
DOE-HDBK-1018/1-93
MECHANICAL SCIENCE

ABSTRACT

The *Mechanical Science* Handbook was developed to assist nuclear facility operating contractors in providing operators, maintenance personnel, and the technical staff with the necessary fundamentals training to ensure a basic understanding of mechanical components and mechanical science. The handbook includes information on diesel engines, heat exchangers, pumps, valves, and miscellaneous mechanical components. This information will provide personnel with a foundation for understanding the construction and operation of mechanical components that are associated with various DOE nuclear facility operations and maintenance.

Key Words: Training Material, Diesel Engine, Heat Exchangers, Pumps, Valves

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OVERVIEW

The *Department of Energy Fundamentals Handbook* entitled *Mechanical Science* was prepared as an information resource for personnel who are responsible for the operation of the Department's nuclear facilities. Almost all processes that take place in the nuclear facilities involve the use of mechanical equipment and components. A basic understanding of mechanical science is necessary for DOE nuclear facility operators, maintenance personnel, and the technical staff to safely operate and maintain the facility and facility support systems. The information in the handbook is presented to provide a foundation for applying engineering concepts to the job. This knowledge will help personnel more fully understand the impact that their actions may have on the safe and reliable operation of facility components and systems.

The *Mechanical Science* handbook consists of five modules that are contained in two volumes. The following is a brief description of the information presented in each module of the handbook.

Volume 1 of 2

Module 1 - Diesel Engine Fundamentals

Provides information covering the basic operating principles of 2-cycle and 4-cycle diesel engines. Includes operation of engine governors, fuel ejectors, and typical engine protective features.

Module 2 - Heat Exchangers

Describes the construction of plate heat exchangers and tube and shell heat exchangers. Describes the flow patterns and temperature profiles in parallel flow, counter flow, and cross flow heat exchangers.

Module 3 - Pumps

Explains the operation of centrifugal and positive displacement pumps. Topics include net positive suction head, cavitation, gas binding, and pump characteristic curves.

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OVERVIEW (Cont.)

Volume 2 of 2

Module 4 - Valves

Introduces the functions of the basic parts common to most types of valves. Provides information on applications of many types of valves. Types of valves covered include gate valves, globe valves, ball valves, plug valves, diaphragm valves, reducing valves, pinch valves, butterfly valves, needle valves, check valves, and safety/relief valves.

Module 5 - Miscellaneous Mechanical Components

Provides information on significant mechanical devices that have widespread application in nuclear facilities but do not fit into the categories of components covered by the other modules. These include cooling towers, air compressors, demineralizers, filters, strainers, etc.

The information contained in this handbook is not all-encompassing. An attempt to present the entire subject of mechanical science would be impractical. However, the *Mechanical Science* handbook presents enough information to provide the reader with the fundamental knowledge necessary to understand the advanced theoretical concepts presented in other subject areas, and to understand basic system and equipment operation.

**Department of Energy
Fundamentals Handbook**

**MECHANICAL SCIENCE
Module 1
Diesel Engine Fundamentals**

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TERMINAL OBJECTIVE

- 1.0 Without references, **DESCRIBE** the components and theory of operation for a diesel engine.

ENABLING OBJECTIVES

- 1.1 **DEFINE** the following diesel engine terms:
- a. Compression ratio
 - b. Bore
 - c. Stroke
 - d. Combustion chamber
- 1.2 Given a drawing of a diesel engine, **IDENTIFY** the following:
- a. Piston/rod
 - b. Cylinder
 - c. Blower
 - d. Crankshaft
 - e. Intake ports or valve(s)
 - f. Exhaust ports or valve(s)
 - g. Fuel injector
- 1.3 **EXPLAIN** how a diesel engine converts the chemical energy stored in the diesel fuel into mechanical energy.
- 1.4 **EXPLAIN** how the ignition process occurs in a diesel engine.
- 1.5 **EXPLAIN** the operation of a 4-cycle diesel engine to include when the following events occur during a cycle:
- a. Intake
 - b. Exhaust
 - c. Fuel injection
 - d. Compression
 - e. Power

ENABLING OBJECTIVES (Cont.)

- 1.6 **EXPLAIN** the operation of a 2-cycle diesel engine, including when the following events occur during a cycle:
- a. Intake
 - b. Exhaust
 - c. Fuel injection
 - d. Compression
 - e. Power
- 1.7 **DESCRIBE** how the mechanical-hydraulic governor on a diesel engine controls engine speed.
- 1.8 **LIST** five protective alarms usually found on mid-sized and larger diesel engines.

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DIESEL ENGINES

One of the most common prime movers is the diesel engine. Before gaining an understanding of how the engine operates a basic understanding of the engine's components must be gained. This chapter reviews the major components of a generic diesel engine.

EO 1.1 **DEFINE** the following diesel engine terms:

- a. **Compression ratio**
- b. **Bore**
- c. **Stroke**
- d. **Combustion chamber**

EO 1.2 **Given a drawing of a diesel engine, IDENTIFY** the following:

- a. **Piston/rod**
- b. **Cylinder**
- c. **Blower**
- d. **Crankshaft**
- e. **Intake ports or valve(s)**
- f. **Exhaust ports or valve(s)**
- g. **Fuel injector**

Introduction

Most DOE facilities require some type of prime mover to supply mechanical power for pumping, electrical power generation, operation of heavy equipment, and to act as a backup electrical generator for emergency use during the loss of the normal power source. Although several types of prime movers are available (gasoline engines, steam and gas turbines), the diesel engine is the most commonly used. Diesel engines provide a self-reliant energy source that is available in sizes from a few horsepower to 10,000 hp. Figure 1 provides an illustration of a common skid-mounted, diesel-driven generator. Relatively speaking, diesel engines are small, inexpensive, powerful, fuel efficient, and extremely reliable if maintained properly.

Because of the widespread use of diesel engines at DOE facilities, a basic understanding of the operation of a diesel engine will help ensure they are operated and maintained properly. Due to the large variety of sizes, brands, and types of engines in service, this module is intended to provide the fundamentals and theory of operation of a diesel engine. Specific information on a particular engine should be obtained from the vendor's manual.

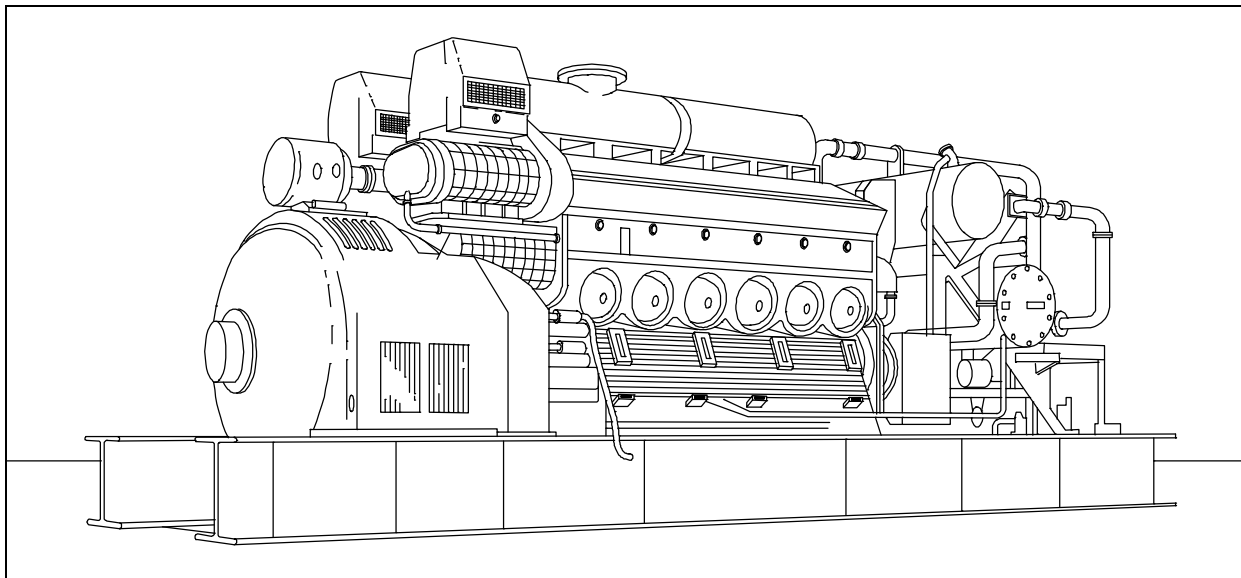


Figure 1 Example of a Large Skid-Mounted, Diesel-Driven Generator

History

The modern diesel engine came about as the result of the internal combustion principles first proposed by Sadi Carnot in the early 19th century. Dr. Rudolf Diesel applied Sadi Carnot's principles into a patented cycle or method of combustion that has become known as the "diesel" cycle. His patented engine operated when the heat generated during the compression of the air fuel charge caused ignition of the mixture, which then expanded at a constant pressure during the full power stroke of the engine.

Dr. Diesel's first engine ran on coal dust and used a compression pressure of 1500 psi to increase its theoretical efficiency. Also, his first engine did not have provisions for any type of cooling system. Consequently, between the extreme pressure and the lack of cooling, the engine exploded and almost killed its inventor. After recovering from his injuries, Diesel tried again using oil as the fuel, adding a cooling water jacket around the cylinder, and lowering the compression pressure to approximately 550 psi. This combination eventually proved successful. Production rights to the engine were sold to Adolphus Bush, who built the first diesel engines for commercial use, installing them in his St. Louis brewery to drive various pumps.

Diesel Engines

A diesel engine is similar to the gasoline engine used in most cars. Both engines are internal combustion engines, meaning they burn the fuel-air mixture within the cylinders. Both are reciprocating engines, being driven by pistons moving laterally in two directions. The majority of their parts are similar. Although a diesel engine and gasoline engine operate with similar components, a diesel engine, when compared to a gasoline engine of equal horsepower, is heavier due to stronger, heavier materials used to withstand the greater dynamic forces from the higher combustion pressures present in the diesel engine.

The greater combustion pressure is the result of the higher compression ratio used by diesel engines. The *compression ratio* is a measure of how much the engine compresses the gasses in the engine's cylinder. In a gasoline engine the compression ratio (which controls the compression temperature) is limited by the air-fuel mixture entering the cylinders. The lower ignition temperature of gasoline will cause it to ignite (burn) at a compression ratio of less than 10:1. The average car has a 7:1 compression ratio. In a diesel engine, compression ratios ranging from 14:1 to as high as 24:1 are commonly used. The higher compression ratios are possible because only air is compressed, and then the fuel is injected. This is one of the factors that allows the diesel engine to be so efficient. Compression ratio will be discussed in greater detail later in this module.

Another difference between a gasoline engine and a diesel engine is the manner in which engine speed is controlled. In any engine, speed (or power) is a direct function of the amount of fuel burned in the cylinders. Gasoline engines are self-speed-limiting, due to the method the engine uses to control the amount of air entering the engine. Engine speed is indirectly controlled by the butterfly valve in the carburetor. The butterfly valve in a carburetor limits the amount of air entering the engine. In a carburetor, the rate of air flow dictates the amount of gasoline that will be mixed with the air. Limiting the amount of air entering the engine limits the amount of fuel entering the engine, and, therefore, limits the speed of the engine. By limiting the amount of air entering the engine, adding more fuel does not increase engine speed beyond the point where the fuel burns 100% of the available air (oxygen).

Diesel engines are not self-speed-limiting because the air (oxygen) entering the engine is always the maximum amount. Therefore, the engine speed is limited solely by the amount of fuel injected into the engine cylinders. Therefore, the engine always has sufficient oxygen to burn and the engine will attempt to accelerate to meet the new fuel injection rate. Because of this, a manual fuel control is not possible because these engines, in an unloaded condition, can accelerate at a rate of more than 2000 revolutions per second. Diesel engines require a speed limiter, commonly called the governor, to control the amount of fuel being injected into the engine.

Unlike a gasoline engine, a diesel engine does not require an ignition system because in a diesel engine the fuel is injected into the cylinder as the piston comes to the top of its compression stroke. When fuel is injected, it vaporizes and ignites due to the heat created by the compression of the air in the cylinder.

Major Components of a Diesel Engine

To understand how a diesel engine operates, an understanding of the major components and how they work together is necessary. Figure 2 is an example of a medium-sized, four-stroke, supercharged, diesel engine with inlet ports and exhaust valves. Figure 3 provides a cross section of a similarly sized V-type diesel engine.

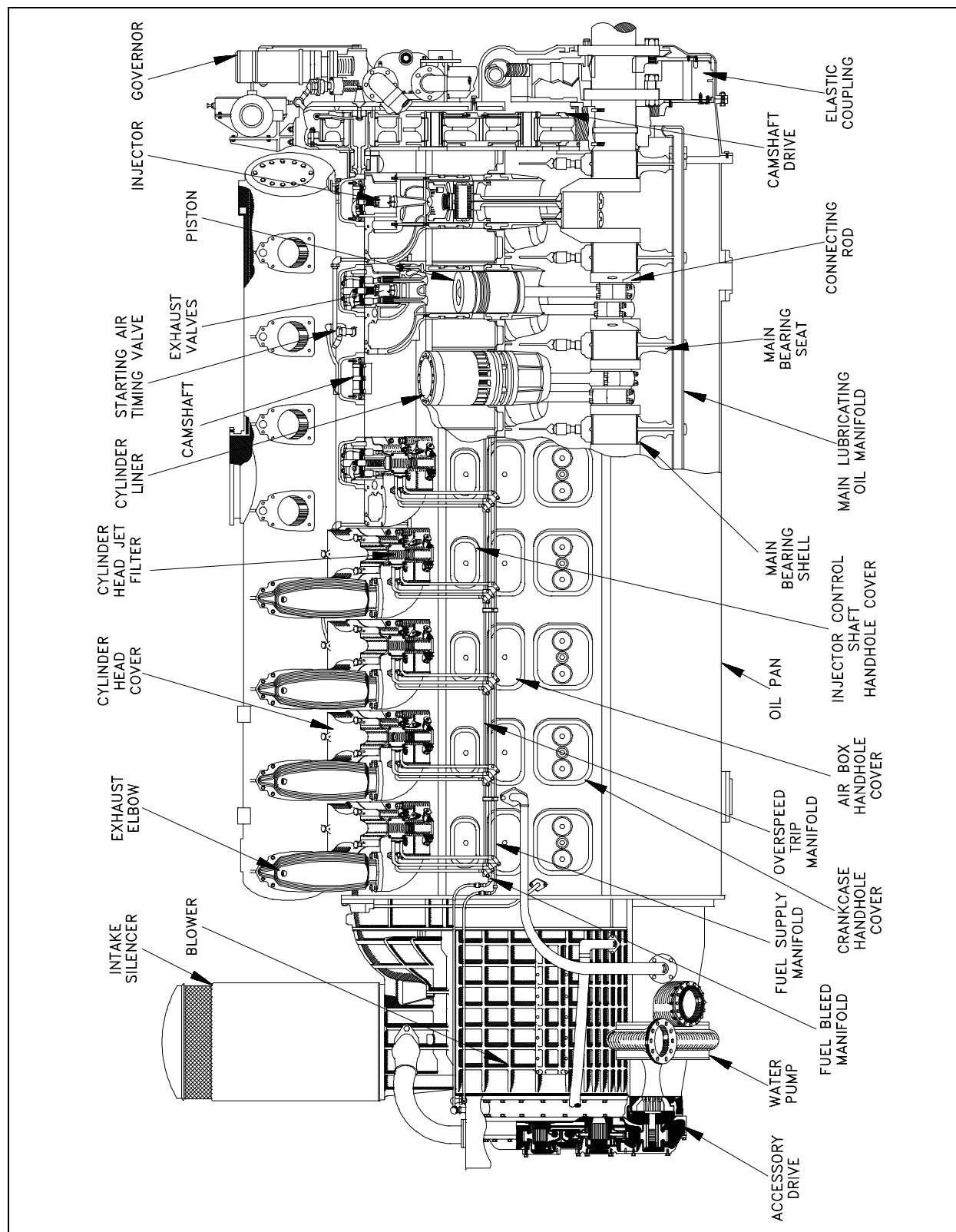


Figure 2 Cutaway of a GM V-16 Four-Stroke Supercharged Diesel Engine

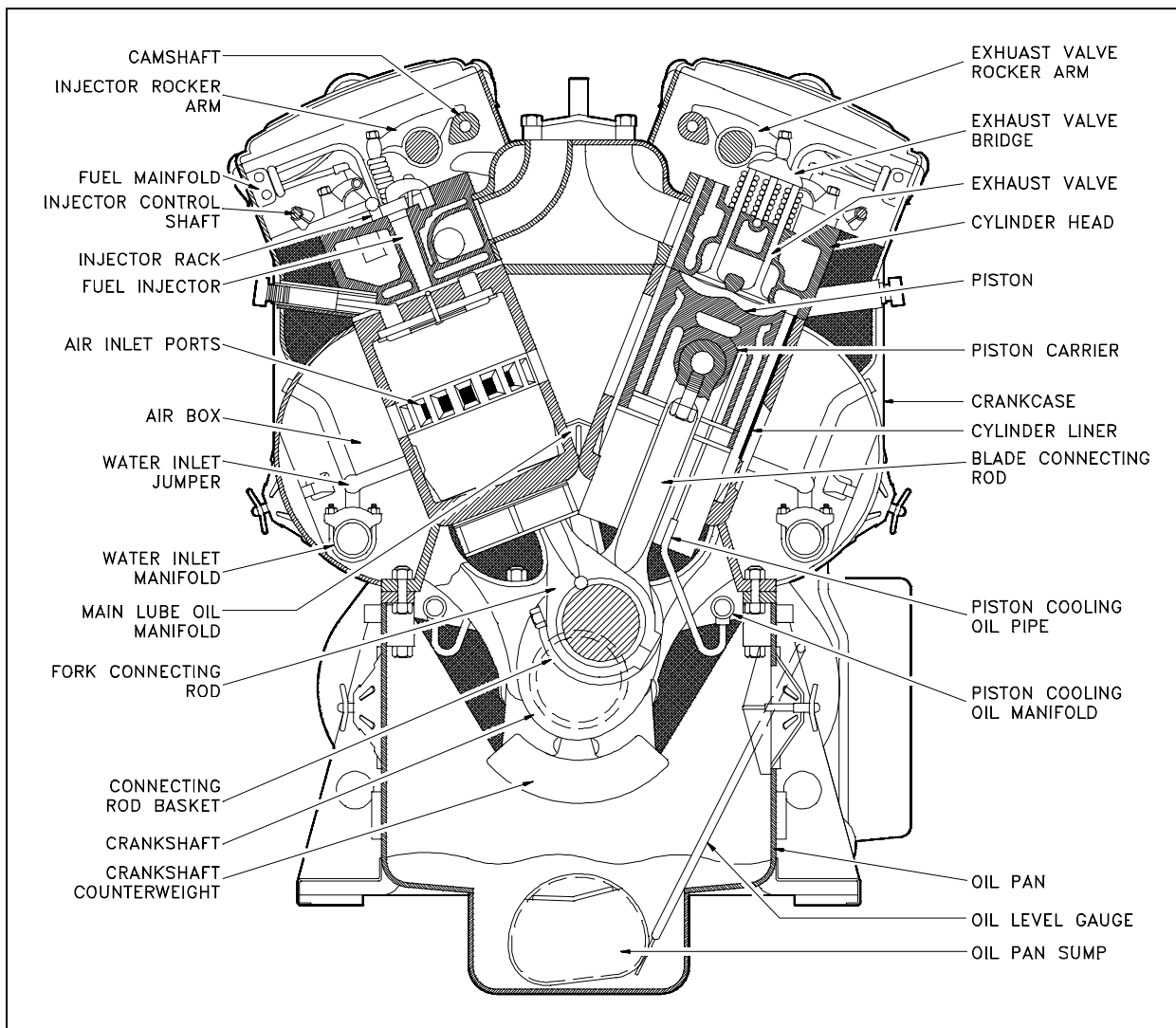


Figure 3 Cross Section of a V-type Four Stroke Diesel Engine

The Cylinder Block

The cylinder block, as shown in Figure 4, is generally a single unit made from cast iron. In a liquid-cooled diesel, the block also provides the structure and rigid frame for the engine's cylinders, water coolant and oil passages, and support for the crankshaft and camshaft bearings.

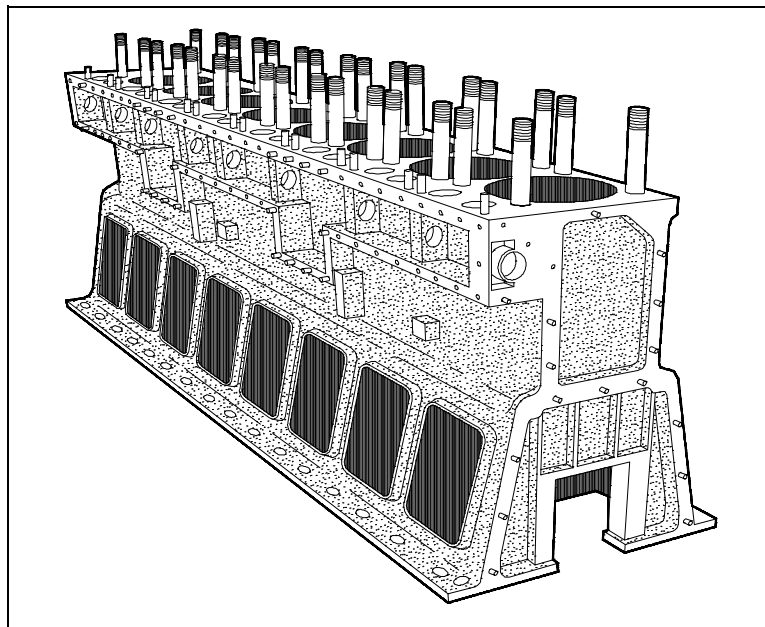


Figure 4 The Cylinder Block

Crankcase and Oil Pan

The *crankcase* is usually located on the bottom of the cylinder block. The crankcase is defined as the area around the crankshaft and crankshaft bearings. This area encloses the rotating crankshaft and crankshaft counter weights and directs returning oil into the oil pan. The oil pan is located at the bottom of the crankcase as shown in Figure 2 and Figure 3. The *oil pan* collects and stores the engine's supply of lubricating oil. Large diesel engines may have the oil pan divided into several separate pans.

Cylinder Sleeve or Bore

Diesel engines use one of two types of cylinders. In one type, each cylinder is simply machined or bored into the block casting, making the block and cylinders an integral part. In the second type, a machined steel sleeve is pressed into the block casting to form the cylinder. Figure 2 and Figure 3 provide examples of sleeved diesel engines. With either method, the *cylinder sleeve* or *bore* provides the engine with the cylindrical structure needed to confine the combustion gasses and to act as a guide for the engine's pistons.

In engines using sleeves, there are two types of sleeves, wet and dry. A dry sleeve is surrounded by the metal of the block and does not come in direct contact with the engine's coolant (water). A wet sleeve comes in direct contact with the engine's coolant. Figure 5 provides an example of a wet sleeve. The volume enclosed by the sleeve or bore is called the combustion chamber and is the space where the fuel is burned.

In either type of cylinder, sleeved or bored, the diameter of the cylinder is called the bore of the engine and is stated in inches. For example, the bore of a 350 cubic inch Chevrolet gasoline engine is 4 inches.

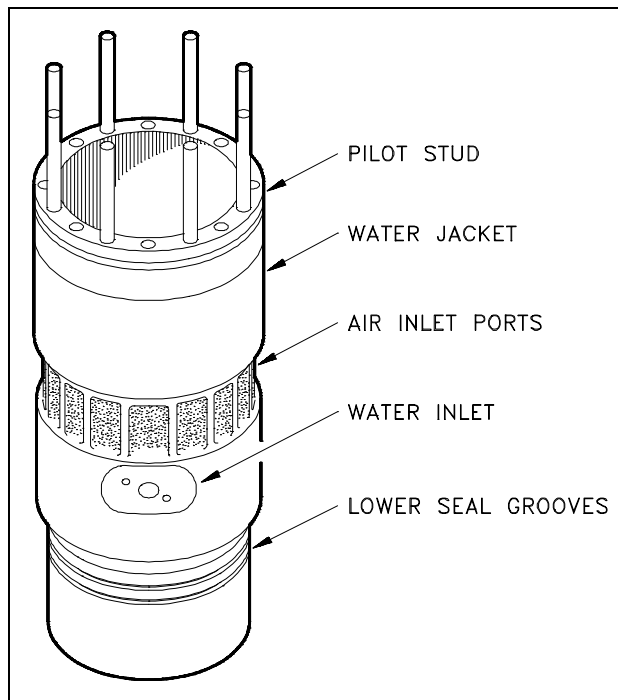


Figure 5 Diesel Engine Wet Cylinder Sleeve

Most diesel engines are multi-cylinder engines and typically have their cylinders arranged in one of two ways, an in-line or a "V", although other combinations exist. In an in-line engine, as the name indicates, all the cylinders are in a row. In a "V" type engine the cylinders are arranged in two rows of cylinders set at an angle to each other that align to a common crankshaft. Each group of cylinders making up one side of the "V" is referred to as a bank of cylinders.

Piston and Piston Rings

The *piston* transforms the energy of the expanding gasses into mechanical energy. The piston rides in the cylinder liner or sleeve as shown in Figure 2 and Figure 3. Pistons are commonly made of aluminum or cast iron alloys.

To prevent the combustion gasses from bypassing the piston and to keep friction to a minimum, each piston has several metal rings around it, as illustrated by Figure 6.

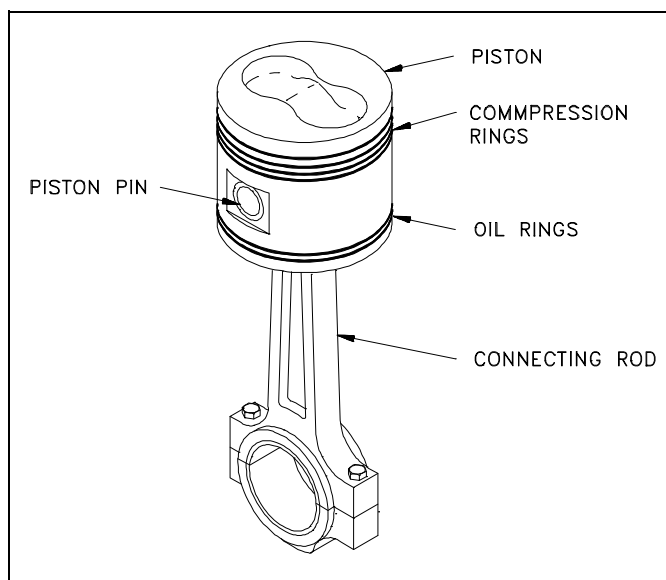


Figure 6 Piston and Piston Rod

These rings function as the seal between the piston and the cylinder wall and also act to reduce friction by minimizing the contact area between the piston and the cylinder wall. The rings are usually made of cast iron and coated with chrome or molybdenum. Most diesel engine pistons have several rings, usually 2 to 5, with each ring performing a distinct function. The top ring(s) acts primarily as the pressure seal. The intermediate ring(s) acts as a wiper ring to remove and control the amount of oil film on the cylinder walls. The bottom ring(s) is an oiler ring and ensures that a supply of lubricating oil is evenly deposited on the cylinder walls.

Connecting Rod

The *connecting rod* connects the piston to the crankshaft. See Figure 2 and Figure 3 for the location of the connecting rods in an engine. The rods are made from drop-forged, heat-treated steel to provide the required strength. Each end of the rod is bored, with the smaller top bore connecting to the piston pin (wrist pin) in the piston as shown in Figure 6. The large bore end of the rod is split in half and bolted to allow the rod to be attached to the crankshaft. Some diesel engine connecting rods are drilled down the center to allow oil to travel up from the crankshaft and into the piston pin and piston for lubrication.

A variation found in V-type engines that affects the connecting rods is to position the cylinders in the left and right banks directly opposite each other instead of staggered (most common configuration). This arrangement requires that the connecting rods of two opposing cylinders share the same main journal bearing on the crankshaft. To allow this configuration, one of the connecting rods must be split or forked around the other.

Crankshaft

The *crankshaft* transforms the linear motion of the pistons into a rotational motion that is transmitted to the load. Crankshafts are made of forged steel. The forged crankshaft is machined to produce the crankshaft bearing and connecting rod bearing surfaces. The rod bearings are eccentric, or offset, from the center of the crankshaft as illustrated in Figure 7. This offset converts the reciprocating (up and down) motion of the piston into the rotary motion of the crankshaft. The amount of offset determines the stroke (distance the piston travels) of the engine (discussed later).

The crankshaft does not ride directly on the cast iron block crankshaft supports, but rides on special bearing material as shown in Figure 7. The connecting rods also have bearings inserted between the crankshaft and the connecting rods. The bearing material is a soft alloy of metals that provides a replaceable wear surface and prevents galling between two similar metals (i.e., crankshaft and connecting rod). Each bearing is split into halves to allow assembly of the engine. The crankshaft is drilled with oil passages that allow the engine to feed oil to each of the crankshaft bearings and connection rod bearings and up into the connecting rod itself.

The crankshaft has large weights, called counter weights, that balance the weight of the connecting rods. These weights ensure an even (balance) force during the rotation of the moving parts.

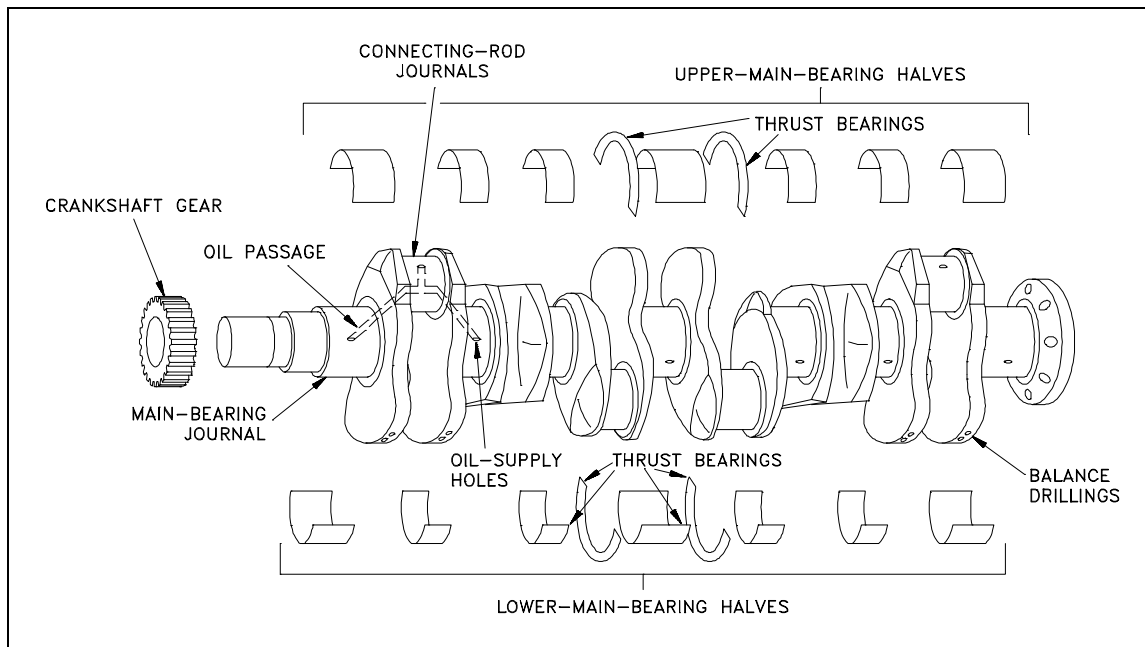


Figure 7 Diesel Engine Crankshaft and Bearings

Flywheel

The *flywheel* is located on one end of the crankshaft and serves three purposes. First, through its inertia, it reduces vibration by smoothing out the power stroke as each cylinder fires. Second, it is the mounting surface used to bolt the engine up to its load. Third, on some diesels, the flywheel has gear teeth around its perimeter that allow the starting motors to engage and crank the diesel.

Cylinder Heads and Valves

A diesel engine's *cylinder heads* perform several functions. First, they provide the top seal for the cylinder bore or sleeve. Second, they provide the structure holding exhaust valves (and intake valves where applicable), the fuel injector, and necessary linkages. A diesel engine's heads are manufactured in one of two ways. In one method, each cylinder has its own head casting, which is bolted to the block. This method is used primarily on the larger diesel engines. In the second method, which is used on smaller engines, the engine's head is cast as one piece (multi-cylinder head).

Diesel engines have two methods of admitting and exhausting gasses from the cylinder. They can use either ports or valves or a combination of both. *Ports* are slots in the cylinder walls located in the lower 1/3 of the bore. See Figure 2 and Figure 3 for examples of intake ports, and note their relative location with respect to the rest of the

engine. When the piston travels below the level of the ports, the ports are "opened" and fresh air or exhaust gasses are able to enter or leave, depending on the type of port.

The ports are then "closed" when the piston travels back above the level of the ports. *Valves* (refer to figure 8) are mechanically opened and closed to admit or exhaust the gasses as needed. The valves are located in the head casting of the engine. The point at which the valve seals against the head is called the *valve seat*. Most medium-sized diesels have either intake ports or exhaust valves or both intake and exhaust valves.

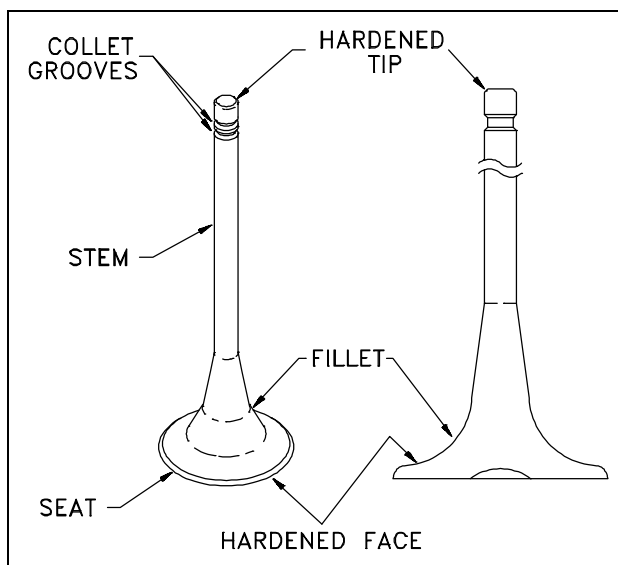


Figure 8 Diesel Engine Valve

In order for a diesel engine to operate, all of its components must perform their functions at very precise intervals in relation to the motion of the piston. To accomplish this, a component called a *camshaft* is used. Figure 9 illustrates a camshaft and camshaft drive gear. Figure 2 and Figure 3 illustrate the location of a camshaft in a large overhead cam diesel engine.

A camshaft is a long bar with egg-shaped eccentric lobes, one lobe for each valve and fuel injector (discussed later). Each lobe has a follower as shown on Figure 10. As the camshaft is rotated, the follower is forced up and down as it follows the profile of the cam lobe. The followers are connected to the engine's valves and fuel injectors through various types of linkages called *pushrods* and *rocker arms*. The

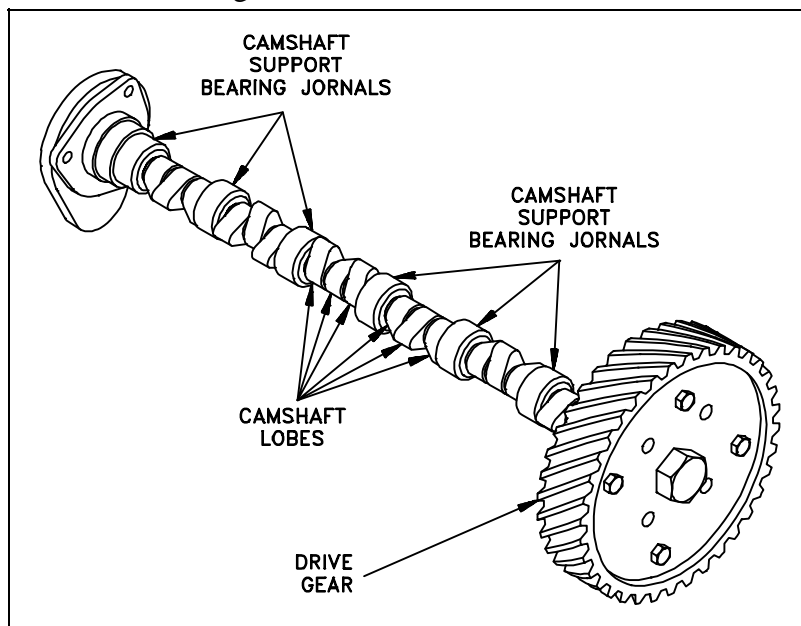


Figure 9 Diesel Engine Camshaft and Drive Gear

pushrods and rocker arms transfer the reciprocating motion generated by the camshaft lobes to the valves and injectors, opening and closing them as needed. The valves are maintained closed by springs.

As the valve is opened by the camshaft, it compresses the valve spring. The energy stored in the valve spring is then used to close the valve as the camshaft lobe rotates out from under the follower. Because an engine experiences fairly large changes in temperature (e.g., ambient to a normal running temperature of about 190°F), its components must be designed to allow for thermal expansion. Therefore, the valves, valve pushrods, and rocker arms must have some method of allowing for the expansion. This is accomplished by the use of valve lash. *Valve lash* is the term given to the "slop" or "give" in the valve train before the cam actually starts to open the valve.

The camshaft is driven by the engine's crankshaft through a series of gears called idler gears and timing gears. The gears allow the rotation of the camshaft to correspond or be in time with, the rotation of the crankshaft and thereby allows the valve opening, valve closing, and injection of fuel to be timed to occur at precise intervals in the piston's travel. To increase the flexibility in timing the valve opening, valve closing, and injection of fuel, and to increase power or to reduce cost, an engine may have one or more camshafts. Typically,

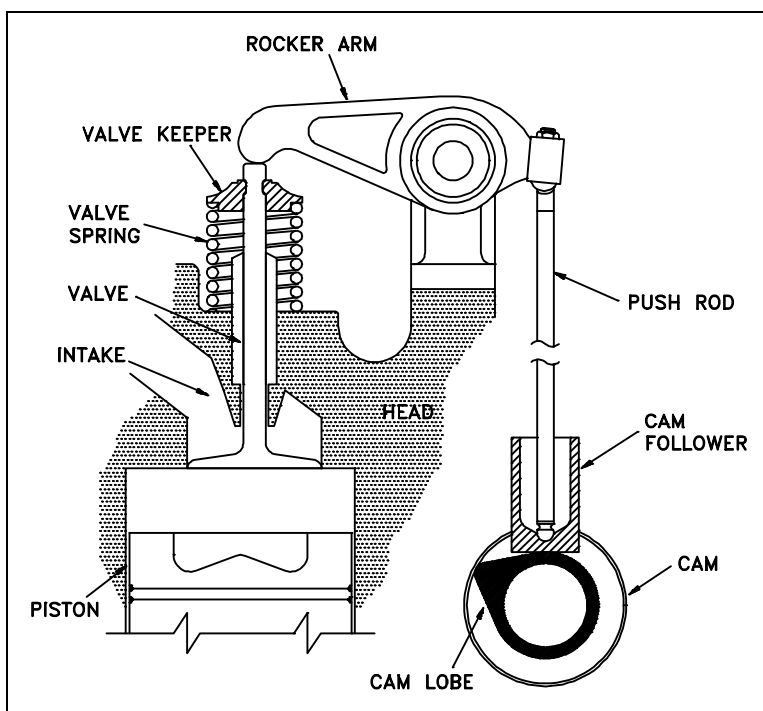


Figure 10 Diesel Engine Valve Train

in a medium to large V-type engine, each bank will have one or more camshafts per head. In the larger engines, the intake valves, exhaust valves, and fuel injectors may share a common camshaft or have independent camshafts.

Depending on the type and make of the engine, the location of the camshaft or shafts varies. The camshaft(s) in an in-line engine is usually found either in the head of the engine or in the top of the block running down one side of the cylinder bank. Figure 10 provides an example of an engine with the camshaft located on the side of the engine. Figure 3 provides an example of an overhead cam arrangement as on a V-type engine. On small or mid-sized V-type engines, the camshaft is usually located in the block at the

center of the "V" between the two banks of cylinders. In larger or multi-camshafted V-type engines, the camshafts are usually located in the heads.

Blower

The diesel engine's *blower* is part of the air intake system and serves to compress the incoming fresh air for delivery to the cylinders for combustion. The location of the blower is shown on Figure 2. The blower can be part of either a turbocharged or supercharged air intake system. Additional information on these two types of blowers is provided later in this module.

Diesel Engine Support Systems

A diesel engine requires five supporting systems in order to operate: cooling, lubrication, fuel injection, air intake, and exhaust. Depending on the size, power, and application of the diesel, these systems vary in size and complexity.

Engine Cooling

Nearly all diesel engines rely on a liquid cooling system to transfer waste heat out of the block and internals as shown in Figure 11. The cooling system consists of a closed loop similar to that of a car engine and contains the following major components: water pump, radiator or heat exchanger, water jacket (which consists of coolant passages in the block and heads), and a thermostat.

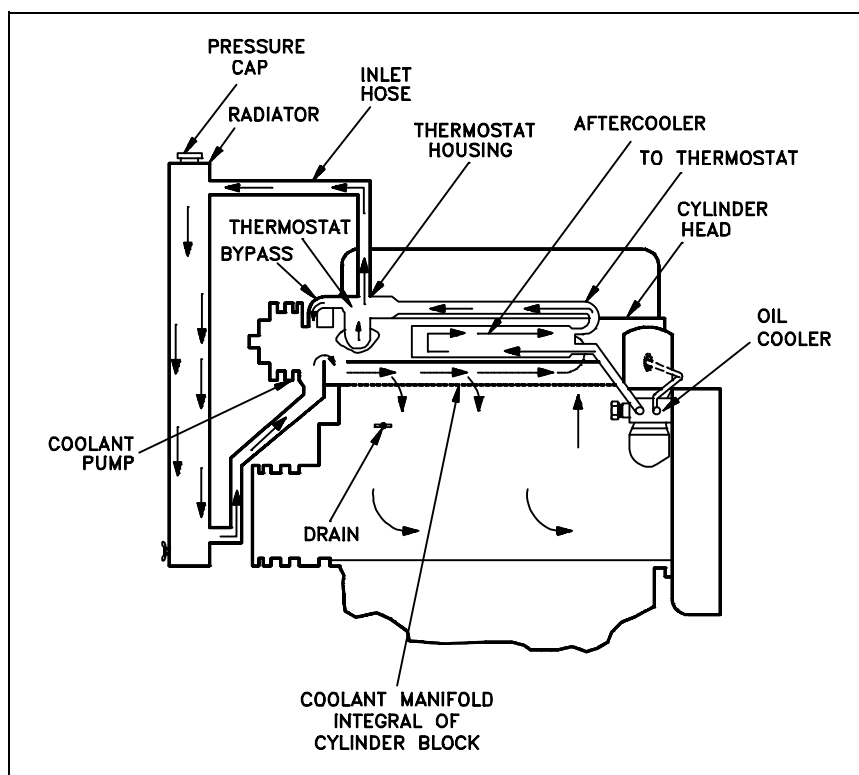


Figure 11 Diesel Engine Cooling System

Engine Lubrication

An internal combustion engine would not run for even a few minutes if the moving parts were allowed to make metal-to-metal contact. The heat generated due to the tremendous amounts of friction would melt the metals, leading to the destruction of the engine. To prevent this, all moving parts ride on a thin film of oil that is pumped between all the moving parts of the engine.

Once between the moving parts, the oil serves two purposes. One purpose is to lubricate the bearing surfaces. The other purpose is to cool the bearings by absorbing the friction-generated heat. The flow of oil to the moving parts is accomplished by the engine's internal lubricating system.

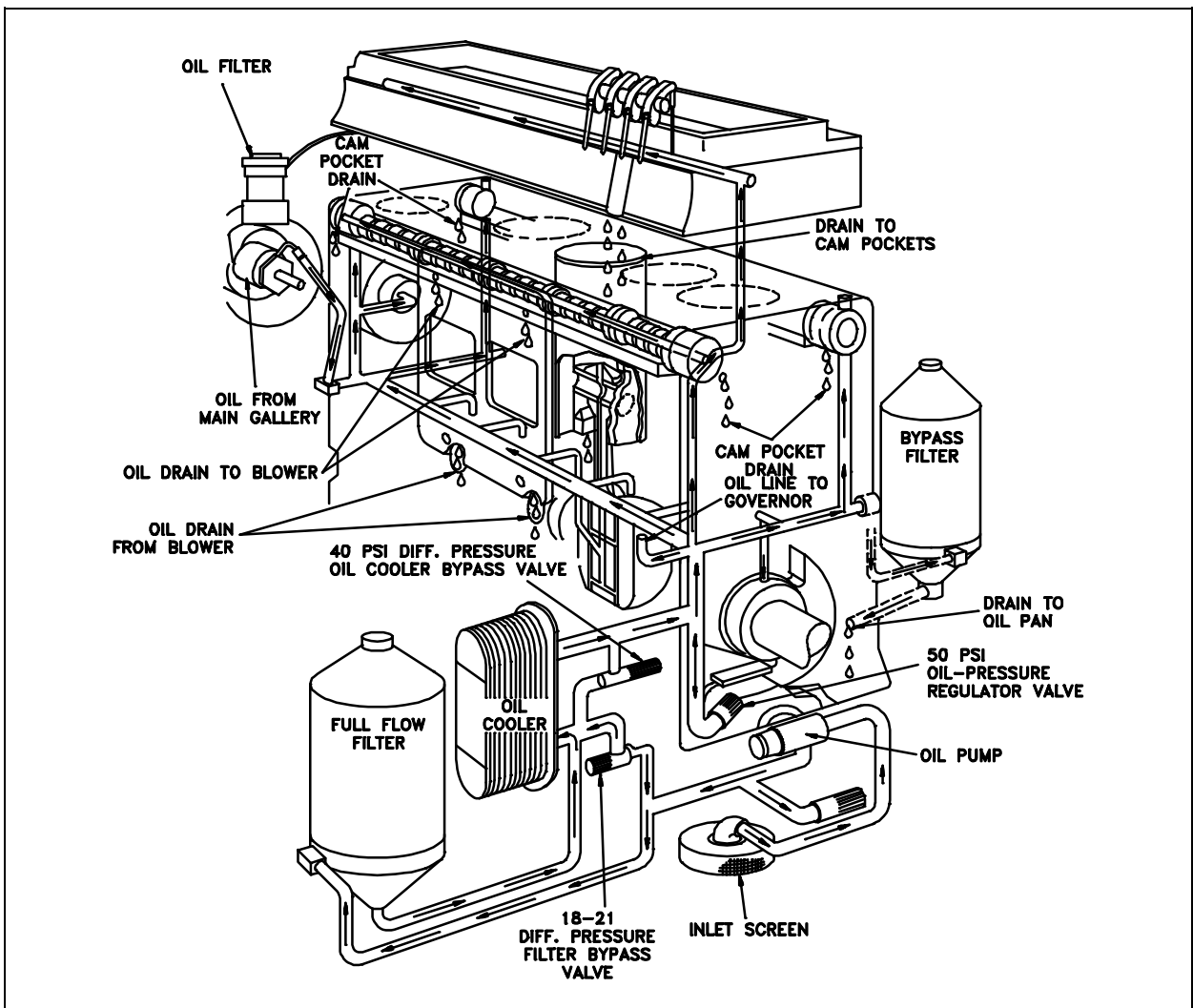


Figure 12 Diesel Engine Internal Lubrication System

Oil is accumulated and stored in the engine's oil pan where one or more oil pumps take a suction and pump the oil through one or more oil filters as shown in Figure 12. The filters clean the oil and remove any metal that the oil has picked up due to wear. The cleaned oil then flows up into the engine's oil galleries. A pressure relief valve(s) maintains oil pressure in the galleries and returns oil to the oil pan upon high pressure. The oil galleries distribute the oil to all the bearing surfaces in the engine.

Once the oil has cooled and lubricated the bearing surfaces, it flows out of the bearing and gravity-flows back into the oil pan. In medium to large diesel engines, the oil is also cooled before being distributed into the block. This is accomplished by either an internal or external oil cooler. The lubrication system also supplies oil to the engine's governor, which is discussed later in this module.

Fuel System

All diesel engines require a method to store and deliver fuel to the engine. Because diesel engines rely on injectors which are precision components with extremely tight tolerances and very small injection hole(s), the fuel delivered to the engine must be extremely clean and free of contaminants.

The fuel system must, therefore, not only deliver the fuel but also ensure its cleanliness. This is usually accomplished through a series of in-line filters. Commonly, the fuel will be filtered once outside the engine and then the fuel will pass through at least one more filter internal to the engine, usually located in the fuel line at each fuel injector.

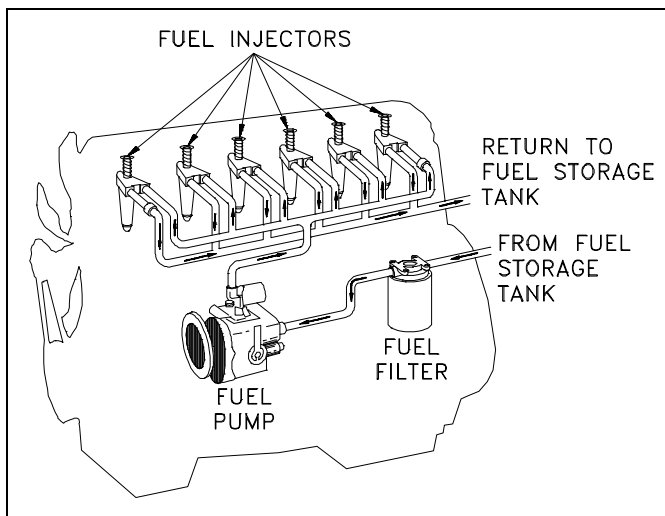


Figure 13 Diesel Engine Fuel Flowpath

In a diesel engine, the fuel system is much more complex than the fuel system on a simple gasoline engine because the fuel serves two purposes. One purpose is obviously to supply the fuel to run the engine; the other is to act as a coolant to the injectors. To meet this second purpose, diesel fuel is kept continuously flowing through the engine's fuel system at a flow rate much higher than required to simply run the engine, an example of a fuel flowpath is shown in Figure 13. The excess fuel is routed back to the fuel pump or the fuel storage tank depending on the application.

Air Intake System

Because a diesel engine requires close tolerances to achieve its compression ratio, and because most diesel engines are either turbocharged or supercharged, the air entering the engine must be clean, free of debris, and as cool as possible. Turbocharging and supercharging are discussed in more detail later in this chapter. Also, to improve a turbocharged or supercharged engine's efficiency, the compressed air must be cooled after being compressed. The air intake system is designed to perform these tasks.

Air intake systems vary greatly from vendor to vendor but are usually one of two types, wet or dry. In a wet filter intake system, as shown in Figure 14, the air is sucked or bubbled through a housing that holds a bath of oil such that the dirt in the air is removed by the oil in the filter. The air then flows through a screen-type material to ensure any entrained oil is removed from the air. In a dry filter system, paper, cloth, or a metal screen material is used to catch and trap dirt before it enters the engine (similar to the type used in automobile engines).

