential pressure.

Surge prevention is critical to prevent damage, so process technicians should adjust the variables listed above (to the extent they have control of them) in a direction away from that which leads to surging.

SEAL OIL PROBLEMS
Seal oil problems can cause loss of process gases. Examples of seal oil problems include dirty hydraulic oil (which causes plugging of passages), vibration or cracking of internal oil tubing, and internal seal failure.

LEAKS
Process technicians should always check compressor cylinders or housing for leaks because leaks can introduce harmful or hazardous substances into the atmosphere and
create process problems. Excessive flows of barrier gas purges indicate seal leakage into or out of the process. Monitoring process gas leakage to the atmosphere allows technicians to determine the condition of the atmospheric seal. Figure 7-31 shows a compressor with an oil leak.

Compressors may be damaged if liquid, which is noncompressible, is inadvertently introduced into compression chambers or between compressor components. Because of this, compressors employ a liquid removal step for gases that may condense inside the compressor, and interstage liquid removal points are provided to prevent the liquid from causing compressor damage.

When equipment is operating under vacuum conditions, monitoring process fluid for oxygen is necessary to determine whether air is leaking into the compressor.

LUBRICATION FLUID CONTAMINATION

Lubrication fluids can be contaminated with materials, such as water, process fluids, and metal particulates. As the contamination increases, the cooling and lubricating capacity of the fluid decreases. Because of this, frequent monitoring of the seal and bearing lubricants is necessary to avoid problems. Monitoring may include frequent inspection of bearing areas with temperature probes to prevent serious heat damage. It may also include a check for low flow or pressure of lubricant to the bearings.

VIBRATION

It is important to recognize excessive vibration because of the potential problems vibration can cause. Common causes of vibration include impeller imbalance or damage, worn bearings, piping pulsation, a misaligned shaft, damaged couplings, and bearing or seal damage. In most cases, vibration monitoring devices are attached to equipment to give an alarm when vibration becomes excessive. However, some installations depend on process technicians to detect vibration.

To prevent major damage, larger compressors are typically equipped with interlock systems that monitor and record the vibration of each compressor. These interlocks are designed to shut the compressor down if high vibration or excessive shaft movement is detected.

INTERLOCK SYSTEM

An interlock is a type of hardware or software that does not allow an action to occur if certain conditions are not met. For example, modern automobiles contain interlocks that prevent you from taking the key out of the ignition unless the transmission is in park. Interlocks are used to ensure that a proper sequence is followed or, if it is important enough, to shut down a process. Larger compressors typically contain interlock systems to prevent major damage.

Examples of interlock protection in compressors include indicators and shutdown systems for low lubrication, low oil pressure or flow, excessive vibration, high liquid level in a suction vessel, high discharge temperature, high differential pressure, or high power
consumption. Many compressors are designed with emergency shutdown (ESD) instrumentation to shut them down if an abnormal condition exists. These types of interlock systems protect against a variety of failure modes. Most of these systems are designed to fail safe (i.e., shutdown the system in a manner that causes little or no equipment damage).

Voting sensor systems are used to reduce the frequency of false shutdowns. In a voting system, multiple temperature transmitters monitor the discharge temperature. The voting sensor system uses two-out-of-three logic to determine an action. In other words, if two out of three transmitters indicate that the temperature is too high, the compressor will shut down. This logic prevents the failure of one transmitter from shutting down the compressor unnecessarily. It also allows faulty transmitters to be repaired without shutting down the compressor.

**LOSS OF CAPACITY**

Most machines are designed with safety factors that allow continuous operation up to the driver's rated capacity. Exceeding the design rate may cause damage to the compressor due to the possibility of liquid carryover from the suction drum into the machine. Unless the liquid carried into the suction is in the form of a slug (a large amount given all at once), the protective instrumentation should be able to protect against significant damage. However, liquid droplets in small quantities carried into suction lines can damage the machine's components over time. Rotary compressors are frequently designed to handle the liquid phase in the suction.

Loss of capacity in a reciprocating compressor can be caused by leaking compression valves and/or leaking piston rings. A leaking compression valve can be indicated by higher-than-normal temperature on the valve's cover plate located on the exterior of the cylinder. Leaking piston rings may also be identified by a loss of rate with normal or lower-than-normal valve cover temperatures.

**MOTOR OVERLOAD**

Compressor motor overload and motor interlock shutdown can occur for a variety of reasons, including higher than designed discharge pressure, high motor amperage, or bearing failure. In some cases, the motor overload may occur if the compressor is used to compress a suction gas with a molecular weight above what the compressor is designed to handle. Compressors with variable speed electric drivers can suffer motor overload situations if the torque demand is high when the revolutions per minute (rpm) are low. This situation is most likely to occur with rotary compressor types.