In addition to cleaning the air, the intake system is usually designed to intake fresh air from as far away from the engine as practicable, usually just outside of the engine's building or enclosure. This provides the engine with a supply of air that has not been heated by the engine's own waste heat.

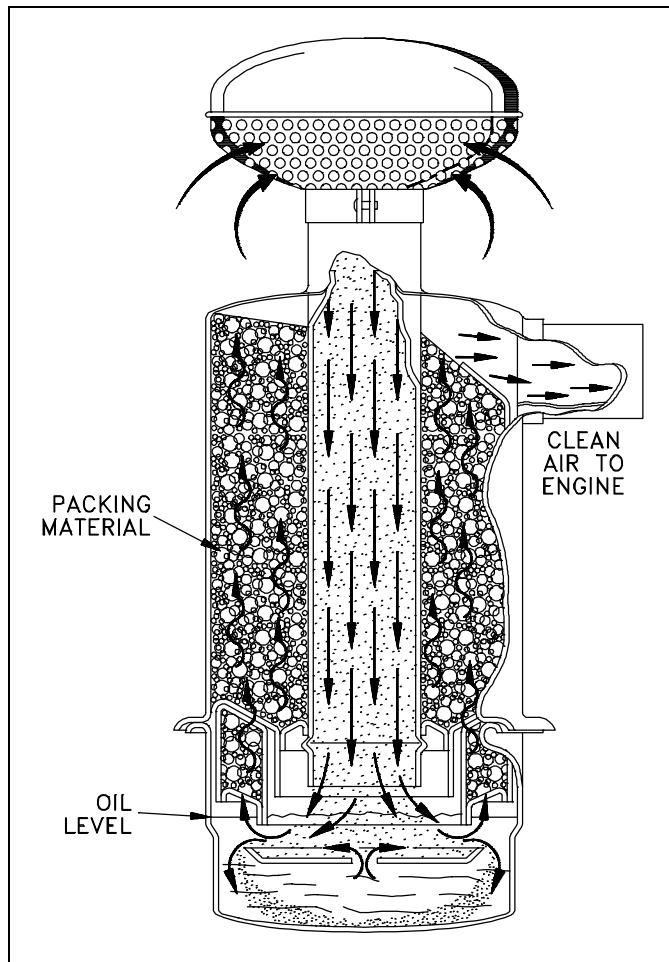


Figure 14 Oil Bath Air Filter

The reason for ensuring that an engine's air supply is as cool as possible is that cool air is more dense than hot air. This means that, per unit volume, cool air has more oxygen than hot air. Thus, cool air provides more oxygen per cylinder charge than less dense, hot air. More oxygen means a more efficient fuel burn and more power.

After being filtered, the air is routed by the intake system into the engine's intake manifold or air box. The manifold or air box is the component that directs the fresh air to each of the engine's intake valves or ports. If the engine is turbocharged or supercharged, the fresh air will be compressed with a blower and possibly cooled before entering the intake manifold or air box. The intake system also serves to reduce the air flow noise.

Turbocharging

Turbocharging an engine occurs when the engine's own exhaust gasses are forced through a turbine (impeller), which rotates and is connected to a second impeller located in the fresh air intake system. The impeller in the fresh air intake system compresses the fresh air. The compressed air serves two functions. First, it increases the engine's available power by increasing the maximum amount of air (oxygen) that is forced into each cylinder. This allows more fuel to be injected and more power to be produced by the engine. The second function is to increase intake pressure. This improves the scavenging of the exhaust gasses out of the cylinder. Turbocharging is commonly found on high power four-stroke engines. It can also be used on two-stroke engines where the increase in intake pressure generated by the turbocharger is required to force the fresh air charge into the cylinder and help force the exhaust gasses out of the cylinder to enable the engine to run.

Supercharging

Supercharging an engine performs the same function as turbocharging an engine. The difference is the source of power used to drive the device that compresses the incoming fresh air. In a supercharged engine, the air is commonly compressed in a device called a blower. The blower is driven through gears directly from the engine's crankshaft. The most common type of blower uses two rotating rotors to compress the air. Supercharging is more commonly found on two-stroke engines where the higher pressures that a supercharger is capable of generating are needed.

Exhaust System

The exhaust system of a diesel engine performs three functions. First, the exhaust system routes the spent combustion gasses away from the engine, where they are diluted by the atmosphere. This keeps the area around the engine habitable. Second, the exhaust system confines and routes the gasses to the turbocharger, if used. Third, the exhaust system allows mufflers to be used to reduce the engine noise.

Operational Terminology

Before a detailed operation of a diesel engine can be explained, several terms must be defined.

Bore and Stroke

Bore and stroke are terms used to define the size of an engine. As previously stated, *bore* refers to the diameter of the engine's cylinder, and *stroke* refers to the distance the piston travels from the top of the cylinder to the bottom. The highest point of travel by the piston is called *top dead center* (TDC), and the lowest point of travel is called *bottom dead center* (BDC). There are 180° of travel between TDC and BDC, or one stroke.

Engine Displacement

Engine displacement is one of the terms used to compare one engine to another. *Displacement* refers to the total volume displaced by all the pistons during one stroke. The displacement is usually given in cubic inches or liters. To calculate the displacement of an engine, the volume of one cylinder must be determined (volume of a cylinder = $(\pi r^2)h$ where h = the stroke). The volume of one cylinder is multiplied by the number of cylinders to obtain the total engine displacement.

Degree of Crankshaft Rotation

All events that occur in an engine are related to the location of the piston. Because the piston is connected to the crankshaft, any location of the piston corresponds directly to a specific number of degrees of crankshaft rotation.

Location of the crank can then be stated as XX degrees before or XX degrees after top or bottom dead center.

Firing Order

Firing order refers to the order in which each of the cylinders in a multicylinder engine fires (power stroke). For example, a four cylinder engine's firing order could be 1-4-3-2. This means that the number 1 cylinder fires, then the number 4 cylinder fires, then the number 3 cylinder fires, and so on. Engines are designed so that the power strokes are as uniform as possible, that is, as the crankshaft rotates a certain number of degrees, one of the cylinders will go through a power stroke. This reduces vibration and allows the power generated by the engine to be applied to the load in a smoother fashion than if they were all to fire at once or in odd multiples.

Compression Ratio and Clearance Volume

Clearance volume is the volume remaining in the cylinder when the piston is at TDC. Because of the irregular shape of the combustion chamber (volume in the head) the clearance volume is calculated empirically by filling the chamber with a measured amount of fluid while the piston is at TDC. This volume is then added to the displacement volume in the cylinder to obtain the cylinders total volume.

An engine's *compression ratio* is determined by taking the volume of the cylinder with piston at TDC (highest point of travel) and dividing the volume of the cylinder when the piston is at BDC (lowest point of travel), as shown in Figure 15. This can be calculated by using the following formula:

$$\text{Compression Ratio} = \frac{\text{displacement volume} + \text{clearance volume}}{\text{clearance volume}}$$

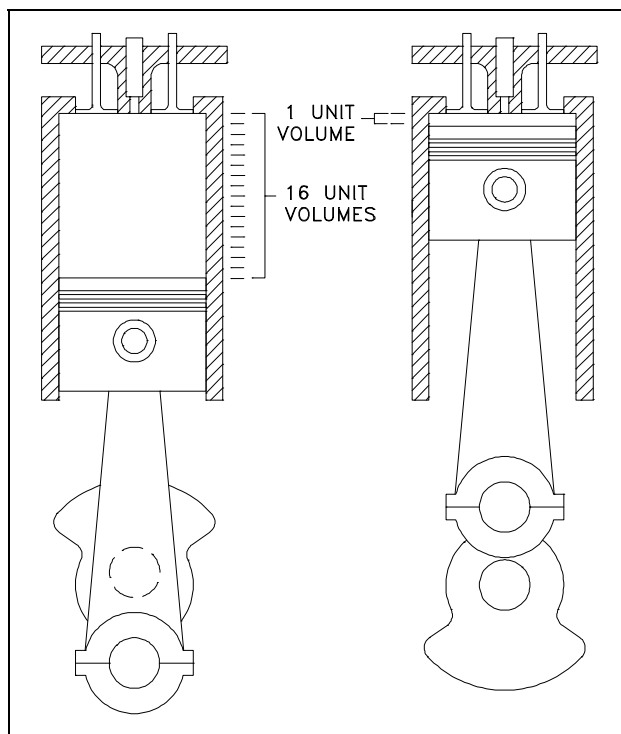


Figure 15 Compression Ratio

Horsepower

Power is the amount of work done per unit time or the rate of doing work. For a diesel engine, power is rated in units of horsepower. *Indicated horsepower* is the power transmitted to the pistons by the gas in the cylinders and is mathematically calculated.

Brake horsepower refers to the amount of usable power delivered by the engine to the crankshaft. Indicated horsepower can be as much as 15% higher than brake horsepower. The difference is due to internal engine friction, combustion inefficiencies, and parasitic losses, for example, oil pump, blower, water pump, etc.

The ratio of an engine's brake horsepower and its indicated horsepower is called the *mechanical efficiency* of the engine. The mechanical efficiency of a four-cycle diesel is about 82 to 90 percent. This is slightly lower than the efficiency of the two-cycle diesel engine. The lower mechanical efficiency is due to the additional friction losses and power needed to drive the piston through the extra 2 strokes.

Engines are rated not only in horsepower but also by the torque they produce. *Torque* is a measure of the engine's ability to apply the power it is generating. Torque is commonly given in units of lb-ft.

Summary

The important information in this chapter is summarized below.

Diesel Engines Summary

- The compression ratio is the volume of the cylinder with piston at TDC divided by the volume of the cylinder with piston at BDC.
- Bore is the diameter of the cylinder.
- Stroke is the distance the piston travels from TDC to BDC, and is determined by the eccentricity of the crankshaft.
- The combustion chamber is the volume of space where the fuel air mixture is burned in an engine. This is in the cylinder of the engine.
- The following components were discussed and identified on a drawing.
 - a. Piston and rod
 - b. Cylinder
 - c. Blower
 - d. Crankshaft
 - e. Intake ports or valve(s)
 - f. Exhaust ports or valve(s)
 - g. Fuel injector

FUNDAMENTALS OF THE DIESEL CYCLE

Diesel engines operate under the principle of the internal combustion engine. There are two basic types of diesel engines, two-cycle and four-cycle. An understanding of how each cycle operates is required to understand how to correctly operate and maintain a diesel engine.

- EO 1.3** **EXPLAIN** how a diesel engine converts the chemical energy stored in the diesel fuel into mechanical energy.
- EO 1.4** **EXPLAIN** how the ignition process occurs in a diesel engine.
- EO 1.5** **EXPLAIN** the operation of a 4-cycle diesel engine, including when the following events occur during a cycle:
- a. **Intake**
 - b. **Exhaust**
 - c. **Fuel injection**
 - d. **Compression**
 - e. **Power**
- EO 1.6** **EXPLAIN** the operation of a 2-cycle diesel engine, including when the following events occur during a cycle:
- a. **Intake**
 - b. **Exhaust**
 - c. **Fuel injection**
 - d. **Compression**
 - e. **Power**
-

The Basic Diesel Cycles

A diesel engine is a type of heat engine that uses the internal combustion process to convert the energy stored in the chemical bonds of the fuel into useful mechanical energy. This occurs in two steps. First, the fuel reacts chemically (burns) and releases energy in the form of heat. Second the heat causes the gasses trapped in the cylinder to expand, and the expanding gases, being confined by the cylinder, must move the piston to expand. The reciprocating motion of the piston is then converted into rotational motion by the crankshaft.

To convert the chemical energy of the fuel into useful mechanical energy all internal combustion engines must go through four events: intake, compression, power, and exhaust. How these events are timed and how they occur differentiates the various types of engines.

All diesel engines fall into one of two categories, two-stroke or four-stroke cycle engines. The word cycle refers to any operation or series of events that repeats itself. In the case of a four-stroke cycle engine, the engine requires four strokes of the piston (intake, compression, power, and exhaust) to complete one full cycle. Therefore, it requires two rotations of the crankshaft, or 720° of crankshaft rotation ($360^\circ \times 2$) to complete one cycle. In a two-stroke cycle engine the events (intake, compression, power, and exhaust) occur in only one rotation of the crankshaft, or 360° .

Timing

In the following discussion of the diesel cycle it is important to keep in mind the time frame in which each of the actions is required to occur. Time is required to move exhaust gas out of the cylinder and fresh air in to the cylinders, to compress the air, to inject fuel, and to burn the fuel. If a four-stroke diesel engine is running at a constant 2100 revolutions per minute (rpm), the crankshaft would be rotating at 35 revolutions, or 12,600 degrees, per second. One stroke is completed in about 0.01429 seconds.

The Four-Stroke Cycle

In a four-stroke engine the camshaft is geared so that it rotates at half the speed of the crankshaft (1:2). This means that the crankshaft must make two complete revolutions before the camshaft will complete one revolution. The following section will describe a four-stroke, normally aspirated, diesel engine having both intake and exhaust valves with a 3.5-inch bore and 4-inch stroke with a 16:1 compression ratio, as it passes through one complete cycle. We will start on the intake stroke. All the timing marks given are generic and will vary from engine to engine. Refer to Figures 10, 16, and 17 during the following discussion.

Intake

As the piston moves upward and approaches 28° before top dead center (BTDC), as measured by crankshaft rotation, the camshaft lobe starts to lift the cam follower. This causes the pushrod to move upward and pivots the rocker arm on the rocker arm shaft. As the valve lash is taken up, the rocker arm pushes the intake valve downward and the valve starts to open. The intake stroke now starts while the exhaust valve is still open. The flow of the exhaust gasses will have created a low

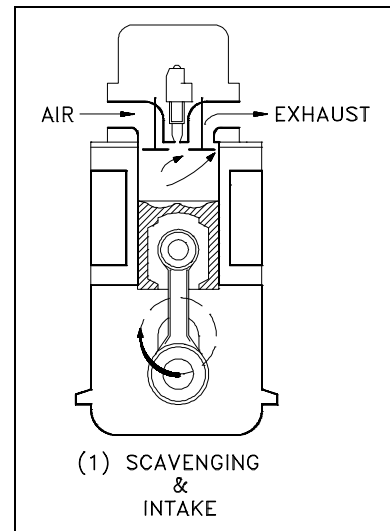


Figure 16 Scavenging and Intake

pressure condition within the cylinder and will help pull in the fresh air charge as shown in Figure 16.

The piston continues its upward travel through top dead center (TDC) while fresh air enters and exhaust gasses leave. At about 12° after top dead center (ATDC), the camshaft exhaust lobe rotates so that the exhaust valve will start to close. The valve is fully closed at 23° ATDC. This is accomplished through the valve spring, which was compressed when the valve was opened, forcing the rocker arm and cam follower back against the cam lobe as it rotates. The time frame during which both the intake and exhaust valves are open is called valve overlap (51° of overlap in this example) and is necessary to allow the fresh air to help scavenge (remove) the spent exhaust gasses and cool the cylinder. In most engines, 30 to 50 times cylinder volume is scavenged through the cylinder during overlap. This excess cool air also provides the necessary cooling effect on the engine parts.

As the piston passes TDC and begins to travel down the cylinder bore, the movement of the piston creates a suction and continues to draw fresh air into the cylinder.

Compression

At 35° after bottom dead center (ABDC), the intake valve starts to close. At 43° ABDC (or 137° BTDC), the intake valve is on its seat and is fully closed. At this point the air charge is at normal pressure (14.7 psia) and ambient air temperature (~80°F), as illustrated in Figure 17.

At about 70° BTDC, the piston has traveled about 2.125 inches, or about half of its stroke, thus reducing the volume in the cylinder by half. The temperature has now doubled to ~160°F and pressure is ~34 psia.

At about 43° BTDC the piston has traveled upward 3.062 inches of its stroke and the volume is once again halved. Consequently, the temperature again doubles to about 320°F and pressure is ~85 psia. When the piston has traveled to 3.530 inches of its stroke the volume is again halved and temperature reaches ~640°F and pressure 277 psia. When the piston has traveled to 3.757 inches of its stroke, or the volume is again halved, the temperature climbs to 1280°F and pressure reaches 742 psia. With a piston area of 9.616 in² the pressure in the cylinder is exerting a force of approximately 7135 lb. or 3-1/2 tons of force.

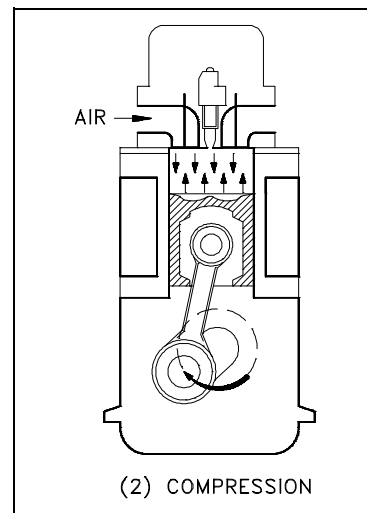


Figure 17 Compression

The above numbers are ideal and provide a good example of what is occurring in an engine during compression. In an actual engine, pressures reach only about 690 psia. This is due primarily to the heat loss to the surrounding engine parts.

Fuel Injection

Fuel in a liquid state is injected into the cylinder at a precise time and rate to ensure that the combustion pressure is forced on the piston neither too early nor too late, as shown in Figure 18. The fuel enters the cylinder where the heated compressed air is present; however, it will only burn when it is in a vaporized state (attained through the addition of heat to cause vaporization) and intimately mixed with a supply of oxygen. The first minute droplets of fuel enter the combustion chamber and are quickly vaporized. The vaporization of the fuel causes the air surrounding the fuel to cool and it requires time for the air to reheat sufficiently to ignite the vaporized fuel. But once ignition has started, the additional heat from combustion helps to further vaporize the new fuel entering the chamber, as long as oxygen is present. Fuel injection starts at 28° BTDC and ends at 3° ATDC; therefore, fuel is injected for a duration of 31°.

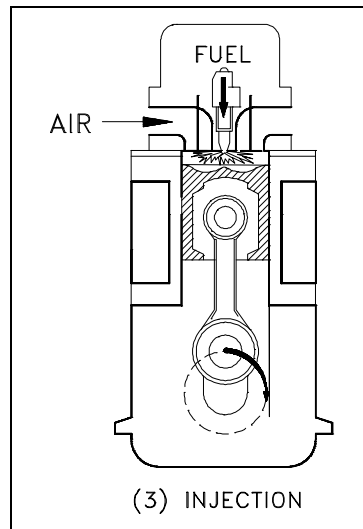


Figure 18 Fuel Injection

Power

Both valves are closed, and the fresh air charge has been compressed. The fuel has been injected and is starting to burn. After the piston passes TDC, heat is rapidly released by the ignition of the fuel, causing a rise in cylinder pressure. Combustion temperatures are around 2336°F. This rise in pressure forces the piston downward and increases the force on the crankshaft for the power stroke as illustrated in Figure 19.

The energy generated by the combustion process is not all harnessed. In a two stroke diesel engine, only about 38% of the generated power is harnessed to do work, about 30% is wasted in the form of heat rejected to the cooling system, and about 32% in the form of heat is rejected out the exhaust. In comparison, the four-stroke diesel engine has a thermal distribution of 42% converted

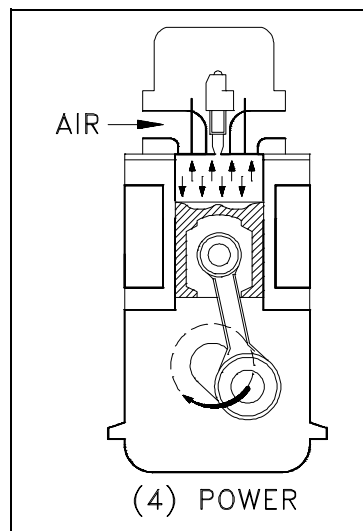


Figure 19 Power

to useful work, 28% heat rejected to the cooling system, and 30% heat rejected out the exhaust.

Exhaust

As the piston approaches 48° BBDC, the cam of the exhaust lobe starts to force the follower upward, causing the exhaust valve to lift off its seat. As shown in Figure 20, the exhaust gasses start to flow out the exhaust valve due to cylinder pressure and into the exhaust manifold. After passing BDC, the piston moves upward and accelerates to its maximum speed at 63° BTDC. From this point on the piston is decelerating. As the piston speed slows down, the velocity of the gasses flowing out of the cylinder creates a pressure slightly lower than atmospheric pressure. At 28° BTDC, the intake valve opens and the cycle starts again.

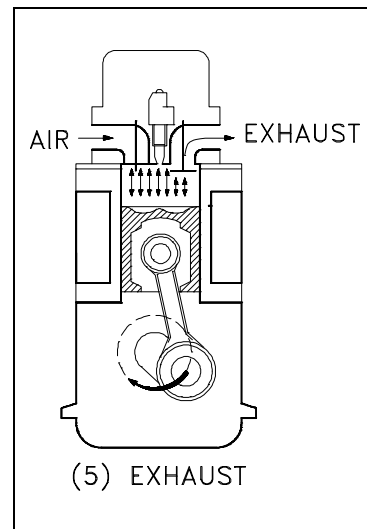


Figure 20 Exhaust

The Two-Stroke Cycle

Like the four-stroke engine, the two-stroke engine must go through the same four events: intake, compression, power, and exhaust. But a two-stroke engine requires only two strokes of the piston to complete one full cycle. Therefore, it requires only one rotation of the crankshaft to complete a cycle. This means several events must occur during each stroke for all four events to be completed in two strokes, as opposed to the four-stroke engine where each stroke basically contains one event.

In a two-stroke engine the camshaft is geared so that it rotates at the same speed as the crankshaft (1:1). The following section will describe a two-stroke, supercharged, diesel engine having intake ports and exhaust valves with a 3.5-inch bore and 4-inch stroke with a 16:1 compression ratio, as it passes through one complete cycle. We will start on the exhaust stroke. All the timing marks given are generic and will vary from engine to engine.

Exhaust and Intake

At 82° ATDC, with the piston near the end of its power stroke, the exhaust cam begins to lift the exhaust valves follower. The valve lash is taken up, and 9° later (91° ATDC), the rocker arm forces the exhaust valve off its seat. The exhaust gasses start to escape into the exhaust manifold, as shown in Figure 21. Cylinder pressure starts to decrease.

After the piston travels three-quarters of its (down) stroke, or 132° ATDC of crankshaft rotation, the piston starts to uncover the inlet ports. As the exhaust valve is still open, the uncovering of the inlet ports lets the compressed fresh air enter the cylinder and helps cool the cylinder and scavenge the cylinder of the remaining exhaust gasses (Figure 22). Commonly, intake and exhaust occur over approximately 96° of crankshaft rotation.

At 43° ABDC, the camshaft starts to close the exhaust valve. At 53° ABDC (117° BTDC), the camshaft has rotated sufficiently to allow the spring pressure to close the exhaust valve. Also, as the piston travels past 48° ABDC (5° after the exhaust valve starts closing), the intake ports are closed off by the piston.

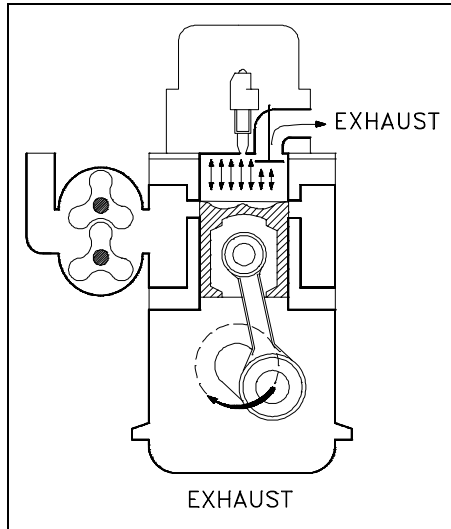


Figure 21 2-Stroke Exhaust

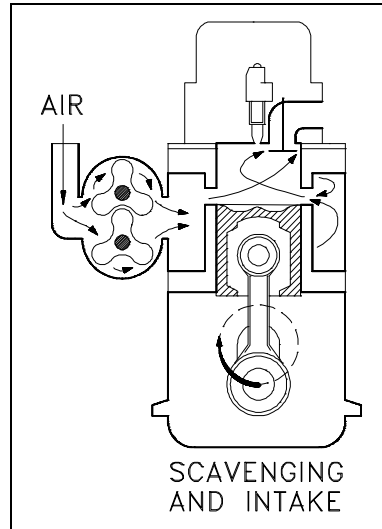


Figure 22 2-Stroke Intake

Compression

After the exhaust valve is on its seat (53° ATDC), the temperature and pressure begin to rise in nearly the same fashion as in the four-stroke engine. Figure 23 illustrates the compression in a 2-stroke engine. At 23° BTDC the injector cam begins to lift the injector follower and pushrod. Fuel injection continues until 6° BTDC (17 total degrees of injection), as illustrated in Figure 24.

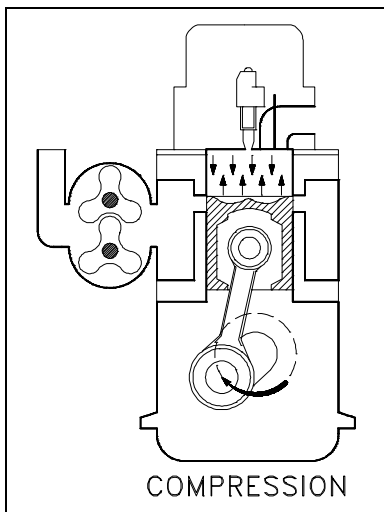


Figure 23 2-Stroke Compression

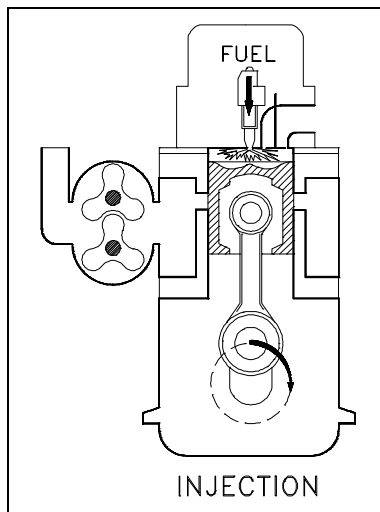


Figure 24 2-Stroke Fuel Injection

Power

The power stroke starts after the piston passes TDC. Figure 25 illustrates the power stroke which continues until the piston reaches 91° ATDC, at which point the exhaust valves start to open and a new cycle begins.

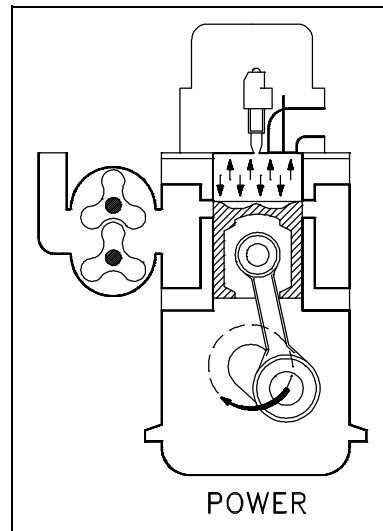


Figure 25 2-Stroke Power

Summary

The important information in this chapter is summarized below.

Fundamentals of the Diesel Cycle Summary

- Ignition occurs in a diesel by injecting fuel into the air charge which has been heated by compression to a temperature greater than the ignition point of the fuel.
- A diesel engine converts the energy stored in the fuel's chemical bonds into mechanical energy by burning the fuel. The chemical reaction of burning the fuel liberates heat, which causes the gasses to expand, forcing the piston to rotate the crankshaft.
- A four-stroke engine requires two rotations of the crankshaft to complete one cycle. The event occur as follows:

Intake - the piston passes TDC, the intake valve(s) open and the fresh air is admitted into the cylinder, the exhaust valve is still open for a few degrees to allow scavenging to occur.

Compression - after the piston passes BDC the intake valve closes and the piston travels up to TDC (completion of the first crankshaft rotation).

Fuel injection - As the piston nears TDC on the compression stroke, the fuel is injected by the injectors and the fuel starts to burn, further heating the gasses in the cylinder.

Power - the piston passes TDC and the expanding gasses force the piston down, rotating the crankshaft.

Exhaust - as the piston passes BDC the exhaust valves open and the exhaust gasses start to flow out of the cylinder. This continues as the piston travels up to TDC, pumping the spent gasses out of the cylinder. At TDC the second crankshaft rotation is complete.

Fundamentals of the Diesel Cycle Summary (Cont.)

- A two-stroke engine requires one rotation of the crankshaft to complete one cycle. The events occur as follows:

Intake - the piston is near BDC and exhaust is in progress. The intake valve or ports open and the fresh air is forced in. The exhaust valves or ports are closed and intake continues.

Compression - after both the exhaust and intake valves or ports are closed, the piston travels up towards TDC. The fresh air is heated by the compression.

Fuel injection - near TDC the fuel is injected by the injectors and the fuel starts to burn, further heating the gasses in the cylinder.

Power - the piston passes TDC and the expanding gasses force the piston down, rotating the crankshaft.

Exhaust - as the piston approaches BDC the exhaust valves or ports open and the exhaust gasses start to flow out of the cylinder.

DIESEL ENGINE SPEED, FUEL CONTROLS, AND PROTECTION

Understanding how diesel engines are controlled and the types of protective instrumentation available is important for a complete understanding of the operation of a diesel engine.

EO 1.7 **DESCRIBE** how the mechanical-hydraulic governor on a diesel engine controls engine speed.

EO 1.8 **LIST** five protective alarms usually found on mid-sized and larger diesel engines.

Engine Control

The control of a diesel engine is accomplished through several components: the camshaft, the fuel injector, and the governor. The camshaft provides the timing needed to properly inject the fuel, the fuel injector provides the component that meters and injects the fuel, and the governor regulates the amount of fuel that the injector is to inject. Together, these three major components ensure that the engine runs at the desired speed.

Fuel Injectors

Each cylinder has a fuel injector designed to meter and inject fuel into the cylinder at the proper instant. To accomplish this function, the injectors are actuated by the engine's camshaft. The camshaft provides the timing and pumping action used by the injector to inject the fuel. The injectors meter the amount of fuel injected into the cylinder on each stroke. The amount of fuel to be injected by each injector is set by a mechanical linkage called the fuel rack. The fuel rack position is controlled by the engine's governor. The governor determines the amount of fuel required to maintain the desired engine speed and adjusts the amount to be injected by adjusting the position of the fuel rack.

Each injector operates in the following manner. As illustrated in Figure 26, fuel under pressure enters the injector through the injector's filter cap and filter element. From the filter element the fuel travels down into the supply chamber (that area between the plunger bushing and the spill deflector). The plunger operates up and down in the bushing, the bore of which is open to the fuel supply in the supply chamber by two funnel-shaped ports in the plunger bushing.

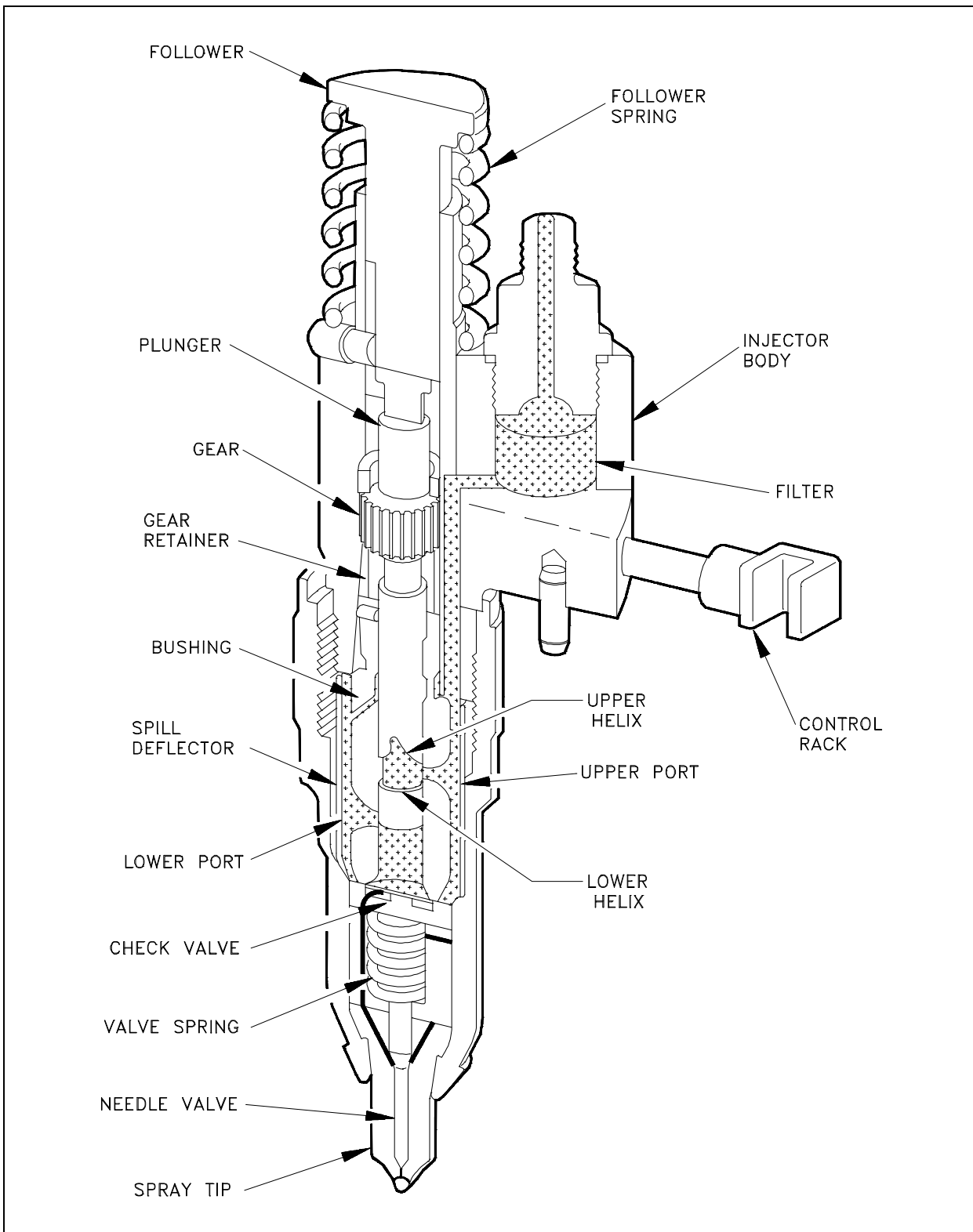


Figure 26 Fuel Injector Cutaway

The motion of the injector rocker arm (not shown) is transmitted to the plunger by the injector follower which bears against the follower spring. As the plunger moves downward under pressure of the injector rocker arm, a portion of the fuel trapped under the plunger is displaced into the supply chamber through the lower port until the port is closed off by the lower end of the plunger. The fuel trapped below the plunger is then forced up through the central bore of the plunger and back out the upper port until the upper port is closed off by the downward motion of the plunger. With the upper and lower ports both closed off, the remaining fuel under the plunger is subjected to an increase in pressure by the downward motion of the plunger.

When sufficient pressure has built up, the injector valve is lifted off its seat and the fuel is forced through small orifices in the spray tip and atomized into the combustion chamber. A check valve, mounted in the spray tip, prevents air in the combustion chamber from flowing back into the fuel injector. The plunger is then returned back to its original position by the injector follower spring.

On the return upward movement of the plunger, the high pressure cylinder within the bushing is again filled with fresh fuel oil through the ports. The constant circulation of fresh, cool fuel through the injector renews the fuel supply in the chamber and helps cool the injector. The fuel flow also effectively removes all traces of air that might otherwise accumulate in the system.

The fuel injector outlet opening, through which the excess fuel returns to the fuel return manifold and then back to the fuel tank, is adjacent to the inlet opening and contains a filter element exactly the same as the one on the fuel inlet side.

In addition to the reciprocating motion of the plunger, the plunger can be rotated during operation around its axis by the gear which meshes with the fuel rack. For metering the fuel, an upper helix and a lower helix are machined in the lower part of the plunger. The relation of the helices to the two ports in the injector bushing changes with the rotation of the plunger.

Changing the position of the helices, by rotating the plunger, retards or advances the closing of the ports and the beginning and ending of the injection period. At the same time, it increases or decreases the amount of fuel injected into the cylinder. Figure 27 illustrates the various plunger positions from NO LOAD to FULL LOAD. With the control rack pulled all the way (no injection), the upper port is not closed by the helix until after the lower port is uncovered. Consequently, with the rack in this position, all of the fuel is forced back into the supply chamber and no injection of fuel takes place. With the control rack pushed all the way in (full injection), the upper port is closed shortly after the lower port has been covered, thus producing a maximum effective stroke and maximum fuel injection. From this no-injection position to the full-injection position (full rack movement), the contour of the upper helix advances the closing of the ports and the beginning of injection.

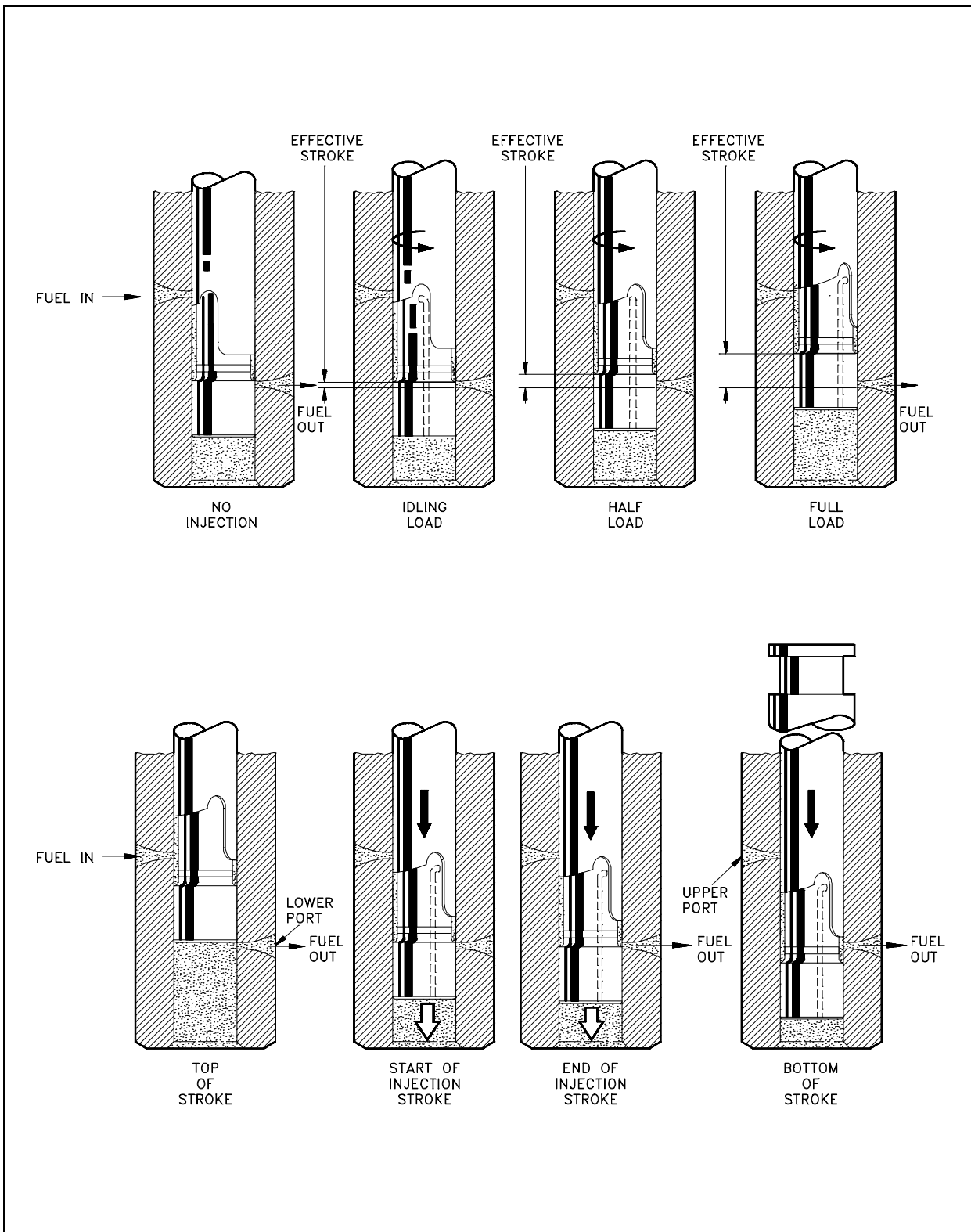


Figure 27 Fuel Injector Plunger

Governor

Diesel engine speed is controlled solely by the amount of fuel injected into the engine by the injectors. Because a diesel engine is not self-speed-limiting, it requires not only a means of changing engine speed (throttle control) but also a means of maintaining the desired speed. The governor provides the engine with the feedback mechanism to change speed as needed and to maintain a speed once reached.

A governor is essentially a speed-sensitive device, designed to maintain a constant engine speed regardless of load variation. Since all governors used on diesel engines control engine speed through the regulation of the quantity of fuel delivered to the cylinders, these governors may be classified as speed-regulating governors. As with the engines themselves there are many types and variations of governors. In this module, only the common mechanical-hydraulic type governor will be reviewed.

The major function of the governor is determined by the application of the engine. In an engine that is required to come up and run at only a single speed regardless of load, the governor is called a constant-speed type governor. If the engine is manually controlled, or controlled by an outside device with engine speed being controlled over a range, the governor is called a variable-speed type governor. If the engine governor is designed to keep the engine speed above a minimum and below a maximum, then the governor is a speed-limiting type. The last category of governor is the load limiting type. This type of governor limits fuel to ensure that the engine is not loaded above a specified limit. Note that many governors act to perform several of these functions simultaneously.

Operation of a Governor

The following is an explanation of the operation of a constant speed, hydraulically compensated governor using the Woodward brand governor as an example. The principles involved are common in any mechanical and hydraulic governor.

The Woodward speed governor operates the diesel engine fuel racks to ensure a constant engine speed is maintained at any load. The governor is a mechanical-hydraulic type governor and receives its supply of oil from the engine lubricating system. This means that a loss of lube oil pressure will cut off the supply of oil to the governor and cause the governor to shut down the engine. This provides the engine with a built-in shutdown device to protect the engine in the event of loss of lubricating oil pressure.

Simplified Operation of the Governor

The governor controls the fuel rack position through a combined action of the hydraulic piston and a set of mechanical flyweights, which are driven by the engine blower shaft. Figure 28 provides an illustration of a functional diagram of a mechanical-hydraulic governor. The position of the flyweights is determined by the speed of the engine. As the engine speeds up or down, the weights move in or out. The movement of the flyweights, due to a change in engine speed, moves a small piston (pilot valve) in the governor's hydraulic system. This motion adjusts flow of hydraulic fluid to a large hydraulic piston (servo-motor piston). The large hydraulic piston is linked to the fuel rack and its motion resets the fuel rack for increased/decreased fuel.

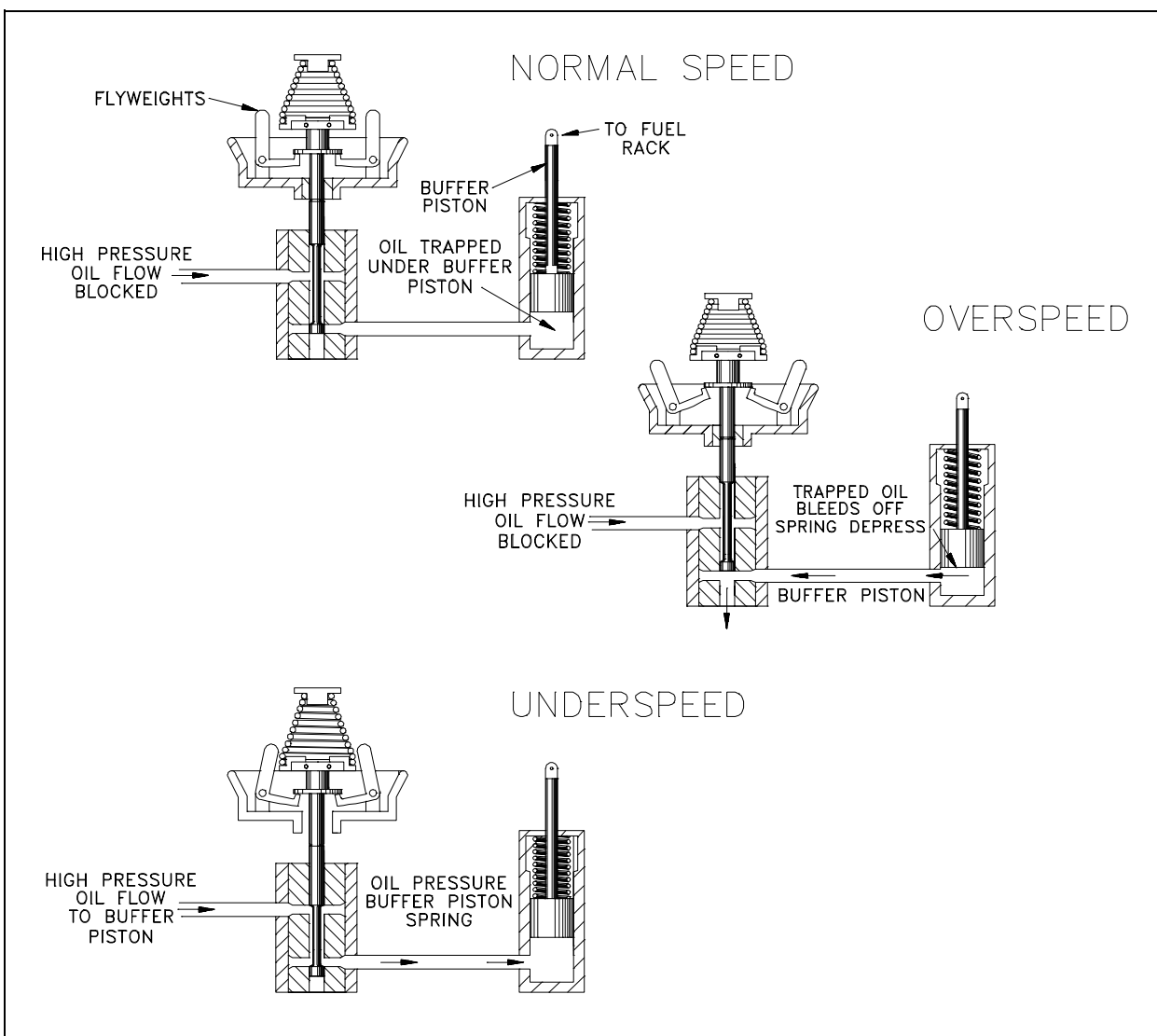


Figure 28 Simplified Mechanical-Hydraulic Governor

Detailed Operation of the Governor

With the engine operating, oil from the engine lubrication system is supplied to the governor pump gears, as illustrated in Figure 29. The pump gears raise the oil pressure to a value determined by the spring relief valve. The oil pressure is maintained in the annular space between the undercut portion of the pilot valve plunger and the bore in the pilot valve bushing. For any given speed setting, the spring speeder exerts a force that is opposed by the centrifugal force of the revolving flyweights. When the two forces are equal, the control land on the pilot valve plunger covers the lower ports in the pilot valve bushing.

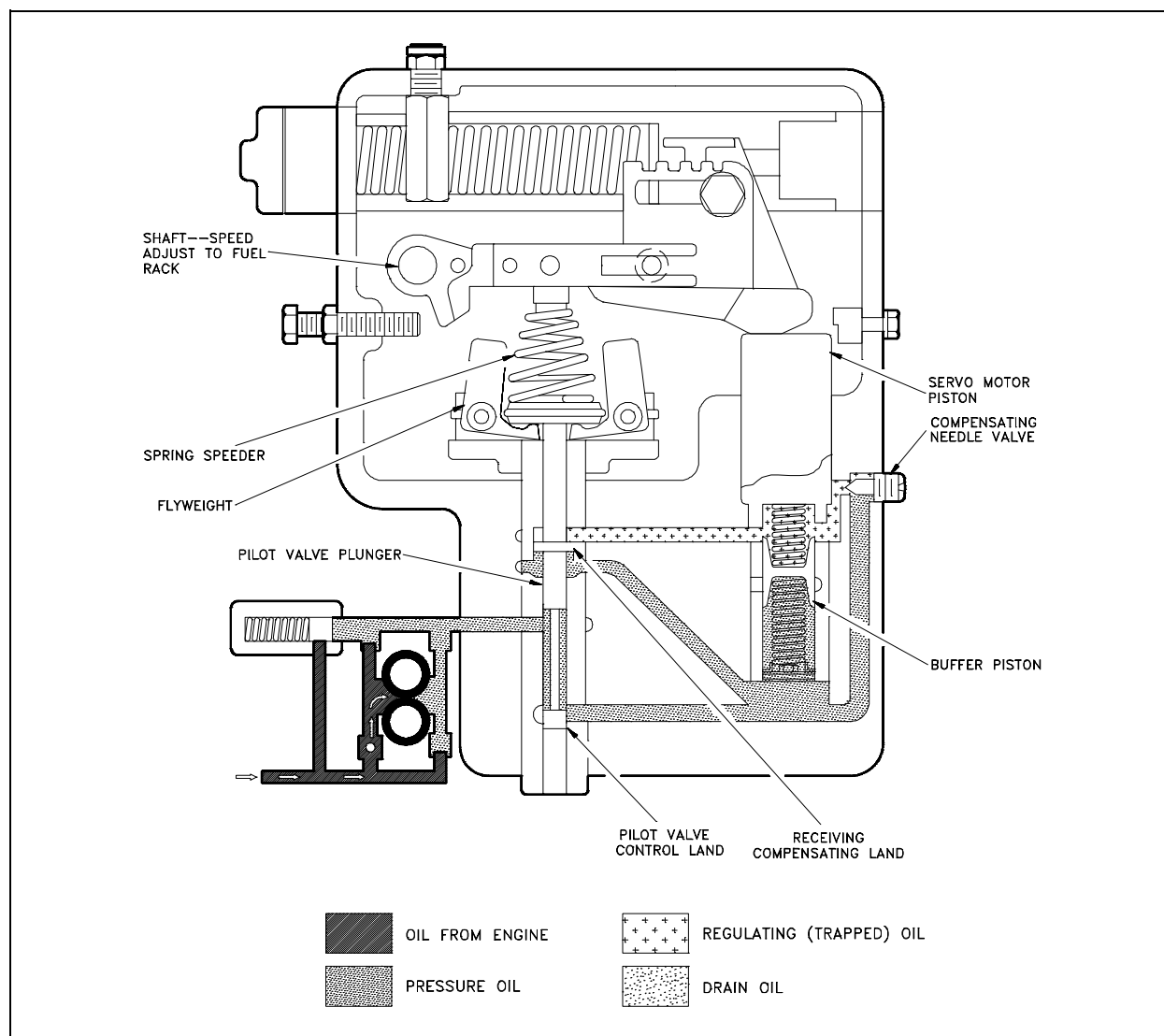


Figure 29 Cutaway of a Woodward Governor

Under these conditions, equal oil pressures are maintained on both sides of the buffer piston and tension on the two buffer springs is equal. Also, the oil pressure is equal on both sides of the receiving compensating land of the pilot valve plunger due to oil passing through the compensating needle valve. Thus, the hydraulic system is in balance, and the engine speed remains constant.

When the engine load increases, the engine starts to slow down in speed. The reduction in engine speed will be sensed by the governor flyweights. The flyweights are forced inward (by the spring), thus lowering the pilot valve plunger (again, due to the downward spring force). Oil under pressure will be admitted under the servo-motor piston (topside of the buffer piston) causing it to rise. This upward motion of the servo-motor piston will be transmitted through the terminal lever to the fuel racks, thus increasing the amount of fuel injected into the engine. The oil that forces the servo-motor piston upward also forces the buffer piston upward because the oil pressure on each side of the piston is unequal. This upward motion of the piston compresses the upper buffer spring and relieves the pressure on the lower buffer spring.

The oil cavities above and below the buffer piston are common to the receiving compensating land on the pilot valve plunger. Because the higher pressure is below the compensating land, the pilot valve plunger is forced upward, recentering the flyweights and causing the control land of the pilot valve to close off the regulating port. Thus, the upward movement of the servo-motor piston stops when it has moved far enough to make the necessary fuel correction.

Oil passing through the compensating needle valve slowly equalizes the pressures above and below the buffer piston, thus allowing the buffer piston to return to the center position, which in turn equalizes the pressure above and below the receiving compensating land. The pilot valve plunger then moves to its central position and the engine speed returns to its original setting because there is no longer any excessive outward force on the flyweights.

The action of the flyweights and the hydraulic feedback mechanism produces stable engine operation by permitting the governor to move instantaneously in response to the load change and to make the necessary fuel adjustment to maintain the initial engine speed.

Starting Circuits

Diesel engines have as many different types of starting circuits as there are types, sizes, and manufacturers of diesel engines. Commonly, they can be started by air motors, electric motors, hydraulic motors, and manually. The start circuit can be a simple manual start pushbutton, or a complex auto-start circuit. But in almost all cases the following events must occur for the starting engine to start.

1. The start signal is sent to the starting motor. The air, electric, or hydraulic motor, will engage the engine's flywheel.
2. The starting motor will crank the engine. The starting motor will spin the engine at a high enough rpm to allow the engine's compression to ignite the fuel and start the engine running.
3. The engine will then accelerate to idle speed. When the starter motor is overdriven by the running motor it will disengage the flywheel.

Because a diesel engine relies on compression heat to ignite the fuel, a cold engine can rob enough heat from the gasses that the compressed air falls below the ignition temperature of the fuel. To help overcome this condition, some engines (usually small to medium sized engines) have glowplugs. Glowplugs are located in the cylinder head of the combustion chamber and use electricity to heat up the electrode at the top of the glowplug. The heat added by the glowplug is sufficient to help ignite the fuel in the cold engine. Once the engine is running, the glowplugs are turned off and the heat of combustion is sufficient to heat the block and keep the engine running.

Larger engines usually heat the block and/or have powerful starting motors that are able to spin the engine long enough to allow the compression heat to fire the engine. Some large engines use air start manifolds that inject compressed air into the cylinders which rotates the engine during the start sequence.

Engine Protection

A diesel engine is designed with protection systems to alert the operators of abnormal conditions and to prevent the engine from destroying itself.

Overspeed device - Because a diesel is not self-speed-limiting, a failure in the governor, injection system, or sudden loss of load could cause the diesel to overspeed. An overspeed condition is extremely dangerous because engine failure is usually catastrophic and can possibly cause the engine to fly apart.

An overspeed device, usually some type of mechanical flyweight, will act to cut off fuel to the engine and alarm at a certain preset rpm. This is usually accomplished by isolating the governor from its oil supply, causing it to travel to the no-fuel position, or it can override the governor and directly trip the fuel rack to the no-fuel position.

Water jacket -

Water-cooled engines can overheat if the cooling water system fails to remove waste heat. Removal of the waste heat prevents the engine from seizing due to excessive expansion of the components under a high temperature condition. The cooling water jacket is commonly where the sensor for the cooling water system is located.

The water jacket temperature sensors provide early warning of abnormal engine temperature, usually an alarm function only. The setpoint is set such that if the condition is corrected in a timely manner, significant engine damage will be avoided. But continued engine operation at the alarm temperature or higher temperatures will lead to engine damage.

Exhaust
temperatures -

In a diesel engine, exhaust temperatures are very important and can provide a vast amount of information regarding the operation of the engine. High exhaust temperature can indicate an overloading of the engine or possible poor performance due to inadequate scavenging (the cooling effect) in the engine. Extended operation with high exhaust temperatures can result in damage to the exhaust valves, piston, and cylinders. The exhaust temperature usually provides only an alarm function.

Low lube oil
pressure -

Low oil pressure or loss of oil pressure can destroy an engine in short order. Therefore, most medium to larger engines will stop upon low or loss of oil pressure. Loss of oil pressure can result in the engine seizing due to lack of lubrication. Engines with mechanical-hydraulic governors will also stop due to the lack of oil to the governor.

The oil pressure sensor usually stops the engine. The oil pressure sensors on larger engines usually have two low pressure setpoints. One setpoint provides early warning of abnormal oil pressure, an alarm function only. The second setpoint can be set to shutdown the engine before permanent damage is done.

High crankcase
pressure -

High crankcase pressure is usually caused by excessive blow-by (gas pressure in the cylinder blowing by the piston rings and into the crankcase). The high pressure condition indicates the engine is in poor condition. The high crankcase pressure is usually used only as an alarm function.

Summary

The important information in this chapter is summarized below.

Diesel Engine Speed, Fuel Controls, and Protection Summary

- A mechanical-hydraulic governor controls engine speed by balancing engine speed (mechanical flyweights) against hydraulic pressure. As the engine speeds up or slows down, the weights move the hydraulic plunger in or out. This in turn actuates a hydraulic valve which controls the hydraulic pressure to the buffer piston. The buffer piston is connected to the fuel rack. Therefore, any motion of the buffer piston will control fuel to the cylinder by adjusting the position of the fuel rack, which regulates the amount of fuel in the injectors.
- Most mid-sized to large diesel engines have (as a minimum) the following protective alarms and trips.

Engine overspeed alarm/trip

High water jacket temperature alarm

High exhaust temperature alarm

Low lube oil pressure (alarm and/or trip)

High crankcase pressure alarm

**Department of Energy
Fundamentals Handbook**

**MECHANICAL SCIENCE
Module 2
Heat Exchangers**

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TERMINAL OBJECTIVE

- 1.0 Without references, **DESCRIBE** the purpose, construction, and principles of operation for each major type of heat exchanger: parallel flow, counter flow, and cross flow.

ENABLING OBJECTIVES

- 1.1 **STATE** the two types of heat exchanger construction.
- 1.2 Provided with a drawing of a heat exchanger, **IDENTIFY** the following internal parts:
- a. Tubes
 - b. Tube sheet
 - c. Shell
 - d. Baffles
- 1.3 **DESCRIBE** hot and cold fluid flow in parallel flow, counter flow, and cross flow heat exchangers.
- 1.4 **DIFFERENTIATE** between the following types of heat exchangers:
- a. Single-pass versus multi-pass heat exchangers.
 - b. Regenerative versus non-regenerative heat exchangers.
- 1.5 **LIST** at least three applications of heat exchangers.
- 1.6 **STATE** the purpose of a condenser.
- 1.7 **DEFINE** the following terms:
- a. Hotwell
 - b. Condensate depression
- 1.8 **STATE** why condensers in large steam cycles are operated at a vacuum.

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TYPES OF HEAT EXCHANGERS

In almost any nuclear, chemical, or mechanical system, heat must be transferred from one place to another or from one fluid to another. Heat exchangers are used to transfer heat from one fluid to another. A basic understanding of the mechanical components of a heat exchanger is important to understanding how they function and operate.

- EO 1.1** **STATE** the two types of heat exchanger construction.
- EO 1.2** **Provided with a drawing of a heat exchanger, IDENTIFY** the following internal parts:
- | | | | |
|-----------|-------------------|-----------|----------------|
| a. | Tubes | c. | Shell |
| b. | Tube sheet | d. | Baffles |
- EO 1.3** **DESCRIBE** hot and cold fluid flow in parallel flow, counter flow, and cross flow heat exchangers.
- EO 1.4** **DIFFERENTIATE** between the following types of heat exchangers:
- | | |
|-----------|---|
| a. | Single-pass versus multi-pass heat exchangers |
| b. | Regenerative versus non-regenerative heat exchangers |
-

Introduction

A heat exchanger is a component that allows the transfer of heat from one fluid (liquid or gas) to another fluid. Reasons for heat transfer include the following:

1. To heat a cooler fluid by means of a hotter fluid
2. To reduce the temperature of a hot fluid by means of a cooler fluid
3. To boil a liquid by means of a hotter fluid
4. To condense a gaseous fluid by means of a cooler fluid
5. To boil a liquid while condensing a hotter gaseous fluid

Regardless of the function the heat exchanger fulfills, in order to transfer heat the fluids involved must be at different temperatures and they must come into thermal contact. Heat can flow only from the hotter to the cooler fluid.

In a heat exchanger there is no direct contact between the two fluids. The heat is transferred from the hot fluid to the metal isolating the two fluids and then to the cooler fluid.

Types of Heat Exchanger Construction

Although heat exchangers come in every shape and size imaginable, the construction of most heat exchangers fall into one of two categories: tube and shell, or plate. As in all mechanical devices, each type has its advantages and disadvantages.

Tube and Shell

The most basic and the most common type of heat exchanger construction is the tube and shell, as shown in Figure 1. This type of heat exchanger consists of a set of *tubes* in a container called a *shell*. The fluid flowing inside the tubes is called the tube side fluid and the fluid flowing on the outside of the tubes is the shell side fluid. At the ends of the tubes, the tube side fluid is separated from the shell side fluid by the tube sheet(s). The tubes are rolled and press-fitted or welded into the tube sheet to provide a leak tight seal. In systems where the two fluids are at vastly different pressures, the higher pressure fluid is typically directed through the tubes and the lower pressure fluid is circulated on the shell side. This is due to economy, because the heat exchanger tubes can be made to withstand higher pressures than the shell of the heat exchanger for a much lower cost. The support plates shown on Figure 1 also act as baffles to direct the flow of fluid within the shell back and forth across the tubes.

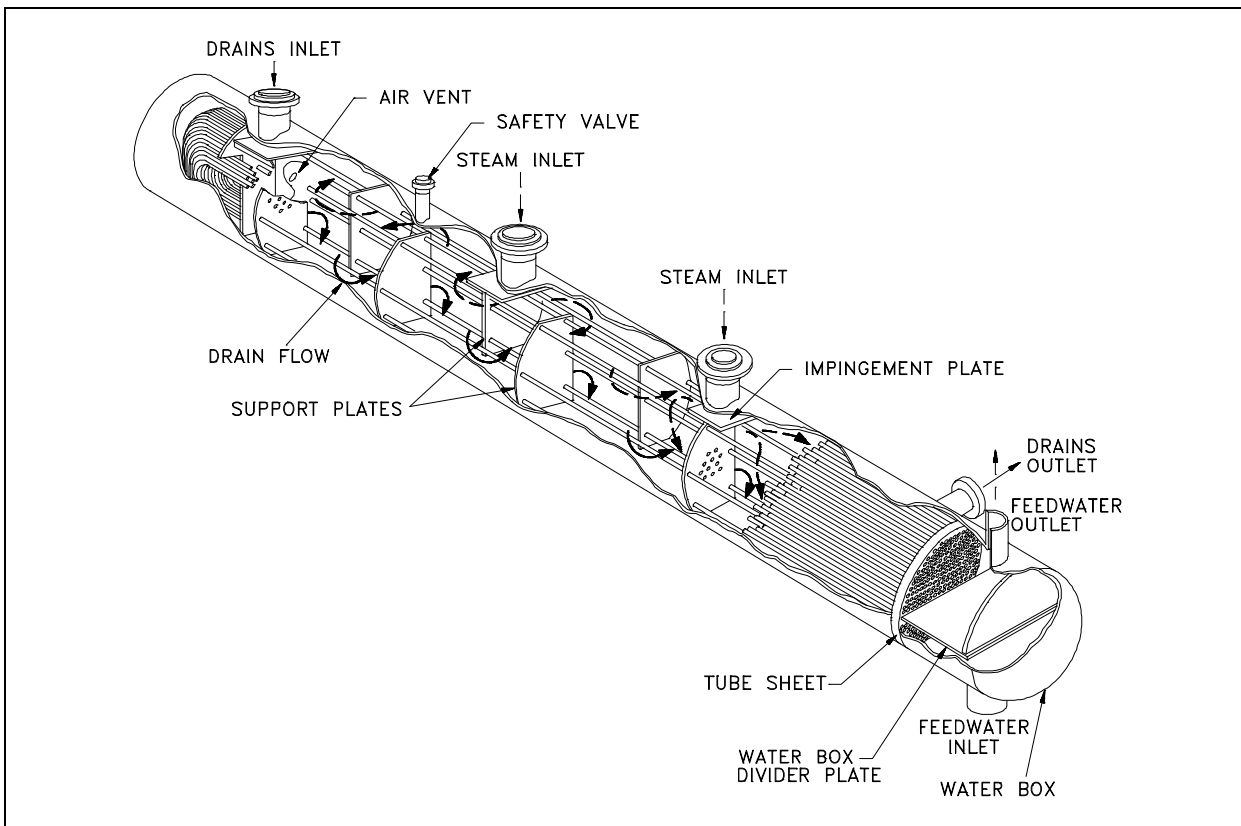


Figure 1 Tube and Shell Heat Exchanger

Plate

A plate type heat exchanger, as illustrated in Figure 2, consists of plates instead of tubes to separate the hot and cold fluids. The hot and cold fluids alternate between each of the plates. Baffles direct the flow of fluid between plates. Because each of the plates has a very large surface area, the plates provide each of the fluids with an extremely large heat transfer area. Therefore a plate type heat exchanger, as compared to a similarly sized tube and shell heat exchanger, is capable of transferring much more heat. This is due to the larger area the plates provide over tubes. Due to the high heat transfer efficiency of the plates, plate type heat exchangers are usually very small when compared to a tube and shell type heat exchanger with the same heat transfer capacity. Plate type heat exchangers are not widely used because of the inability to reliably seal the large gaskets between each of the plates. Because of this problem, plate type heat exchangers have only been used in small, low pressure applications such as on oil coolers for engines. However, new improvements in gasket design and overall heat exchanger design have allowed some large scale applications of the plate type heat exchanger. As older facilities are upgraded or newly designed facilities are built, large plate type heat exchangers are replacing tube and shell heat exchangers and becoming more common.

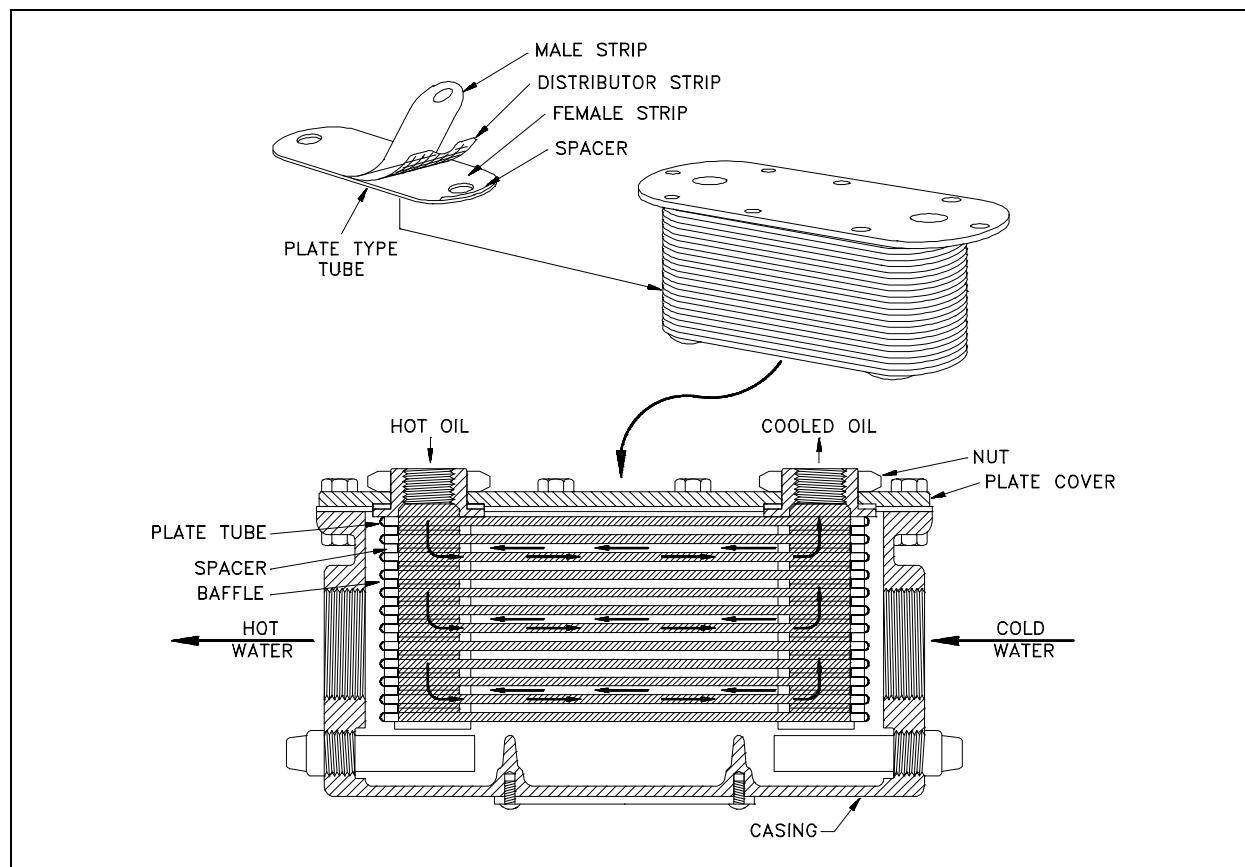


Figure 2 Plate Heat Exchanger

Types of Heat Exchangers

Because heat exchangers come in so many shapes, sizes, makes, and models, they are categorized according to common characteristics. One common characteristic that can be used to categorize them is the direction of flow the two fluids have relative to each other. The three categories are parallel flow, counter flow and cross flow.

Parallel flow, as illustrated in Figure 3, exists when both the tube side fluid and the shell side fluid flow in the same direction. In this case, the two fluids enter the heat exchanger from the same end with a large temperature difference. As the fluids transfer heat, hotter to cooler, the temperatures of the two fluids approach each other. Note that the hottest cold-fluid temperature is always less than the coldest hot-fluid temperature.

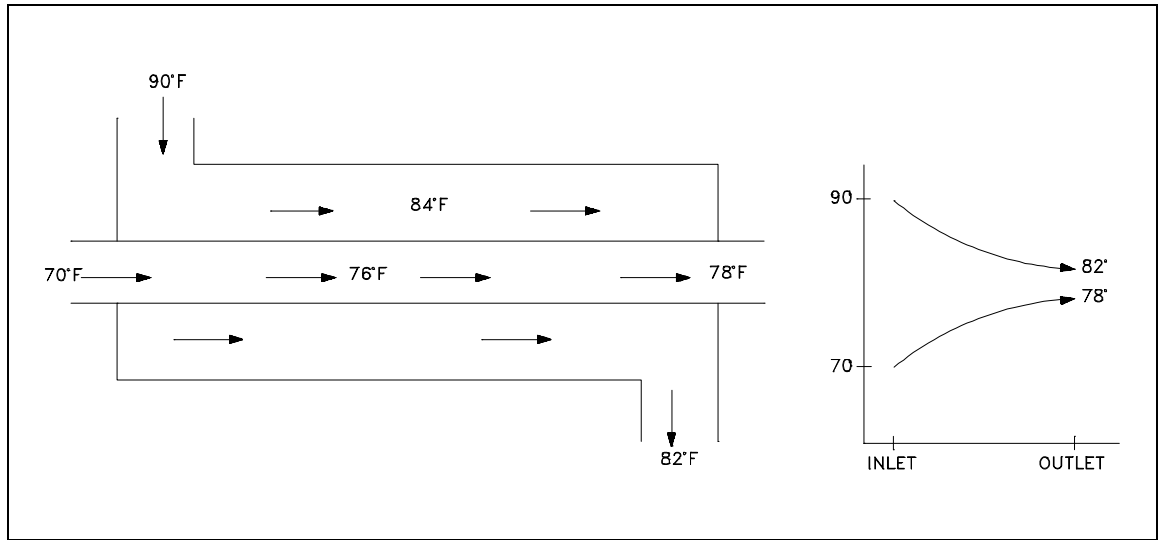


Figure 3 Parallel Flow Heat Exchanger

Counter flow, as illustrated in Figure 4, exists when the two fluids flow in opposite directions. Each of the fluids enters the heat exchanger at opposite ends. Because the cooler fluid exits the counter flow heat exchanger at the end where the hot fluid enters the heat exchanger, the cooler fluid will approach the inlet temperature of the hot fluid. Counter flow heat exchangers are the most efficient of the three types. In contrast to the parallel flow heat exchanger, the counter flow heat exchanger can have the hottest cold-fluid temperature greater than the coldest hot-fluid temperature.

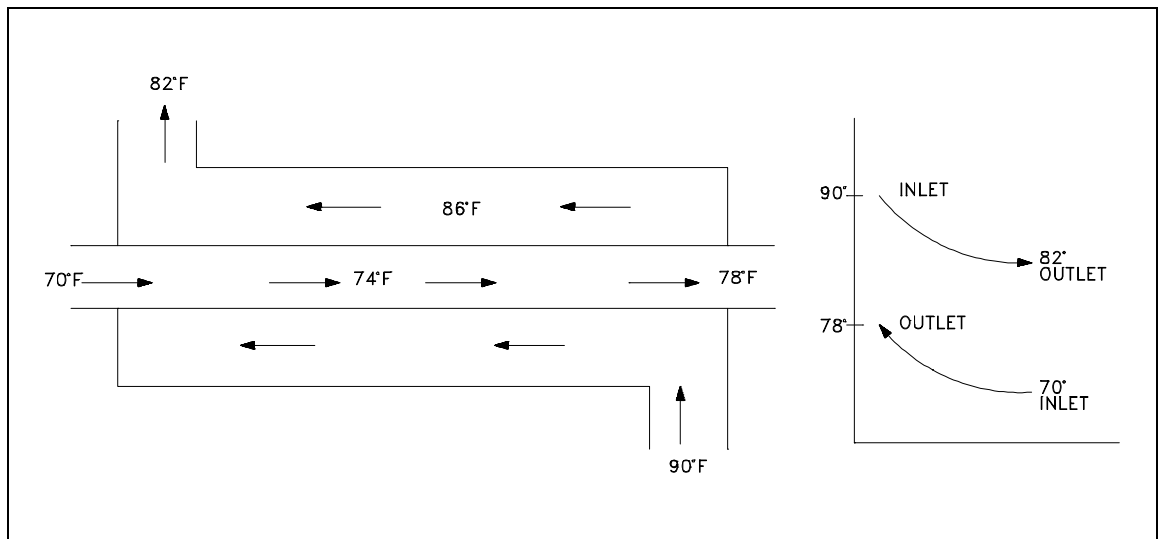


Figure 4 Counter Flow Heat Exchange

Cross flow, as illustrated in Figure 5, exists when one fluid flows perpendicular to the second fluid; that is, one fluid flows through tubes and the second fluid passes around the tubes at 90° angle. Cross flow heat exchangers are usually found in applications where one of the fluids changes state (2-phase flow). An example is a steam system's condenser, in which the steam exiting the turbine enters the condenser shell side, and the cool water flowing in the tubes absorbs the heat from the steam, condensing it into water. Large volumes of vapor may be condensed using this type of heat exchanger flow.

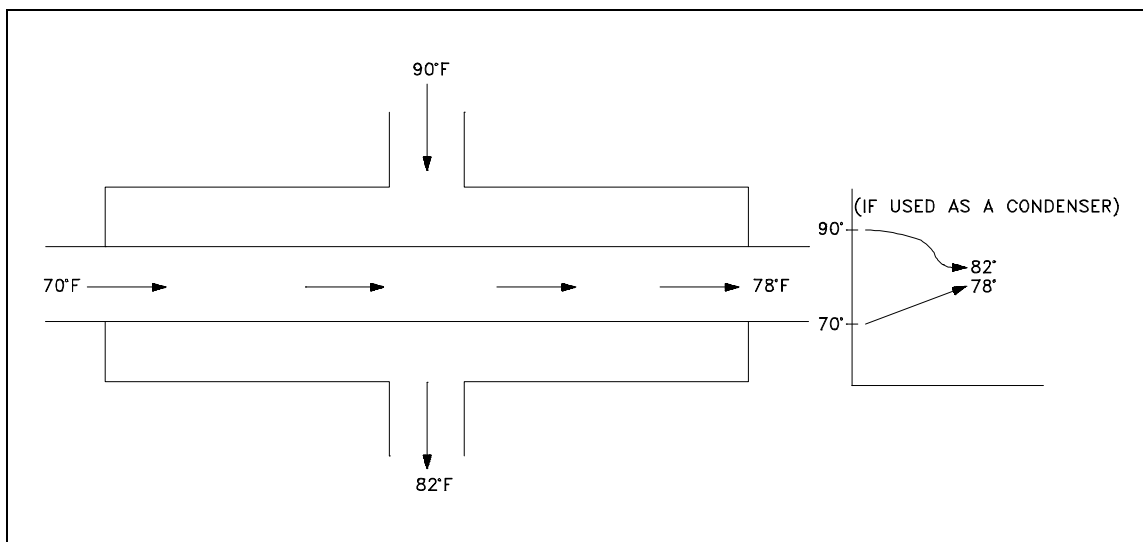


Figure 5 Cross Flow Heat Exchanger

Comparison of the Types of Heat Exchangers

Each of the three types of heat exchangers has advantages and disadvantages. But of the three, the counter flow heat exchanger design is the most efficient when comparing heat transfer rate per unit surface area. The efficiency of a counter flow heat exchanger is due to the fact that the average ΔT (difference in temperature) between the two fluids over the length of the heat exchanger is maximized, as shown in Figure 4. Therefore the log mean temperature for a counter flow heat exchanger is larger than the log mean temperature for a similar parallel or cross flow heat exchanger. (See the Thermodynamics, Heat Transfer, and Fluid Flow Fundamentals Handbook for a review of log mean temperature). This can be seen by comparing the graphs in Figure 3, Figure 4, and Figure 5. The following exercise demonstrates how the higher log mean temperature of the counter flow heat exchanger results in a larger heat transfer rate. The log mean temperature for a heat exchanger is calculated using the following equation.

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}} \quad (2-1)$$

Heat transfer in a heat exchanger is by conduction and convection. The rate of heat transfer, "Q", in a heat exchanger is calculated using the following equation.

$$\dot{Q} = U_o A_o \Delta T_{lm} \quad (2-2)$$

Where:

\dot{Q} = Heat transfer rate (BTU/hr)

U_o = Overall heat transfer coefficient (BTU/hr-ft²-°F)

A_o = Cross sectional heat transfer area (ft²)

ΔT_{lm} = Log mean temperature difference (°F)

Consider the following example of a heat exchanger operated under identical conditions as a counter flow and then a parallel flow heat exchanger.

T_1 = represents the hot fluid temperature

T_{1in} = 200°F

T_{1out} = 145°F

U_o = 70 BTU/hr-ft²-°F

A_o = 75ft²

T_2 = represents the cold fluid temperature

T_{2in} = 80°F

T_{2out} = 120°F

$$\text{Counter flow } \Delta T_{lm} = \frac{(200-120^\circ\text{F}) - (145-80^\circ\text{F})}{\ln \frac{(200-120^\circ\text{F})}{(145-80^\circ\text{F})}} = 72^\circ\text{F}$$

$$\text{Parallel flow } \Delta T_{lm} = \frac{(200-80^{\circ}\text{F}) - (145-120^{\circ}\text{F})}{\ln \frac{(200-80^{\circ}\text{F})}{(145-120^{\circ}\text{F})}} = 61^{\circ}\text{F}$$

Inserting the above values into heat transfer Equation (2-2) for the counter flow heat exchanger yields the following result.

$$\dot{Q} = \left(70 \frac{\text{BTU}}{\text{hr-ft}^2-^{\circ}\text{F}}\right) (75\text{ft}^2) (72^{\circ}\text{F})$$

$$\dot{Q} = 3.8 \times 10^5 \frac{\text{BTU}}{\text{hr}}$$

Inserting the above values into the heat transfer Equation (2-2) for parallel flow heat exchanger yields the following result.

$$\dot{Q} = \left(70 \frac{\text{BTU}}{\text{hr-ft}^2-^{\circ}\text{F}}\right) (75\text{ft}^2) (61^{\circ}\text{F})$$

$$\dot{Q} = 3.2 \times 10^5 \frac{\text{BTU}}{\text{hr}}$$

The results demonstrate that given the same operating conditions, operating the same heat exchanger in a counter flow manner will result in a greater heat transfer rate than operating in parallel flow.

In actuality, most large heat exchangers are not purely parallel flow, counter flow, or cross flow; they are usually a combination of the two or all three types of heat exchangers. This is due to the fact that actual heat exchangers are more complex than the simple components shown in the idealized figures used above to depict each type of heat exchanger. The reason for the combination of the various types is to maximize the efficiency of the heat exchanger within the restrictions placed on the design. That is, size, cost, weight, required efficiency, type of fluids, operating pressures, and temperatures, all help determine the complexity of a specific heat exchanger.

One method that combines the characteristics of two or more heat exchangers and improves the performance of a heat exchanger is to have the two fluids pass each other several times within a single heat exchanger. When a heat exchanger's fluids pass each other more than once, a heat exchanger is called a *multi-pass heat exchanger*. If the fluids pass each other only once, the heat exchanger is called a *single-pass heat exchanger*. See Figure 6 for an example of both types. Commonly, the multi-pass heat exchanger reverses the flow in the tubes by use of one or more sets of "U" bends in the tubes. The "U" bends allow the fluid to flow back and forth across the length of the heat exchanger. A second method to achieve multiple passes is to insert baffles on the shell side of the heat exchanger. These direct the shell side fluid back and forth across the tubes to achieve the multi-pass effect.

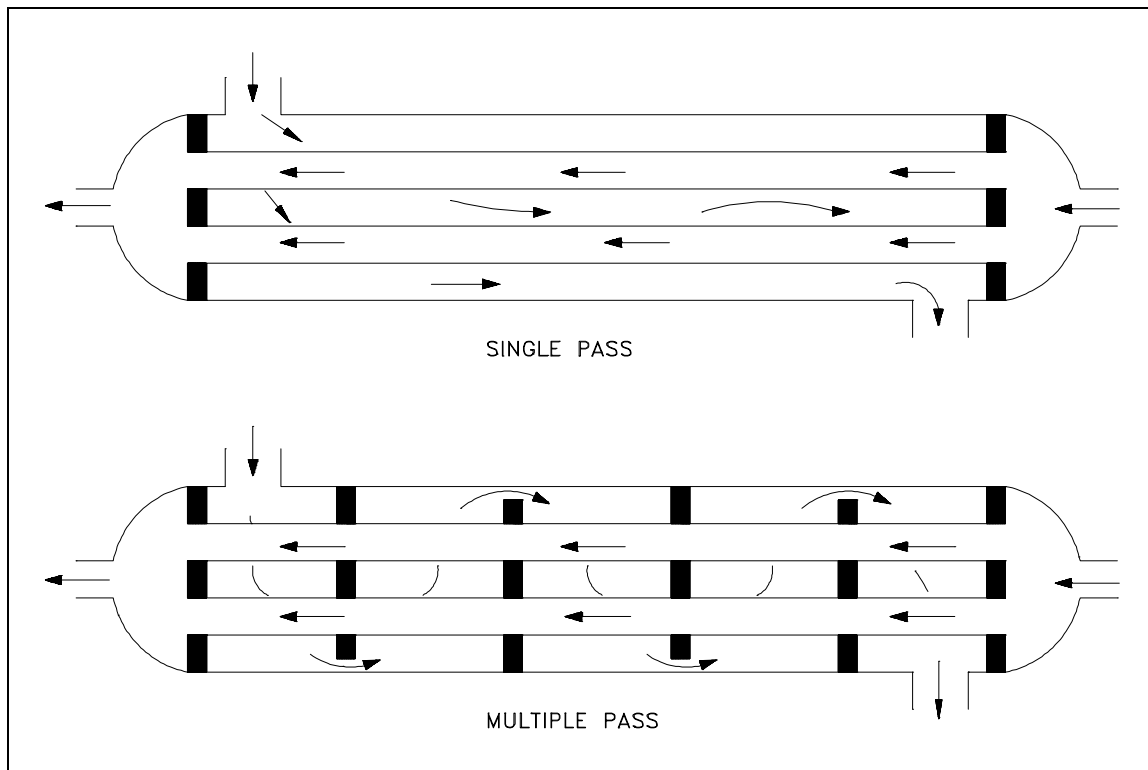


Figure 6 Single and Multi-Pass Heat Exchangers

Heat exchangers are also classified by their function in a particular system. One common classification is regenerative or nonregenerative. A *regenerative* heat exchanger is one in which the same fluid is both the cooling fluid and the cooled fluid, as illustrated in Figure 7. That is, the hot fluid leaving a system gives up its heat to "regenerate" or heat up the fluid returning to the system. Regenerative heat exchangers are usually found in high temperature systems where a portion of the system's fluid is removed from the main process, and then returned. Because the fluid removed from the main process contains energy (heat), the heat from the fluid leaving the main system is used to reheat (regenerate) the returning fluid instead of being rejected to an external cooling medium to improve efficiency. It is important to remember that the term regenerative/nonregenerative only refers to "how" a heat exchanger functions in a system, and does not indicate any single type (tube and shell, plate, parallel flow, counter flow, etc.).

In a *nonregenerative* heat exchanger, as illustrated in Figure 7, the hot fluid is cooled by fluid from a separate system and the energy (heat) removed is not returned to the system.

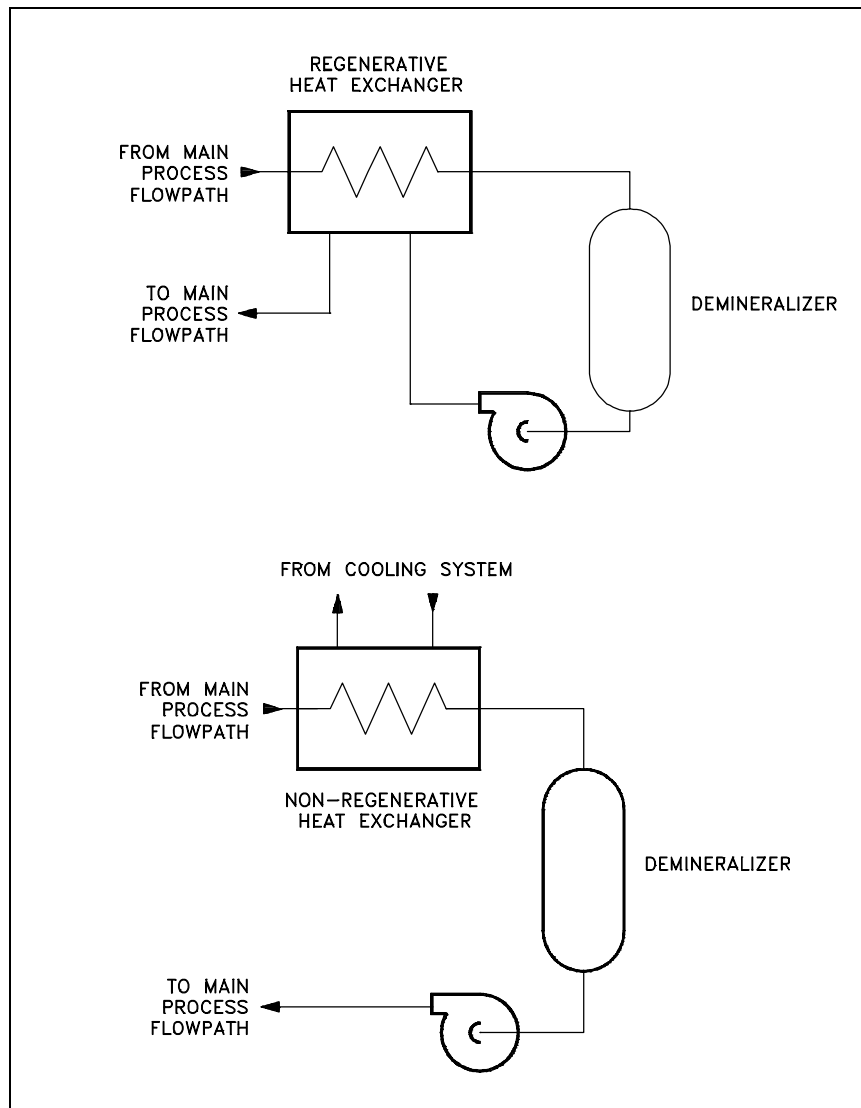


Figure 7 Regenerative and Non-Regenerative Heat Exchangers

Summary

The important information from this chapter is summarized below.

Types of Heat Exchangers Summary

- There are two methods of constructing heat exchangers: plate type and tube type.
- Parallel flow - the hot fluid and the coolant flow in the same direction.
- Counter flow - The hot fluid and the coolant flow in opposite directions.
- Cross flow - the hot fluid and the coolant flow at 90° angles (perpendicular) to each other.
- The four heat exchanger parts identified were:
 - Tubes
 - Tube Sheet
 - Shell
 - Baffles
- Single-pass heat exchangers have fluids that pass each other only once.
- Multi-pass heat exchangers have fluids that pass each other more than once through the use of U tubes and baffles.
- Regenerative heat exchangers use the same fluid for heating and cooling.
- Non-regenerative heat exchangers use separate fluids for heating and cooling.

HEAT EXCHANGER APPLICATIONS

This chapter describes some specific applications of heat exchangers.

- EO 1.5** **LIST at least three applications of heat exchangers.**
- EO 1.6** **STATE the purpose of a condenser.**
- EO 1.7** **DEFINE the following terms:**
- a.** **Hotwell**
 - b.** **Condensate depression**
- EO 1.8** **STATE why condensers in large steam cycles are operated at a vacuum.**
-

Introduction

Heat exchangers are found in most chemical or mechanical systems. They serve as the system's means of gaining or rejecting heat. Some of the more common applications are found in heating, ventilation and air conditioning (HVAC) systems, radiators on internal combustion engines, boilers, condensers, and as preheaters or coolers in fluid systems. This chapter will review some specific heat exchanger applications. The intent is to provide several specific examples of how each heat exchanger functions in the system, not to cover every possible application.

Preheater

In large steam systems, or in any process requiring high temperatures, the input fluid is usually preheated in stages, instead of trying to heat it in one step from ambient to the final temperature. Preheating in stages increases the plant's efficiency and minimizes thermal shock stress to components, as compared to injecting ambient temperature liquid into a boiler or other device that operates at high temperatures. In the case of a steam system, a portion of the process steam is tapped off and used as a heat source to reheat the feedwater in preheater stages. Figure 8 is an example of the construction and internals of a U-tube feedwater heat exchanger found in a large power generation facility in a preheater stage. As the steam enters the heat exchanger and flows over and around the tubes, it transfers its thermal energy and is condensed. Note that the steam enters from the top into the shell side of the heat exchanger, where it not only transfers sensible heat (temperature change) but also gives up its latent heat of vaporization (condenses steam into water). The condensed steam then exits as a liquid at the bottom of the heat exchanger. The feedwater enters the heat exchanger on the bottom right end and flows into the tubes. Note that most of these tubes will be below the fluid level on the shell side.

This means the feedwater is exposed to the condensed steam first and then travels through the tubes and back around to the top right end of the heat exchanger. After making the 180° bend, the partially heated feedwater is then subjected to the hotter steam entering the shell side.

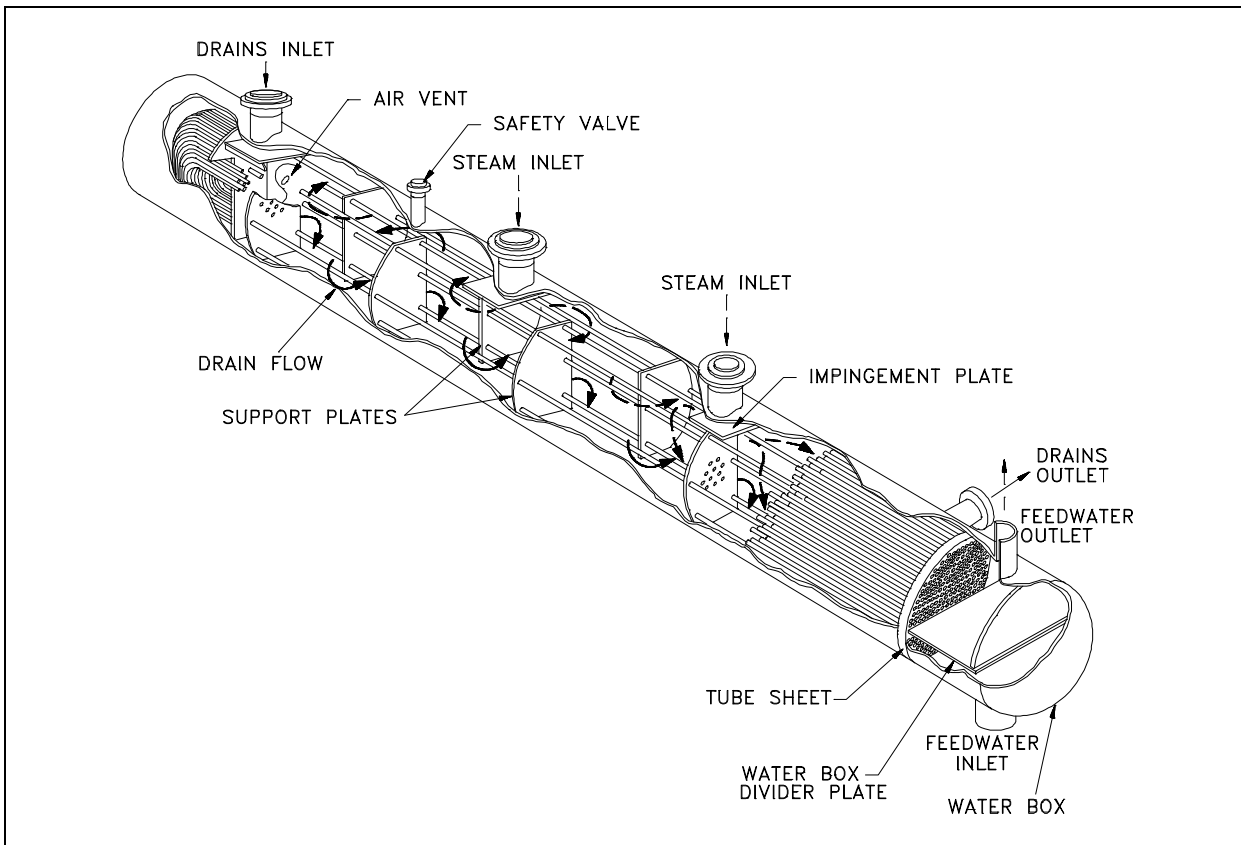


Figure 8 U-tube Feedwater Heat Exchanger

The feedwater is further heated by the hot steam and then exits the heat exchanger. In this type of heat exchanger, the shell side fluid level is very important in determining the efficiency of the heat exchanger, as the shell side fluid level determines the number of tubes exposed to the hot steam.

Radiator

Commonly, heat exchangers are thought of as liquid-to-liquid devices only. But a heat exchanger is any device that transfers heat from one fluid to another. Some of a facility's equipment depend on air-to-liquid heat exchangers. The most familiar example of an air-to-liquid heat exchanger is a car radiator. The coolant flowing in the engine picks up heat from the engine block and carries it to the radiator. From the radiator, the hot coolant flows into the tube side of the radiator (heat exchanger). The relatively cool air flowing over the outside of the tubes picks up the heat, reducing the temperature of the coolant.

Because air is such a poor conductor of heat, the heat transfer area between the metal of the radiator and the air must be maximized. This is done by using fins on the outside of the tubes. The fins improve the efficiency of a heat exchanger and are commonly found on most liquid-to-air heat exchangers and in some high efficiency liquid-to-liquid heat exchangers.

Air Conditioner Evaporator and Condenser

All air conditioning systems contain at least two heat exchangers, usually called the evaporator and the condenser. In either case, evaporator or condenser, the refrigerant flows into the heat exchanger and transfers heat, either gaining or releasing it to the cooling medium. Commonly, the cooling medium is air or water. In the case of the condenser, the hot, high pressure refrigerant gas must be condensed to a subcooled liquid.

The condenser accomplishes this by cooling the gas, transferring its heat to either air or water. The cooled gas then condenses into a liquid. In the evaporator, the subcooled refrigerant flows into the heat exchanger, but the heat flow is reversed, with the relatively cool refrigerant absorbing heat from the hotter air flowing on the outside of the tubes. This cools the air and boils the refrigerant.

Large Steam System Condensers

The steam condenser, shown in Figure 9, is a major component of the steam cycle in power generation facilities. It is a closed space into which the steam exits the turbine and is forced to give up its latent heat of vaporization. It is a necessary component of the steam cycle for two reasons. One, it converts the used steam back into water for return to the steam generator or boiler as feedwater. This lowers the operational cost of the plant by allowing the clean and treated condensate to be reused, and it is far easier to pump a liquid than steam. Two, it increases the cycle's efficiency by allowing the cycle to operate with the largest possible delta-T and delta-P between the source (boiler) and the heat sink (condenser).

Because condensation is taking place, the term latent heat of condensation is used instead of latent heat of vaporization. The steam's latent heat of condensation is passed to the water flowing through the tubes of the condenser.

After the steam condenses, the saturated liquid continues to transfer heat to the cooling water as it falls to the bottom of the condenser, or *hotwell*. This is called subcooling, and a certain amount is desirable. A few degrees subcooling prevents condensate pump cavitation. The difference between the saturation temperature for the existing condenser vacuum and the temperature of the condensate is termed *condensate depression*. This is expressed as a number of degrees condensate depression or degrees subcooled. Excessive condensate depression decreases the operating efficiency of the plant because the subcooled condensate must be reheated in the boiler, which in turn requires more heat from the reactor, fossil fuel, or other heat source.

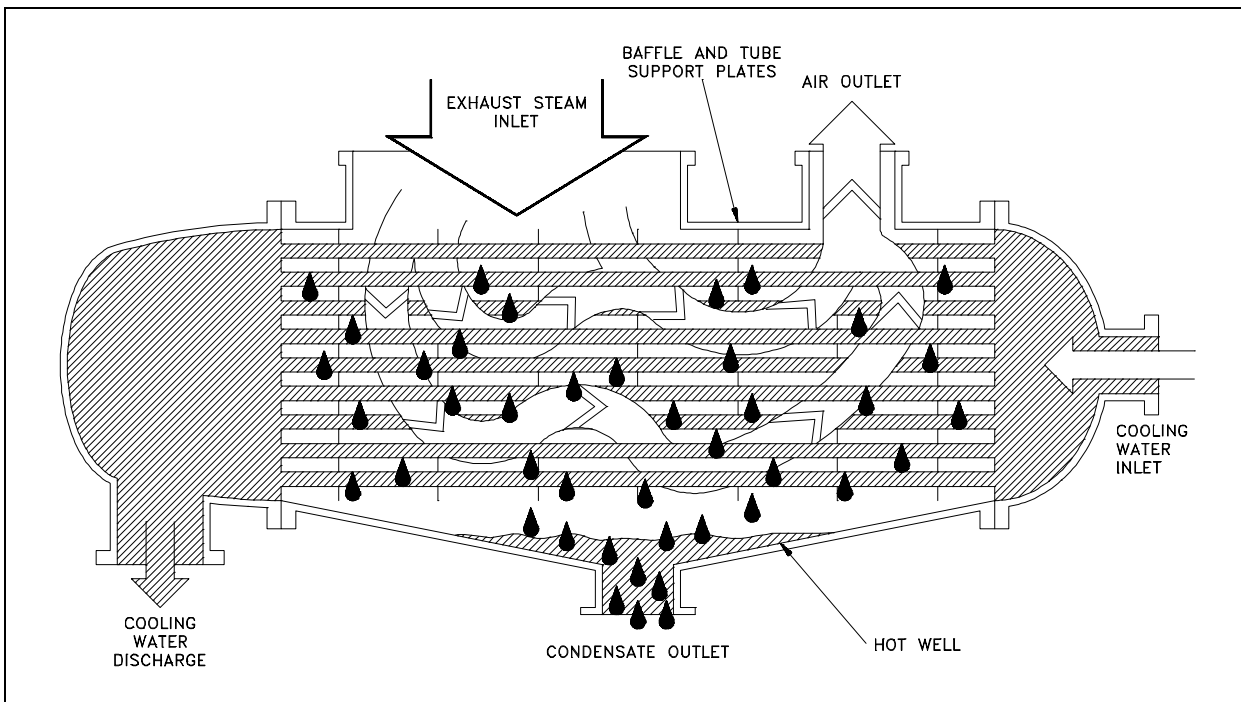


Figure 9 Single-Pass Condenser

There are different condenser designs, but the most common, at least in the large power generation facilities, is the straight-through, single-pass condenser illustrated Figure 9. This condenser design provides cooling water flow through straight tubes from the inlet water box on one end, to the outlet water box on the other end. The cooling water flows once through the condenser and is termed a single pass. The separation between the water box areas and the steam condensing area is accomplished by a tube sheet to which the cooling water tubes are attached. The cooling water tubes are supported within the condenser by the tube support sheets. Condensers normally have a series of baffles that redirect the steam to minimize direct impingement on the cooling water tubes. The bottom area of the condenser is the hotwell, as shown in Figure 9. This is where the condensate collects and the condensate pump takes its suction. If noncondensable gasses are allowed to build up in the condenser, vacuum will decrease and the saturation temperature at which the steam will condense increases.

Non-condensable gasses also blanket the tubes of the condenser, thus reducing the heat transfer surface area of the condenser. This surface area can also be reduced if the condensate level is allowed to rise over the lower tubes of the condenser. A reduction in the heat transfer surface has the same effect as a reduction in cooling water flow. If the condenser is operating near its design capacity, a reduction in the effective surface area results in difficulty maintaining condenser vacuum.

The temperature and flow rate of the cooling water through the condenser controls the temperature of the condensate. This in turn controls the saturation pressure (vacuum) of the condenser.

To prevent the condensate level from rising to the lower tubes of the condenser, a hotwell level control system may be employed. Varying the flow of the condensate pumps is one method used to accomplish hotwell level control. A level sensing network controls the condensate pump speed or pump discharge flow control valve position. Another method employs an overflow system that spills water from the hotwell when a high level is reached.

Condenser vacuum should be maintained as close to 29 inches Hg as practical. This allows maximum expansion of the steam, and therefore, the maximum work. If the condenser were perfectly air-tight (no air or noncondensable gasses present in the exhaust steam), it would be necessary only to condense the steam and remove the condensate to create and maintain a vacuum. The sudden reduction in steam volume, as it condenses, would maintain the vacuum. Pumping the water from the condenser as fast as it is formed would maintain the vacuum. It is, however, impossible to prevent the entrance of air and other noncondensable gasses into the condenser. In addition, some method must exist to initially cause a vacuum to exist in the condenser. This necessitates the use of an air ejector or vacuum pump to establish and help maintain condenser vacuum.