**HIGH/LOW FLOW**

Lubricant flow that is too high or too low may indicate eminent bearing or seal failure. Because of this, lubricant flow monitoring systems are designed to sound an alarm should flow that is too high or too low be detected.

Gas flow that is too high through the compressor may be caused by a compressor operating at excessive rpm, which could result in compressor damage. Gas flow that is too low through the compressor may indicate suction side restrictions or the onset of compressor surge conditions.

**Safety and Environmental Hazards**

Hazards associated with normal and abnormal compressor operations can affect personal safety, equipment, and the environment. Table 7-1 lists some of these hazards and their effects.

**Process Technician’s Role in Operations and Maintenance**

When working with compressors, process technicians should always conduct monitoring and control activities to ensure the compressor is not overpressurizing, overheating, or leaking. On a periodic basis, process technicians should check vibration, oil flow, oil...
level, temperature, and pressure. They should also make sure that connectors, hoses, and pipes are in proper condition; they should examine overspeed trips and oil levels, and check for leaks at seals, packing, and flanges.

Failure to perform proper monitoring and control could affect the process and result in equipment damage. All process technicians should monitor equipment and guard against hazards by following the appropriate procedures, which may include the following:

- Wear the appropriate personal protective equipment and observe all safety rules.
- Observe the compressor operation for signs of compressor failure or maintenance needs during normal operation.
- Check and record pressures, temperatures, and flow rates periodically to identify a problem trend.
- Check rotating equipment frequently for mechanical problems, such as lack of lubrication, seal leakage, overheating of compressors and drivers, and excessive vibration.
- Check lubrication systems to ensure proper temperatures and lubricant levels because seals become worn and weak and because motor, turbine, and compressor bearings become worn and overheat.

When working with compressors, process technicians should look, listen, and feel for the items listed in Table 7-2. In addition to operational maintenance, process technicians may perform additional tasks for routine and preventive maintenance.

**Typical Procedures**

Process technicians should be aware of the various compressor procedures, including startup, shutdown, lockout/tagout, and emergency procedures.

**STARTUP AND SHUTDOWN**

Compressors should be started under no load or low load conditions by opening the recycle valves and establishing minimum flow. Compressor drivers and the type of compressor being used determine automatic control schemes. Automatic control systems control compressor driver speed by either turbine or variable speed motors. These control systems make it easier to establish the operating conditions of the compressor.
Startup procedures vary considerably from machine to machine. However, the following steps apply to most compressors:

1. Assure that the machine is completely assembled and ready for startup, and that the process is ready for the compressor to come on line.
2. Place ancillary lubricating and seal oil systems, housing vent lines, and other components into operation.
3. Use an inert gas, such as carbon dioxide or nitrogen, to purge the compressor case or cylinders of air, if required.
4. With pressure on the machine, drain the compressor’s case or cylinders to remove any liquid, and then check for leaks.
5. Adjust the controls for minimum driver load at startup (e.g., unload reciprocating compressor cylinders).
6. Put the driver into condition to be started (e.g., prepare steam systems and superheaters and/or remove tagout devices from electrical switches).
7. Start the machine at low load. As applicable for variable speed drivers, bring the machine up to operating speed. Avoid running the equipment in its critical speed ranges.
8. For reciprocating compressors, adjust the cylinder loadings for efficient operation once you are satisfied that the machine is running smoothly.
9. Closely monitor operation as the machine runs in and comes to normal operating conditions.

**LOCKOUT/TAGOUT**

The following is a generic lockout/tagout procedure similar to the ones followed by process technicians preparing a compressor for maintenance:

1. De-energize the driver to all equipment per an energy isolation plan. If possible, physically disconnect the driver from the compressor.
2. Close all block valves to isolate the compressor following lockout/tagout (LOTO) and standard operating procedure (SOP).
3. De-pressurize the compressor.

Again, the procedures may differ from facility to facility, so process technicians should always follow the procedures specific to their unit. Figure 7-32 shows an example of a lockout/tagout sign.

**EMERGENCY PROCEDURES**

Emergency procedures include additional actions by a technician beyond those normally required during a shutdown. Process technicians should always follow the specific emergency operating procedures for their unit and company.
Summary

Compressors are used in the process industries to compress gases and vapors so that they may be used in a system that requires a higher pressure. Compressors are similar to pumps in the way that they operate. The primary difference is the service in which they are used. Pumps are used to move liquids and slurries, while compressors are used in gas or vapor service.