Air ejectors are essentially jet pumps or eductors, as illustrated in Figure 10. In operation, the jet pump has two types of fluids. They are the high pressure fluid that flows through the nozzle, and the fluid being pumped which flows around the nozzle into the throat of the diffuser. The high velocity fluid enters the diffuser where its molecules strike other molecules. These molecules are in turn carried along with the high velocity fluid out of the diffuser creating a low pressure area around the mouth of the nozzle. This process is called entrainment. The low pressure area will draw more fluid from around the nozzle into the throat of the diffuser. As the fluid moves down the diffuser, the increasing area converts the velocity back to pressure. Use of steam at a pressure between 200 psi and 300 psi as the high pressure fluid enables a single-stage air ejector to draw a vacuum of about 26 inches Hg.

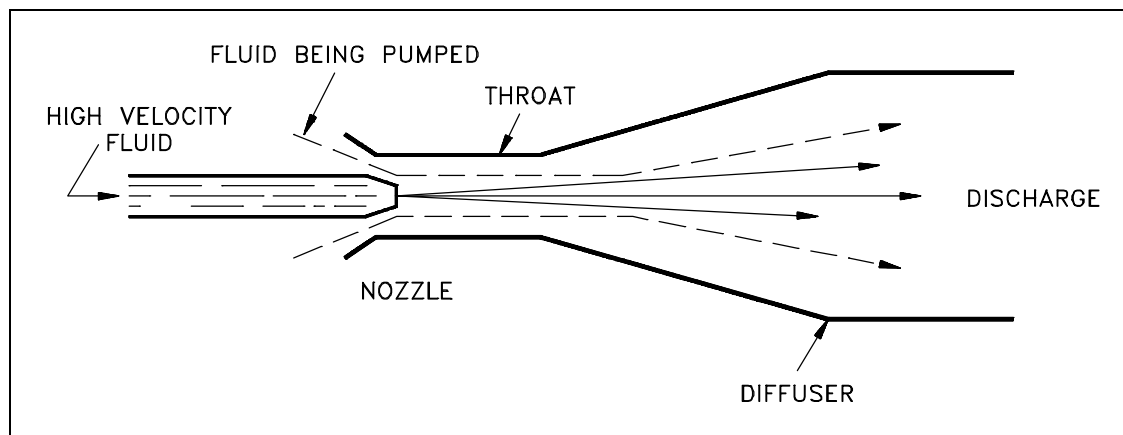


Figure 10 Jet Pump

Normally, air ejectors consist of two suction stages. The first stage suction is located on top of the condenser, while the second stage suction comes from the diffuser of the first stage. The exhaust steam from the second stage must be condensed. This is normally accomplished by an air ejector condenser that is cooled by condensate. The air ejector condenser also preheats the condensate returning to the boiler. Two-stage air ejectors are capable of drawing vacuums to 29 inches Hg.

A vacuum pump may be any type of motor-driven air compressor. Its suction is attached to the condenser, and it discharges to the atmosphere. A common type uses rotating vanes in an elliptical housing. Single-stage, rotary-vane units are used for vacuums to 28 inches Hg. Two stage units can draw vacuums to 29.7 inches Hg. The vacuum pump has an advantage over the air ejector in that it requires no source of steam for its operation. They are normally used as the initial source of vacuum for condenser start-up.

Summary

The important information from this chapter is summarized below.

Heat Exchanger Applications Summary

- Heat exchangers are often used in the following applications.
 - Preheater
 - Radiator
 - Air conditioning evaporator and condenser
 - Steam condenser
- The purpose of a condenser is to remove the latent heat of vaporization, condensing the vapor into a liquid.
- Heat exchangers condense the steam vapor into a liquid for return to the boiler.
- The cycle's efficiency is increased by ensuring the maximum ΔT between the source and the heat sink.
- The hotwell is the area at the bottom of the condenser where the condensed steam is collected to be pumped back into the system feedwater.
- Condensate depression is the amount the condensate in a condenser is cooled below saturation (degrees subcooled).
- Condensers operate at a vacuum to ensure the temperature (and thus the pressure) of the steam is as low as possible. This maximizes the ΔT and ΔP between the source and the heat sink, ensuring the highest cycle efficiency possible.

**Department of Energy
Fundamentals Handbook**

**MECHANICAL SCIENCE
Module 3
Pumps**

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TERMINAL OBJECTIVE

- 1.0 Without references, **DESCRIBE** the purpose, construction, and principles of operation for centrifugal pumps.

ENABLING OBJECTIVES

- 1.1 **STATE** the purposes of the following centrifugal pump components:
- | | |
|-------------|-----------------|
| a. Impeller | d. Packing |
| b. Volute | e. Lantern Ring |
| c. Diffuser | f. Wearing ring |
- 1.2 Given a drawing of a centrifugal pump, **IDENTIFY** the following major components:
- | | |
|-----------------|-----------------------------|
| a. Pump casing | f. Stuffing box gland |
| b. Pump shaft | g. Packing |
| c. Impeller | h. Lantern Ring |
| d. Volute | i. Impeller wearing ring |
| e. Stuffing box | j. Pump casing wearing ring |
- 1.3 **DEFINE** the following terms:
- | | |
|--|-----------------|
| a. Net Positive Suction Head Available | d. Shutoff head |
| b. Cavitation | e. Pump runoff |
| c. Gas binding | |
- 1.4 **STATE** the relationship between net positive suction head available and net positive suction head required that is necessary to avoid cavitation.
- 1.5 **LIST** three indications that a centrifugal pump may be cavitating.
- 1.6 **LIST** five changes that can be made in a pump or its surrounding system that can reduce cavitation.
- 1.7 **LIST** three effects of cavitation.
- 1.8 **DESCRIBE** the shape of the characteristic curve for a centrifugal pump.
- 1.9 **DESCRIBE** how centrifugal pumps are protected from the conditions of dead heading and pump runoff.

TERMINAL OBJECTIVE

- 2.0 Without references, **DESCRIBE** the purpose, construction, and principle of operation for positive displacement pumps.

ENABLING OBJECTIVES

- 2.1 **STATE** the difference between the flow characteristics of centrifugal and positive displacement pumps.
- 2.2 Given a simplified drawing of a positive displacement pump, **CLASSIFY** the pump as one of the following:
- a. Reciprocating piston pump
 - b. Gear-type rotary pump
 - c. Screw-type rotary pump
 - d. Lobe-type rotary pump
 - e. Moving vane pump
 - f. Diaphragm pump
- 2.3 **EXPLAIN** the importance of viscosity as it relates to the operation of a reciprocating positive displacement pump.
- 2.4 **DESCRIBE** the characteristic curve for a positive displacement pump.
- 2.5 **DEFINE** the term slippage.
- 2.6 **STATE** how positive displacement pumps are protected against overpressurization.

CENTRIFUGAL PUMPS

Centrifugal pumps are the most common type of pumps found in DOE facilities. Centrifugal pumps enjoy widespread application partly due to their ability to operate over a wide range of flow rates and pump heads.

EO 1.1 STATE the purposes of the following centrifugal pump components:

- | | |
|---|--|
| <p>a. Impeller</p> <p>b. Volute</p> <p>c. Diffuser</p> | <p>d. Packing</p> <p>e. Lantern Ring</p> <p>f. Wearing ring</p> |
|---|--|

EO 1.2 Given a drawing of a centrifugal pump, IDENTIFY the following major components:

- | | |
|--|---|
| <p>a. Pump casing</p> <p>b. Pump shaft</p> <p>c. Impeller</p> <p>d. Volute</p> <p>e. Stuffing box</p> | <p>f. Stuffing box gland</p> <p>g. Packing</p> <p>h. Lantern Ring</p> <p>i. Impeller wearing ring</p> <p>j. Pump casing wearing ring</p> |
|--|---|

Introduction

Centrifugal pumps basically consist of a stationary pump casing and an impeller mounted on a rotating shaft. The pump casing provides a pressure boundary for the pump and contains channels to properly direct the suction and discharge flow. The pump casing has suction and discharge penetrations for the main flow path of the pump and normally has small drain and vent fittings to remove gases trapped in the pump casing or to drain the pump casing for maintenance.

Figure 1 is a simplified diagram of a typical centrifugal pump that shows the relative locations of the pump suction, impeller, volute, and discharge. The pump casing guides the liquid from the suction connection to the center, or eye, of the impeller. The vanes of the rotating *impeller* impart a radial and rotary motion to the liquid, forcing it to the outer periphery of the pump casing where it is collected in the outer part of the pump casing called the *volute*. The *volute* is a region that expands in cross-sectional area as it wraps around the pump casing. The purpose of the volute is to collect the liquid discharged from the periphery of the impeller at high velocity and gradually cause a reduction in fluid velocity by increasing the flow area. This converts the velocity head to static pressure. The fluid is then discharged from the pump through the discharge connection.

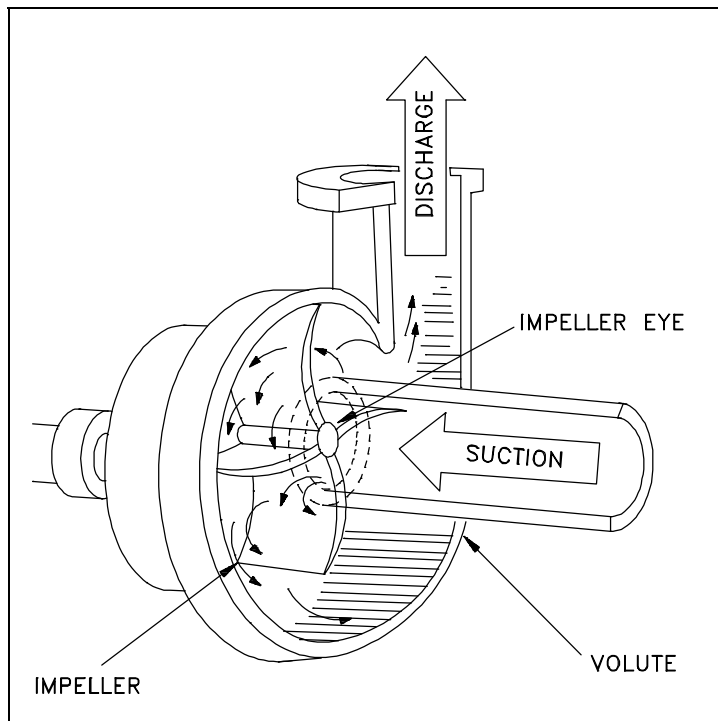


Figure 1 Centrifugal Pump

Centrifugal pumps can also be constructed in a manner that results in two distinct volutes, each receiving the liquid that is discharged from a 180° region of the impeller at any given time. Pumps of this type are called double volute pumps (they may also be referred to a split volute pumps). In some applications the double volute minimizes radial forces imparted to the shaft and bearings due to imbalances in the pressure around the impeller. A comparison of single and double volute centrifugal pumps is shown on Figure 2.

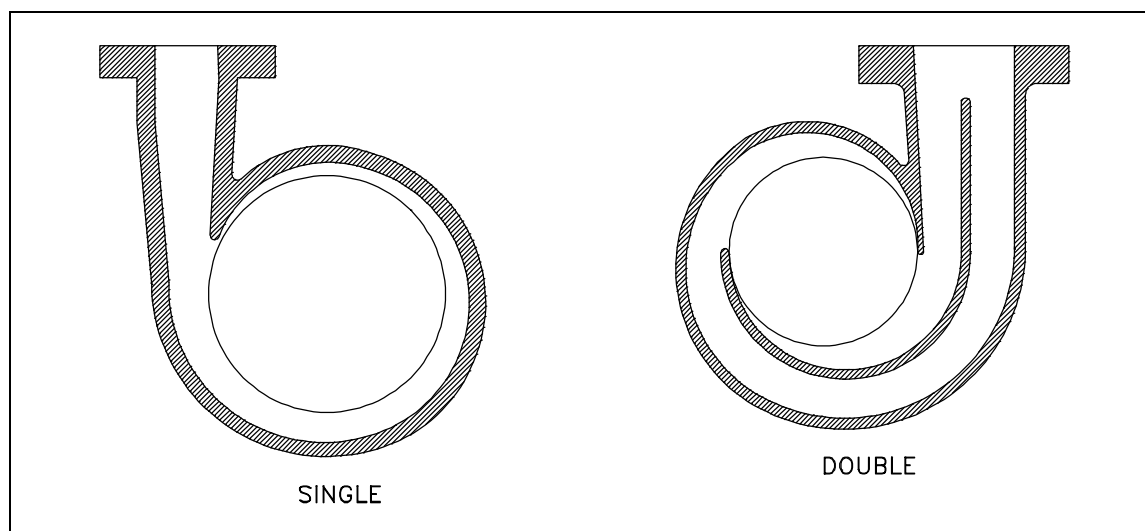


Figure 2 Single and Double Volute

Diffuser

Some centrifugal pumps contain diffusers. A *diffuser* is a set of stationary vanes that surround the impeller. The purpose of the diffuser is to increase the efficiency of the centrifugal pump by allowing a more gradual expansion and less turbulent area for the liquid to reduce in velocity. The diffuser vanes are designed in a manner that the liquid exiting the impeller will encounter an ever-increasing flow area as it passes through the diffuser. This increase in flow area causes a reduction in flow velocity, converting kinetic energy into flow pressure.

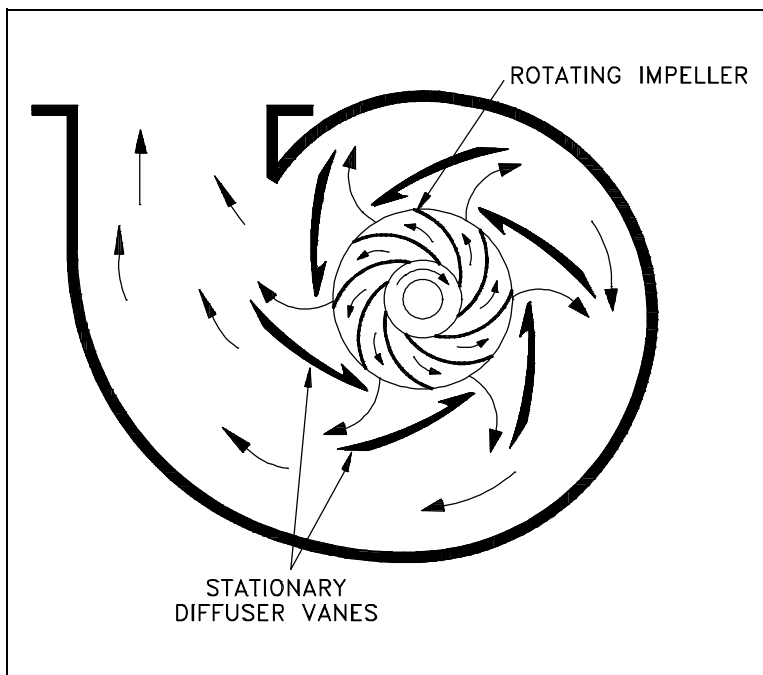


Figure 3 Centrifugal Pump Diffuser

Impeller Classification

Impellers of pumps are classified based on the number of points that the liquid can enter the impeller and also on the amount of webbing between the impeller blades.

Impellers can be either single-suction or double-suction. A single-suction impeller allows liquid to enter the center of the blades from only one direction. A double-suction impeller allows liquid to enter the center of the impeller blades from both sides simultaneously. Figure 4 shows simplified diagrams of single and double-suction impellers.

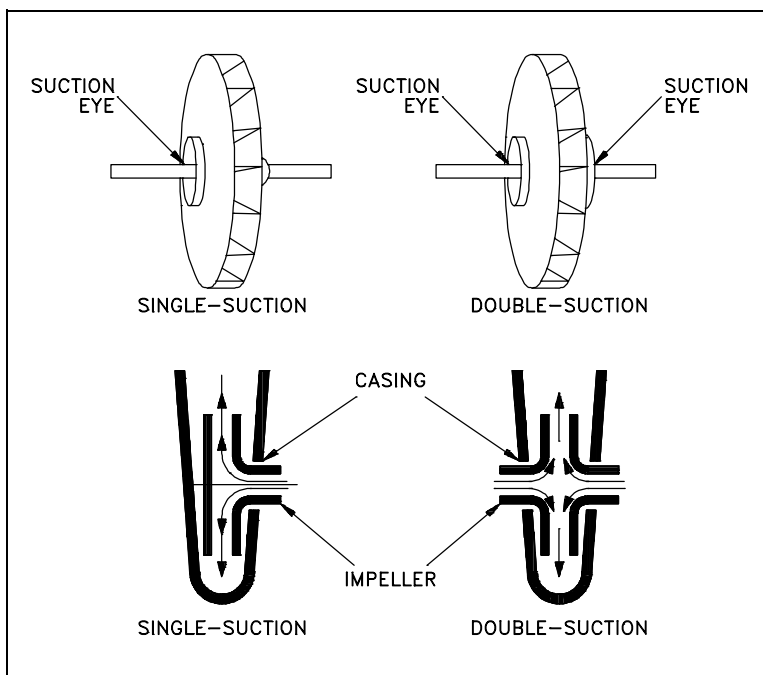


Figure 4 Single-Suction and Double-Suction Impellers

Impellers can be open, semi-open, or enclosed. The open impeller consists only of blades attached to a hub. The semi-open impeller is constructed with a circular plate (the web) attached to one side of the blades. The enclosed impeller has circular plates attached to both sides of the blades. Enclosed impellers are also referred to as shrouded impellers. Figure 5 illustrates examples of open, semi-open, and enclosed impellers.

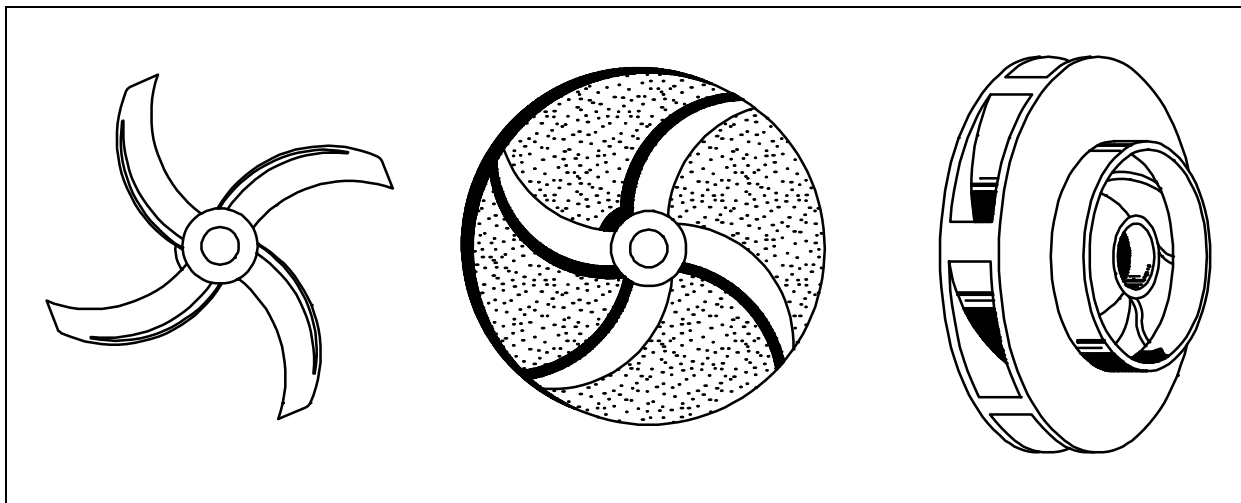


Figure 5 Open, Semi-Open, and Enclosed Impellers

The impeller sometimes contains balancing holes that connect the space around the hub to the suction side of the impeller. The balancing holes have a total cross-sectional area that is considerably greater than the cross-sectional area of the annular space between the wearing ring and the hub. The result is suction pressure on both sides of the impeller hub, which maintains a hydraulic balance of axial thrust.

Centrifugal Pump Classification by Flow

Centrifugal pumps can be classified based on the manner in which fluid flows through the pump. The manner in which fluid flows through the pump is determined by the design of the pump casing and the impeller. The three types of flow through a centrifugal pump are radial flow, axial flow, and mixed flow.

Radial Flow Pumps

In a radial flow pump, the liquid enters at the center of the impeller and is directed out along the impeller blades in a direction at right angles to the pump shaft. The impeller of a typical radial flow pump and the flow through a radial flow pump are shown in Figure 6.

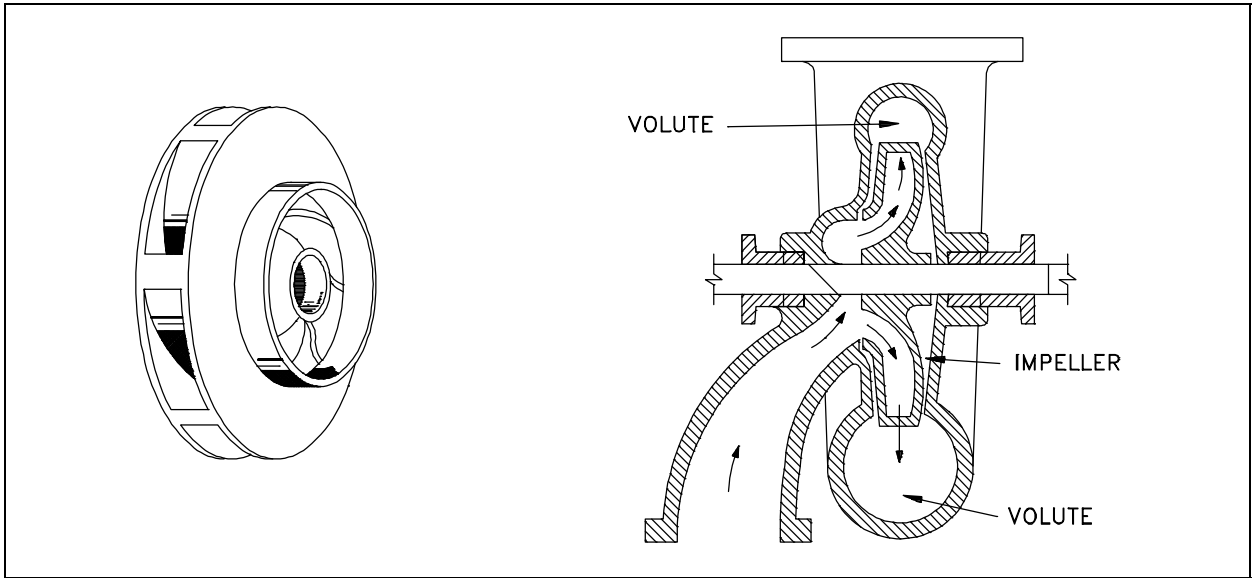


Figure 6 Radial Flow Centrifugal Pump

Axial Flow Pumps

In an axial flow pump, the impeller pushes the liquid in a direction parallel to the pump shaft. Axial flow pumps are sometimes called propeller pumps because they operate essentially the same as the propeller of a boat. The impeller of a typical axial flow pump and the flow through a radial flow pump and the flow through a radial flow pump are shown in Figure 7.

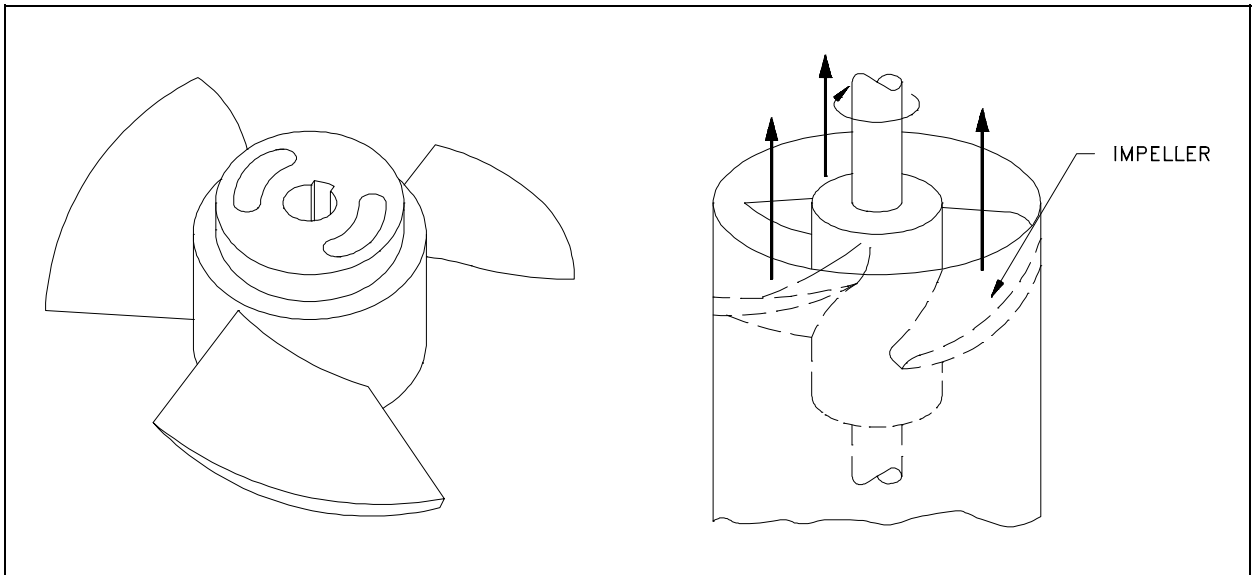


Figure 7 Axial Flow Centrifugal Pump

Mixed Flow Pumps

Mixed flow pumps borrow characteristics from both radial flow and axial flow pumps. As liquid flows through the impeller of a mixed flow pump, the impeller blades push the liquid out away from the pump shaft and to the pump suction at an angle greater than 90°. The impeller of a typical mixed flow pump and the flow through a mixed flow pump are shown in Figure 8.

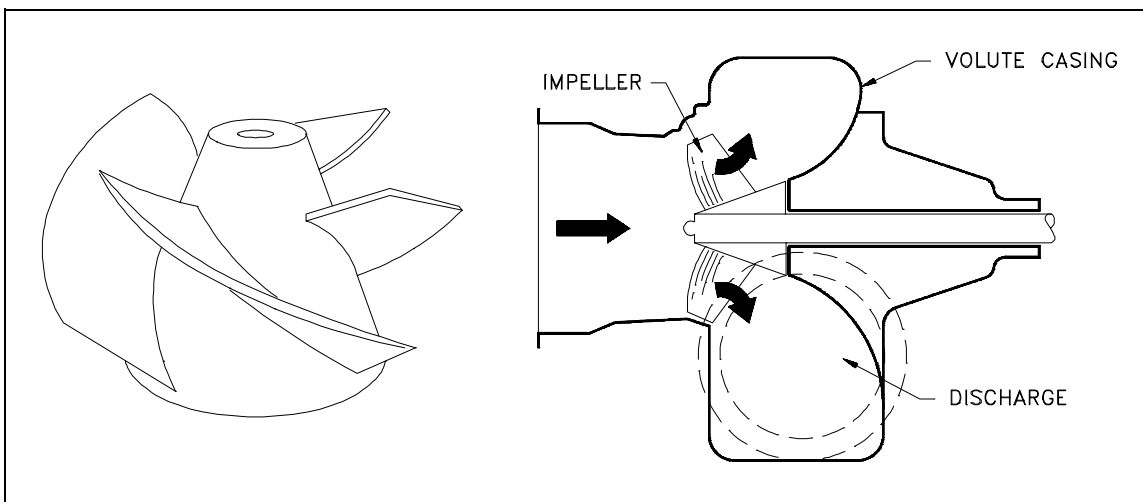


Figure 8 Mixed Flow Centrifugal Pump

Multi-Stage Centrifugal Pumps

A centrifugal pump with a single impeller that can develop a differential pressure of more than 150 psid between the suction and the discharge is difficult and costly to design and construct. A more economical approach to developing high pressures with a single centrifugal pump is to include multiple impellers on a common shaft within the same pump casing. Internal channels in the pump casing route the discharge of one impeller to the suction of another impeller. Figure 9 shows a diagram of the arrangement of the impellers of a four-stage pump. The water enters the pump from the top left and passes through each of the four impellers in series, going from left to right. The water goes from the volute surrounding the discharge of one impeller to the suction of the next impeller.

A *pump stage* is defined as that portion of a centrifugal pump consisting of one impeller and its associated components. Most centrifugal pumps are single-stage pumps, containing only one impeller. A pump containing seven impellers within a single casing would be referred to as a seven-stage pump or, or generally, as a multi-stage pump.

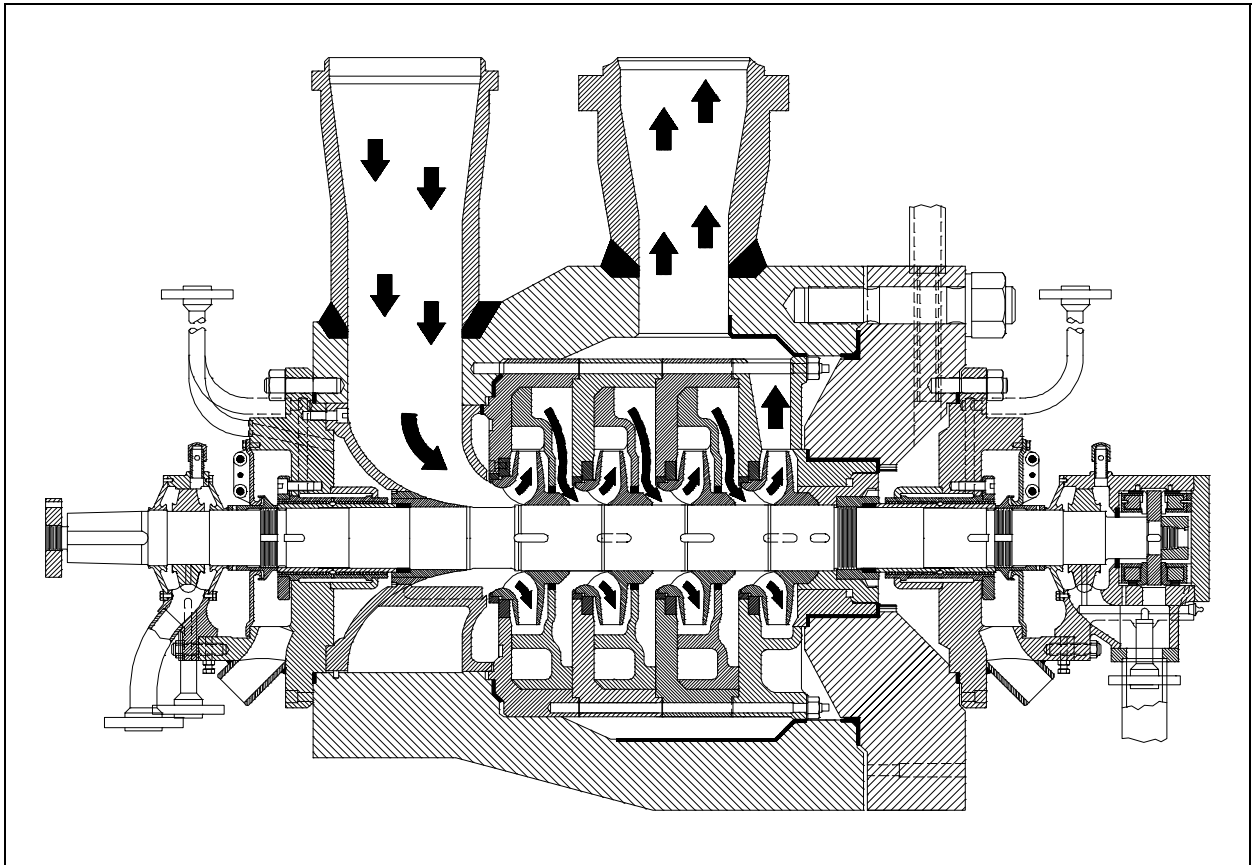


Figure 9 Multi-Stage Centrifugal Pump

Centrifugal Pump Components

Centrifugal pumps vary in design and construction from simple pumps with relatively few parts to extremely complicated pumps with hundreds of individual parts. Some of the most common components found in centrifugal pumps are wearing rings, stuffing boxes, packing, and lantern rings. These components are shown in Figure 10 and described on the following pages.

Wearing Rings

Centrifugal pumps contain rotating impellers within stationary pump casings. To allow the impeller to rotate freely within the pump casing, a small clearance is designed to be maintained between the impeller and the pump casing. To maximize the efficiency of a centrifugal pump, it is necessary to minimize the amount of liquid leaking through this clearance from the high pressure or discharge side of the pump back to the low pressure or suction side.

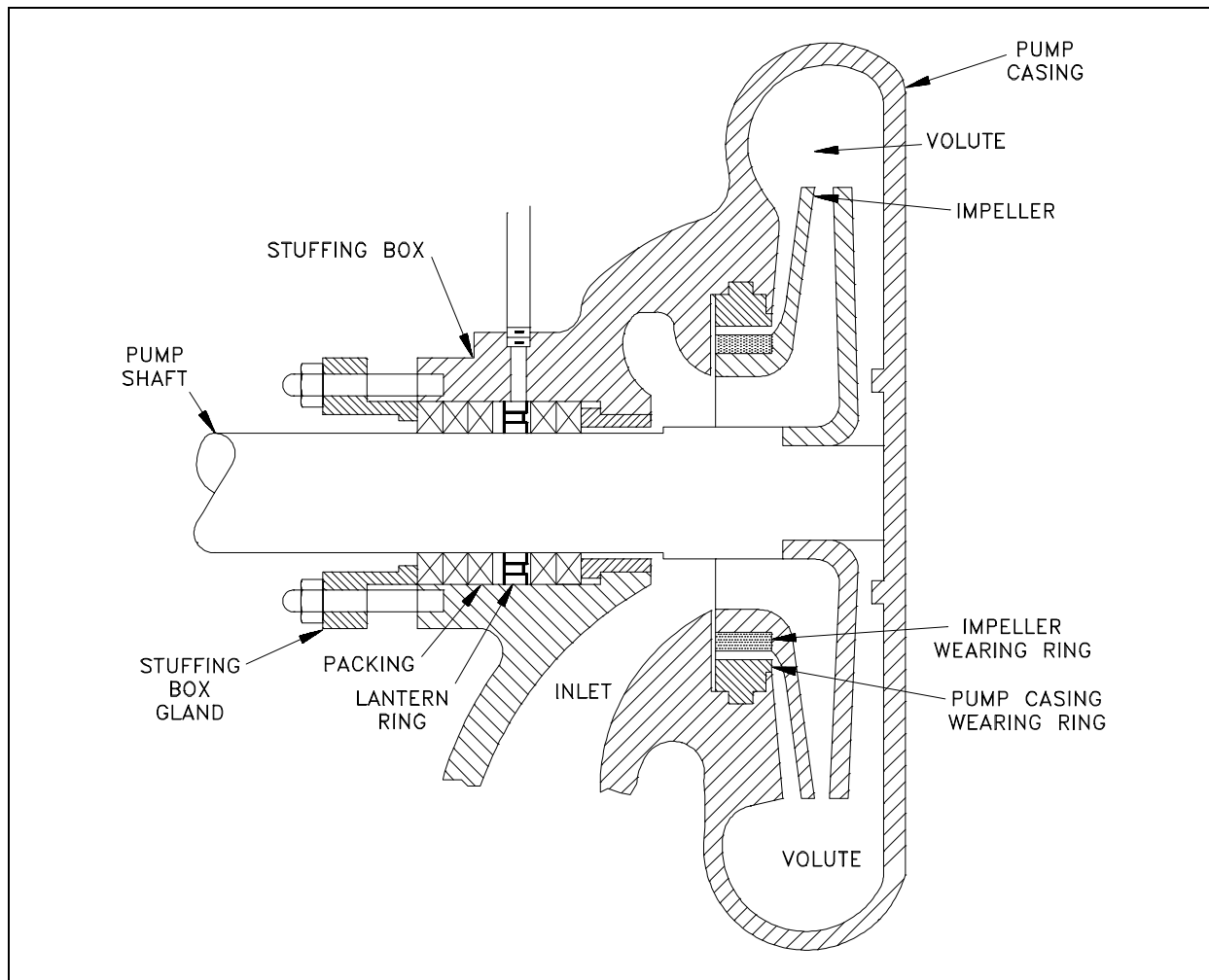


Figure 10 Centrifugal Pump Components

Some wear or erosion will occur at the point where the impeller and the pump casing nearly come into contact. This wear is due to the erosion caused by liquid leaking through this tight clearance and other causes. As wear occurs, the clearances become larger and the rate of leakage increases. Eventually, the leakage could become unacceptably large and maintenance would be required on the pump.

To minimize the cost of pump maintenance, many centrifugal pumps are designed with wearing rings. *Wearing rings* are replaceable rings that are attached to the impeller and/or the pump casing to allow a small running clearance between the impeller and the pump casing without causing wear of the actual impeller or pump casing material. These wearing rings are designed to be replaced periodically during the life of a pump and prevent the more costly replacement of the impeller or the casing.

Stuffing Box

In almost all centrifugal pumps, the rotating shaft that drives the impeller penetrates the pressure boundary of the pump casing. It is important that the pump is designed properly to control the amount of liquid that leaks along the shaft at the point that the shaft penetrates the pump casing. There are many different methods of sealing the shaft penetration of the pump casing. Factors considered when choosing a method include the pressure and temperature of the fluid being pumped, the size of the pump, and the chemical and physical characteristics of the fluid being pumped.

One of the simplest types of shaft seal is the stuffing box. The *stuffing box* is a cylindrical space in the pump casing surrounding the shaft. Rings of packing material are placed in this space. *Packing* is material in the form of rings or strands that is placed in the stuffing box to form a seal to control the rate of leakage along the shaft. The packing rings are held in place by a gland. The gland is, in turn, held in place by studs with adjusting nuts. As the adjusting nuts are tightened, they move the gland in and compress the packing. This axial compression causes the packing to expand radially, forming a tight seal between the rotating shaft and the inside wall of the stuffing box.

The high speed rotation of the shaft generates a significant amount of heat as it rubs against the packing rings. If no lubrication and cooling are provided to the packing, the temperature of the packing increases to the point where damage occurs to the packing, the pump shaft, and possibly nearby pump bearings. Stuffing boxes are normally designed to allow a small amount of controlled leakage along the shaft to provide lubrication and cooling to the packing. The leakage rate can be adjusted by tightening and loosening the packing gland.

Lantern Ring

It is not always possible to use a standard stuffing box to seal the shaft of a centrifugal pump. The pump suction may be under a vacuum so that outward leakage is impossible or the fluid may be too hot to provide adequate cooling of the packing. These conditions require a modification to the standard stuffing box.

One method of adequately cooling the packing under these conditions is to include a lantern ring. A *lantern ring* is a perforated hollow ring located near the center of the packing box that receives relatively cool, clean liquid from either the discharge of the pump or from an external source and distributes the liquid uniformly around the shaft to provide lubrication and cooling. The fluid entering the lantern ring can cool the shaft and packing, lubricate the packing, or seal the joint between the shaft and packing against leakage of air into the pump in the event the pump suction pressure is less than that of the atmosphere.

Mechanical Seals

In some situations, packing material is not adequate for sealing the shaft. One common alternative method for sealing the shaft is with mechanical seals. Mechanical seals consist of two basic parts, a rotating element attached to the pump shaft and a stationary element attached to the pump casing. Each of these elements has a highly polished sealing surface. The polished faces of the rotating and stationary elements come into contact with each other to form a seal that prevents leakage along the shaft.

Summary

The important information in this chapter is summarized below.

Centrifugal Pumps Summary

- The impeller contains rotating vanes that impart a radial and rotary motion to the liquid.
- The volute collects the liquid discharged from the impeller at high velocity and gradually causes a reduction in fluid velocity by increasing the flow area, converting the velocity head to a static head.
- A diffuser increases the efficiency of a centrifugal pump by allowing a more gradual expansion and less turbulent area for the liquid to slow as the flow area expands.
- Packing material provides a seal in the area where the pump shaft penetrates the pump casing.
- Wearing rings are replaceable rings that are attached to the impeller and/or the pump casing to allow a small running clearance between the impeller and pump casing without causing wear of the actual impeller or pump casing material.
- The lantern ring is inserted between rings of packing in the stuffing box to receive relatively cool, clean liquid and distribute the liquid uniformly around the shaft to provide lubrication and cooling to the packing.

CENTRIFUGAL PUMP OPERATION

Improper operation of centrifugal pumps can result in damage to the pump and loss of function of the system that the pump is installed in. It is helpful to know what conditions can lead to pump damage to allow better understanding of pump operating procedures and how the procedures aid the operator in avoiding pump damage.

EO 1.3 **DEFINE** the following terms:

- | | | | |
|-----------|--|-----------|---------------------|
| a. | Net Positive Suction Head Available | c. | Gas binding |
| b. | Cavitation | d. | Shutoff head |
| | | e. | Pump runout |

EO 1.4 **STATE** the relationship between net positive suction head available and net positive suction head required that is necessary to avoid cavitation.

EO 1.5 **LIST** three indications that a centrifugal pump may be cavitating.

EO 1.6 **LIST** five changes that can be made in a pump or its surrounding system that can reduce cavitation.

EO 1.7 **LIST** three effects of cavitation.

EO 1.8 **DESCRIBE** the shape of the characteristic curve for a centrifugal pump.

EO 1.9 **DESCRIBE** how centrifugal pumps are protected from the conditions of dead heading and pump runout.

Introduction

Many centrifugal pumps are designed in a manner that allows the pump to operate continuously for months or even years. These centrifugal pumps often rely on the liquid that they are pumping to provide cooling and lubrication to the pump bearings and other internal components of the pump. If flow through the pump is stopped while the pump is still operating, the pump will no longer be adequately cooled and the pump can quickly become damaged. Pump damage can also result from pumping a liquid whose temperature is close to saturated conditions.

Cavitation

The flow area at the eye of the pump impeller is usually smaller than either the flow area of the pump suction piping or the flow area through the impeller vanes. When the liquid being pumped enters the eye of a centrifugal pump, the decrease in flow area results in an increase in flow velocity accompanied by a decrease in pressure. The greater the pump flow rate, the greater the pressure drop between the pump suction and the eye of the impeller. If the pressure drop is large enough, or if the temperature is high enough, the pressure drop may be sufficient to cause the liquid to flash to vapor when the local pressure falls below the saturation pressure for the fluid being pumped. Any vapor bubbles formed by the pressure drop at the eye of the impeller are swept along the impeller vanes by the flow of the fluid. When the bubbles enter a region where local pressure is greater than saturation pressure farther out the impeller vane, the vapor bubbles abruptly collapse. This process of the formation and subsequent collapse of vapor bubbles in a pump is called *cavitation*.

Cavitation in a centrifugal pump has a significant effect on pump performance. Cavitation degrades the performance of a pump, resulting in a fluctuating flow rate and discharge pressure. Cavitation can also be destructive to pumps internal components. When a pump cavitates, vapor bubbles form in the low pressure region directly behind the rotating impeller vanes. These vapor bubbles then move toward the oncoming impeller vane, where they collapse and cause a physical shock to the leading edge of the impeller vane. This physical shock creates small pits on the leading edge of the impeller vane. Each individual pit is microscopic in size, but the cumulative effect of millions of these pits formed over a period of hours or days can literally destroy a pump impeller. Cavitation can also cause excessive pump vibration, which could damage pump bearings, wearing rings, and seals.

A small number of centrifugal pumps are designed to operate under conditions where cavitation is unavoidable. These pumps must be specially designed and maintained to withstand the small amount of cavitation that occurs during their operation. Most centrifugal pumps are not designed to withstand sustained cavitation.

Noise is one of the indications that a centrifugal pump is cavitating. A cavitating pump can sound like a can of marbles being shaken. Other indications that can be observed from a remote operating station are fluctuating discharge pressure, flow rate, and pump motor current. Methods to stop or prevent cavitation are presented in the following paragraphs.

Net Positive Suction Head

To avoid cavitation in centrifugal pumps, the pressure of the fluid at all points within the pump must remain above saturation pressure. The quantity used to determine if the pressure of the liquid being pumped is adequate to avoid cavitation is the net positive suction head (NPSH). The *net positive suction head available* ($NPSH_A$) is the difference between the pressure at the suction of the pump and the saturation pressure for the liquid being pumped. The *net positive suction head required* ($NPSH_R$) is the minimum net positive suction head necessary to avoid cavitation.

The condition that must exist to avoid cavitation is that the net positive suction head available must be greater than or equal to the net positive suction head required. This requirement can be stated mathematically as shown below.

$$NPSH_A \geq NPSH_R$$

A formula for $NPSH_A$ can be stated as the following equation.

$$NPSH_A = P_{\text{suction}} - P_{\text{saturation}}$$

When a centrifugal pump is taking suction from a tank or other reservoir, the pressure at the suction of the pump is the sum of the absolute pressure at the surface of the liquid in the tank plus the pressure due to the elevation difference between the surface of liquid in the tank and the pump suction less the head losses due to friction in the suction line from the tank to the pump.

$$NPSH_A = P_a + P_{st} - h_f - P_{sat}$$

Where:

- $NPSH_A$ = net positive suction head available
- P_a = absolute pressure on the surface of the liquid
- P_{st} = pressure due to elevation between liquid surface and pump suction
- h_f = head losses in the pump suction piping
- P_{sat} = saturation pressure of the liquid being pumped

Preventing Cavitation

If a centrifugal pump is cavitating, several changes in the system design or operation may be necessary to increase the $NPSH_A$ above the $NPSH_R$ and stop the cavitation. One method for increasing the $NPSH_A$ is to increase the pressure at the suction of the pump. For example, if a pump is taking suction from an enclosed tank, either raising the level of the liquid in the tank or increasing the pressure in the space above the liquid increases suction pressure.

It is also possible to increase the $NPSH_A$ by decreasing the temperature of the liquid being pumped. Decreasing the temperature of the liquid decreases the saturation pressure, causing $NPSH_A$ to increase. Recall from the previous module on heat exchangers that large steam condensers usually subcool the condensate to less than the saturation temperature, called condensate depression, to prevent cavitation in the condensate pumps.

If the head losses in the pump suction piping can be reduced, the $NPSH_A$ will be increased. Various methods for reducing head losses include increasing the pipe diameter, reducing the number of elbows, valves, and fittings in the pipe, and decreasing the length of the pipe.

It may also be possible to stop cavitation by reducing the $NPSH_R$ for the pump. The $NPSH_R$ is not a constant for a given pump under all conditions, but depends on certain factors. Typically, the $NPSH_R$ of a pump increases significantly as flow rate through the pump increases. Therefore, reducing the flow rate through a pump by throttling a discharge valve decreases $NPSH_R$. $NPSH_R$ is also dependent upon pump speed. The faster the impeller of a pump rotates, the greater the $NPSH_R$. Therefore, if the speed of a variable speed centrifugal pump is reduced, the $NPSH_R$ of the pump decreases. However, since a pump's flow rate is most often dictated by the needs of the system on which it is connected, only limited adjustments can be made without starting additional parallel pumps, if available.

The net positive suction head required to prevent cavitation is determined through testing by the pump manufacturer and depends upon factors including type of impeller inlet, impeller design, pump flow rate, impeller rotational speed, and the type of liquid being pumped. The manufacturer typically supplies curves of $NPSH_R$ as a function of pump flow rate for a particular liquid (usually water) in the vendor manual for the pump.

Centrifugal Pump Characteristic Curves

For a given centrifugal pump operating at a constant speed, the flow rate through the pump is dependent upon the differential pressure or head developed by the pump. The lower the pump head, the higher the flow rate. A vendor manual for a specific pump usually contains a curve of pump flow rate versus pump head called a pump characteristic curve. After a pump is installed in a system, it is usually tested to ensure that the flow rate and head of the pump are within the required specifications. A typical centrifugal pump characteristic curve is shown in Figure 11.

There are several terms associated with the pump characteristic curve that must be defined. *Shutoff head* is the maximum head that can be developed by a centrifugal pump operating at a set speed. *Pump runout* is the maximum flow that can be developed by a centrifugal pump without damaging the pump. Centrifugal pumps must be designed and operated to be protected from the conditions of pump runout or operating at shutoff head. Additional information may be found in the handbook on Thermodynamics, Heat Transfer, and Fluid Flow.

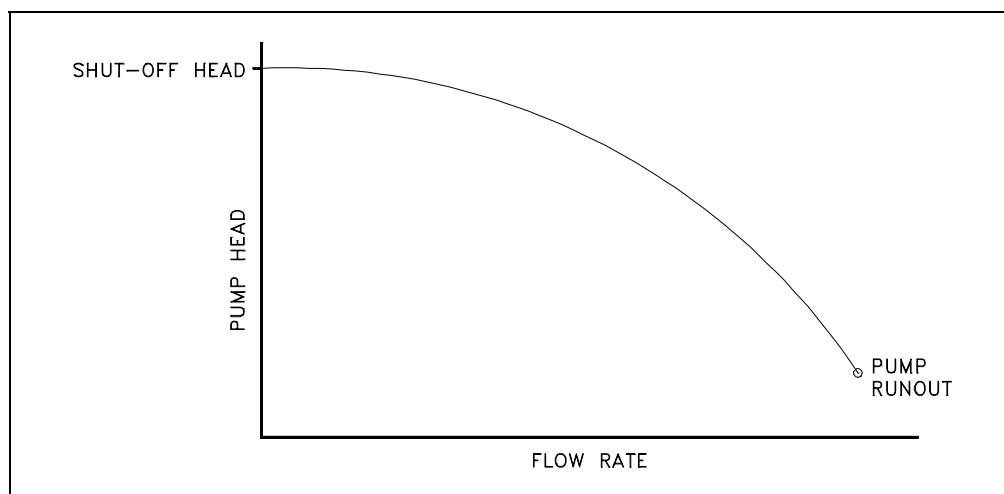


Figure 11 Centrifugal Pump Characteristic Curve

Centrifugal Pump Protection

A centrifugal pump is dead-headed when it is operated with no flow through it, for example, with a closed discharge valve or against a seated check valve. If the discharge valve is closed and there is no other flow path available to the pump, the impeller will churn the same volume of water as it rotates in the pump casing. This will increase the temperature of the liquid (due to friction) in the pump casing to the point that it will flash to vapor. The vapor can interrupt the cooling flow to the pump's packing and bearings, causing excessive wear and heat. If the pump is run in this condition for a significant amount of time, it will become damaged.

When a centrifugal pump is installed in a system such that it may be subjected to periodic shutoff head conditions, it is necessary to provide some means of pump protection. One method for protecting the pump from running dead-headed is to provide a recirculation line from the pump discharge line upstream of the discharge valve, back to the pump's supply source. The recirculation line should be sized to allow enough flow through the pump to prevent overheating and damage to the pump. Protection may also be accomplished by use of an automatic flow control device.

Centrifugal pumps must also be protected from runout. Runout can lead to cavitation and can also cause overheating of the pump's motor due to excessive currents. One method for ensuring that there is always adequate flow resistance at the pump discharge to prevent excessive flow through the pump is to place an orifice or a throttle valve immediately downstream of the pump discharge. Properly designed piping systems are very important to protect from runout.

Gas Binding

Gas binding of a centrifugal pump is a condition where the pump casing is filled with gases or vapors to the point where the impeller is no longer able to contact enough fluid to function correctly. The impeller spins in the gas bubble, but is unable to force liquid through the pump. This can lead to cooling problems for the pump's packing and bearings.

Centrifugal pumps are designed so that their pump casings are completely filled with liquid during pump operation. Most centrifugal pumps can still operate when a small amount of gas accumulates in the pump casing, but pumps in systems containing dissolved gases that are not designed to be self-venting should be periodically vented manually to ensure that gases do not build up in the pump casing.

Priming Centrifugal Pumps

Most centrifugal pumps are not self-priming. In other words, the pump casing must be filled with liquid before the pump is started, or the pump will not be able to function. If the pump casing becomes filled with vapors or gases, the pump impeller becomes gas-bound and incapable of pumping. To ensure that a centrifugal pump remains primed and does not become gas-bound, most centrifugal pumps are located below the level of the source from which the pump is to take its suction. The same effect can be gained by supplying liquid to the pump suction under pressure supplied by another pump placed in the suction line.

Summary

The important information in this chapter is summarized below.

Centrifugal Pump Operation Summary

- There are three indications that a centrifugal pump is cavitating.
 - Noise
 - Fluctuating discharge pressure and flow
 - Fluctuating pump motor current
- Steps that can be taken to stop pump cavitation include:
 - Increase the pressure at the suction of the pump.
 - Reduce the temperature of the liquid being pumped.
 - Reduce head losses in the pump suction piping.
 - Reduce the flow rate through the pump.
 - Reduce the speed of the pump impeller.
- Three effects of pump cavitation are:
 - Degraded pump performance
 - Excessive pump vibration
 - Damage to pump impeller, bearings, wearing rings, and seals
- To avoid pump cavitation, the net positive suction head available must be greater than the net positive suction head required.
- Net positive suction head available is the difference between the pump suction pressure and the saturation pressure for the liquid being pumped.
- Cavitation is the process of the formation and subsequent collapse of vapor bubbles in a pump.
- Gas binding of a centrifugal pump is a condition where the pump casing is filled with gases or vapors to the point where the impeller is no longer able to contact enough fluid to function correctly.
- Shutoff head is the maximum head that can be developed by a centrifugal pump operating at a set speed.

Centrifugal Pump Operation Summary (Cont.)

- Pump runout is the maximum flow that can be developed by a centrifugal pump without damaging the pump.
- The greater the head against which a centrifugal pump operates, the lower the flow rate through the pump. The relationship between pump flow rate and head is illustrated by the characteristic curve for the pump.
- Centrifugal pumps are protected from dead-heading by providing a recirculation from the pump discharge back to the supply source of the pump.
- Centrifugal pumps are protected from runout by placing an orifice or throttle valve immediately downstream of the pump discharge and through proper piping system design.

POSITIVE DISPLACEMENT PUMPS

Positive displacement pumps operate on a different principle than centrifugal pumps. Positive displacement pumps physically entrap a quantity of liquid at the suction of the pump and push that quantity out the discharge of the pump.

- EO 2.1** **STATE** the difference between the flow characteristics of centrifugal and positive displacement pumps.
- EO 2.2** **Given a simplified drawing of a positive displacement pump, CLASSIFY** the pump as one of the following:
- a. **Reciprocating piston pump**
 - b. **Gear-type rotary pump**
 - c. **Screw-type rotary pump**
 - d. **Lobe-type rotary pump**
 - e. **Moving vane pump**
 - f. **Diaphragm pump**
- EO 2.3** **EXPLAIN** the importance of viscosity as it relates to the operation of a reciprocating positive displacement pump.
- EO 2.4** **DESCRIBE** the characteristic curve for a positive displacement pump.
- EO 2.5** **DEFINE** the term slippage.
- EO 2.6** **STATE** how positive displacement pumps are protected against overpressurization.
-

Introduction

A positive displacement pump is one in which a definite volume of liquid is delivered for each cycle of pump operation. This volume is constant regardless of the resistance to flow offered by the system the pump is in, provided the capacity of the power unit driving the pump or pump component strength limits are not exceeded. The positive displacement pump delivers liquid in separate volumes with no delivery in between, although a pump having several chambers may have an overlapping delivery among individual chambers, which minimizes this effect. The positive displacement pump differs from centrifugal pumps, which deliver a continuous flow for any given pump speed and discharge resistance.

Positive displacement pumps can be grouped into three basic categories based on their design and operation. The three groups are reciprocating pumps, rotary pumps, and diaphragm pumps.

Principle of Operation

All positive displacement pumps operate on the same basic principle. This principle can be most easily demonstrated by considering a reciprocating positive displacement pump consisting of a single reciprocating piston in a cylinder with a single suction port and a single discharge port as shown in Figure 12. Check valves in the suction and discharge ports allow flow in only one direction.

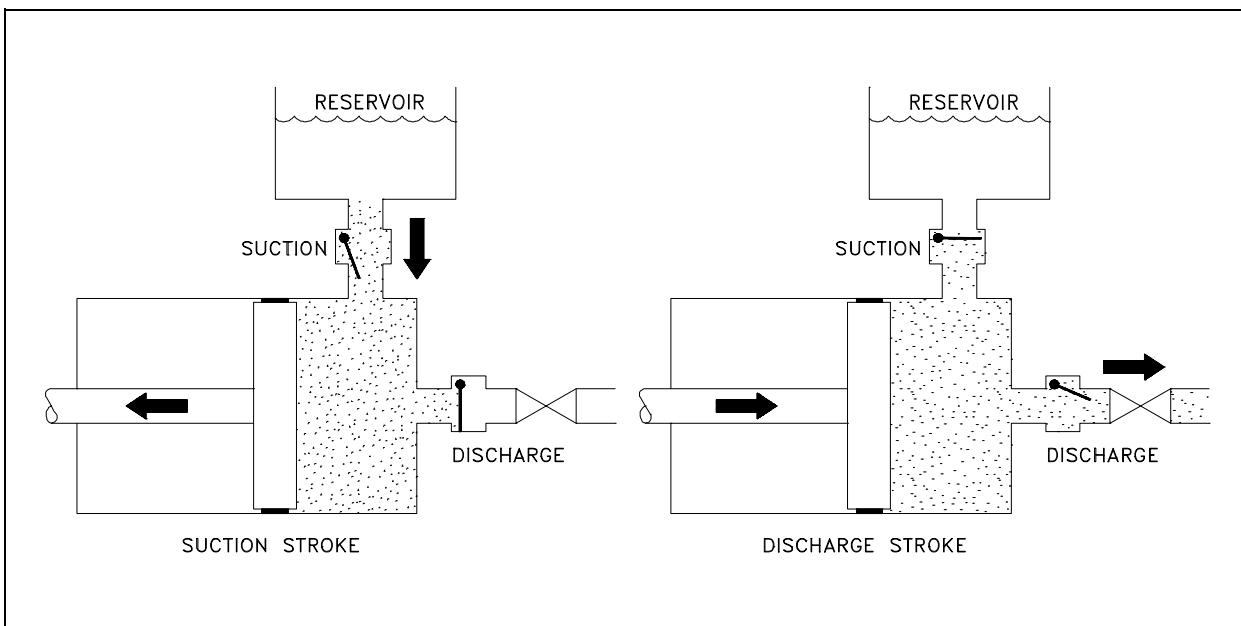


Figure 12 Reciprocating Positive Displacement Pump Operation

During the suction stroke, the piston moves to the left, causing the check valve in the suction line between the reservoir and the pump cylinder to open and admit water from the reservoir. During the discharge stroke, the piston moves to the right, seating the check valve in the suction line and opening the check valve in the discharge line. The volume of liquid moved by the pump in one cycle (one suction stroke and one discharge stroke) is equal to the change in the liquid volume of the cylinder as the piston moves from its farthest left position to its farthest right position.

Reciprocating Pumps

Reciprocating positive displacement pumps are generally categorized in four ways: direct-acting or indirect-acting; simplex or duplex; single-acting or double-acting; and power pumps.

Direct-Acting and Indirect-Acting Pumps

Some reciprocating pumps are powered by prime movers that also have reciprocating motion, such as a reciprocating pump powered by a reciprocating steam piston. The piston rod of the steam piston may be directly connected to the liquid piston of the pump or it may be indirectly connected with a beam or linkage. *Direct-acting* pumps have a plunger on the liquid (pump) end that is directly driven by the pump rod (also the piston rod or extension thereof) and carries the piston of the power end. *Indirect-acting* pumps are driven by means of a beam or linkage connected to and actuated by the power piston rod of a separate reciprocating engine.

Simplex and Duplex Pumps

A *simplex* pump, sometimes referred to as a single pump, is a pump having a single liquid (pump) cylinder. A *duplex* pump is the equivalent of two simplex pumps placed side by side on the same foundation.

The driving of the pistons of a duplex pump is arranged in such a manner that when one piston is on its upstroke the other piston is on its downstroke, and vice versa. This arrangement doubles the capacity of the duplex pump compared to a simplex pump of comparable design.

Single-Acting and Double-Acting Pumps

A *single-acting* pump is one that takes a suction, filling the pump cylinder on the stroke in only one direction, called the suction stroke, and then forces the liquid out of the cylinder on the return stroke, called the discharge stroke. A *double-acting* pump is one that, as it fills one end of the liquid cylinder, is discharging liquid from the other end of the cylinder. On the return stroke, the end of the cylinder just emptied is filled, and the end just filled is emptied. One possible arrangement for single-acting and double-acting pumps is shown in Figure 13.

Power Pumps

Power pumps convert rotary motion to low speed reciprocating motion by reduction gearing, a crankshaft, connecting rods and crossheads. Plungers or pistons are driven by the crosshead drives. Rod and piston construction, similar to duplex double-acting steam pumps, is used by the liquid ends of the low pressure, higher capacity units. The higher pressure units are normally single-acting plungers, and usually employ three (triplex) plungers. Three or more plungers substantially reduce flow pulsations relative to simplex and even duplex pumps.

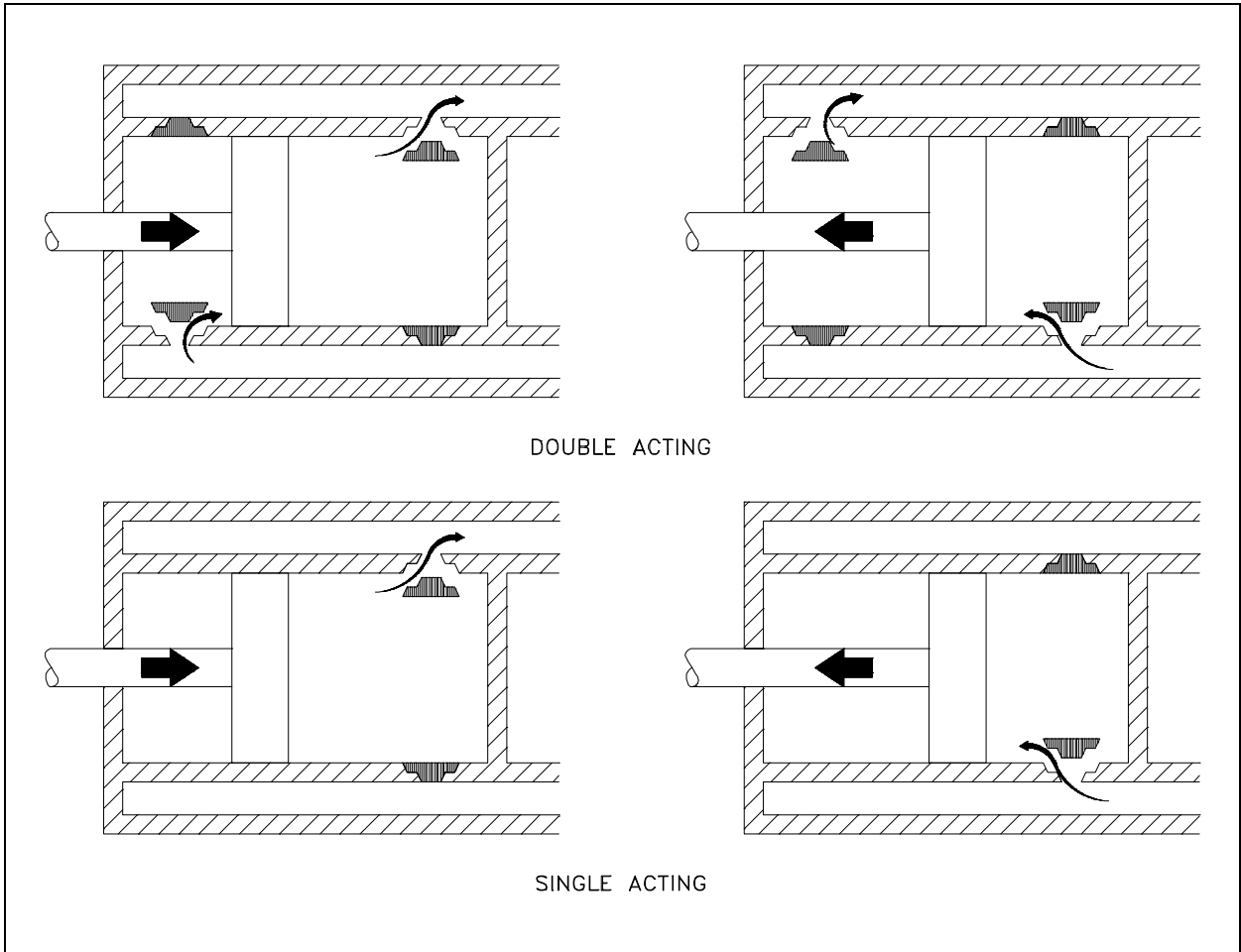


Figure 13 Single-Acting and Double-Acting Pumps

Power pumps typically have high efficiency and are capable of developing very high pressures. They can be driven by either electric motors or turbines. They are relatively expensive pumps and can rarely be justified on the basis of efficiency over centrifugal pumps. However, they are frequently justified over steam reciprocating pumps where continuous duty service is needed due to the high steam requirements of direct-acting steam pumps.

In general, the effective flow rate of reciprocating pumps decreases as the viscosity of the fluid being pumped increases because the speed of the pump must be reduced. In contrast to centrifugal pumps, the differential pressure generated by reciprocating pumps is independent of fluid density. It is dependent entirely on the amount of force exerted on the piston. For more information on viscosity, density, and positive displacement pump theory, refer to the handbook on Thermodynamics, Heat Transfer, and Fluid Flow.

Rotary Pumps

Rotary pumps operate on the principle that a rotating vane, screw, or gear traps the liquid in the suction side of the pump casing and forces it to the discharge side of the casing. These pumps are essentially self-priming due to their capability of removing air from suction lines and producing a high suction lift. In pumps designed for systems requiring high suction lift and self-priming features, it is essential that all clearances between rotating parts, and between rotating and stationary parts, be kept to a minimum in order to reduce slippage. *Slippage* is leakage of fluid from the discharge of the pump back to its suction.

Due to the close clearances in rotary pumps, it is necessary to operate these pumps at relatively low speed in order to secure reliable operation and maintain pump capacity over an extended period of time. Otherwise, the erosive action due to the high velocities of the liquid passing through the narrow clearance spaces would soon cause excessive wear and increased clearances, resulting in slippage.

There are many types of positive displacement rotary pumps, and they are normally grouped into three basic categories that include gear pumps, screw pumps, and moving vane pumps.

Simple Gear Pump

There are several variations of gear pumps. The simple gear pump shown in Figure 14 consists of two spur gears meshing together and revolving in opposite directions within a casing. Only a few thousandths of an inch clearance exists between the case and the gear faces and teeth extremities. Any liquid that fills the space bounded by two successive gear teeth and the case must follow along with the teeth as they revolve. When the gear teeth mesh with the teeth of the other gear, the space between the teeth is reduced, and the entrapped liquid is forced out the pump discharge pipe. As the gears revolve and the teeth disengage, the space again opens on the suction side of the pump, trapping new quantities of liquid and carrying it around the pump case to the discharge. As liquid is carried away from the suction side, a lower pressure is created, which draws liquid in through the suction line.

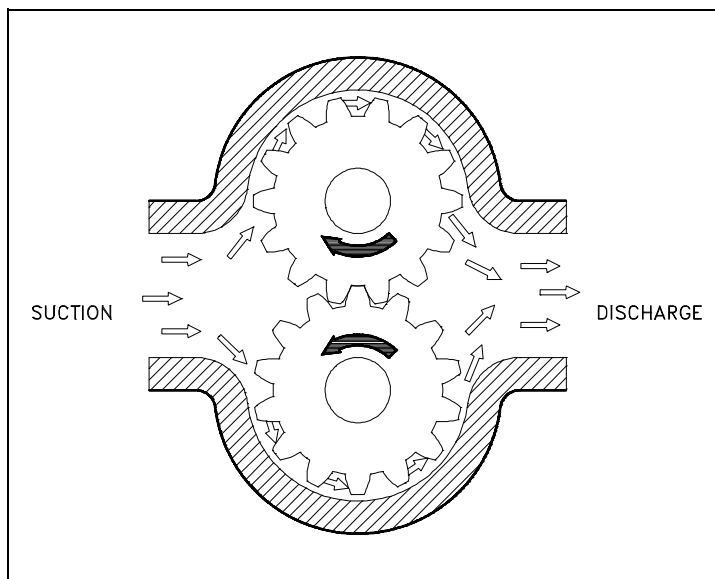


Figure 14 Simple Gear Pump

With the large number of teeth usually employed on the gears, the discharge is relatively smooth and continuous, with small quantities of liquid being delivered to the discharge line in rapid succession. If designed with fewer teeth, the space between the teeth is greater and the capacity increases for a given speed; however, the tendency toward a pulsating discharge increases. In all simple gear pumps, power is applied to the shaft of one of the gears, which transmits power to the driven gear through their meshing teeth.

There are no valves in the gear pump to cause friction losses as in the reciprocating pump. The high impeller velocities, with resultant friction losses, are not required as in the centrifugal pump. Therefore, the gear pump is well suited for handling viscous fluids such as fuel and lubricating oils.

Other Gear Pumps

There are two types of gears used in gear pumps in addition to the simple spur gear. One type is the helical gear. A helix is the curve produced when a straight line moves up or down the surface of a cylinder. The other type is the herringbone gear. A herringbone gear is composed of two helixes spiraling in different directions from the center of the gear. Spur, helical, and herringbone gears are shown in Figure 15.

The helical gear pump has advantages over the simple spur gear. In a spur gear, the entire length of the gear tooth engages at the same time. In a helical gear, the point of engagement moves along the length of the gear tooth as the gear rotates. This makes the helical gear operate with a steadier discharge pressure and fewer pulsations than a spur gear pump.

The herringbone gear pump is also a modification of the simple gear pump. Its principal difference in operation from the simple spur gear pump is that the pointed center section of the space between two teeth begins discharging before the divergent outer ends of the preceding space complete discharging. This overlapping tends to provide a steadier discharge pressure. The power transmission from the driving to the driven gear is also smoother and quieter.

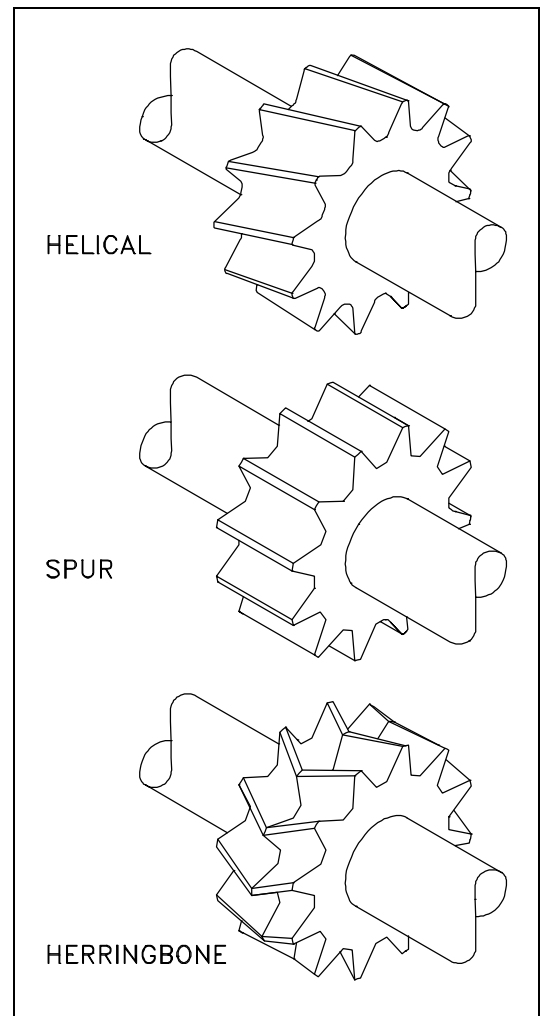


Figure 15 Types of Gears Used In Pumps

Lobe Type Pump

The lobe type pump shown in Figure 16 is another variation of the simple gear pump. It is considered as a simple gear pump having only two or three teeth per rotor; otherwise, its operation or the explanation of the function of its parts is no different. Some designs of lobe pumps are fitted with replaceable gibs, that is, thin plates carried in grooves at the extremity of each lobe where they make contact with the casing. The gib promotes tightness and absorbs radial wear.

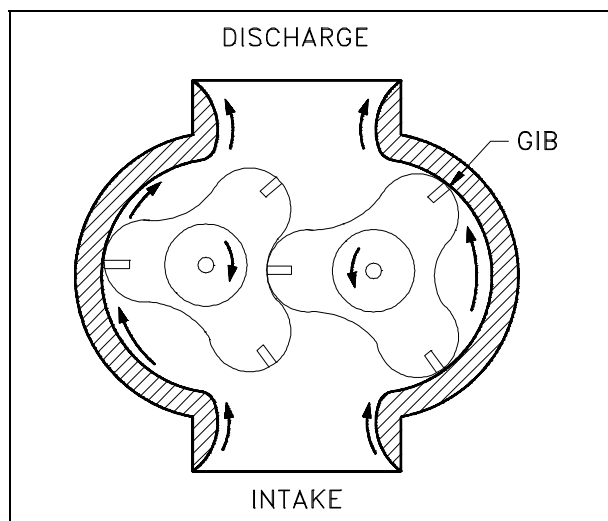


Figure 16 Lobe Type Pump

Screw-Type Positive Displacement Rotary Pump

There are many variations in the design of the screw type positive displacement, rotary pump. The primary differences consist of the number of intermeshing screws involved, the pitch of the screws, and the general direction of fluid flow. Two common designs are the two-screw, low-pitch, double-flow pump and the three-screw, high-pitch, double-flow pump.

Two-Screw, Low-Pitch, Screw Pump

The two-screw, low-pitch, screw pump consists of two screws that mesh with close clearances, mounted on two parallel shafts. One screw has a right-handed thread, and the other screw has a left-handed thread. One shaft is the driving shaft and drives the other shaft through a set of herringbone timing gears. The gears serve to maintain clearances between the screws as they turn and to promote quiet operation. The screws rotate in closely fitting duplex cylinders that have overlapping bores. All clearances are small, but there is no actual contact between the two screws or between the screws and the cylinder walls.

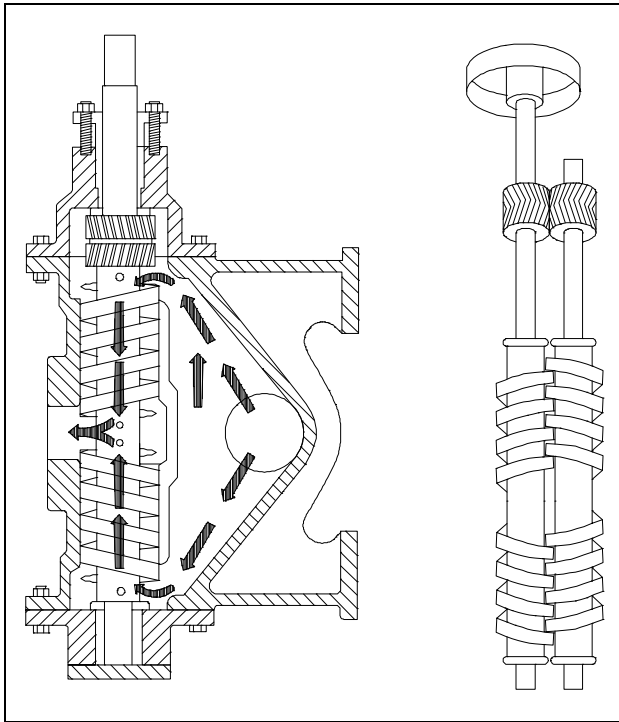


Figure 17 Two-Screw, Low-Pitch, Screw Pump

The complete assembly and the usual flow path are shown in Figure 17. Liquid is trapped at the outer end of each pair of screws. As the first space between the screw threads rotates away from the opposite screw, a one-turn, spiral-shaped quantity of liquid is enclosed when the end of the screw again meshes with the opposite screw. As the screw continues to rotate, the entrapped spiral turns of liquid slide along the cylinder toward the center discharge space while the next slug is being entrapped. Each screw functions similarly, and each pair of screws discharges an equal quantity of liquid in opposed streams toward the center, thus eliminating hydraulic thrust. The removal of liquid from the suction end by the screws produces a reduction in pressure, which draws liquid through the suction line.

Three-Screw, High-Pitch, Screw Pump

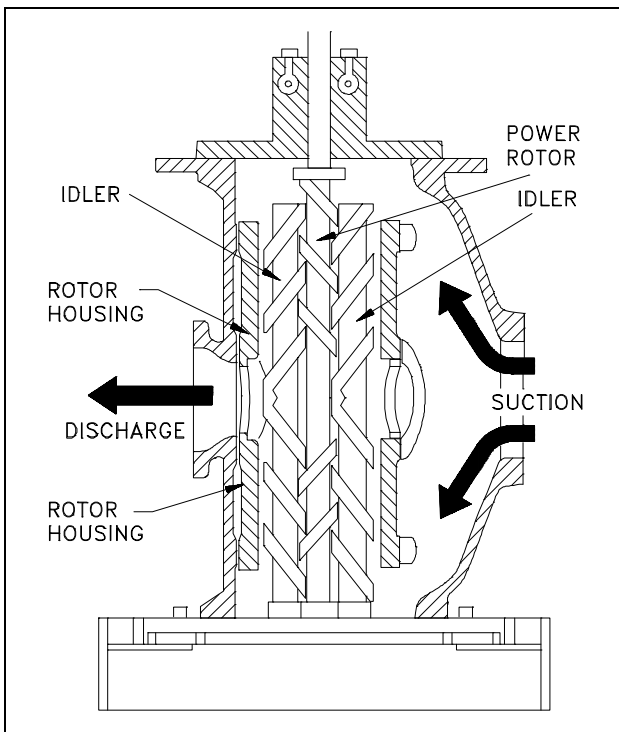


Figure 18 Three-Screw, High-Pitch, Screw Pump

The three-screw, high-pitch, screw pump, shown in Figure 18, has many of the same elements as the two-screw, low-pitch, screw pump, and their operations are similar. Three screws, oppositely threaded on each end, are employed. They rotate in a triple cylinder, the two outer bores of which overlap the center bore. The pitch of the screws is much higher than in the low pitch screw pump; therefore, the center screw, or power rotor, is used to drive the two outer idler rotors directly without external timing gears. Pedestal bearings at the base support the weight of the rotors and maintain their axial position. The liquid being pumped enters the suction opening, flows through passages around the rotor housing, and through the screws from each end, in opposed streams, toward the center discharge. This eliminates unbalanced hydraulic thrust. The screw pump is used for pumping viscous fluids, usually lubricating, hydraulic, or fuel oil.

Rotary Moving Vane Pump

The rotary moving vane pump shown in Figure 19 is another type of positive displacement pump used. The pump consists of a cylindrically bored housing with a suction inlet on one side and a discharge outlet on the other. A cylindrically shaped rotor with a diameter smaller than the cylinder is driven about an axis placed above the centerline of the cylinder. The clearance between rotor and cylinder is small at the top but increases at the bottom. The rotor carries vanes that move in and out as it rotates to maintain sealed spaces between the rotor and the cylinder wall. The vanes trap liquid or gas on the suction side and carry it to the discharge side, where contraction of the space expels it through the discharge line. The vanes may swing on pivots, or they may slide in slots in the rotor.

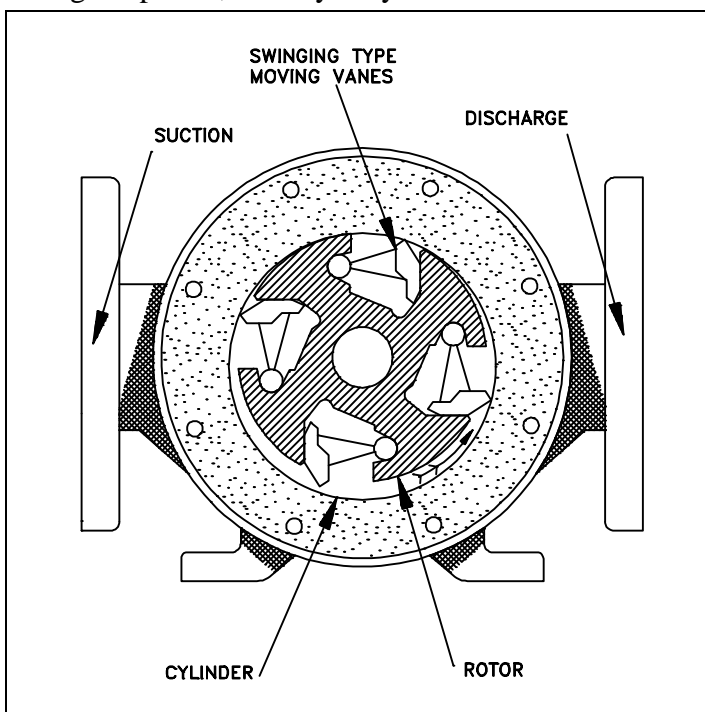


Figure 19 Rotary Moving Vane Pump

Diaphragm Pumps

Diaphragm pumps are also classified as positive displacement pumps because the diaphragm acts as a limited displacement piston. The pump will function when a diaphragm is forced into reciprocating motion by mechanical linkage, compressed air, or fluid from a pulsating, external source. The pump construction eliminates any contact between the liquid being pumped and the source of energy. This eliminates the possibility of leakage, which is important when handling toxic or very expensive liquids. Disadvantages include limited head and capacity range, and the necessity of check valves in the suction and discharge nozzles. An example of a diaphragm pump is shown in Figure 20.

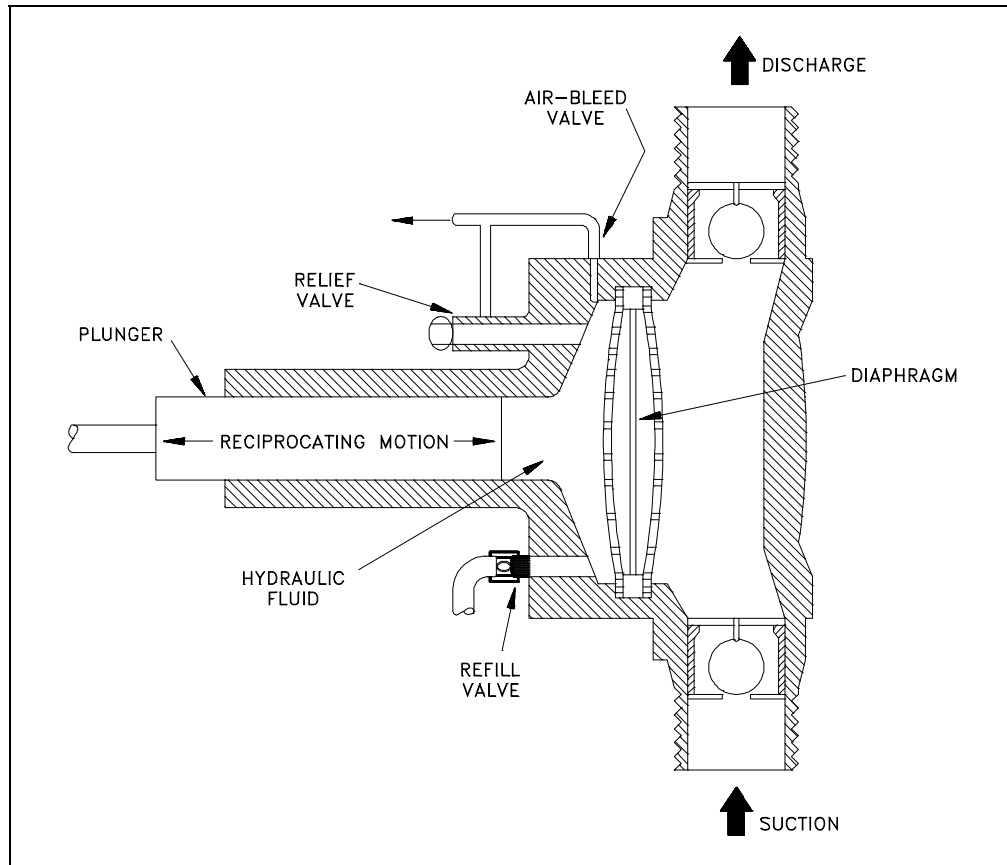


Figure 20 Diaphragm Pump

Positive Displacement Pump Characteristic Curves

Positive displacement pumps deliver a definite volume of liquid for each cycle of pump operation. Therefore, the only factor that effects flow rate in an ideal positive displacement pump is the speed at which it operates. The flow resistance of the system in which the pump is operating will not effect the flow rate through the pump. Figure 21 shows the characteristic curve for a positive displacement pump.

The dashed line in Figure 21 shows actual positive displacement pump performance. This line reflects the fact that as the discharge pressure of the pump increases, some amount of liquid will leak from the discharge of the pump back to the pump suction, reducing the effective flow rate of the pump. The rate at which liquid leaks from the pump discharge to its suction is called *slippage*.

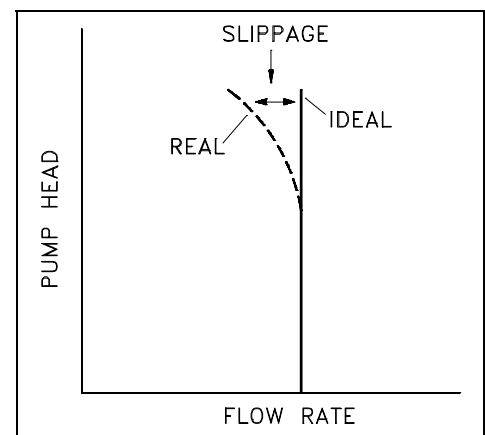


Figure 21
 Positive Displacement Pump
 Characteristic Curve

Positive Displacement Pump Protection

Positive displacement pumps are normally fitted with relief valves on the upstream side of their discharge valves to protect the pump and its discharge piping from overpressurization. Positive displacement pumps will discharge at the pressure required by the system they are supplying. The relief valve prevents system and pump damage if the pump discharge valve is shut during pump operation or if any other occurrence such as a clogged strainer blocks system flow.

Summary

The important information in this chapter is summarized below.

Positive Displacement Pumps Summary

- The flow delivered by a centrifugal pump during one revolution of the impeller depends upon the head against which the pump is operating. The positive displacement pump delivers a definite volume of fluid for each cycle of pump operation regardless of the head against which the pump is operating.
- Positive displacement pumps may be classified in the following ways:
 - Reciprocating piston pump
 - Gear-type rotary pump
 - Lobe-type rotary pump
 - Screw-type rotary pump
 - Moving vane pump
 - Diaphragm pump
- As the viscosity of a liquid increases, the maximum speed at which a reciprocating positive displacement pump can properly operate decreases. Therefore, as viscosity increases, the maximum flow rate through the pump decreases.
- The characteristic curve for a positive displacement pump operating at a certain speed is a vertical line on a graph of head versus flow.
- Slippage is the rate at which liquid leaks from the discharge of the pump back to the pump suction.
- Positive displacement pumps are protected from overpressurization by a relief valve on the upstream side of the pump discharge valve.

**Department of Energy
Fundamentals Handbook**

**MECHANICAL SCIENCE
Module 4
Valves**

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TERMINAL OBJECTIVE

- 1.0 Without references, **DESCRIBE** the construction and operation of a given type of valve, valve component, or valve actuator, as presented in this module.

ENABLING OBJECTIVES

- 1.1 **DESCRIBE** the four basic types of flow control elements employed in valve design.
- 1.2 **DESCRIBE** how valve stem leakage is controlled.
- 1.3 Given a drawing of a valve, **IDENTIFY** the following:
- | | |
|-------------|------------|
| a. Body | e. Packing |
| b. Bonnet | f. Seat |
| c. Stem | g. Disk |
| d. Actuator | |
- 1.4 Given a drawing of a valve, **IDENTIFY** each of the following types of valves:
- | | |
|--------------|------------------|
| a. Globe | g. Diaphragm |
| b. Gate | h. Pinch |
| c. Plug | i. Check |
| d. Ball | j. Stop check |
| e. Needle | k. Safety/relief |
| f. Butterfly | l. Reducing |
- 1.5 **DESCRIBE** the application of the following types of valves:
- | | |
|--------------|------------------|
| a. Globe | g. Diaphragm |
| b. Gate | h. Pinch |
| c. Plug | i. Check |
| d. Ball | j. Safety/relief |
| e. Needle | k. Reducing |
| f. Butterfly | |
- 1.6 **DESCRIBE** the construction and principle of operation for the following types of valve actuators:
- | | |
|-------------------|--------------|
| a. Manual | d. Hydraulic |
| b. Electric motor | e. Solenoid |
| c. Pneumatic | |

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VALVE FUNCTIONS AND BASIC PARTS

Valves are the most common single piece of equipment found in DOE facilities. Although there are many types, shapes, and sizes of valves, they all have the same basic parts. This chapter will review the common parts and functions of a valve.

EO 1.1 **DESCRIBE the four basic types of flow control elements employed in valve design.**

EO 1.2 **DESCRIBE how valve stem leakage is controlled.**

EO 1.3 **Given a drawing of a valve, IDENTIFY the following:**

- | | | | |
|-----------|-----------------|-----------|----------------|
| a. | Body | e. | Packing |
| b. | Bonnet | f. | Seat |
| c. | Stem | g. | Disk |
| d. | Actuator | | |

Introduction

A valve is a mechanical device that controls the flow of fluid and pressure within a system or process. A valve controls system or process fluid flow and pressure by performing any of the following functions:

- Stopping and starting fluid flow
- Varying (throttling) the amount of fluid flow
- Controlling the direction of fluid flow
- Regulating downstream system or process pressure
- Relieving component or piping over pressure

There are many valve designs and types that satisfy one or more of the functions identified above. A multitude of valve types and designs safely accommodate a wide variety of industrial applications.

Regardless of type, all valves have the following basic parts: the body, bonnet, trim (internal elements), actuator, and packing. The basic parts of a valve are illustrated in Figure 1.

Valve Body

The *body*, sometimes called the shell, is the primary pressure boundary of a valve. It serves as the principal element of a valve assembly because it is the framework that holds everything together.

The body, the first pressure boundary of a valve, resists fluid pressure loads from connecting piping. It receives inlet and outlet piping through threaded, bolted, or welded joints.

Valve bodies are cast or forged into a variety of shapes. Although a sphere or a cylinder would theoretically be the most economical shape to resist fluid pressure when a valve is open, there are many other considerations. For example, many valves require a partition across the valve body to support the seat opening, which is the throttling orifice. With the valve closed, loading on the body is difficult to determine. The valve end connections also distort loads on a simple sphere and more complicated shapes. Ease of manufacture, assembly, and costs are additional important considerations. Hence, the basic form of a valve body typically is not spherical, but ranges from simple block shapes to highly complex shapes in which the bonnet, a removable piece to make assembly possible, forms part of the pressure-resisting body.

Narrowing of the fluid passage (venturi effect) is also a common method for reducing the overall size and cost of a valve. In other instances, large ends are added to the valve for connection into a larger line.

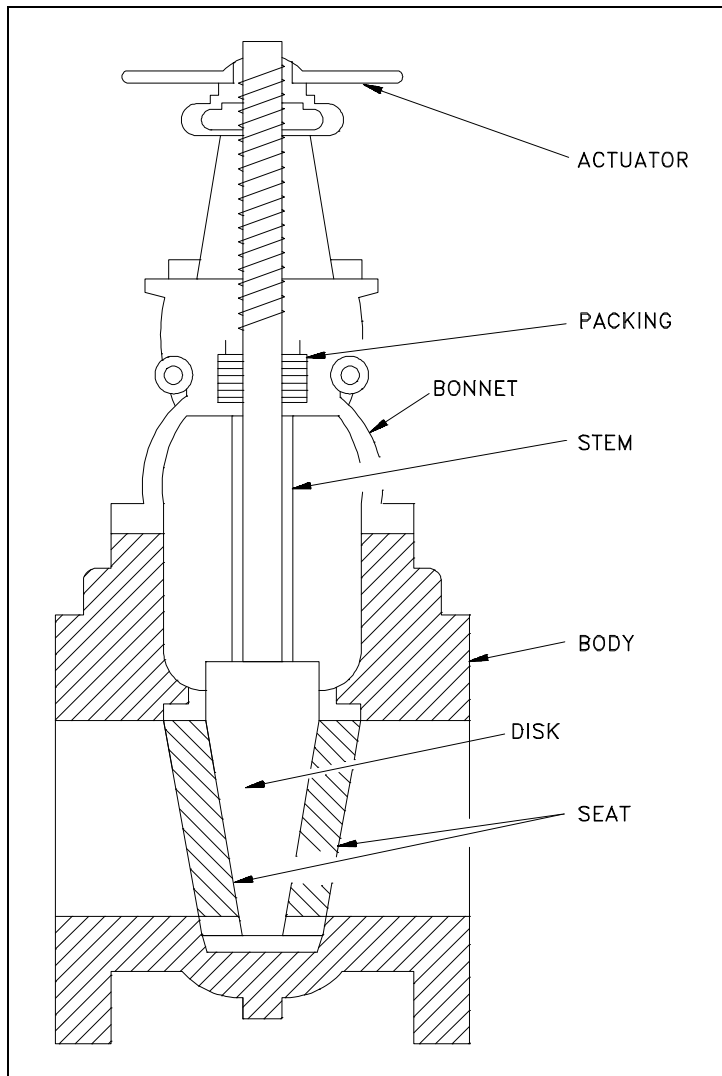


Figure 1 Basic Parts of a Valve

Valve Bonnet

The cover for the opening in the valve body is the *bonnet*. In some designs, the body itself is split into two sections that bolt together. Like valve bodies, bonnets vary in design. Some bonnets function simply as valve covers, while others support valve internals and accessories such as the stem, disk, and actuator.

The bonnet is the second principal pressure boundary of a valve. It is cast or forged of the same material as the body and is connected to the body by a threaded, bolted, or welded joint. In all cases, the attachment of the bonnet to the body is considered a pressure boundary. This means that the weld joint or bolts that connect the bonnet to the body are pressure-retaining parts.

Valve bonnets, although a necessity for most valves, represent a cause for concern. Bonnets can complicate the manufacture of valves, increase valve size, represent a significant cost portion of valve cost, and are a source for potential leakage.

Valve Trim

The internal elements of a valve are collectively referred to as a valve's *trim*. The trim typically includes a *disk*, *seat*, *stem*, and *sleeves* needed to guide the stem. A valve's performance is determined by the disk and seat interface and the relation of the disk position to the seat.

Because of the trim, basic motions and flow control are possible. In rotational motion trim designs, the disk slides closely past the seat to produce a change in flow opening. In linear motion trim designs, the disk lifts perpendicularly away from the seat so that an annular orifice appears.

Disk and Seat

For a valve having a bonnet, the disk is the third primary principal pressure boundary. The disk provides the capability for permitting and prohibiting fluid flow. With the disk closed, full system pressure is applied across the disk if the outlet side is depressurized. For this reason, the disk is a pressure-retaining part. Disks are typically forged and, in some designs, hard-surfaced to provide good wear characteristics. A fine surface finish of the seating area of a disk is necessary for good sealing when the valve is closed. Most valves are named, in part, according to the design of their disks.

The seat or seal rings provide the seating surface for the disk. In some designs, the body is machined to serve as the seating surface and seal rings are not used. In other designs, forged seal rings are threaded or welded to the body to provide the seating surface. To improve the wear-resistance of the seal rings, the surface is often hard-faced by welding and then machining the contact surface of the seal ring. A fine surface finish of the seating area is necessary for good sealing when the valve is closed. Seal rings are not usually considered pressure boundary parts because the body has sufficient wall thickness to withstand design pressure without relying upon the thickness of the seal rings.

Stem

The *stem*, which connects the actuator and disk, is responsible for positioning the disk. Stems are typically forged and connected to the disk by threaded or welded joints. For valve designs requiring stem packing or sealing to prevent leakage, a fine surface finish of the stem in the area of the seal is necessary. Typically, a stem is not considered a pressure boundary part.

Connection of the disk to the stem can allow some rocking or rotation to ease the positioning of the disk on the seat. Alternately, the stem may be flexible enough to let the disk position itself against the seat. However, constant fluttering or rotation of a flexible or loosely connected disk can destroy the disk or its connection to the stem.

Two types of valve stems are rising stems and nonrising stems. Illustrated in Figures 2 and 3, these two types of stems are easily distinguished by observation. For a rising stem valve, the stem will rise above the actuator as the valve is opened. This occurs because the stem is threaded and mated with the bushing threads of a yoke that is an integral part of, or is mounted to, the bonnet.

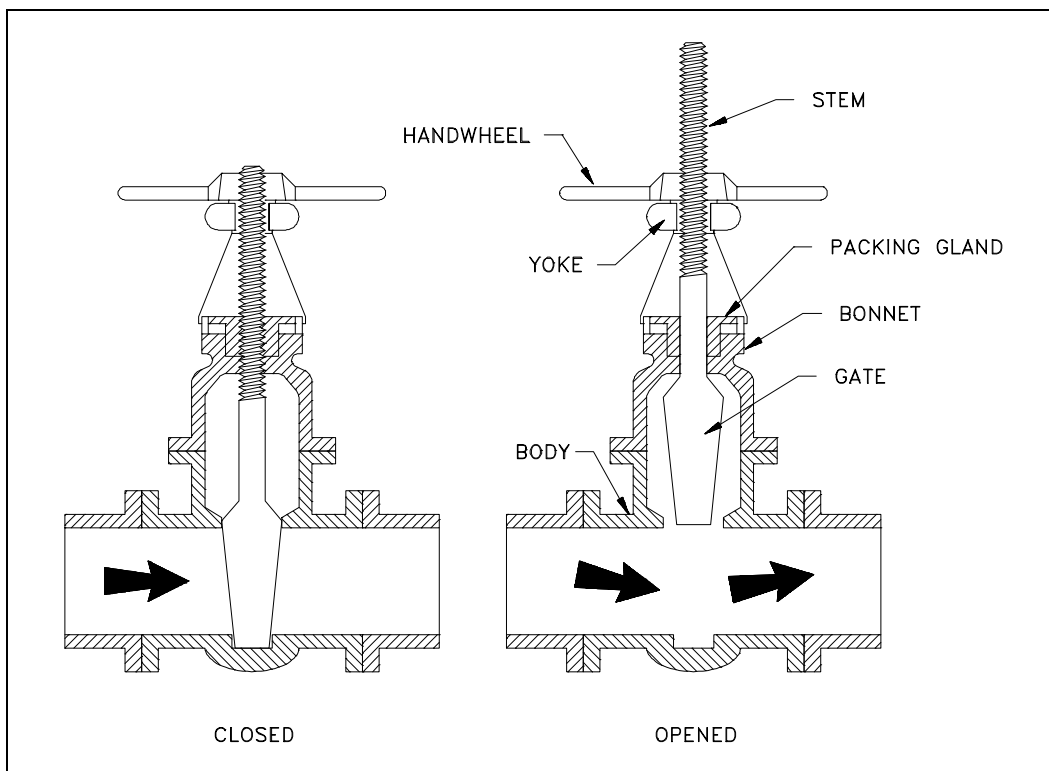


Figure 2 Rising Stems

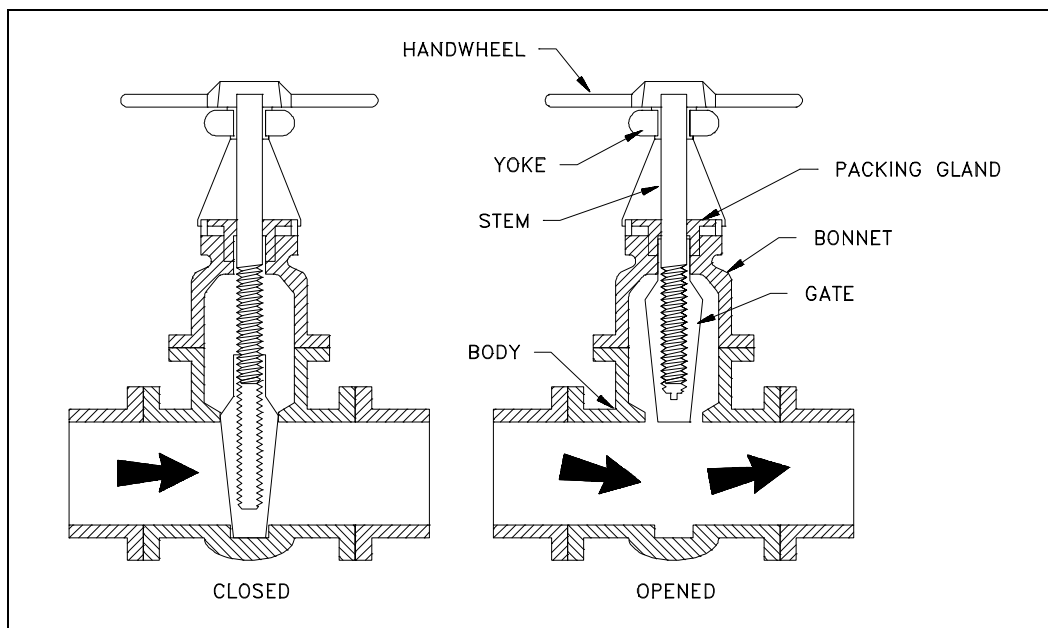


Figure 3 Nonrising Stems

There is no upward stem movement from outside the valve for a nonrising stem design. For the nonrising stem design, the valve disk is threaded internally and mates with the stem threads.

Valve Actuator

The *actuator* operates the stem and disk assembly. An actuator may be a manually operated handwheel, manual lever, motor operator, solenoid operator, pneumatic operator, or hydraulic ram. In some designs, the actuator is supported by the bonnet. In other designs, a yoke mounted to the bonnet supports the actuator.

Except for certain hydraulically controlled valves, actuators are outside of the pressure boundary. Yokes, when used, are always outside of the pressure boundary.

Valve Packing

Most valves use some form of packing to prevent leakage from the space between the stem and the bonnet. *Packing* is commonly a fibrous material (such as flax) or another compound (such as teflon) that forms a seal between the internal parts of a valve and the outside where the stem extends through the body.

Valve packing must be properly compressed to prevent fluid loss and damage to the valve's stem. If a valve's packing is too loose, the valve will leak, which is a safety hazard. If the packing is too tight, it will impair the movement and possibly damage the stem.