The two most common types of compressors are positive displacement and dynamic. Positive displacement compressors use screws, sliding vanes, lobes, gears, or pistons for compression. Positive displacement compressors include reciprocating and rotary compressors.

Reciprocating compressors use an inward stroke to draw gas into a chamber to positively displace the gas. Piston type reciprocating compressors use pistons connected to a crankshaft that converts the rotational motion of a driver to the reciprocating motion of the piston.

Rotary compressors move gas by rotating a screw, a set of lobes, or a set of vanes. Liquid ring compressors use an eccentric impeller with vanes to transmit centrifugal force into a sealing fluid and drive it against the wall of a cylindrical casing.

Dynamic compressors are nonpositive displacement compressors that use centrifugal or rotational force to move gases. Types of dynamic compressors include centrifugal and axial compressors. In a centrifugal compressor, gas enters through the suction inlet and goes into the casing where a rotating impeller spins, creating centrifugal force. Axial compressors use a series of rotor and stator blades to move gas along the shaft.

Compressors can be single- or multistage. In a single-stage compressor, the gas enters the compressor and is compressed one time. In a multistage compressor the gas is compressed multiple times, thereby delivering higher pressures.

Engineers use a compressor curve supplied by the manufacturer to design a compressor system. Process technicians use the curve to monitor the performance of compressors.

Auxiliary equipment associated with compressors includes lubrication systems, seal systems, antisurge devices, intercooler, after-cooler, and separators.

Potential problems associated with compressors include overpressurization, overheating, surging, seal oil problems, leaks, lubrication fluid contamination, vibration, interlock systems, loss of capacity, motor overload, high/low flow, and governor malfunction.

Process technicians are required to be aware of safety and environmental hazards associated with compressors and to follow the standard operating procedures for conditions of the unit operation.
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Checking Your Knowledge

1. Define the following terms:
   a. Axial compressor
   b. Centrifugal compressor
   c. Dynamic compressor
   d. Liquid ring compressor
   e. Multistage compressor
   f. Positive displacement compressor
   g. Reciprocating compressor
   h. Rotary compressor
   i. Single-stage compressor
   j. Cylinder
   k. Interlock
   l. Packing
   m. Piston
   n. Shaft
   o. Surging

2. Which type of compressor uses pistons, lobes, screws, or vanes to compress gases?
   a. Dynamic
   b. Positive displacement

3. Which type of compressor uses impellers to generate centrifugal force?
   a. Dynamic
   b. Positive displacement

4. Which type of compressor uses sliding vanes to force gases out of a chamber?
   a. Axial
   b. Centrifugal
   c. Positive displacement

5. (True or False) In an axial compressor, the flow of gas moves parallel to the shaft.

6. On the diagram below, identify the following parts of a centrifugal compressor.
   a. Casing
   b. Discharge
   c. Impeller
   d. Shaft
   e. Suction
   f. Bearings

7. Which type of rotary compressor uses an impeller with vanes to transmit centrifugal force into a sealing fluid (e.g., water), driving it against the wall of a cylindrical casing?
   a. Screw
   b. Lobe
   c. Sliding vane
   d. Liquid ring

8. (True or False) In a centrifugal compressor, a rotating impeller spins, creating centrifugal force that decreases the velocity of the gas.

9. A lubrication system in a compressor:
   a. provides circulation and cooling of sealing and lubrication oils
   b. minimizes total leakage
   c. increases the pressure on process gases
   d. transfers heat to the seals

10. Surging can cause (select all that apply):
    a. seal leakage
    b. vibration
    c. destruction of the machinery
    d. dead heading conditions

11. (True or False) Interlock systems are used to bypass emergency shutdown systems in order to keep production running so a particular unit can meet its production goals.
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Student Activities

1. Given a cutaway or a diagram of a centrifugal compressor, identify the following components:
   a. Casing
   b. Discharge
   c. Impeller
   d. Shaft
   e. Suction

2. Given a cutaway or diagram of a reciprocating compressor, identify the following components:
   a. Casing
   b. Connecting rods
   c. Suction valve
   d. Discharge valve
   e. Piston

3. Using a P&ID provided by your instructor, locate and identify the type of compressor. Prepare a written report discussing potential problems that can arise from a compressor malfunction and the systems it can affect.

4. Using a P&ID provided by your instructor, locate the compressors. Prepare a presentation about the auxiliary equipment associated with each compressor and how it can enhance production.

5. Write a report about surging and the importance of antisurge prevention in compressors. Draw a diagram of an antisurge device for a compressor system or, using a P&ID provided by your instructor, design an antisurge device to improve the existing system shown on the P&ID.