Introduction to the Types of Valves

Because of the diversity of the types of systems, fluids, and environments in which valves must operate, a vast array of valve types have been developed. Examples of the common types are the globe valve, gate valve, ball valve, plug valve, butterfly valve, diaphragm valve, check valve, pinch valve, and safety valve. Each type of valve has been designed to meet specific needs. Some valves are capable of throttling flow, other valve types can only stop flow, others work well in corrosive systems, and others handle high pressure fluids. Each valve type has certain inherent advantages and disadvantages. Understanding these differences and how they effect the valve's application or operation is necessary for the successful operation of a facility.

Although all valves have the same basic components and function to control flow in some fashion, the method of controlling the flow can vary dramatically. In general, there are four methods of controlling flow through a valve.

1. Move a disc, or plug into or against an orifice (for example, globe or needle type valve).
2. Slide a flat, cylindrical, or spherical surface across an orifice (for example, gate and plug valves).
3. Rotate a disc or ellipse about a shaft extending across the diameter of an orifice (for example, a butterfly or ball valve).
4. Move a flexible material into the flow passage (for example, diaphragm and pinch valves).

Each method of controlling flow has characteristics that makes it the best choice for a given application of function.

Summary

The following important information in this chapter is summarized below:

Valve Functions and Basic Parts Summary

- There are four basic types of flow control elements employed in valve design.
 1. Move a disc, or plug into or against an orifice (for example, globe or needle type valve).
 2. Slide a flat, cylindrical, or spherical surface across an orifice (for example, gate and plug valves).
 3. Rotate a disc or ellipse about a shaft extending across the diameter of an orifice (for example, a butterfly or ball valve).
 4. Move a flexible material into the flow passage (for example, diaphragm and pinch valves).
- Valve stem leakage is usually controlled by properly compressing the packing around the valve stem.
- There are seven basic parts common to most valves.

TYPES OF VALVES

Due to the various environments, system fluids, and system conditions in which flow must be controlled, a large number of valve designs have been developed. A basic understanding of the differences between the various types of valves, and how these differences affect valve function, will help ensure the proper application of each valve type during design and the proper use of each valve type during operation.

EO 1.4 **Given a drawing of a valve, IDENTIFY each of the following types of valves:**

- | | |
|--|---|
| <ul style="list-style-type: none"> a. Globe b. Gate c. Plug d. Ball e. Needle f. Butterfly | <ul style="list-style-type: none"> g. Diaphragm h. Pinch i. Check j. Safety/relief k. Reducing |
|--|---|

EO 1.5 **DESCRIBE the application of the following types of valves:**

- | | |
|--|---|
| <ul style="list-style-type: none"> a. Globe b. Gate c. Plug d. Ball e. Needle f. Butterfly | <ul style="list-style-type: none"> g. Diaphragm h. Pinch i. Check j. Safety/relief k. Reducing |
|--|---|

Gate Valves

A *gate* valve is a linear motion valve used to start or stop fluid flow; however, it does not regulate or throttle flow. The name gate is derived from the appearance of the disk in the flow stream. Figure 4 illustrates a gate valve.

The disk of a gate valve is completely removed from the flow stream when the valve is fully open. This characteristic offers virtually no resistance to flow when the valve is open. Hence, there is little pressure drop across an open gate valve.

When the valve is fully closed, a disk-to-seal ring contact surface exists for 360°, and good sealing is provided. With the proper mating of a disk to the seal ring, very little or no leakage occurs across the disk when the gate valve is closed.

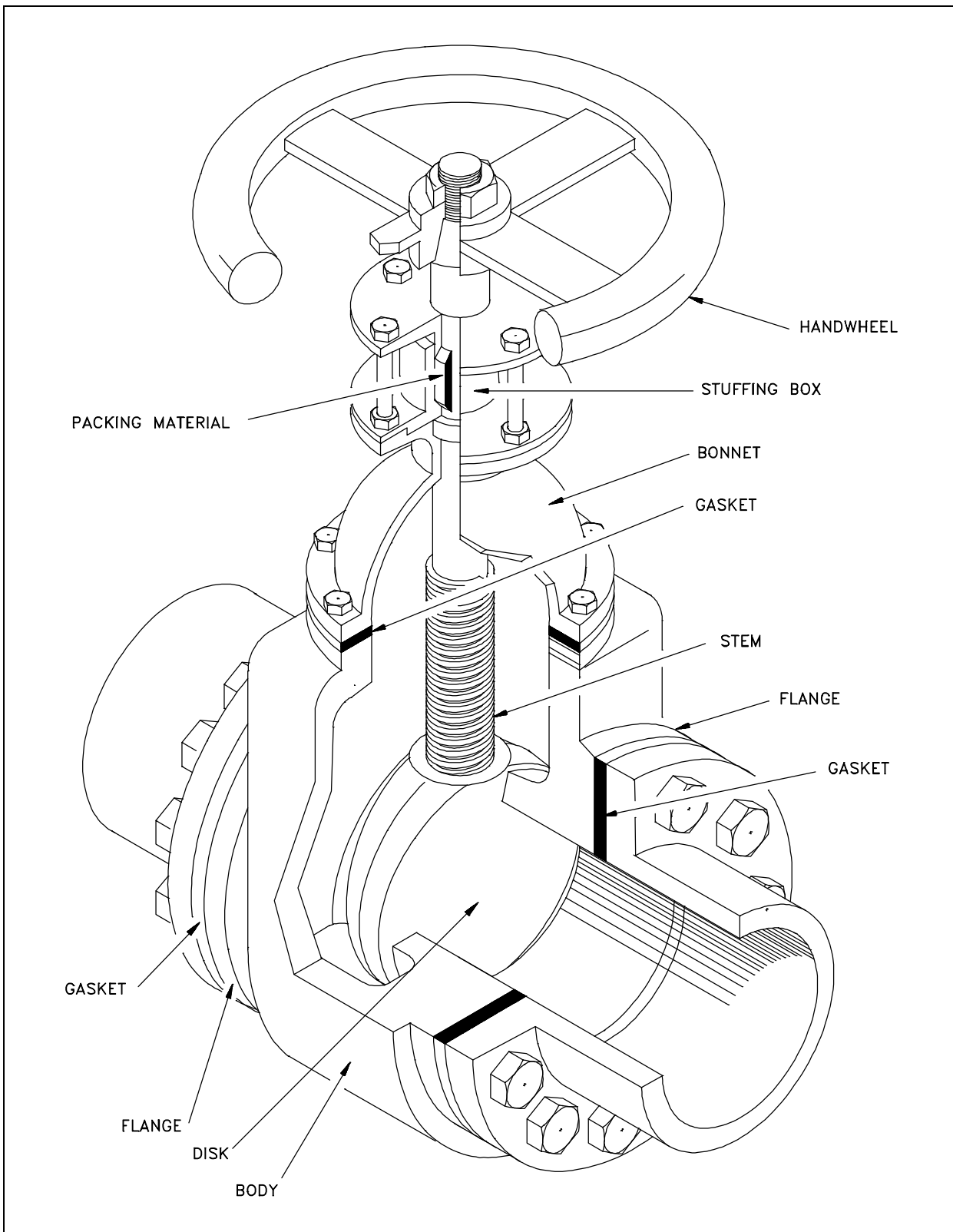


Figure 4 Gate Valve

On opening the gate valve, the flow path is enlarged in a highly nonlinear manner with respect to percent of opening. This means that flow rate does not change evenly with stem travel. Also, a partially open gate disk tends to vibrate from the fluid flow. Most of the flow change occurs near shutoff with a relatively high fluid velocity causing disk and seat wear and eventual leakage if used to regulate flow. For these reasons, gate valves are not used to regulate or throttle flow.

A gate valve can be used for a wide variety of fluids and provides a tight seal when closed. The major disadvantages to the use of a gate valve are:

- It is not suitable for throttling applications.
- It is prone to vibration in the partially open state.
- It is more subject to seat and disk wear than a globe valve.
- Repairs, such as lapping and grinding, are generally more difficult to accomplish.

Gate Valve Disk Design

Gate valves are available with a variety of disks. Classification of gate valves is usually made by the type disk used: solid wedge, flexible wedge, split wedge, or parallel disk.

Solid wedges, flexible wedges, and split wedges are used in valves having inclined seats. Parallel disks are used in valves having parallel seats.

Regardless of the style of wedge or disk used, the disk is usually replaceable. In services where solids or high velocity may cause rapid erosion of the seat or disk, these components should have a high surface hardness and should have replacement seats as well as disks. If the seats are not replaceable, seat damage requires removal of the valve from the line for refacing of the seat, or refacing of the seat in place. Valves being used in corrosion service should normally be specified with replaceable seats.

Solid Wedge

The solid wedge gate valve shown in Figure 5 is the most commonly used disk because of its simplicity and strength. A valve with this type of wedge may be installed in any position and it is suitable for almost all fluids. It is practical for turbulent flow.

Flexible Wedge

The flexible wedge gate valve illustrated in Figure 6 is a one-piece disk with a cut around the perimeter to improve the ability to match error or change in the angle between the seats. The cut varies in size, shape, and depth. A shallow, narrow cut gives little flexibility but retains strength. A deeper and wider cut, or cast-in recess, leaves little material at the center, which allows more flexibility but compromises strength.

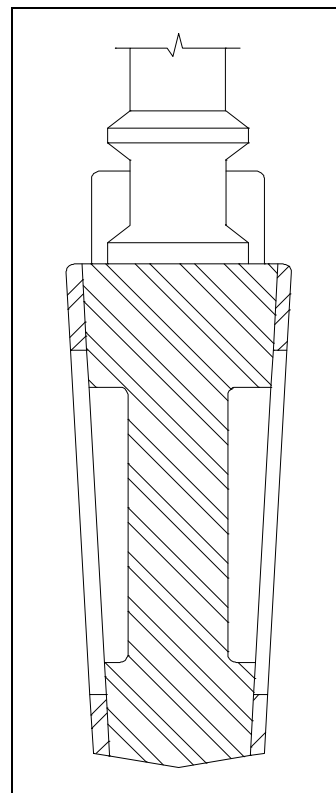


Figure 5
Solid Wedge Gate Valve

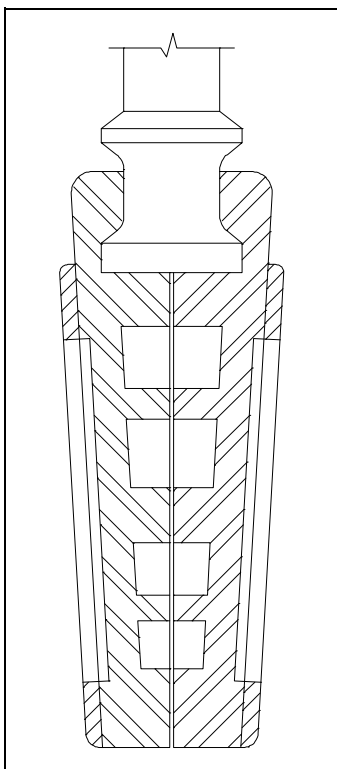


Figure 6
Flexible Wedge Gate Valve

A correct profile of the disk half in the flexible wedge design can give uniform deflection properties at the disk edge, so that the wedging force applied in seating will force the disk seating surface uniformly and tightly against the seat.

Gate valves used in steam systems have flexible wedges. The reason for using a flexible gate is to prevent binding of the gate within the valve when the valve is in the closed position. When steam lines are heated, they expand and cause some distortion of valve bodies. If a solid gate fits snugly between the seat of a valve in a cold steam system, when the system is heated and pipes elongate, the seats will compress against the gate and clamp the valve shut. This problem is overcome by using a flexible gate, whose design allows the gate to flex as the valve seat compresses it.

The major problem associated with flexible gates is that water tends to collect in the body neck. Under certain conditions, the admission of steam may cause the valve body neck to rupture, the bonnet to lift off, or the seat ring to collapse. Following correct warming procedures prevent these problems.

Split Wedge

Split wedge gate valves, as shown in Figure 7, are of the ball and socket design. These are self-adjusting and self-aligning to both seating surfaces. The disk is free to adjust itself to the seating surface if one-half of the disk is slightly out of alignment because of foreign matter lodged between the disk half and the seat ring. This type of wedge is suitable for handling noncondensing gases and liquids at normal temperatures, particularly corrosive liquids. Freedom of movement of the disk in the carrier prevents binding even though the valve may have been closed when hot and later contracted due to cooling. This type of valve should be installed with the stem in the vertical position.

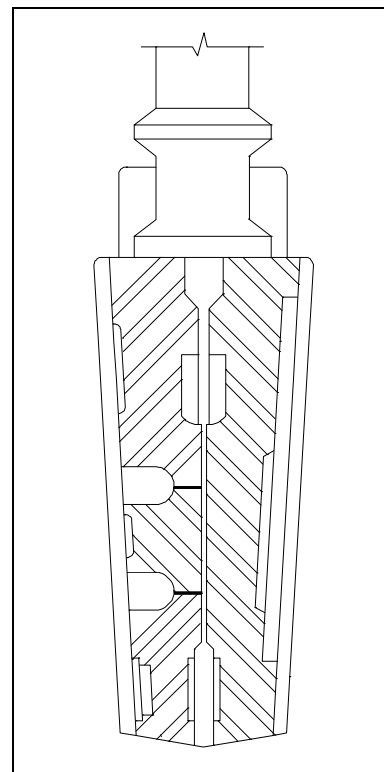


Figure 7 Split Wedge Gate Valve

Parallel Disk

The parallel disk gate valve illustrated in Figure 8 is designed to prevent valve binding due to thermal transients. This design is used in both low and high pressure applications.

The wedge surfaces between the parallel face disk halves are caused to press together under stem thrust and spread apart the disks to seal against the seats. The tapered wedges may be part of the disk halves or they may be separate elements. The lower wedge may bottom out on a rib at the valve bottom so that the stem can develop seating force. In one version, the wedge contact surfaces are curved to keep the point of contact close to the optimum.

In other parallel disk gates, the two halves do not move apart under wedge action. Instead, the upstream pressure holds the downstream disk against the seat. A carrier ring lifts the disks, and a spring or springs hold the disks apart and seated when there is no upstream pressure.

Another parallel gate disk design provides for sealing only one port. In these designs, the high pressure side pushes the disk open (relieving the disk) on the high pressure side, but forces the disk closed on the low pressure side. With such designs, the amount of seat leakage tends to decrease as differential pressure across the seat increases. These valves will usually have a flow direction marking which will show which side is the high pressure (relieving) side. Care should be taken to ensure that these valves are not installed backwards in the system.

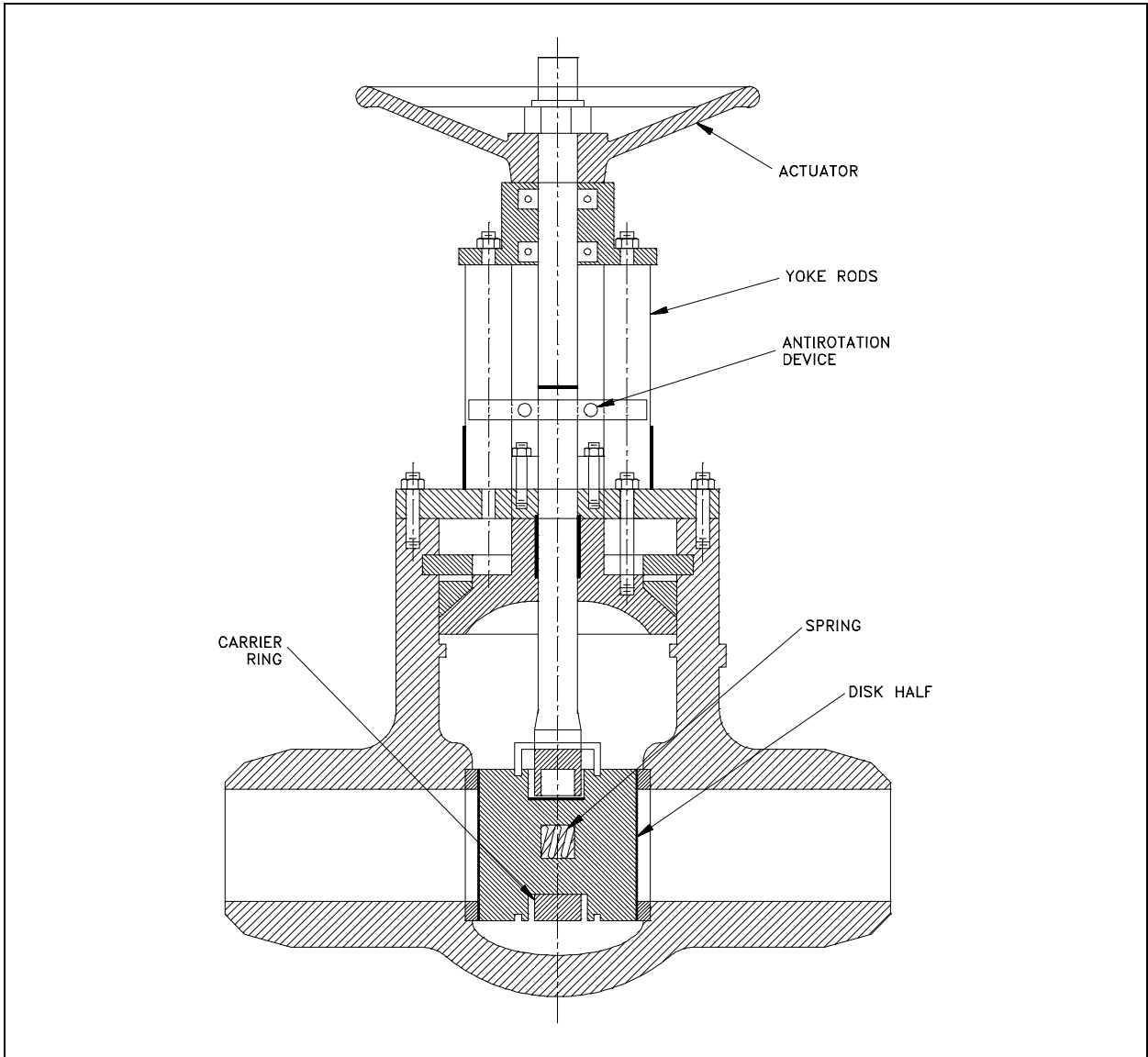


Figure 8 Parallel Disk Gate Valve

Some parallel disk gate valves used in high pressure systems are made with an integral bonnet vent and bypass line. A three-way valve is used to position the line to bypass in order to equalize pressure across the disks prior to opening. When the gate valve is closed, the three-way valve is positioned to vent the bonnet to one side or the other. This prevents moisture from accumulating in the bonnet. The three-way valve is positioned to the high pressure side of the gate valve when closed to ensure that flow does not bypass the isolation valve. The high pressure acts against spring compression and forces one gate off of its seat. The three-way valve vents this flow back to the pressure source.

Gate Valve Stem Design

Gate valves are classified as either rising stem or nonrising stem valves. For the nonrising stem gate valve, the stem is threaded on the lower end into the gate. As the hand wheel on the stem is rotated, the gate travels up or down the stem on the threads while the stem remains vertically stationary. This type valve will almost always have a pointer-type indicator threaded onto the upper end of the stem to indicate valve position. Figures 2 and 3 illustrate rising-stem gate valves and nonrising stem gate valves.

The nonrising stem configuration places the stem threads within the boundary established by the valve packing out of contact with the environment. This configuration assures that the stem merely rotates in the packing without much danger of carrying dirt into the packing from outside to inside.

Rising stem gate valves are designed so that the stem is raised out of the flowpath when the valve is open. Rising stem gate valves come in two basic designs. Some have a stem that rises through the handwheel while others have a stem that is threaded to the bonnet.

Gate Valve Seat Design

Seats for gate valves are either provided integral with the valve body or in a seat ring type of construction. Seat ring construction provides seats which are either threaded into position or are pressed into position and seal welded to the valve body. The latter form of construction is recommended for higher temperature service.

Integral seats provide a seat of the same material of construction as the valve body while the pressed-in or threaded-in seats permit variation. Rings with hard facings may be supplied for the application where they are required.

Small, forged steel, gate valves may have hard faced seats pressed into the body. In some series, this type of valve in sizes from 1/2 to 2 inches is rated for 2500 psig steam service. In large gate valves, disks are often of the solid wedge type with seat rings threaded in, welded in, or pressed in. Screwed in seat rings are considered replaceable since they may be removed and new seat rings installed.

Globe Valves

A globe valve is a linear motion valve used to stop, start, and regulate fluid flow. A Z-body globe valve is illustrated in Figure 9.

As shown in Figure 9, the globe valve disk can be totally removed from the flowpath or it can completely close the flowpath. The essential principle of globe valve operation is the perpendicular movement of the disk away from the seat. This causes the annular space between the disk and seat ring to gradually close as the valve is closed. This characteristic gives the globe valve good throttling ability, which permits its use in regulating flow. Therefore, the globe valve may be used for both stopping and starting fluid flow and for regulating flow.

When compared to a gate valve, a globe valve generally yields much less seat leakage. This is because the disk-to-seat ring contact is more at right angles, which permits the force of closing to tightly seat the disk.

Globe valves can be arranged so that the disk closes against or in the same direction of fluid flow. When the disk closes against the direction of flow, the kinetic energy of the fluid impedes closing but aids opening of the valve. When the disk closes in the same direction of flow, the kinetic energy of the fluid aids closing but impedes opening. This characteristic is preferable to other designs when quick-acting stop valves are necessary.

Globe valves also have drawbacks. The most evident shortcoming of the simple globe valve is the high head loss from two or more right angle turns of flowing fluid. Obstructions and discontinuities in the flowpath lead to head loss. In a large high pressure line, the fluid dynamic effects from pulsations, impacts, and pressure drops can damage trim, stem packing, and actuators. In addition, large valve sizes require considerable power to operate and are especially noisy in high pressure applications.

Other drawbacks of globe valves are the large openings necessary for disk assembly, heavier weight than other valves of the same flow rating, and the cantilevered mounting of the disk to the stem.

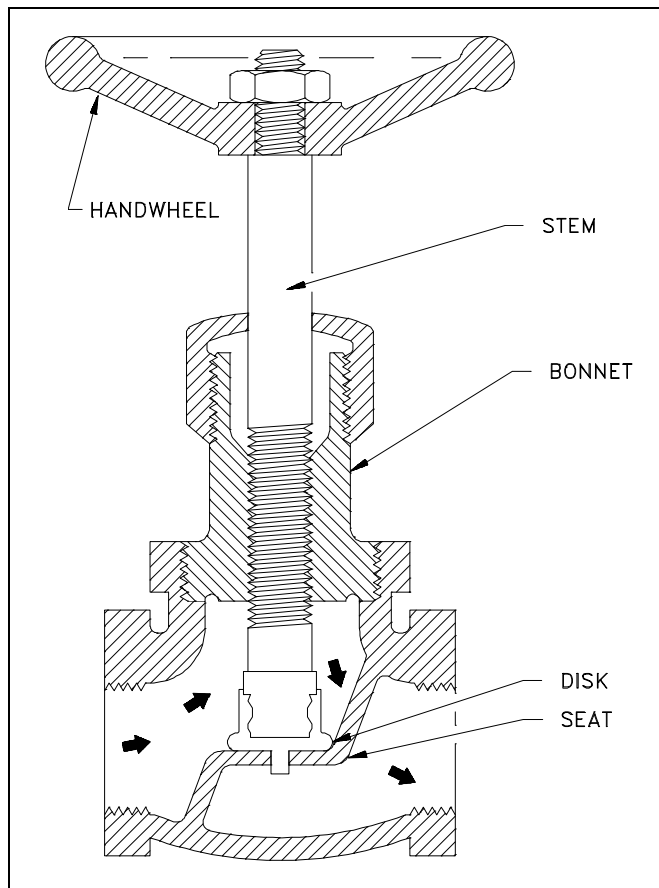


Figure 9 Z-Body Globe Valve

Globe Valve Body Designs

The three primary body designs for globe valves are Z-body, Y-body, and Angle.

Z-Body Design

The simplest design and most common for water applications is the Z-body. The Z-body is illustrated in Figure 9. For this body design, the Z-shaped diaphragm or partition across the globular body contains the seat. The horizontal setting of the seat allows the stem and disk to travel at right angles to the pipe axis. The stem passes through the bonnet which is attached to a large opening at the top of the valve body. This provides a symmetrical form that simplifies manufacture, installation, and repair.

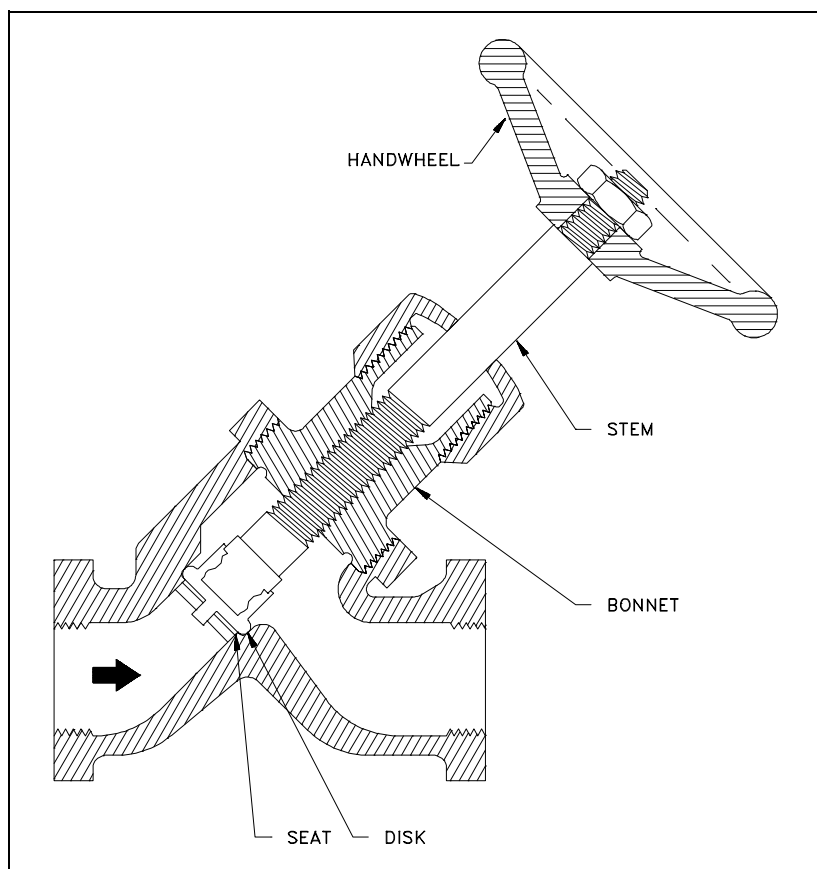


Figure 10 Y-Body Globe Valve

Y-Body Design

Figure 10 illustrates a typical Y-body globe valve. This design is a remedy for the high pressure drop inherent in globe valves. The seat and stem are angled at approximately 45°. The angle yields a straighter flowpath (at full opening) and provides the stem, bonnet, and packing a relatively pressure-resistant envelope.

Y-body globe valves are best suited for high pressure and other severe services. In small sizes for intermittent flows, the pressure loss may not be as important as the other considerations favoring the Y-body design. Hence, the flow passage of small Y-body globe valves is not as carefully streamlined as that for larger valves.

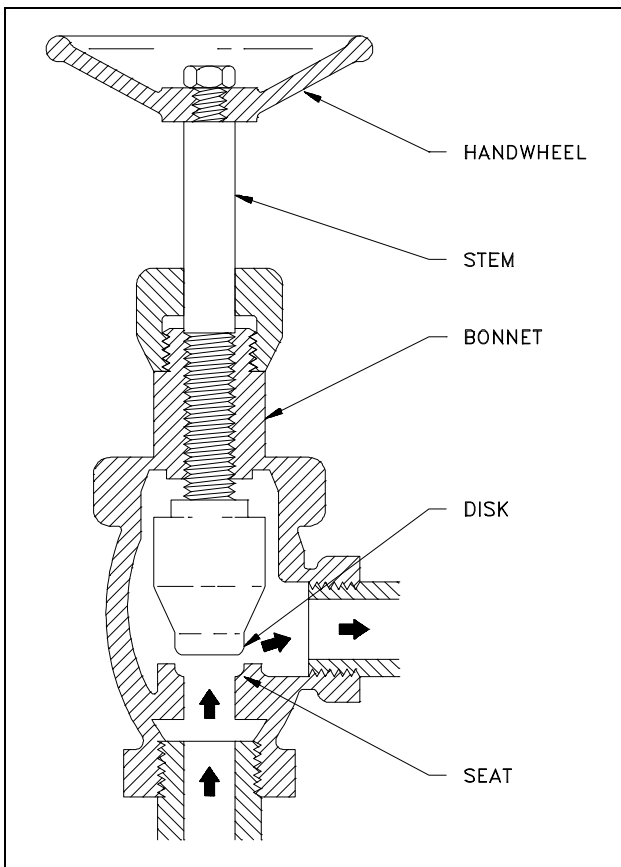


Figure 11 Angle Globe Valve

Angle Valve Design

The angle body globe valve design, illustrated in Figure 11, is a simple modification of the basic globe valve. Having ends at right angles, the diaphragm can be a simple flat plate. Fluid is able to flow through with only a single 90° turn and discharge downward more symmetrically than the discharge from an ordinary globe. A particular advantage of the angle body design is that it can function as both a valve and a piping elbow.

For moderate conditions of pressure, temperature, and flow, the angle valve closely resembles the ordinary globe. The angle valve's discharge conditions are favorable with respect to fluid dynamics and erosion.

Globe Valve Disks

Most globe valves use one of three basic disk designs: the ball disk, the composition disk, and the plug disk.

Ball Disk

The ball disk fits on a tapered, flat-surfaced seat. The ball disk design is used primarily in relatively low pressure and low temperature systems. It is capable of throttling flow, but is primarily used to stop and start flow.

Composition Disk

The composition disk design uses a hard, nonmetallic insert ring on the disk. The insert ring creates a tighter closure. Composition disks are primarily used in steam and hot water applications. They resist erosion and are sufficiently resilient to close on solid particles without damaging the valve. Composition disks are replaceable.

Plug Disk

Because of its configuration, the plug disk provides better throttling than ball or composition designs. Plug disks are available in a variety of specific configurations. In general, they are all long and tapered.

Globe Valve Disk and Stem Connections

Globe valves employ two methods for connecting disk and stem: T-slot construction and disk nut construction. In the T-slot design, the disk slips over the stem. In the disk nut design, the disk is screwed into the stem.

Globe Valve Seats

Globe valve seats are either integral with or screwed into the valve body. Many globe valves have backseats. A backseat is a seating arrangement that provides a seal between the stem and bonnet. When the valve is fully open, the disk seats against the backseat. The backseat design prevents system pressure from building against the valve packing.

Globe Valve Direction of Flow

For low temperature applications, globe and angle valves are ordinarily installed so that pressure is under the disk. This promotes easy operation, helps protect the packing, and eliminates a certain amount of erosive action to the seat and disk faces. For high temperature steam service, globe valves are installed so that pressure is above the disk. Otherwise, the stem will contract upon cooling and tend to lift the disk off the seat.

Ball Valves

A ball valve is a rotational motion valve that uses a ball-shaped disk to stop or start fluid flow. The ball, shown in Figure 12, performs the same function as the disk in the globe valve. When the valve handle is turned to open the valve, the ball rotates to a point where the hole through the ball is in line with the valve body inlet and outlet. When the valve is shut, the ball is rotated so that the hole is perpendicular to the flow openings of the valve body and the flow is stopped.

Most ball valve actuators are of the quick-acting type, which require a 90° turn of the valve handle to operate the valve. Other ball valve actuators are planetary gear-operated. This type of gearing allows the use of a relatively small handwheel and operating force to operate a fairly large valve.

Some ball valves have been developed with a spherical surface coated plug that is off to one side in the open position and rotates into the flow passage until it blocks the flowpath completely. Seating is accomplished by the eccentric movement of the plug. The valve requires no lubrication and can be used for throttling service.

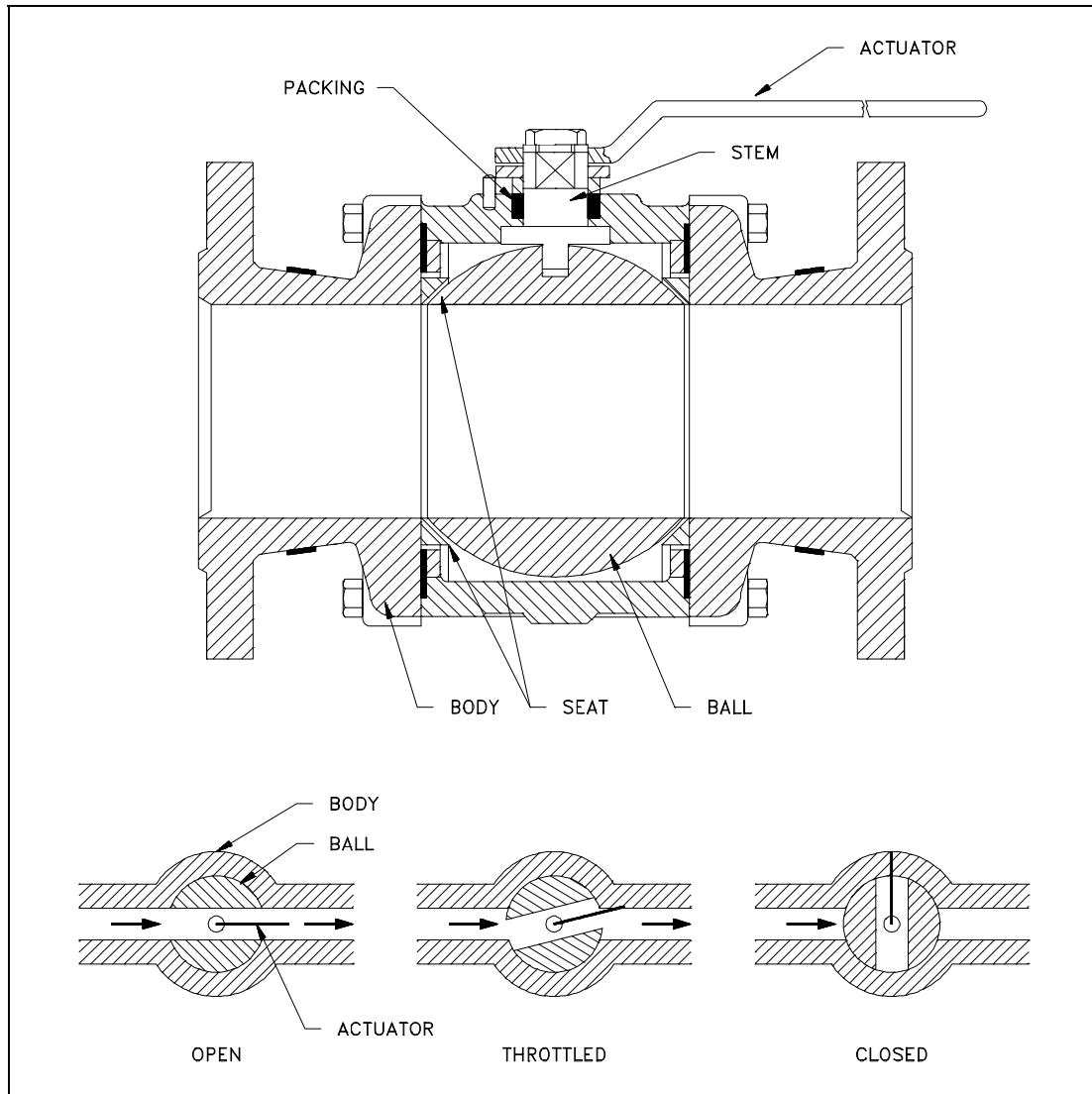


Figure 12 Typical Ball Valve

Advantages

A ball valve is generally the least expensive of any valve configuration and has low maintenance costs. In addition to quick, quarter turn on-off operation, ball valves are compact, require no lubrication, and give tight sealing with low torque.

Disadvantages

Conventional ball valves have relatively poor throttling characteristics. In a throttling position, the partially exposed seat rapidly erodes because of the impingement of high velocity flow.

Port Patterns

Ball valves are available in the venturi, reduced, and full port pattern. The full port pattern has a ball with a bore equal to the inside diameter of the pipe.

Valve Materials

Balls are usually metallic in metallic bodies with trim (seats) produced from elastomeric (elastic materials resembling rubber) materials. Plastic construction is also available.

The resilient seats for ball valves are made from various elastomeric material. The most common seat materials are teflon (TFE), filled TFE, Nylon, Buna-N, Neoprene, and combinations of these materials. Because of the elastomeric materials, these valves cannot be used at elevated temperatures. Care must be used in the selection of the seat material to ensure that it is compatible with the materials being handled by the valve.

Ball Valve Stem Design

The stem in a ball valve is not fastened to the ball. It normally has a rectangular portion at the ball end which fits into a slot cut into the ball. The enlargement permits rotation of the ball as the stem is turned.

Ball Valve Bonnet Design

A bonnet cap fastens to the body, which holds the stem assembly and ball in place. Adjustment of the bonnet cap permits compression of the packing, which supplies the stem seal. Packing for ball valve stems is usually in the configuration of die-formed packing rings normally of TFE, TFE-filled, or TFE-impregnated material. Some ball valve stems are sealed by means of O-rings rather than packing.

Ball Valve Position

Some ball valves are equipped with stops that permit only 90° rotation. Others do not have stops and may be rotated 360°. With or without stops, a 90° rotation is all that is required for closing or opening a ball valve.

The handle indicates valve ball position. When the handle lies along the axis of the valve, the valve is open. When the handle lies 90° across the axis of the valve, the valve is closed. Some ball valve stems have a groove cut in the top face of the stem that shows the flowpath through the ball. Observation of the groove position indicates the position of the port through the ball. This feature is particularly advantageous on multiport ball valves.

Plug Valves

A plug valve is a rotational motion valve used to stop or start fluid flow. The name is derived from the shape of the disk, which resembles a plug. A plug valve is shown in Figure 13. The simplest form of a plug valve is the petcock. The body of a plug valve is machined to receive the tapered or cylindrical plug. The disk is a solid plug with a bored passage at a right angle to the longitudinal axis of the plug.

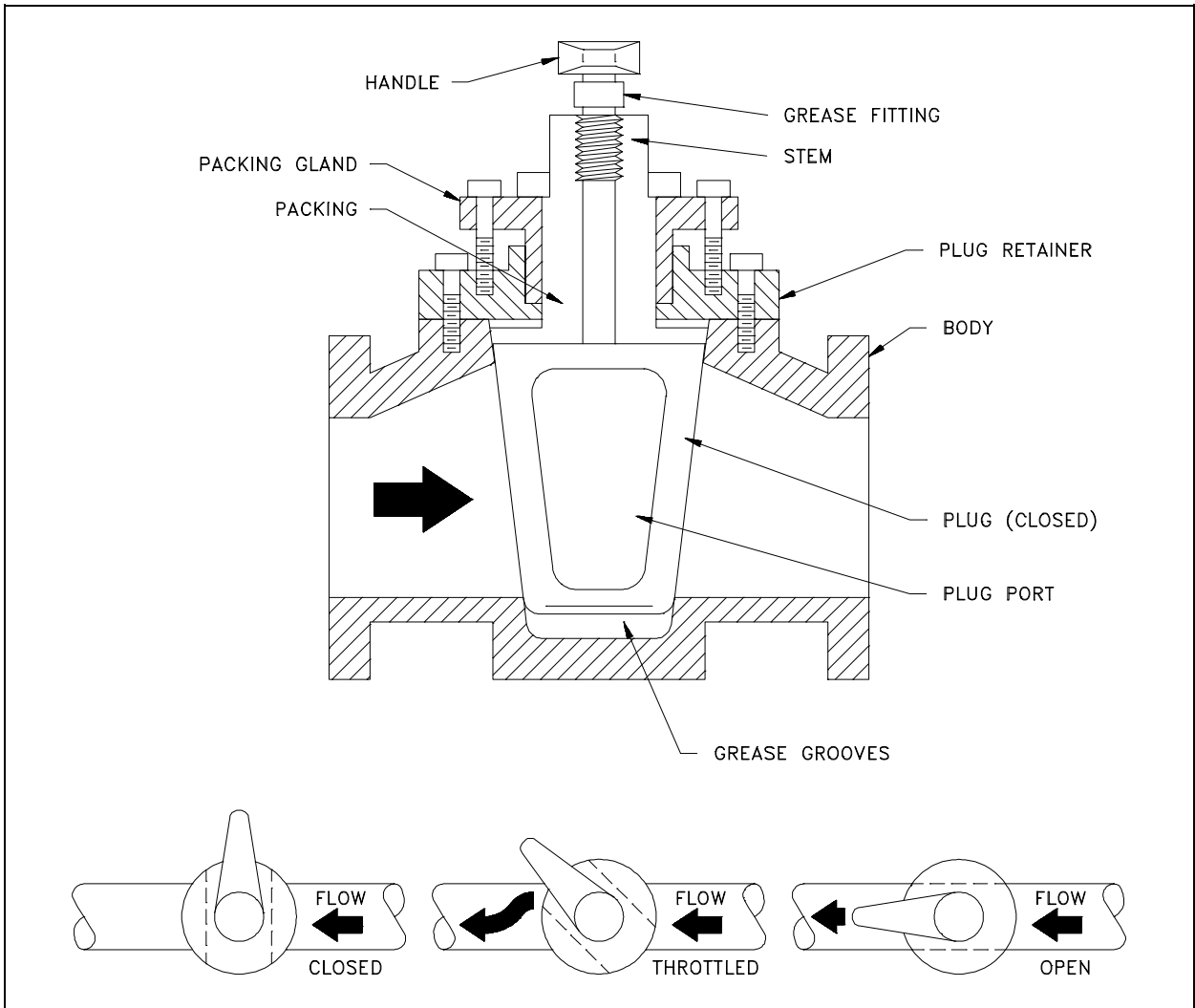


Figure 13 Plug Valve

In the open position, the passage in the plug lines up with the inlet and outlet ports of the valve body. When the plug is turned 90° from the open position, the solid part of the plug blocks the ports and stops fluid flow.

Plug valves are available in either a lubricated or nonlubricated design and with a variety of styles of port openings through the plug as well as a number of plug designs.

Plug Ports

An important characteristic of the plug valve is its easy adaptation to multiport construction. Multiport valves are widely used. Their installation simplifies piping, and they provide a more convenient operation than multiple gate valves. They also eliminate pipe fittings. The use of a multiport valve, depending upon the number of ports in the plug valve, eliminates the need of as many as four conventional shutoff valves.

Plug valves are normally used in non-throttling, on-off operations, particularly where frequent operation of the valve is necessary. These valves are not normally recommended for throttling service because, like the gate valve, a high percentage of flow change occurs near shutoff at high velocity. However, a diamond-shaped port has been developed for throttling service.

Multiport Plug Valves

Multiport valves are particularly advantageous on transfer lines and for diverting services. A single multiport valve may be installed in lieu of three or four gate valves or other types of shutoff valve. A disadvantage is that many multiport valve configurations do not completely shut off flow.

In most cases, one flowpath is always open. These valves are intended to divert the flow of one line while shutting off flow from the other lines. If complete shutoff of flow is a requirement, it is necessary that a style of multiport valve be used that permits this, or a secondary valve should be installed on the main line ahead of the multiport valve to permit complete shutoff of flow.

In some multiport configurations, simultaneous flow to more than one port is also possible. Great care should be taken in specifying the particular port arrangement required to guarantee that proper operation will be possible.

Plug Valve Disks

Plugs are either round or cylindrical with a taper. They may have various types of port openings, each with a varying degree of area relative to the corresponding inside diameter of the pipe.

Rectangular Port Plug

The most common port shape is the rectangular port. The rectangular port represents at least 70% of the corresponding pipe's cross-sectional area.

Round Port Plug

Round port plug is a term that describes a valve that has a round opening through the plug. If the port is the same size or larger than the pipe's inside diameter, it is referred to as a full port. If the opening is smaller than the pipe's inside diameter, the port is referred to as a standard round port. Valves having standard round ports are used only where restriction of flow is unimportant.

Diamond Port Plug

A diamond port plug has a diamond-shaped port through the plug. This design is for throttling service. All diamond port valves are venturi restricted flow type.

Lubricated Plug Valve Design

Clearances and leakage prevention are the chief considerations in plug valves. Many plug valves are of all metal construction. In these versions, the narrow gap around the plug can allow leakage. If the gap is reduced by sinking the taper plug deeper into the body, actuation torque climbs rapidly and galling can occur. To remedy this condition, a series of grooves around the body and plug port openings is supplied with grease prior to actuation. Applying grease lubricates the plug motion and seals the gap between plug and body. Grease injected into a fitting at the top of the stem travels down through a check valve in the passageway, past the plug top to the grooves on the plug, and down to a well below the plug. The lubricant must be compatible with the temperature and nature of the fluid. All manufacturers of lubricated plug valves have developed a series of lubricants that are compatible with a wide range of media. Their recommendation should be followed as to which lubricant is best suited for the service.

The most common fluids controlled by plug valves are gases and liquid hydrocarbons. Some water lines have these valves, provided that lubricant contamination is not a serious danger. Lubricated plug valves may be as large as 24 inches and have pressure capabilities up to 6000 psig. Steel or iron bodies are available. The plug can be cylindrical or tapered.

Nonlubricated Plugs

There are two basic types of nonlubricated plug valves: lift-type and elastomer sleeve or plug coated. Lift-type valves provide a means of mechanically lifting the tapered plug slightly to disengage it from the seating surface to permit easy rotation. The mechanical lifting can be accomplished with a cam or external lever.

In a common, nonlubricated, plug valve having an elastomer sleeve, a sleeve of TFE completely surrounds the plug. It is retained and locked in place by a metal body. This design results in a primary seal being maintained between the sleeve and the plug at all times regardless of position. The TFE sleeve is durable and inert to all but a few rarely encountered chemicals. It also has a low coefficient of friction and is, therefore, self-lubricating.

Manually Operated Plug Valve Installation

When installing plug valves, care should be taken to allow room for the operation of the handle, lever, or wrench. The manual operator is usually longer than the valve, and it rotates to a position parallel to the pipe from a position 90° to the pipe.

Plug Valve Glands

The gland of the plug valve is equivalent to the bonnet of a gate or globe valve. The gland secures the stem assembly to the valve body. There are three general types of glands: single gland, screwed gland, and bolted gland.

To ensure a tight valve, the plug must be seated at all times. Gland adjustment should be kept tight enough to prevent the plug from becoming unseated and exposing the seating surfaces to the live fluid. Care should be exercised to not overtighten the gland, which will result in a metal-to-metal contact between the body and the plug. Such a metal-to-metal contact creates an additional force which will require extreme effort to operate the valve.

Diaphragm Valves

A diaphragm valve is a linear motion valve that is used to start, regulate, and stop fluid flow. The name is derived from its flexible disk, which mates with a seat located in the open area at the top of the valve body to form a seal. A diaphragm valve is illustrated in Figure 14.

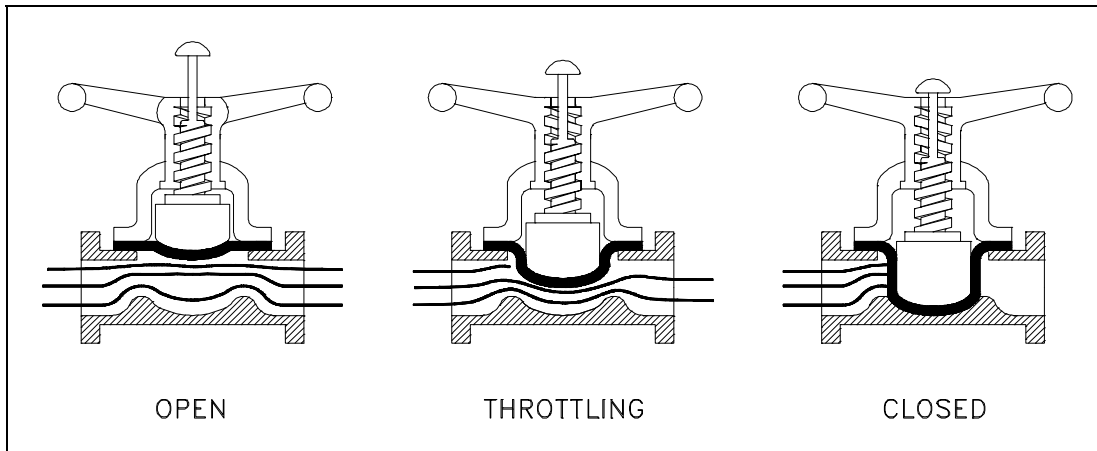


Figure 14 Straight Through Diaphragm Valve

Diaphragm valves are, in effect, simple "pinch clamp" valves. A resilient, flexible diaphragm is connected to a compressor by a stud molded into the diaphragm. The compressor is moved up and down by the valve stem. Hence, the diaphragm lifts when the compressor is raised. As the compressor is lowered, the diaphragm is pressed against the contoured bottom in the straight through valve illustrated in Figure 14 or the body weir in the weir-type valve illustrated in Figure 15.

Diaphragm valves can also be used for throttling service. The weir-type is the better throttling valve but has a limited range. Its throttling characteristics are essentially those of a quick-opening valve because of the large shutoff area along the seat.

A weir-type diaphragm valve is available to control small flows. It uses a two-piece compressor component. Instead of the entire diaphragm lifting off the weir when the valve is opened, the first increments of stem travel raise an inner compressor component that causes only the central part of the diaphragm to lift. This creates a relatively small opening through the center of the valve. After the inner compressor is completely open, the outer compressor component is raised along with the inner compressor and the remainder of the throttling is similar to the throttling that takes place in a conventional valve.

Diaphragm valves are particularly suited for the handling of corrosive fluids, fibrous slurries, radioactive fluids, or other fluids that must remain free from contamination.

Diaphragm Construction

The operating mechanism of a diaphragm valve is not exposed to the media within the pipeline. Sticky or viscous fluids cannot get into the bonnet to interfere with the operating mechanism. Many fluids that would clog, corrode, or gum up the working parts of most other types of valves will pass through a diaphragm valve without causing problems. Conversely, lubricants used for the operating mechanism cannot be allowed to contaminate the fluid being handled. There are no packing glands to maintain and no possibility of stem leakage. There is a wide choice of available diaphragm materials. Diaphragm life depends upon the nature of the material handled, temperature, pressure, and frequency of operation.

Some elastomeric diaphragm materials may be unique in their excellent resistance to certain chemicals at high temperatures. However, the mechanical properties of any elastomeric material will be lowered at the higher temperature with possible destruction of the diaphragm at high pressure. Consequently, the manufacturer should be consulted when they are used in elevated temperature applications.

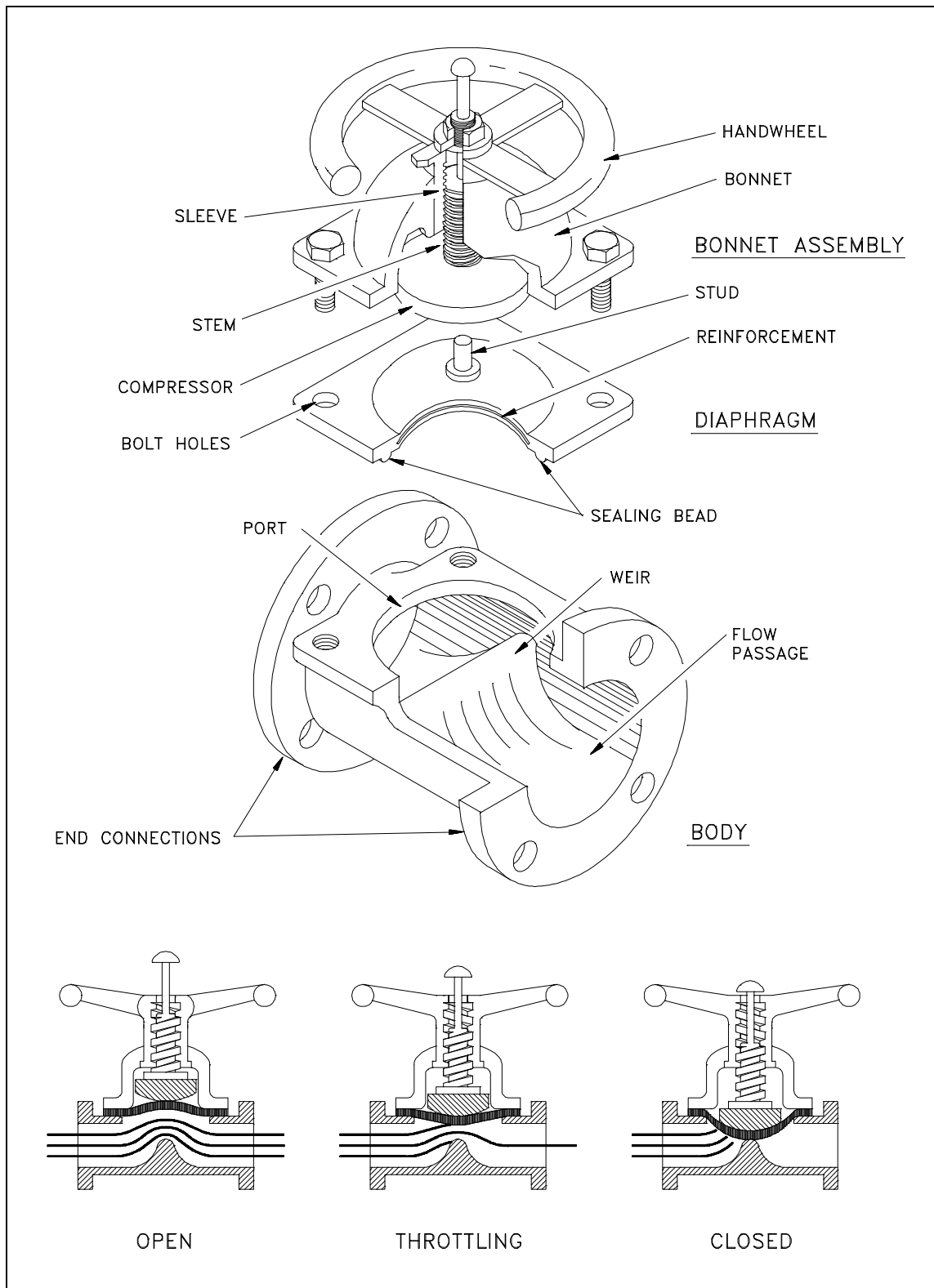


Figure 15 Weir Diaphragm Valve

All elastomeric materials operate best below 150°F. Some will function at higher temperatures. Viton, for example, is noted for its excellent chemical resistance and stability at high temperatures. However, when fabricated into a diaphragm, Viton is subject to lowered tensile strength just as any other elastomeric material would be at elevated temperatures. Fabric bonding strength is also lowered at elevated temperatures, and in the case of Viton, temperatures may be reached where the bond strength could become critical.

Fluid concentrations is also a consideration for diaphragm selection. Many of the diaphragm materials exhibit satisfactory corrosion resistance to certain corrodents up to a specific concentration and/or temperature. The elastomer may also have a maximum temperature limitation based on mechanical properties which could be in excess of the allowable operating temperature depending upon its corrosion resistance. This should be checked from a corrosion table.

Diaphragm Valve Stem Assemblies

Diaphragm valves have stems that do not rotate. The valves are available with indicating and nonindicating stems. The indicating stem valve is identical to the nonindicating stem valve except that a longer stem is provided to extend up through the handwheel. For the nonindicating stem design, the handwheel rotates a stem bushing that engages the stem threads and moves the stem up and down. As the stem moves, so does the compressor that is pinned to the stem. The diaphragm, in turn, is secured to the compressor.

Diaphragm Valve Bonnet Assemblies

Some diaphragm valves use a quick-opening bonnet and lever operator. This bonnet is interchangeable with the standard bonnet on conventional weir-type bodies. A 90° turn of the lever moves the diaphragm from full open to full closed. Diaphragm valves may also be equipped with chain wheel operators, extended stems, bevel gear operators, air operators, and hydraulic operators.

Many diaphragm valves are used in vacuum service. Standard bonnet construction can be employed in vacuum service through 4 inches in size. On valves 4 inches and larger, a sealed, evacuated, bonnet should be employed. This is recommended to guard against premature diaphragm failure.

Sealed bonnets are supplied with a seal bushing on the nonindicating types and a seal bushing plus O-ring on the indicating types. Construction of the bonnet assembly of a diaphragm valve is illustrated in Figure 15. This design is recommended for valves that are handling dangerous liquids and gases. In the event of a diaphragm failure, the hazardous materials will not be released to the atmosphere. If the materials being handled are extremely hazardous, it is recommended that a means be provided to permit a safe disposal of the corrodents from the bonnet.

Reducing Valves

Reducing valves automatically reduce supply pressure to a preselected pressure as long as the supply pressure is at least as high as the selected pressure. As illustrated in Figure 16, the principal parts of the reducing valve are the main valve; an upward-seating valve that has a piston on top of its valve stem, an upward-seating auxiliary (or controlling) valve, a controlling diaphragm, and an adjusting spring and screw.

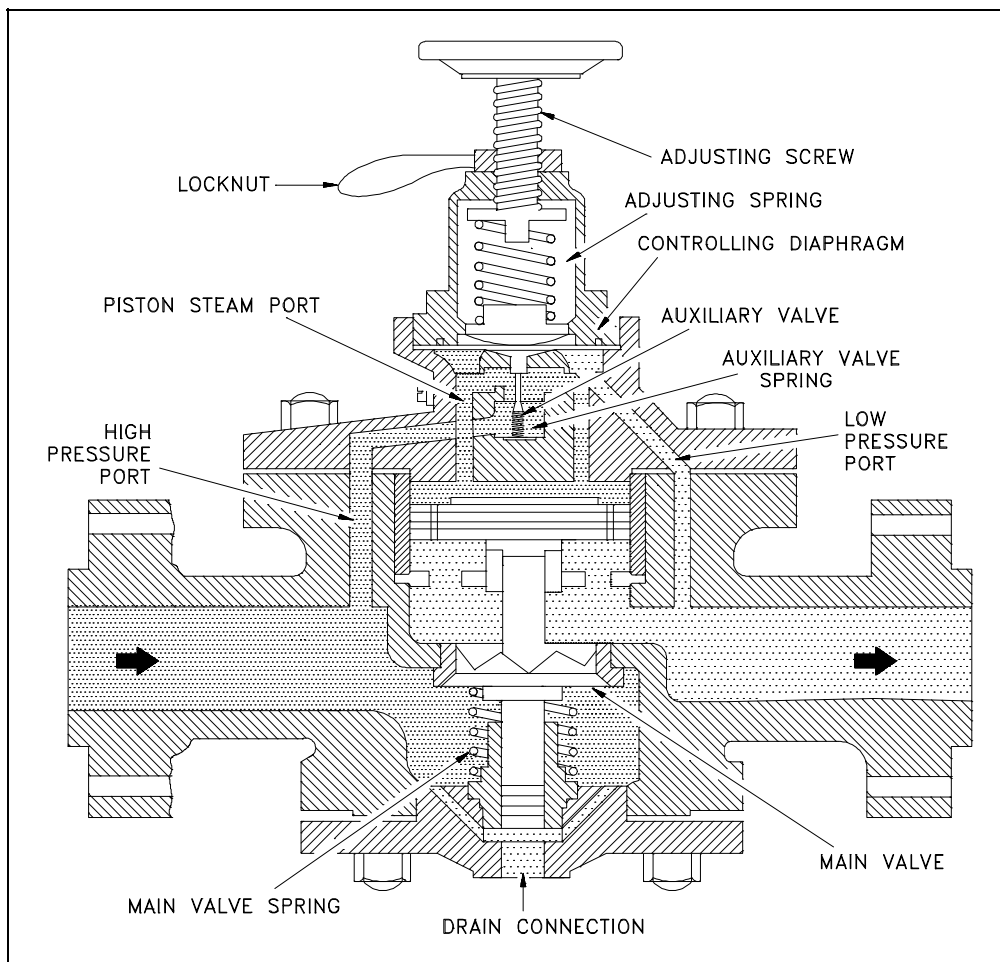


Figure 16 Variable Reducing Valve

Reducing valve operation is controlled by high pressure at the valve inlet and the adjusting screw on top of the valve assembly. The pressure entering the main valve assists the main valve spring in keeping the reducing valve closed by pushing upward on the main valve disk. However, some of the high pressure is bled to an auxiliary valve on top of the main valve. The auxiliary valve controls the admission of high pressure to the piston on top of the main valve. The piston has a larger surface area than the main valve disk, resulting in a net downward force to open the main valve. The auxiliary valve is controlled by a controlling diaphragm located directly over the auxiliary valve.

The controlling diaphragm transmits a downward force that tends to open the auxiliary valve. The downward force is exerted by the adjusting spring, which is controlled by the adjusting screw. Reduced pressure from the main valve outlet is bled back to a chamber beneath the diaphragm to counteract the downward force of the adjusting spring. The position of the auxiliary valve, and ultimately the position of the main valve, is determined by the position of the diaphragm. The position of the diaphragm is determined by the strength of the opposing forces of the downward force of the adjusting spring versus the upward force of the outlet reduced pressure. Other reducing valves work on the same basic principle, but may use gas, pneumatic, or hydraulic controls in place of the adjusting spring and screw.

Non-variable reducing valves, illustrated in Figure 17, replace the adjusting spring and screw with a pre-pressurized dome over the diaphragm. The valve stem is connected either directly or indirectly to the diaphragm. The valve spring below the diaphragm keeps the valve closed. As in the variable valve, reduced pressure is bled through an orifice to beneath the diaphragm to open the valve. Valve position is determined by the strength of the opposing forces of the downward force of the pre-pressurized dome versus the upward force of the outlet-reduced pressure.

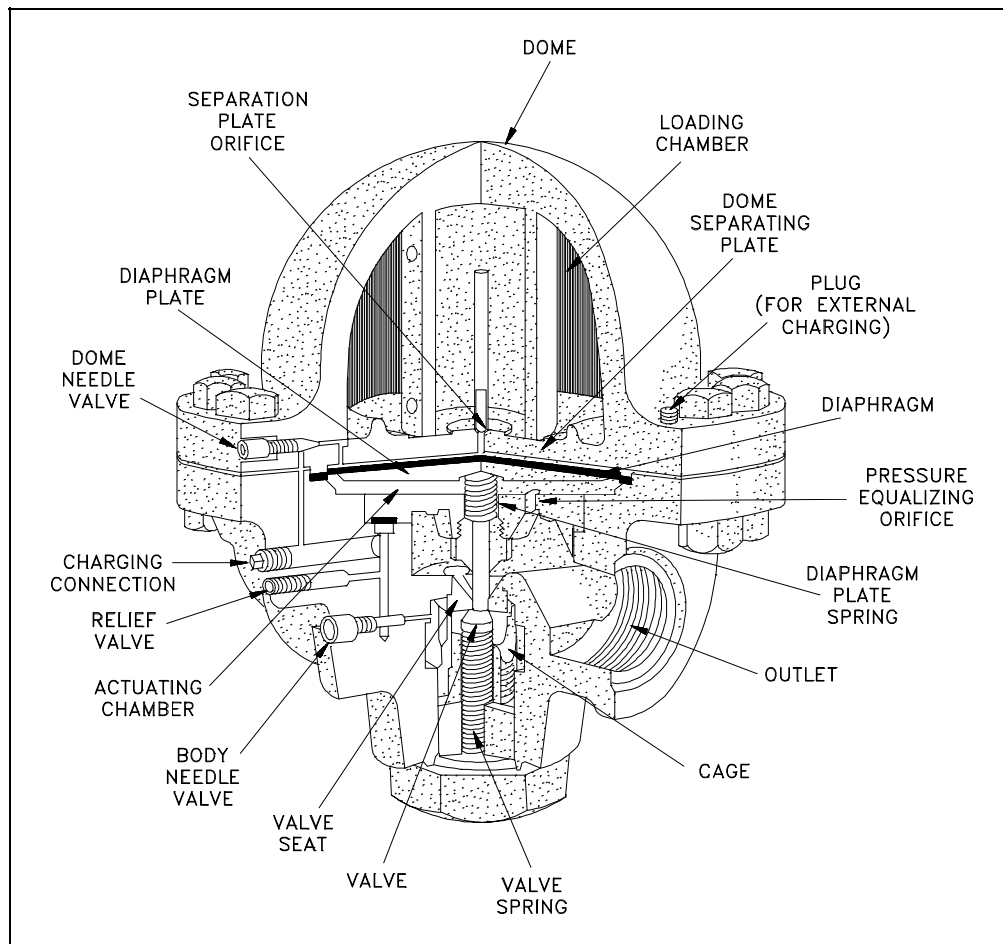


Figure 17 Non-Variable Reducing Valve

Non-variable reducing valves eliminate the need for the intermediate auxiliary valve found in variable reducing valves by having the opposing forces react directly on the diaphragm. Therefore, non-variable reducing valves are more responsive to large pressure variations and are less susceptible to failure than are variable reducing valves.

Pinch Valves

The relatively inexpensive pinch valve, illustrated in Figure 18, is the simplest in any valve design. It is simply an industrial version of the pinch cock used in the laboratory to control the flow of fluids through rubber tubing.

Pinch valves are suitable for on-off and throttling services. However, the effective throttling range is usually between 10% and 95% of the rated flow capacity.

Pinch valves are ideally suited for the handling of slurries, liquids with large amounts of suspended solids, and systems that convey solids pneumatically. Because the operating mechanism is completely isolated from the fluid, these valves also find application where corrosion or metal contamination of the fluid might be a problem.

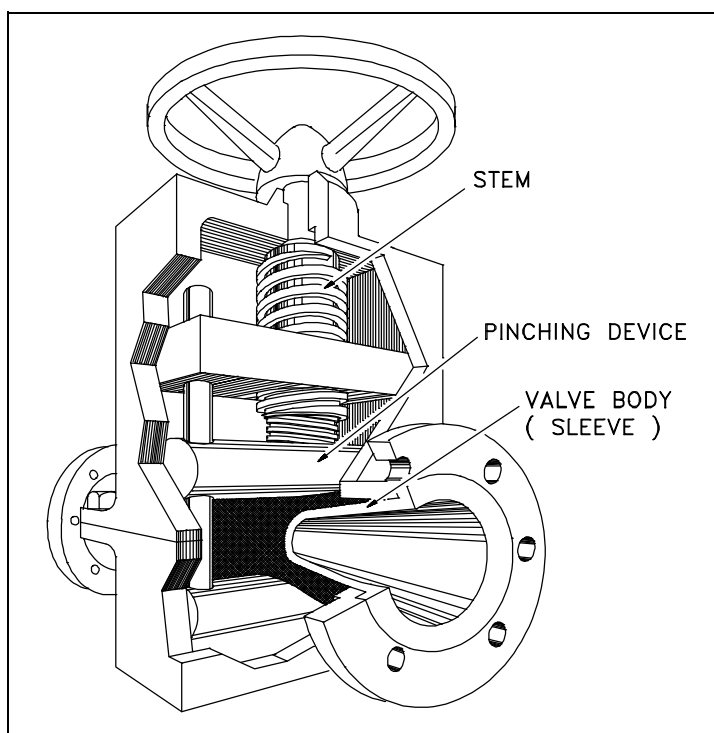


Figure 18 Pinch Valves

The pinch control valve consists of a sleeve molded of rubber or other synthetic material and a pinching mechanism. All of the operating portions are completely external to the valve. The molded sleeve is referred to as the valve body.

Pinch valve bodies are manufactured of natural and synthetic rubbers and plastics which have good abrasion resistance properties. These properties permit little damage to the valve sleeve, thereby providing virtually unimpeded flow. Sleeves are available with either extended hubs and clamps designed to slip over a pipe end, or with a flanged end having standard dimensions.

Pinch Valve Bodies

Pinch valves have molded bodies reinforced with fabric. Pinch valves generally have a maximum operating temperature of 250°F. At 250°F, maximum operating pressure varies generally from 100 psig for a 1-inch diameter valve and decreases to 15 psig for a 12-inch diameter valve. Special pinch valves are available for temperature ranges of -100°F to 550°F and operating pressures of 300 psig.

Most pinch valves are supplied with the sleeve (valve body) exposed. Another style fully encloses the sleeve within a metallic body. This type controls flow either with the conventional wheel and screw pinching device, hydraulically, or pneumatically with the pressure of the liquid or gas within the metal case forcing the sleeve walls together to shut off flow.

Most exposed sleeve valves have limited vacuum application because of the tendency of the sleeves to collapse when vacuum is applied. Some of the encased valves can be used on vacuum service by applying a vacuum within the metal casing and thus preventing the collapse of the sleeve.

Butterfly Valves

A butterfly valve, illustrated in Figure 19, is a rotary motion valve that is used to stop, regulate, and start fluid flow. Butterfly valves are easily and quickly operated because a 90° rotation of the handle moves the disk from a fully closed to fully opened position. Larger butterfly valves are actuated by handwheels connected to the stem through gears that provide mechanical advantage at the expense of speed.

Butterfly valves possess many advantages over gate, globe, plug, and ball valves, especially for large valve applications. Savings in weight, space, and cost are the most obvious advantages. The maintenance costs are usually low because there are a minimal number of moving parts and there are no pockets to trap fluids.

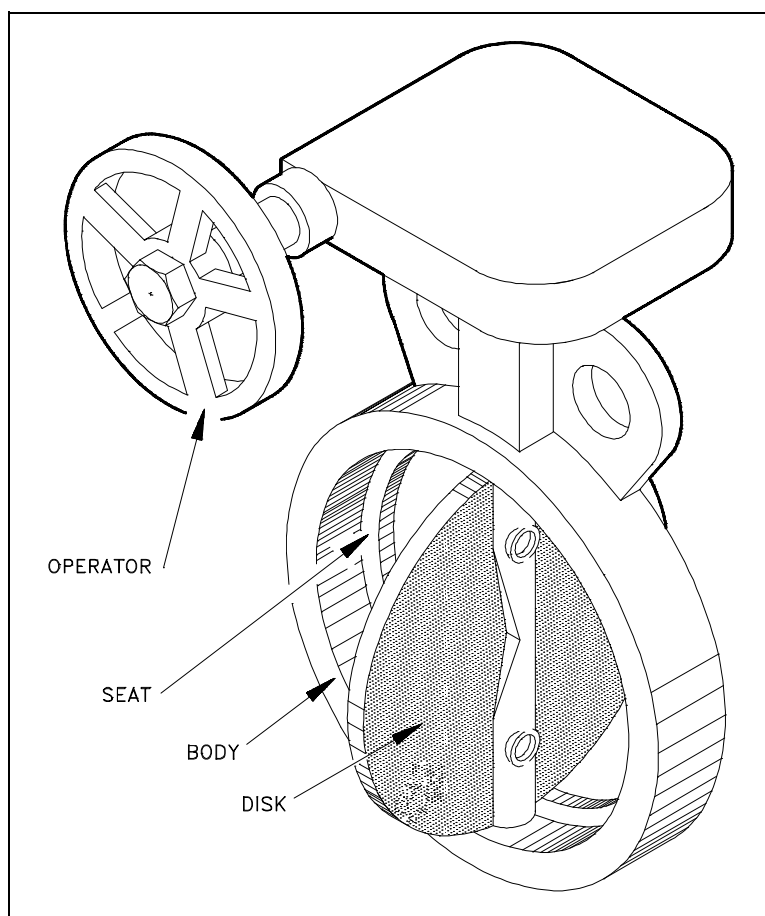


Figure 19 Typical Butterfly Valve

Butterfly valves are especially well-suited for the handling of large flows of liquids or gases at relatively low pressures and for the handling of slurries or liquids with large amounts of suspended solids.

Butterfly valves are built on the principle of a pipe damper. The flow control element is a disk of approximately the same diameter as the inside diameter of the adjoining pipe, which rotates on either a vertical or horizontal axis. When the disk lies parallel to the piping run, the valve is fully opened. When the disk approaches the perpendicular position, the valve is shut. Intermediate positions, for throttling purposes, can be secured in place by handle-locking devices.

Butterfly Valve Seat Construction

Stoppage of flow is accomplished by the valve disk sealing against a seat that is on the inside diameter periphery of the valve body. Many butterfly valves have an elastomeric seat against which the disk seals. Other butterfly valves have a seal ring arrangement that uses a clamp-ring and backing-ring on a serrated edged rubber ring. This design prevents extrusion of the O-rings. In early designs, a metal disk was used to seal against a metal seat. This arrangement did not provide a leak-tight closure, but did provide sufficient closure in some applications (i.e., water distribution lines).

Butterfly Valve Body Construction

Butterfly valve body construction varies. The most economical is the wafer type that fits between two pipeline flanges. Another type, the lug wafer design, is held in place between two pipe flanges by bolts that join the two flanges and pass through holes in the valve's outer casing. Butterfly valves are available with conventional flanged ends for bolting to pipe flanges, and in a threaded end construction.

Butterfly Valve Disk and Stem Assemblies

The stem and disk for a butterfly valve are separate pieces. The disk is bored to receive the stem. Two methods are used to secure the disk to the stem so that the disk rotates as the stem is turned. In the first method, the disk is bored through and secured to the stem with bolts or pins. The alternate method involves boring the disk as before, then shaping the upper stem bore to fit a squared or hex-shaped stem. This method allows the disk to "float" and seek its center in the seat. Uniform sealing is accomplished and external stem fasteners are eliminated. This method of assembly is advantageous in the case of covered disks and in corrosive applications.

In order for the disk to be held in the proper position, the stem must extend beyond the bottom of the disk and fit into a bushing in the bottom of the valve body. One or two similar bushings are along the upper portion of the stem as well. These bushings must be either resistant to the media being handled or sealed so that the corrosive media cannot come into contact with them.

Stem seals are accomplished either with packing in a conventional stuffing box or by means of O-ring seals. Some valve manufacturers, particularly those specializing in the handling of corrosive materials, place a stem seal on the inside of the valve so that no material being handled by the valve can come into contact with the valve stem. If a stuffing box or external O-ring is employed, the fluid passing through the valve will come into contact with the valve stem.

Needle Valves

A needle valve, as shown in Figure 20, is used to make relatively fine adjustments in the amount of fluid flow.

The distinguishing characteristic of a needle valve is the long, tapered, needle-like point on the end of the valve stem. This "needle" acts as a disk. The longer part of the needle is smaller than the orifice in the valve seat and passes through the orifice before the needle seats. This arrangement permits a very gradual increase or decrease in the size of the opening. Needle valves are often used as component parts of other, more complicated valves. For example, they are used in some types of reducing valves.

Needle Valve Applications

Most constant pressure pump governors have needle valves to minimize the effects of fluctuations in pump discharge pressure. Needle valves are also used in some components of automatic combustion control systems where very precise flow regulation is necessary.

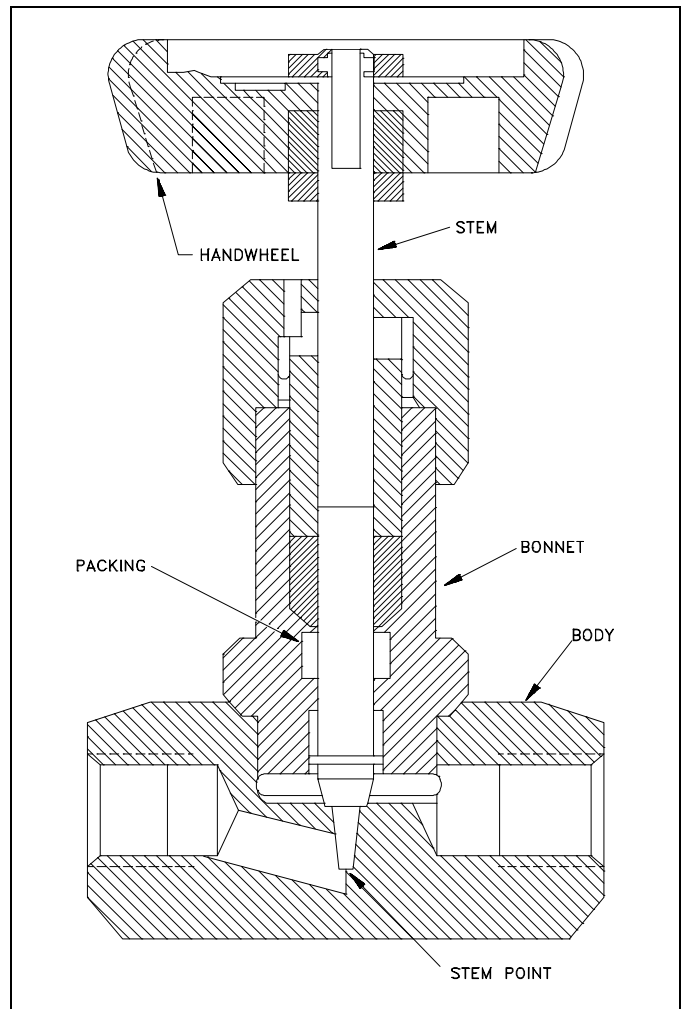


Figure 20 Needle Valve

Needle Valve Body Designs

One type of body design for a needle valve is the bar stock body. Bar stock bodies are common, and, in globe types, a ball swiveling in the stem provides the necessary rotation for seating without damage. The bar stock body is illustrated in Figure 21.

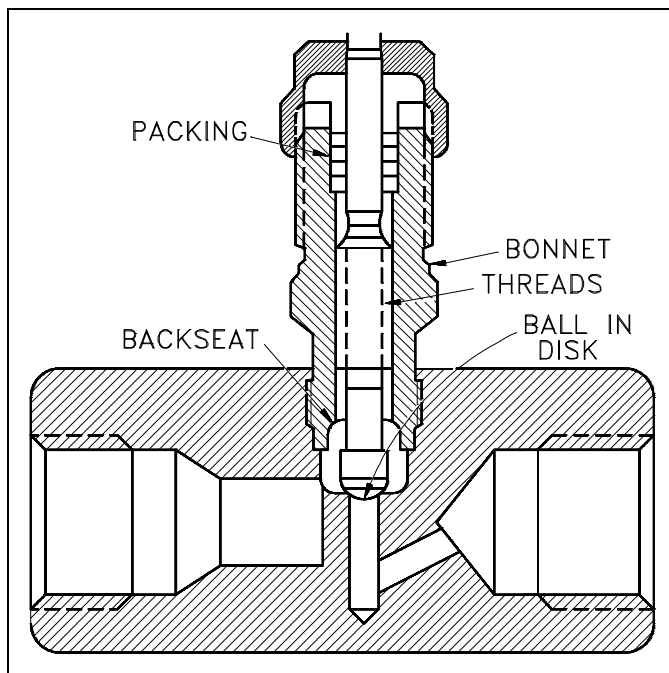


Figure 21 Bar-Stock Instrument Valve

Needle valves are frequently used as metering valves. Metering valves are used for extremely fine flow control. The thin disk or orifice allows for linear flow characteristics. Therefore, the number of handwheel turns can be directly correlated to the amount of flow. A typical metering valve has a stem with 40 threads per inch.

Needle valves generally use one of two styles of stem packing: an O-ring with TFE backing rings or a TFE packing cylinder. Needle valves are often equipped with replaceable seats for ease of maintenance.

Check Valves

Check valves are designed to prevent the reversal of flow in a piping system. These valves are activated by the flowing material in the pipeline. The pressure of the fluid passing through the system opens the valve, while any reversal of flow will close the valve. Closure is accomplished by the weight of the check mechanism, by back pressure, by a spring, or by a combination of these means. The general types of check valves are swing, tilting-disk, piston, butterfly, and stop.

Swing Check Valves

A swing check valve is illustrated in Figure 22. The valve allows full, unobstructed flow and automatically closes as pressure decreases. These valves are fully closed when the flow reaches zero and prevent back flow. Turbulence and pressure drop within the valve are very low.

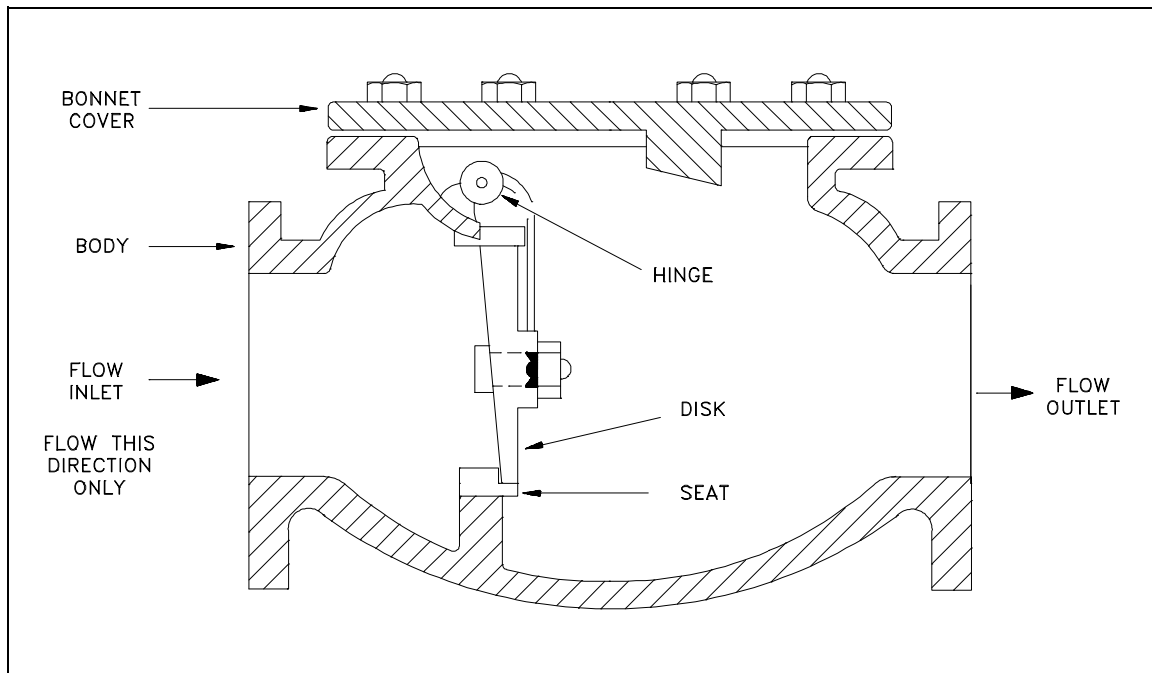


Figure 22 Swing Check Valve

A swing check valve is normally recommended for use in systems employing gate valves because of the low pressure drop across the valve. Swing check valves are available in either Y-pattern or straight body design. A straight check valve is illustrated in Figure 22. In either style, the disk and hinge are suspended from the body by means of a hinge pin. Seating is either metal-to-metal or metal seat to composition disk. Composition disks are usually recommended for services where dirt or other particles may be present in the fluid, where noise is objectionable, or where positive shutoff is required.

Straight body swing check valves contain a disk that is hinged at the top. The disk seals against the seat, which is integral with the body. This type of check valve usually has replaceable seat rings. The seating surface is placed at a slight angle to permit easier opening at lower pressures, more positive sealing, and less shock when closing under higher pressures.

Swing check valves are usually installed in conjunction with gate valves because they provide relatively free flow. They are recommended for lines having low velocity flow and should not be used on lines with pulsating flow when the continual flapping or pounding would be destructive to the seating elements. This condition can be partially corrected by using an external lever and weight.

Tilting Disk Check Valves

The tilting disk check valve, illustrated in Figure 23, is similar to the swing check valve. Like the swing check, the tilting disk type keeps fluid resistance and turbulence low because of its straight-through design.

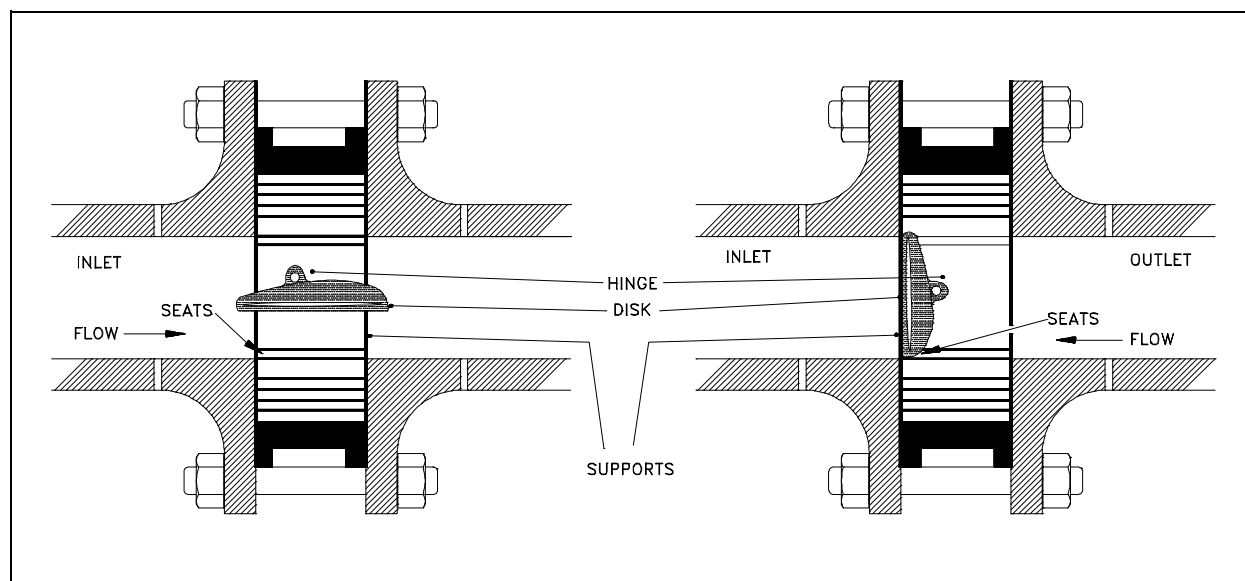


Figure 23 Operation of Tilting Disk Check Valve

Tilting disk check valves can be installed in horizontal lines and vertical lines having upward flow. Some designs simply fit between two flange faces and provide a compact, lightweight installation, particularly in larger diameter valves.

The disk lifts off of the seat to open the valve. The airfoil design of the disk allows it to "float" on the flow. Disk stops built into the body position the disk for optimum flow characteristics. A large body cavity helps minimize flow restriction. As flow decreases, the disk starts closing and seals before reverse flow occurs. Backpressure against the disk moves it across the soft seal into the metal seat for tight shutoff without slamming. If the reverse flow pressure is insufficient to cause a tight seal, the valve may be fitted with an external lever and weight.

These valves are available with a soft seal ring, metal seat seal, or a metal-to-metal seal. The latter is recommended for high temperature operation. The soft seal rings are replaceable, but the valve must be removed from the line to make the replacement.

Lift Check Valves

A lift check valve, illustrated in Figure 24, is commonly used in piping systems in which globe valves are being used as a flow control valve. They have similar seating arrangements as globe valves.

Lift check valves are suitable for installation in horizontal or vertical lines with upward flow. They are recommended for use with steam, air, gas, water, and on vapor lines with high flow velocities. These valves are available in three body patterns: horizontal, angle, and vertical.

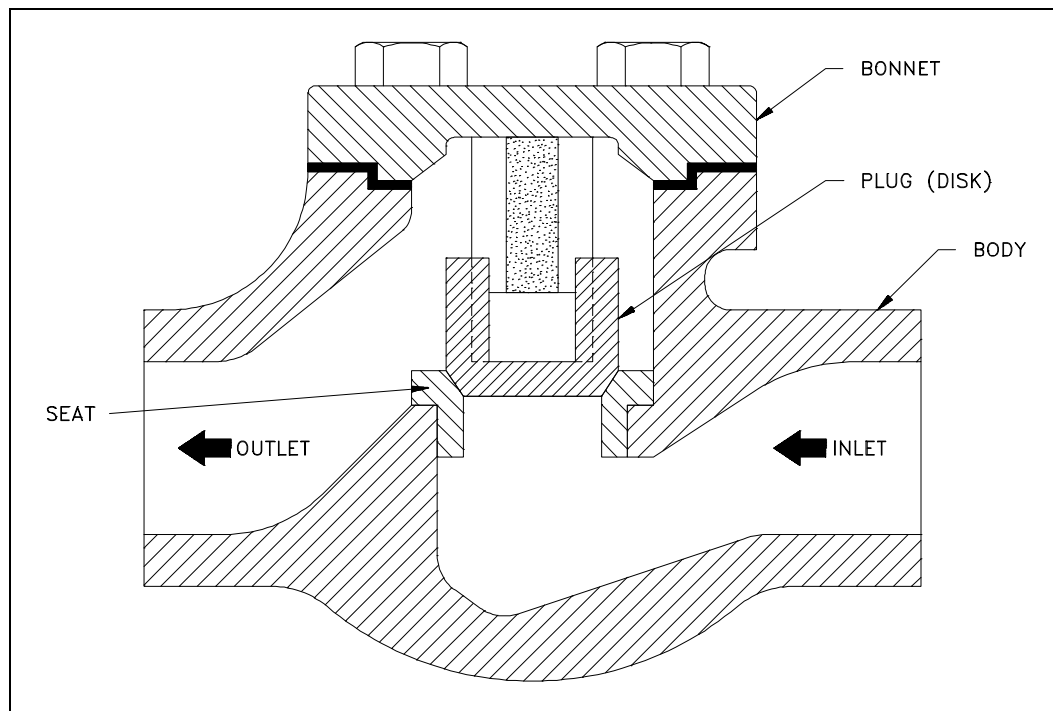


Figure 24 Lift Check Valve

Flow to lift check valves must always enter below the seat. As the flow enters, the disk or ball is raised within guides from the seat by the pressure of the upward flow. When the flow stops or reverses, the disk or ball is forced onto the seat of the valve by both the backflow and gravity.

Some types of lift check valves may be installed horizontally. In this design, the ball is suspended by a system of guide ribs. This type of check valve design is generally employed in plastic check valves.

The seats of metallic body lift check valves are either integral with the body or contain renewable seat rings. Disk construction is similar to the disk construction of globe valves with either metal or composition disks. Metal disk and seat valves can be reground using the same techniques as is used for globe valves.

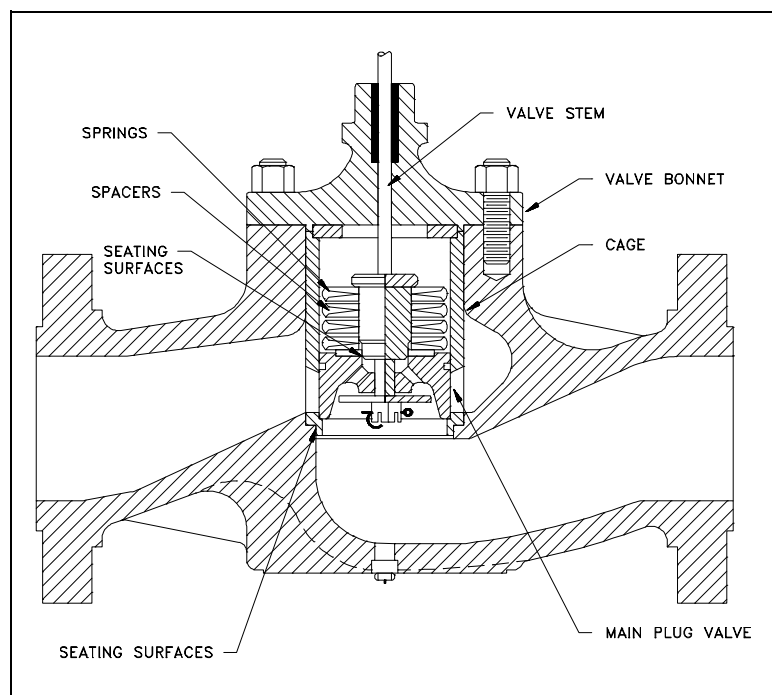


Figure 25 Piston Check Valve

Piston Check Valves

A piston check valve, illustrated in Figure 25, is essentially a lift check valve. It has a dashpot consisting of a piston and cylinder that provides a cushioning effect during operation. Because of the similarity in design to lift check valves, the flow characteristics through a piston check valve are essentially the same as through a lift check valve.

Installation is the same as for a lift check in that the flow must enter from under the seat. Construction of the seat and disk of a piston check valve is the same as for lift check valves.

Piston check valves are used primarily in conjunction with globe and angle valves in piping systems experiencing very frequent changes in flow direction. Valves of this type are used on water, steam, and air systems.

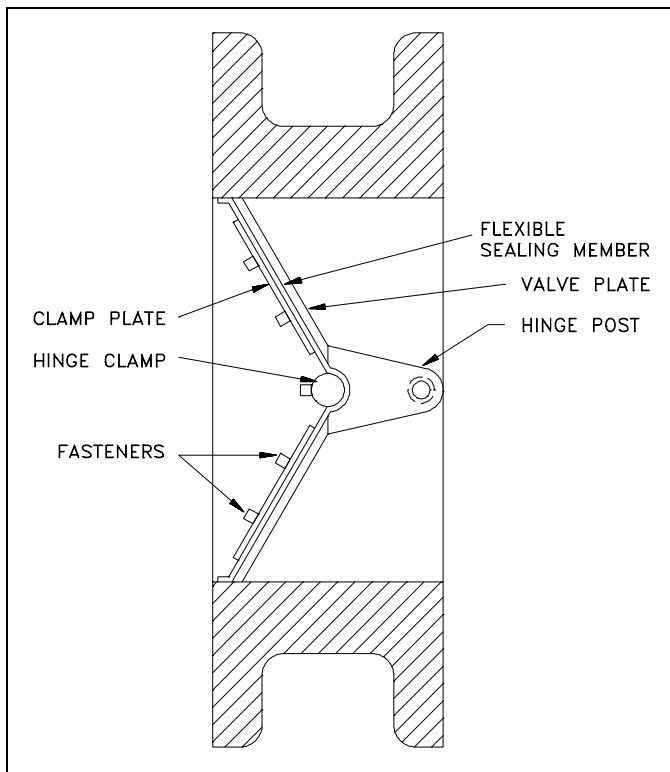


Figure 26 Butterfly Check Valve

Butterfly Check Valves

Butterfly check valves have a seating arrangement similar to the seating arrangement of butterfly valves. Flow characteristics through these check valves are similar to the flow characteristics through butterfly valves. Consequently, butterfly check valves are quite frequently used in systems using butterfly valves. In addition, the construction of the butterfly check valve body is such that ample space is provided for unobstructed movement of the butterfly valve disk within the check valve body without the necessity of installing spacers.

The butterfly check valve design is based on a flexible sealing member against the bore of the valve body at an angle of 45°. The short distance the disk must move from full open to full closed inhibits the "slamming" action found in some other types of check valves. Figure 26

illustrates the internal assembly of the butterfly check valve.

Because the flow characteristics are similar to the flow characteristics of butterfly valves, applications of these valves are much the same. Also, because of their relatively quiet operation they find application in heating, ventilation, and air conditioning systems. Simplicity of design also permits their construction in large diameters - up to 72 inches.

As with butterfly valves, the basic body design lends itself to the installation of seat liners constructed of many materials. This permits the construction of a corrosion-resistant valve at less expense than would be encountered if it were necessary to construct the entire body of the higher alloy or more expensive metal. This is particularly true in constructions such as those of titanium.

Flexible sealing members are available in Buna-N, Neoprene, Nordel, Hypalon, Viton, Tyon, Urethane, Butyl, Silicone, and TFE as standard, with other materials available on special order.

The valve body essentially is a length of pipe that is fitted with flanges or has threaded, grooved, or plain ends. The interior is bored to a fine finish. The flanged end units can have liners of various metals or plastics installed depending upon the service requirements. Internals and fasteners are always of the same material as the liner.

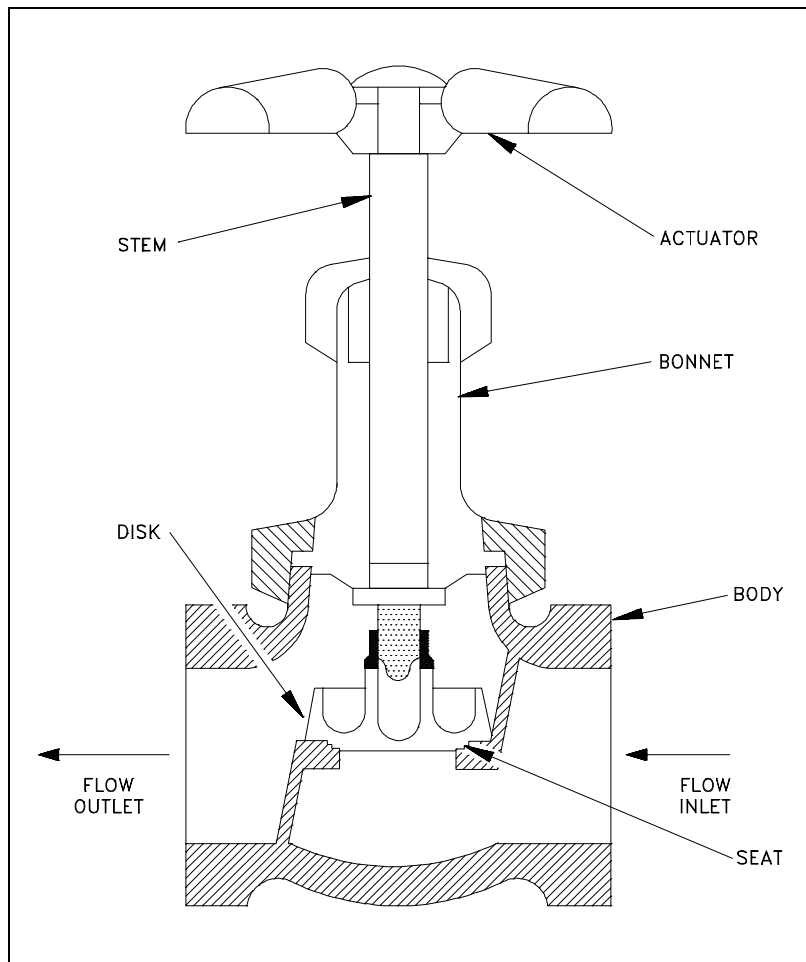


Figure 27 Stop Check Valve

Butterfly check valves may be installed horizontally or vertically with the vertical flow either upward or downward. Care should be taken to ensure that the valve is installed so that the entering flow comes from the hinge post end of the valve; otherwise, all flow will be stopped.

Stop Check Valves

A stop check valve, illustrated in Figure 27, is a combination of a lift check valve and a globe valve. It has a stem which, when closed, prevents the disk from coming off the seat and provides a tight seal (similar to a globe valve). When the stem is operated to the open position, the valve operates as a lift check. The stem is not connected to the disk and functions to close the valve tightly or to limit the travel of the valve disk in the open direction.

Relief and Safety Valves

Relief and safety valves prevent equipment damage by relieving accidental over-pressurization of fluid systems. The main difference between a relief valve and a safety valve is the extent of opening at the setpoint pressure.

A relief valve, illustrated in Figure 28, gradually opens as the inlet pressure increases above the setpoint. A relief valve opens only as necessary to relieve the over-pressure condition. A safety valve, illustrated in Figure 29, rapidly pops fully open as soon as the pressure setting is reached. A safety valve will stay fully open until the pressure drops below a reset pressure. The reset pressure is lower than the actuating pressure setpoint. The difference between the actuating pressure setpoint and the pressure at which the safety valve resets is called *blowdown*. Blowdown is expressed as a percentage of the actuating pressure setpoint.

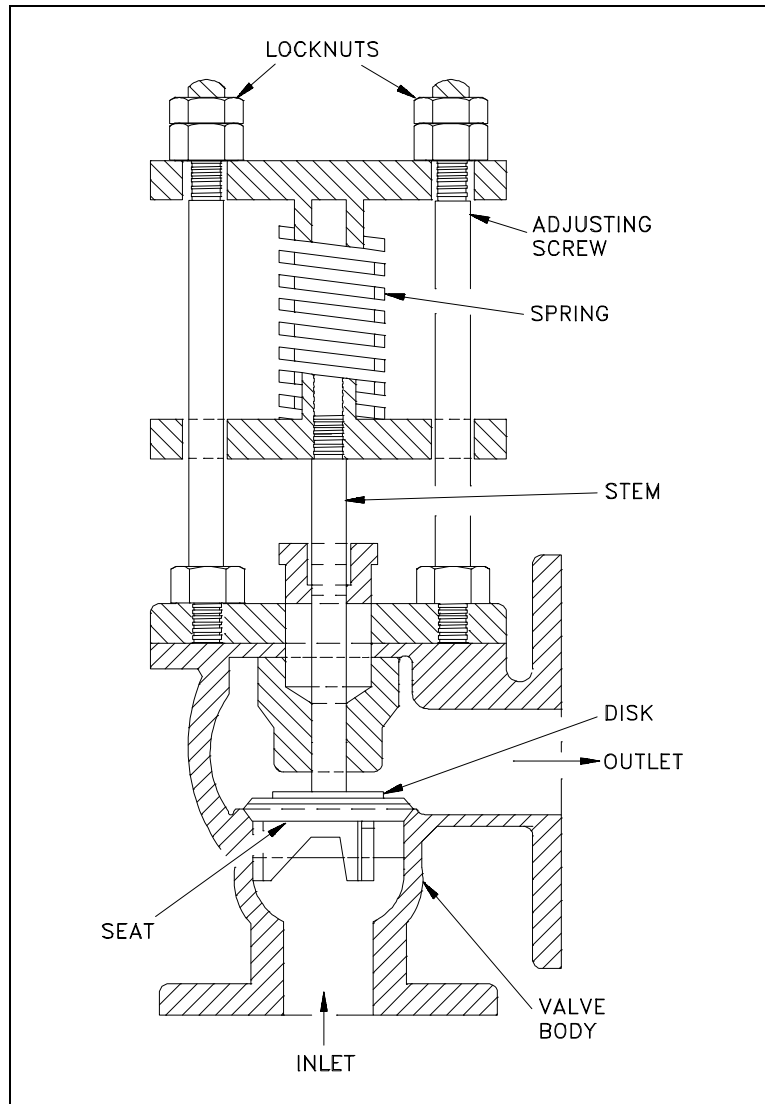


Figure 28 Relief Valve

Relief valves are typically used for incompressible fluids such as water or oil. Safety valves are typically used for compressible fluids such as steam or other gases. Safety valves can often be distinguished by the presence of an external lever at the top of the valve body, which is used as an operational check.

As indicated in Figure 29, system pressure provides a force that is attempting to push the disk of the safety valve off its seat. Spring pressure on the stem is forcing the disk onto the seat. At the pressure determined by spring compression, system pressure overcomes spring pressure and the relief valve opens. As system pressure is relieved, the valve closes when spring pressure again overcomes system pressure. Most relief and safety valves open against the force of a compression spring. The pressure setpoint is adjusted by turning the adjusting nuts on top of the yoke to increase or decrease the spring compression.

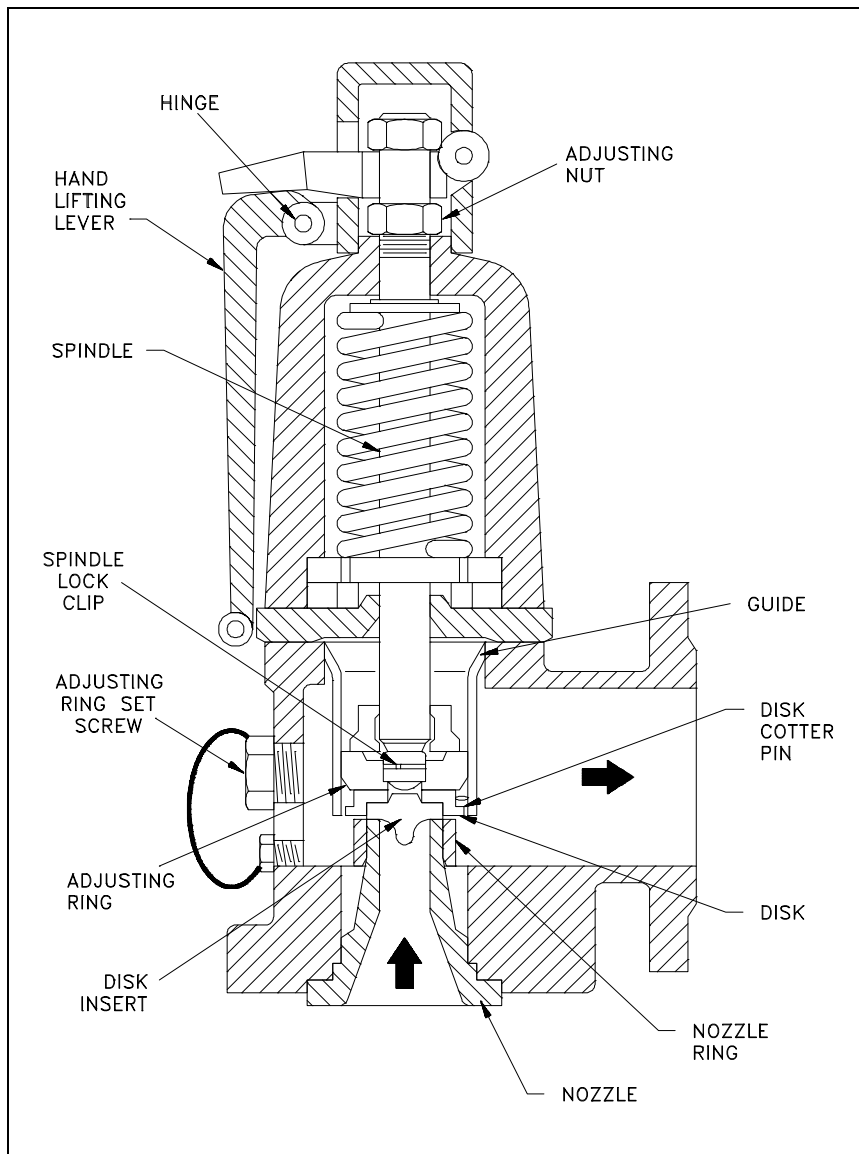


Figure 29 Safety Valve

Pilot-Operated Relief Valves

Pilot-operated relief valves are designed to maintain pressure through the use of a small passage to the top of a piston that is connected to the stem such that system pressure closes the main relief valve. When the small pilot valve opens, pressure is relieved from the piston, and system pressure under the disk opens the main relief valve. Such pilot valves are typically solenoid-operated, with the energizing signal originating from pressure measuring systems.

Summary

The following important information in this chapter is summarized below.

Types of Valves Summary

- Gate valves are generally used in systems where low flow resistance for a fully open valve is desired and there is no need to throttle the flow.
- Globe valves are used in systems where good throttling characteristics and low seat leakage are desired and a relatively high head loss in an open valve is acceptable.
- Ball valves allow quick, quarter turn on-off operation and have poor throttling characteristics.
- Plug valves are often used to direct flow between several different ports through use of a single valve.
- Diaphragm valves and pinch valves are used in systems where it is desirable for the entire operating mechanism to be completely isolated from the fluid.
- Butterfly valves provide significant advantages over other valve designs in weight, space, and cost for large valve applications.
- Check valves automatically open to allow flow in one direction and seat to prevent flow in the reverse direction.
- A stop check valve is a combination of a lift check valve and a globe valve and incorporates the characteristics of both.
- Safety/relief valves are used to provide automatic overpressurization protection for a system.

VALVE ACTUATORS

Some type of actuator is necessary to allow for the positioning of a valve. Actuators vary from simple manual handwheels to relatively complex electrical and hydraulic manipulators.

EO 1.6 DESCRIBE the construction and principle of operation for the following types of valve actuators:

- a. **Manual**
- b. **Electric motor**
- c. **Pneumatic**
- d. **Hydraulic**
- e. **Solenoid**

Introduction

Valve actuators are selected based upon a number of factors including torque necessary to operate the valve and the need for automatic actuation. Types of actuators include manual handwheel, manual lever, electrical motor, pneumatic, solenoid, hydraulic piston, and self-actuated. All actuators except manual handwheel and lever are adaptable to automatic actuation.

Manual, Fixed, and Hammer Actuators

Manual actuators are capable of placing the valve in any position but do not permit automatic operation. The most common type mechanical actuator is the handwheel. This type includes handwheels fixed to the stem, hammer handwheels, and handwheels connected to the stem through gears.

Handwheels Fixed to Stem

As illustrated in Figure 30, handwheels fixed to the stem provide only the mechanical advantage of the wheel. When these valves are exposed to high operating temperatures, valve binding makes operation difficult.

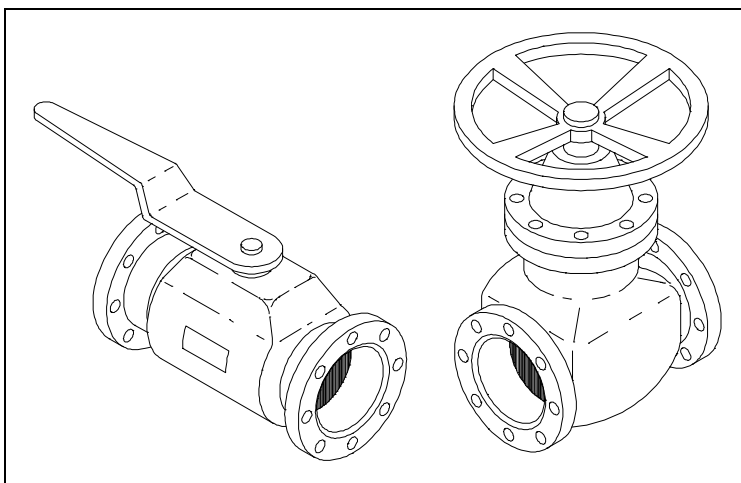
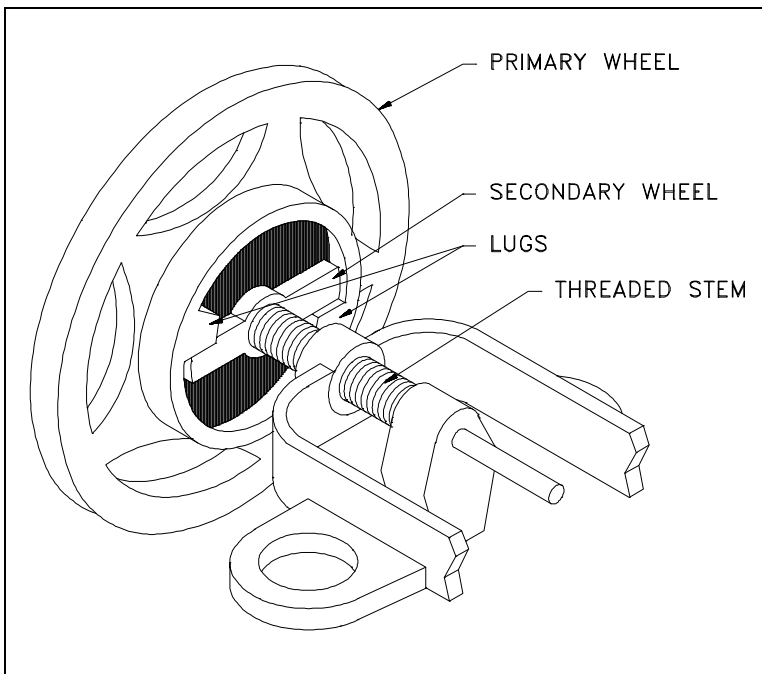


Figure 30 Fixed Handwheel



Hammer Handwheel

As illustrated in Figure 31, the hammer handwheel moves freely through a portion of its turn and then hits against a lug on a secondary wheel. The secondary wheel is attached to the valve stem. With this arrangement, the valve can be pounded shut for tight closure or pounded open if it is stuck shut.

Figure 31 Hammer Handwheel

Gears

If additional mechanical advantage is necessary for a manually-operated valve, the valve bonnet is fitted with manually-operated gear heads as illustrated in Figure 32. A special wrench or handwheel attached to the pinion shaft permits one individual to operate the valve when two individuals might be needed without the gear advantage. Because several turns of the pinion are necessary to produce one turn of the valve stem, the operating time of large valves is exceptionally long. The use of portable air motors connected to the pinion shaft decreases the valve operating time.

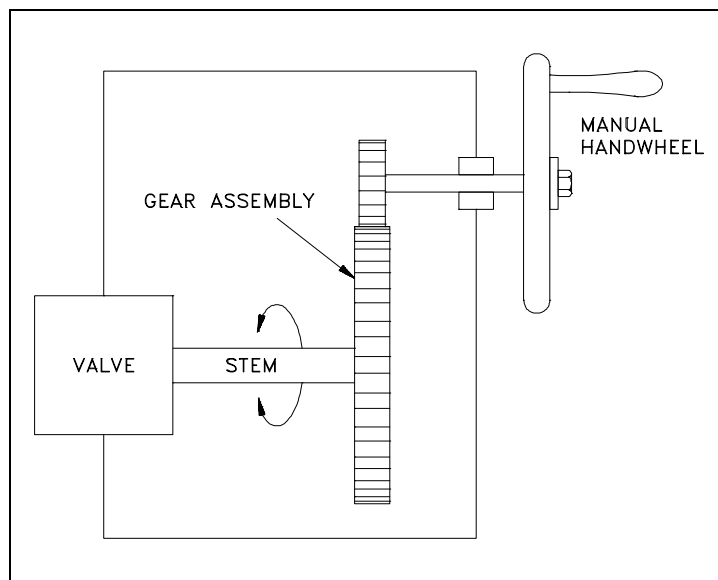


Figure 32 Manual Gear Head

Electric Motor Actuators

Electric motors permit manual, semi-automatic, and automatic operation of the valve. Motors are used mostly for open-close functions, although they are adaptable to positioning the valve to any point opening as illustrated in Figure 33. The motor is usually a reversible, high speed type connected through a gear train to reduce the motor speed and thereby increase the torque at the stem. Direction of motor rotation determines direction of disk motion. The electrical actuation can be semi-automatic, as when the motor is started by a control system. A handwheel, which can be engaged to the gear train, provides for manual operating of the valve. Limit switches are normally provided to stop the motor automatically at full open and full closed valve positions. Limit switches are operated either physically by position of the valve or torsionally by torque of the motor.

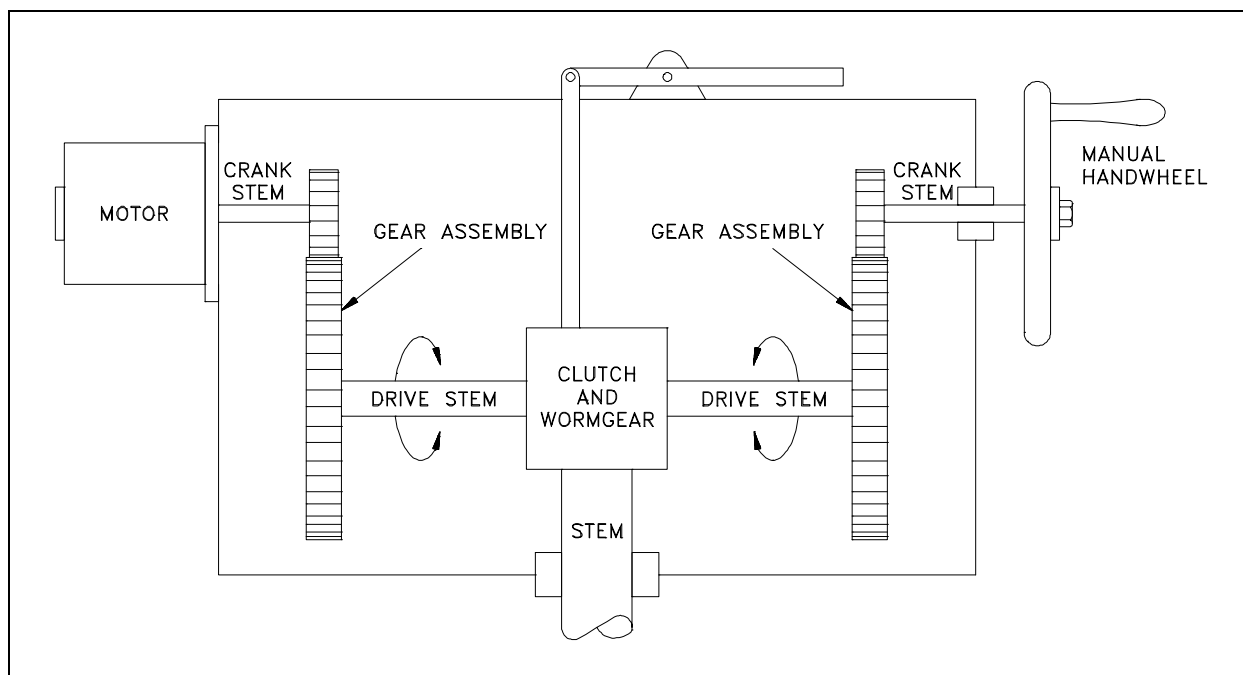


Figure 33 Electric Motor Actuator

Pneumatic Actuators

Pneumatic actuators as illustrated in Figure 34 provide for automatic or semi-automatic valve operation. These actuators translate an air signal into valve stem motion by air pressure acting on a diaphragm or piston connected to the stem. Pneumatic actuators are used in throttle valves for open-close positioning where fast action is required. When air pressure closes the valve and spring action opens the valve, the actuator is termed direct-acting. When air pressure opens the valve and spring action closes the valve, the actuator is termed reverse-acting. Duplex actuators have air supplied to both sides of the diaphragm. The differential pressure across the diaphragm positions the valve stem. Automatic operation is provided when the air signals are automatically controlled by circuitry. Semi-automatic operation is provided by manual switches in the circuitry to the air control valves.

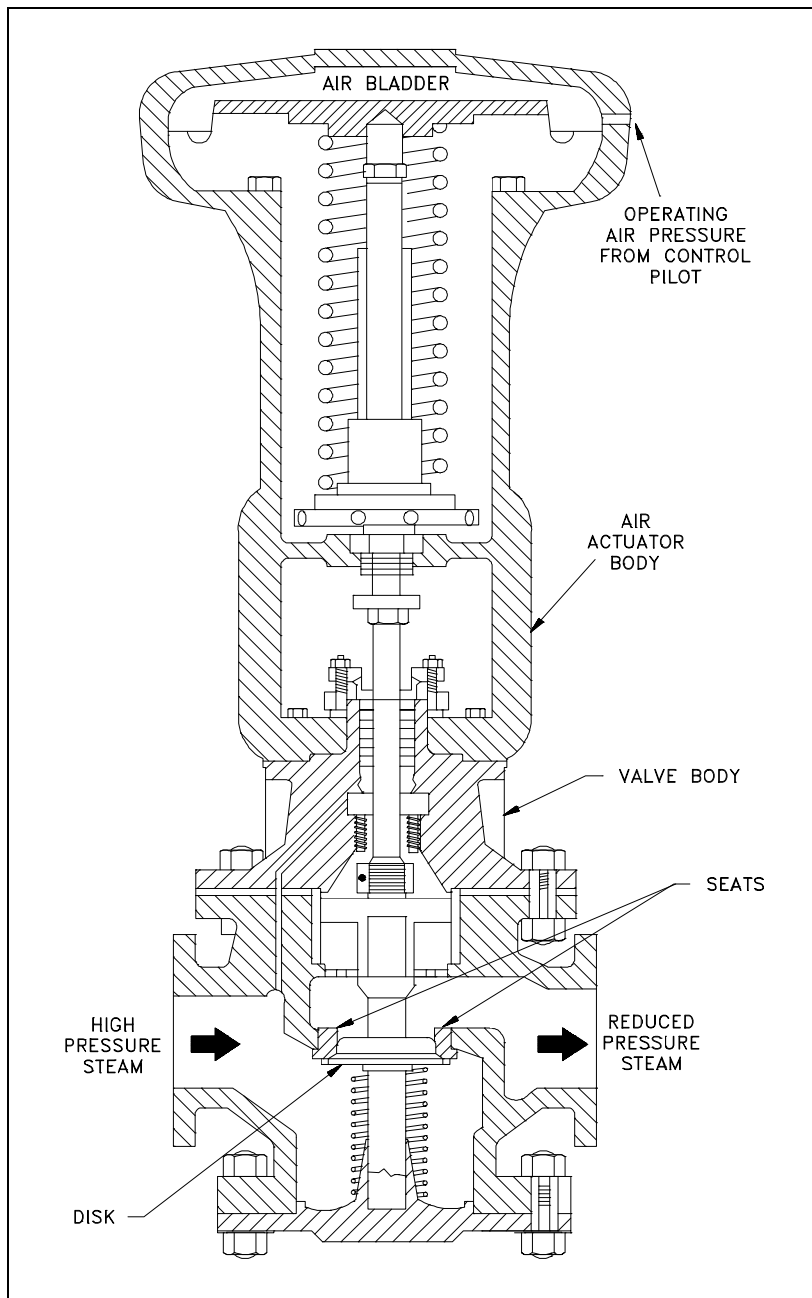


Figure 34 Pneumatic Actuator

Hydraulic Actuators

Hydraulic actuators provide for semi-automatic or automatic positioning of the valve, similar to the pneumatic actuators. These actuators use a piston to convert a signal pressure into valve stem motion. Hydraulic fluid is fed to either side of the piston while the other side is drained or bled. Water or oil is used as the hydraulic fluid. Solenoid valves are typically used for automatic control of the hydraulic fluid to direct either opening or closing of the valve. Manual valves can also be used for controlling the hydraulic fluid; thus providing semi-automatic operation.

Self-Actuated Valves

Self-actuated valves use the system fluid to position the valve. Relief valves, safety valves, check valves, and steam traps are examples of self-actuated valves. All of these valves use some characteristic of the system fluid to actuate the valve. No source of power outside the system fluid energy is necessary for operation of these valves.

Solenoid Actuated Valves

Solenoid actuated valves provide for automatic open-close valve positioning as illustrated in Figure 35. Most solenoid actuated valves also have a manual override that permits manual positioning of the valve for as long as the override is manually positioned. Solenoids position the valve by attracting a magnetic slug attached to the valve stem. In single solenoid valves, spring pressure acts against the motion of the slug when power is applied to the solenoid. These valves can be arranged such that power to the solenoid either opens or closes the valve. When power to the solenoid is removed, the spring returns the valve to the opposite position. Two solenoids can be used to provide for both opening and closing by applying power to the appropriate solenoid.

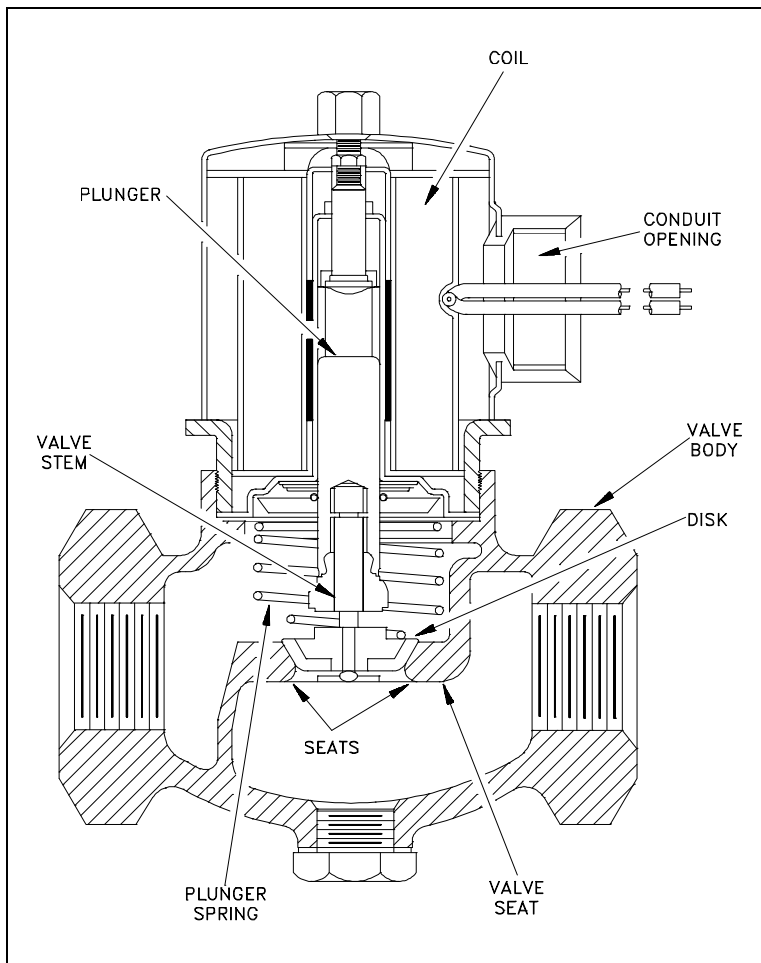


Figure 35 Solenoid Actuated Valve

Single solenoid valves are termed fail open or fail closed depending on the position of the valve with the solenoid de-energized. Fail open solenoid valves are opened by spring pressure and closed by energizing the solenoid. Fail closed solenoid valves are closed by spring pressure and opened by energizing the solenoid. Double solenoid valves typically fail "as is." That is, the valve position does not change when both solenoids are de-energized.

One application of solenoid valves is in air systems such as those used to supply air to pneumatic valve actuators. The solenoid valves are used to control the air supply to the pneumatic actuator and thus the position of the pneumatic actuated valve.

Speed of Power Actuators

Plant safety considerations dictate valve speeds for certain safety-related valves. Where a system must be very quickly isolated or opened, very fast valve actuation is required. Where the opening of a valve results in injection of relatively cold water to a hot system, slower opening is necessary to minimize thermal shock. Engineering design selects the actuator for safety-related valves based upon speed and power requirements and availability of energy to the actuator.

In general, fastest actuation is provided by hydraulic, pneumatic, and solenoid actuators. However, solenoids are not practical for large valves because their size and power requirements would be excessive. Also, hydraulic and pneumatic actuators require a system for providing hydraulic or pneumatic energy. The speed of actuation in either case can be set by installing appropriately sized orifices in the hydraulic or pneumatic lines. In certain cases, the valve is closed by spring pressure, which is opposed by hydraulic or pneumatic pressure to keep the valve open.

Electrical motors provide relatively fast actuation. Actual valve speed is set by the combination of motor speed and gear ratio. This combination can be selected to provide full valve travel within a range from about two seconds to several seconds.

Valve Position Indication

Operators require indication of the position of certain valves to permit knowledgeable operation of the plant. For such valves, remote valve position indication is provided in the form of position lights that indicate if valves are open or closed. Remote valve position indication circuits use a position detector that senses stem and disk position or actuator position. One type of position detector is the mechanical limit switch, which is physically operated by valve movement.

Another type is magnetic switches or transformers that sense movement of their magnetic cores, which are physically operated by valve movement.

Local valve position indication refers to some visually discernable characteristic of the valve that indicates valve position. Rising stem valve position is indicated by the stem position. Nonrising stem valves sometimes have small mechanical pointers that are operated by the valve actuator simultaneously with valve operation. Power actuated valves typically have a mechanical pointer that provides local valve position indication. On the other hand, some valves do not have any feature for position indication.

Summary

The important information in this chapter is summarized below.

Valve Actuators Summary

- Manual actuators are the most common type of valve actuators. Manual actuators include handwheels attached to the valve stem directly and handwheels attached through gears to provide a mechanical advantage.
- Electric motor actuators consist of reversible electric motors connected to the valve stem through a gear train that reduces rotational speed and increases torque.
- Pneumatic actuators use air pressure on either one or both sides of a diaphragm to provide the force to position the valve.
- Hydraulic actuators use a pressurized liquid on one or both sides of a piston to provide the force required to position the valve.
- Solenoid actuators have a magnetic slug attached to the valve stem. The force to position the valve comes from the magnetic attraction between the slug on the valve stem and the coil of the electromagnet in the valve actuator.

**Department of Energy
Fundamentals Handbook**

**MECHANICAL SCIENCE
Module 5
Miscellaneous Mechanical Components**

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TERMINAL OBJECTIVE

- 1.0 Without references, **DESCRIBE** the purpose, construction, and operation of miscellaneous mechanical components.

ENABLING OBJECTIVES

- 1.1 **STATE** the three common types of air compressors.
- 1.2 **DESCRIBE** the basic operation of the following types of air compressors:
- a. Reciprocating
 - b. Centrifugal
 - c. Rotary
- 1.3 **STATE** the reason for using cooling systems in air compressors.
- 1.4 **STATE** three hazards associated with pressurized air systems.
- 1.5 Given the appropriate information, **CALCULATE** the pressure or force achieved in a hydraulic piston.
- 1.6 **DESCRIBE** the basic operation of a hydraulic system.
- 1.7 **DESCRIBE** the basic operation of a boiler.
- 1.8 **IDENTIFY** the following components of a typical boiler:
- a. Steam drum
 - b. Distribution header(s)
 - c. Combustion chamber
 - d. Downcomer
 - e. Risers
- 1.9 **STATE** the purpose of cooling towers.
- 1.10 **DESCRIBE** the operation of the following types of cooling towers.
- a. Forced draft
 - b. Natural convection

ENABLING OBJECTIVES (Cont.)

- 1.11 **STATE** the purpose of a demineralizer.
- 1.12 **STATE** the four purposes of a pressurizer.
- 1.13 **DEFINE** the following terms attributable to a dynamic pressurizer:
- | | |
|-----------------|-----------------|
| a. Spray nozzle | c. Outsurge |
| b. Insurge | d. Surge volume |
- 1.14 **STATE** the purpose and general operation of a steam trap.
- 1.15 **IDENTIFY** the following types of steam traps:
- | | |
|--------------------------|-----------------------|
| a. Ball float steam trap | c. Bucket steam trap |
| b. Bellow steam trap | d. Impulse steam trap |
- 1.16 **DESCRIBE** each of the following types of strainers and filters, including an example of typical use.
- | | |
|----------------------|--------------------|
| a. Cartridge filters | d. Bucket strainer |
| b. Precoated filters | e. Duplex strainer |
| c. Deep-bed filters | |
- 1.17 **EXPLAIN** the application and operation of a strainer or filter backwash.

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AIR COMPRESSORS

The purpose of an air compressor is to provide a continuous supply of pressurized air. This chapter will describe the various types of compressors and their basic operation.

- EO 1.1** **STATE** the three common types of air compressors.
- EO 1.2** **DESCRIBE** the basic operation of the following types of air compressors:
- a. **Reciprocating**
 - b. **Centrifugal**
 - c. **Rotary**
- EO 1.3** **STATE** the reason for using cooling systems in air compressors.
- EO 1.4** **STATE** three hazards associated with pressurized air systems.
-

Introduction

Air compressors of various designs are used widely throughout DOE facilities in numerous applications. Compressed air has numerous uses throughout a facility including the operation of equipment and portable tools. Three types of designs include reciprocating, rotary, and centrifugal air compressors.

Reciprocating Compressors

The reciprocating air compressor, illustrated in Figure 1, is the most common design employed today.

The reciprocating compressor normally consists of the following elements.

- a. The compressing element, consisting of air cylinders, heads and pistons, and air inlet and discharge valves.
- b. A system of connecting rods, piston rods, crossheads, and a crankshaft and flywheel for transmitting the power developed by the driving unit to the air cylinder piston.

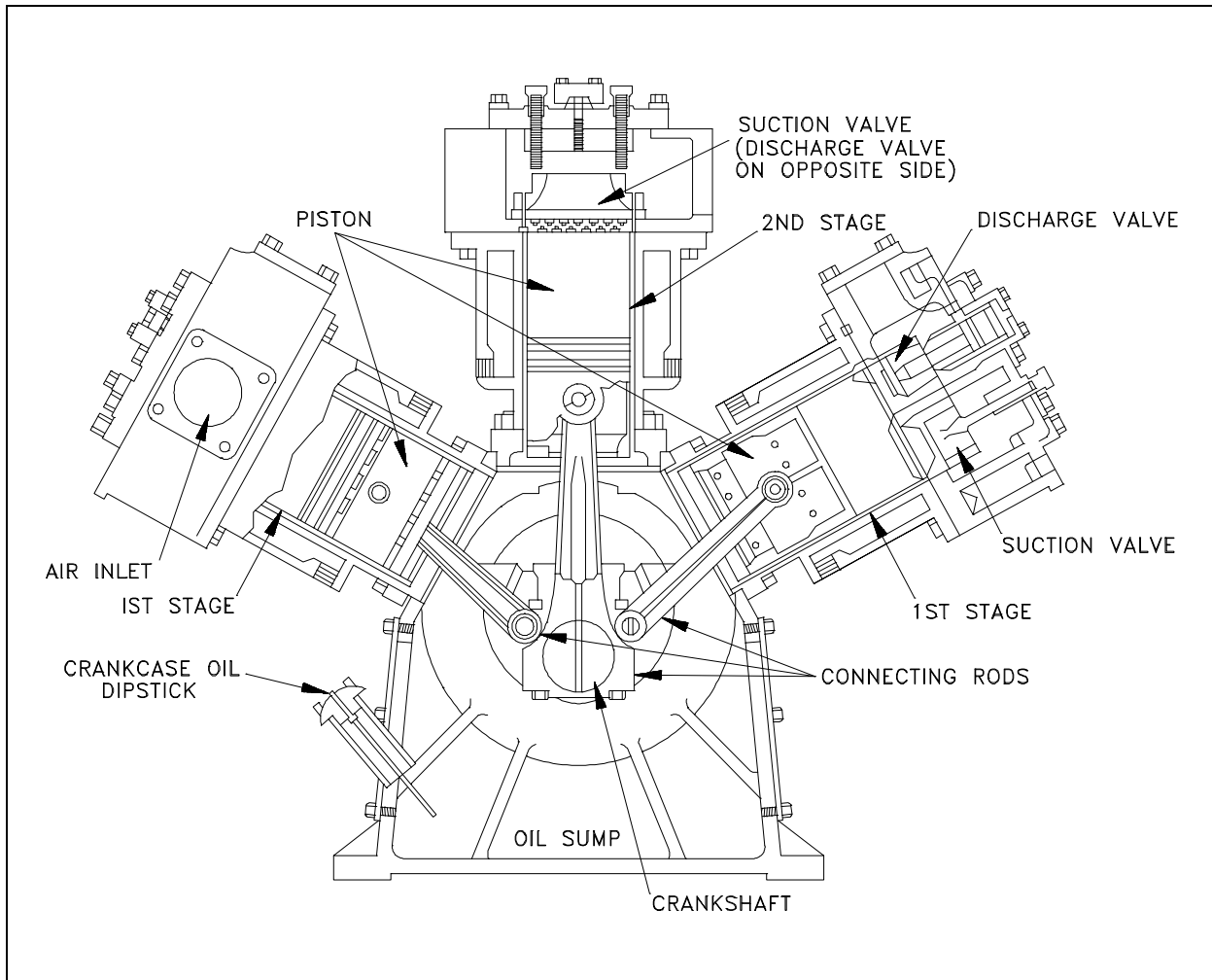


Figure 1 Reciprocating Air Compressor

- c. A self-contained lubricating system for bearings, gears, and cylinder walls, including a reservoir or sump for the lubricating oil, and a pump, or other means of delivering oil to the various parts. On some compressors a separate force-fed lubricator is installed to supply oil to the compressor cylinders.
- d. A regulation or control system designed to maintain the pressure in the discharge line and air receiver (storage tank) within a predetermined range of pressure.
- e. An unloading system, which operates in conjunction with the regulator, to reduce or eliminate the load put on the prime mover when starting the unit.

A section of a typical reciprocating single-stage, single-acting compressor cylinder is shown in Figure 2. Inlet and discharge valves are located in the clearance space and connected through ports in the cylinder head to the inlet and discharge connections.

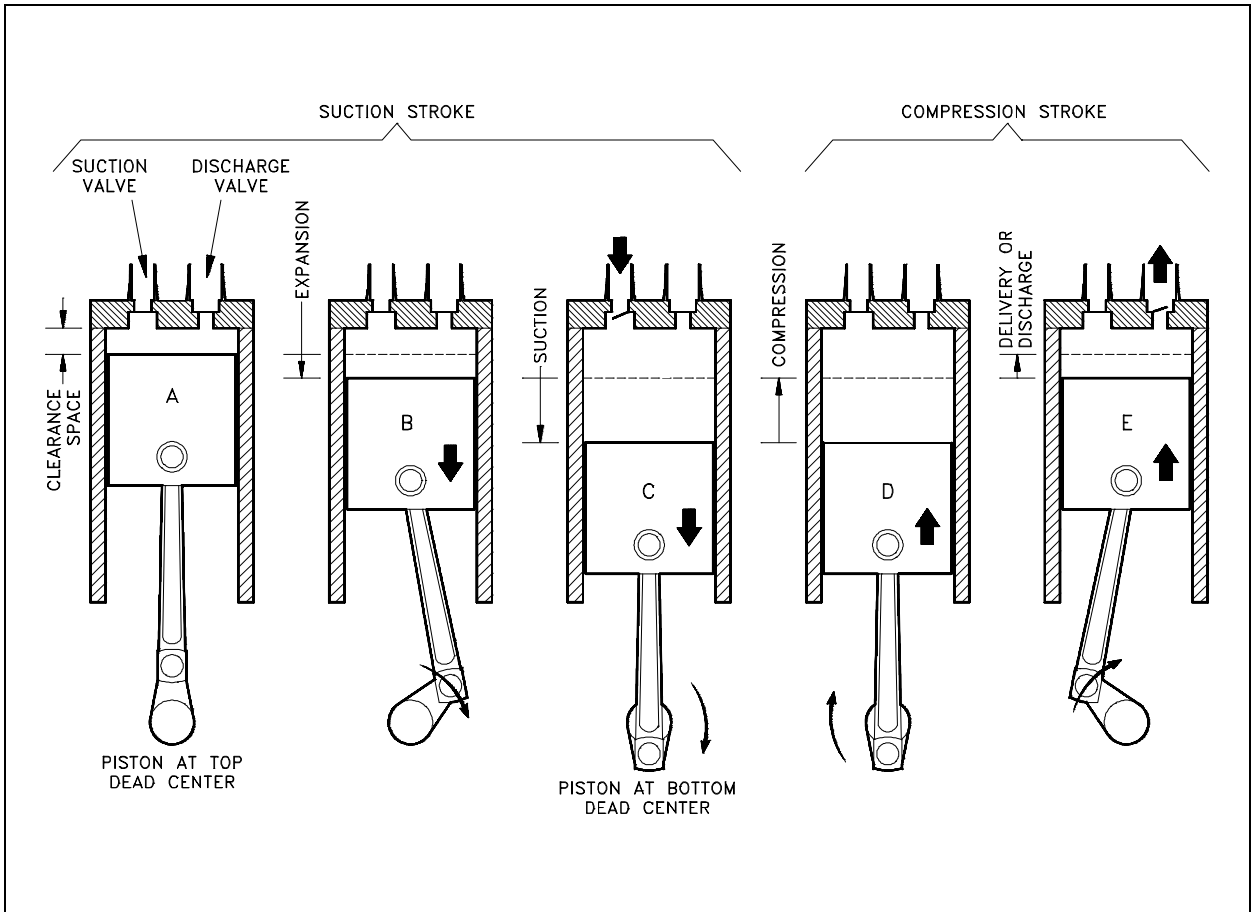


Figure 2 Single-Acting Air Compressor Cylinder

During the suction stroke the compressor piston starts its downward stroke and the air under pressure in the clearance space rapidly expands until the pressure falls below that on the opposite side of the inlet valve (Figures 2B and 2C). This difference in pressure causes the inlet valve to open into the cylinder until the piston reaches the bottom of its stroke (Figure 2C).

During the compression stroke the piston starts upward, compression begins, and at point D has reached the same pressure as the compressor intake. The spring-loaded inlet valve then closes. As the piston continues upward, air is compressed until the pressure in the cylinder becomes great enough to open the discharge valve against the pressure of the valve springs and the pressure of the discharge line (Figure 2E). From this point, to the end of the stroke (Figures 2E and 2A), the air compressed within the cylinder is discharged at practically constant pressure.

Rotary Compressors

The rotary compressor is adaptable to direct drive by induction motors or multicylinder gasoline or diesel engines. The units are compact, relatively inexpensive, and require a minimum of operating attention and maintenance. They occupy a fraction of the space and weight of a reciprocating machine of equivalent capacity. Rotary compressor units are classified into three general groups, slide vane-type, lobe-type, and liquid seal ring-type.

The rotary slide vane-type, as illustrated in Figure 3, has longitudinal vanes, sliding radially in a slotted rotor mounted eccentrically in a cylinder. The centrifugal force carries the sliding vanes against the cylindrical case with the vanes forming a number of individual longitudinal cells in the eccentric annulus between the case and rotor. The suction port is located where the longitudinal cells are largest. The size of each cell is reduced by the eccentricity of the rotor as the vanes approach the discharge port, thus compressing the air.

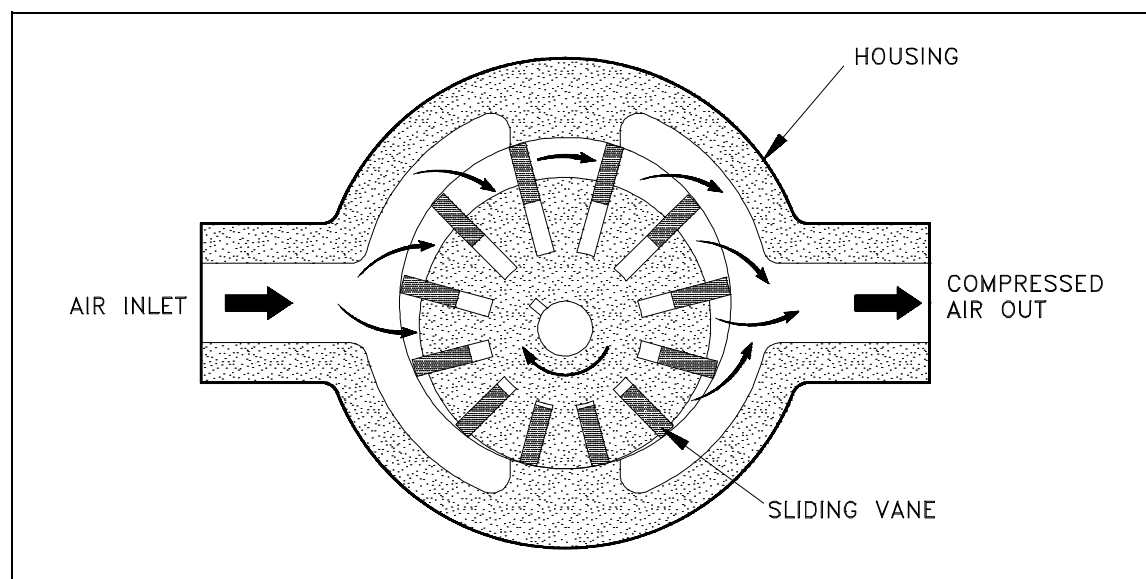


Figure 3 Rotary Slide Vane Air Compressor

The rotary lobe-type, illustrated in Figure 4, features two mating lobe-type rotors mounted in a case. The lobes are gear driven at close clearance, but without metal-to-metal contact. The suction to the unit is located where the cavity made by the lobes is largest. As the lobes rotate, the cavity size is reduced, causing compression of the vapor within. The compression continues until the discharge port is reached, at which point the vapor exits the compressor at a higher pressure.

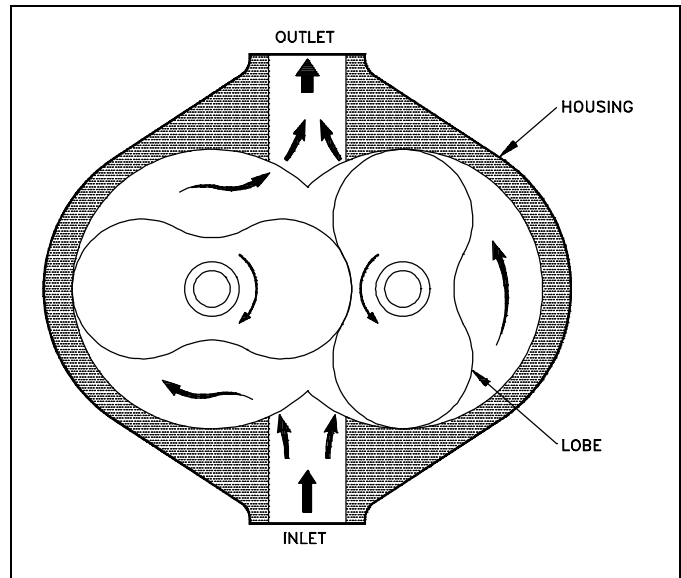


Figure 4 Rotary Lobe Air Compressor

The rotary liquid seal ring-type, illustrated in Figure 5, features a forward inclined, open impeller, in an oblong cavity filled with liquid. As the impeller rotates, the centrifugal force causes the seal liquid to collect at the outer edge of the oblong cavity. Due to the oblong configuration of the compressor case, large longitudinal cells are created and reduced to smaller ones. The suction port is positioned where the longitudinal cells are the largest, and for the discharge port, where they are smallest, thus causing the vapor within the cell to compress as the rotor rotates. The rotary liquid seal compressor is frequently used in specialized applications for the compression of extremely corrosive and exothermic gasses and is commonly used in commercial nuclear plants as a means of establishing initial condenser vacuum.

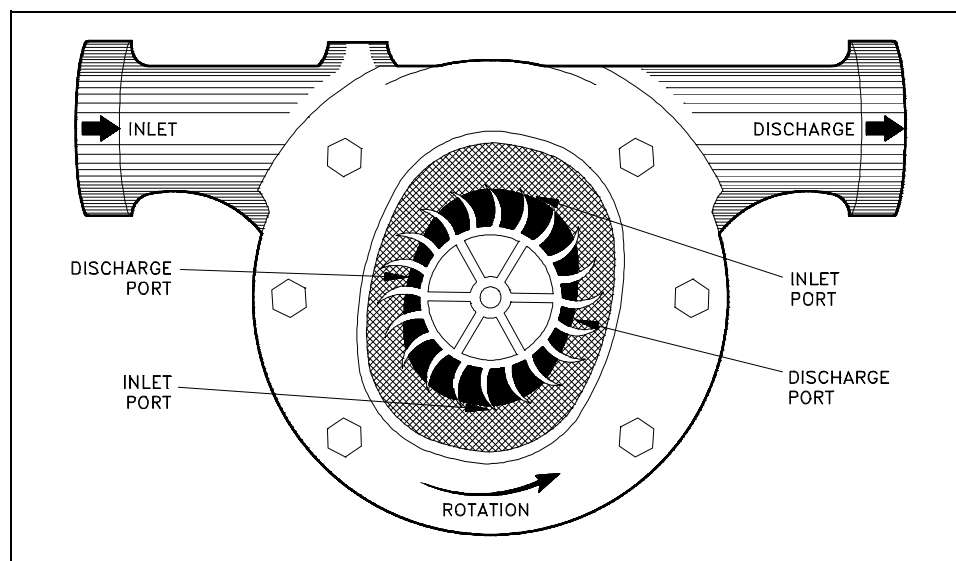


Figure 5 Rotary Liquid Seal Ring Air Compressor

Centrifugal Compressors

The centrifugal compressor, originally built to handle only large volumes of low pressure gas and air (maximum of 40 psig), has been developed to enable it to move large volumes of gas with discharge pressures up to 3,500 psig. However, centrifugal compressors are now most frequently used for medium volume and medium pressure air delivery. One advantage of a centrifugal pump is the smooth discharge of the compressed air.

The centrifugal force utilized by the centrifugal compressor is the same force utilized by the centrifugal pump. The air particles enter the eye of the impeller, designated D in Figure 6. As the impeller rotates, air is thrown against the casing of the compressor. The air becomes compressed as more and more air is thrown out to the casing by the impeller blades. The air is pushed along the path designated A, B, and C in Figure 6. The pressure of the air is increased as it is pushed along this path. Note in Figure 6 that the impeller blades curve forward, which is opposite to the backward curve used in typical centrifugal liquid pumps. Centrifugal compressors can use a variety of blade orientation including both forward and backward curves as well as other designs.

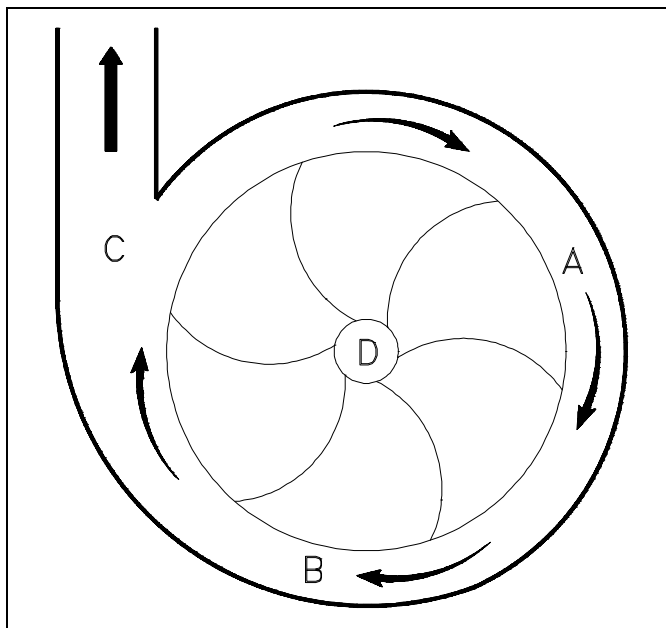


Figure 6 Simplified Centrifugal Pump

There may be several stages to a centrifugal air compressor, as in the centrifugal pump, and the result would be the same; a higher pressure would be produced. The air compressor is used to create compressed or high pressure air for a variety of uses. Some of its uses are pneumatic control devices, pneumatic sensors, pneumatic valve operators, pneumatic motors, and starting air for diesel engines.

Compressor Coolers

The amount of moisture that air can hold is inversely proportional to the pressure of the air. As the pressure of the air increases, the amount of moisture that air can hold decreases. The amount of moisture that air can hold is also proportional to the temperature of the air. As the temperature of the air increases, the amount of moisture it can hold increases. However, the pressure change of compressed air is larger than the temperature change of the compressed air. This causes the moisture in the air to condense. Moisture in compressed air systems can cause serious damage. The condensed moisture can cause corrosion, water hammers, and freeze damage; therefore, it is important to avoid moisture in compressed air systems. Coolers are used to minimize the problems caused by heat and moisture in compressed air systems.

Coolers used on the discharge of a compressor are called aftercoolers. Their purpose is to remove the heat generated during the compression of the air. The decrease in temperature promotes the condensing of any moisture present in the compressed air. This moisture is collected in condensate traps that are either automatically or manually drained.

If the compressor is multi-staged, there may be an intercooler, which is usually located after the first stage discharge and before the second stage suction. The principle of the intercooler is the same as that of the aftercoolers. The result is drier, cooler, compressed air. The structure of a particular cooler depends on the pressure and volume of the air it cools. Figure 7 illustrates a typical compressor air cooler. Air coolers are used because drier compressed air helps prevent corrosion and cooler compressed air allows more air to be compressed for a set volume.

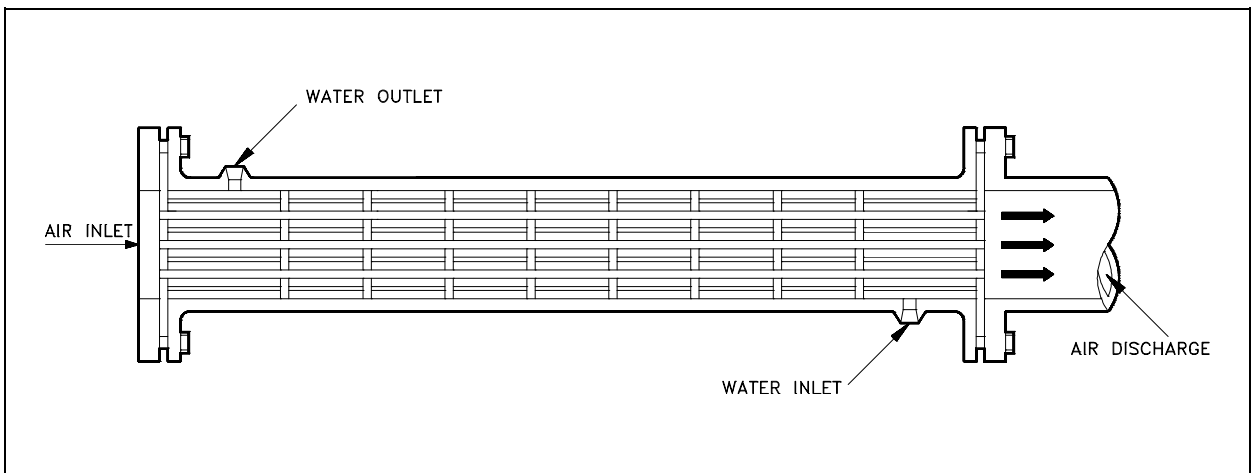


Figure 7 Compressor Air Cooler

Hazards of Compressed Air

People often lack respect for the power in compressed air because air is so common and is often viewed as harmless. At sufficient pressures, compressed air can cause serious damage if handled incorrectly. To minimize the hazards of working with compressed air, all safety precautions should be followed closely.

Small leaks or breaks in the compressed air system can cause minute particles to be blown at extremely high speeds. Always wear safety glasses when working in the vicinity of any compressed air system. Safety goggles are recommended if contact lenses are worn.

Compressors can make an exceptional amount of noise while running. The noise of the compressor, in addition to the drain valves lifting, creates enough noise to require hearing protection. The area around compressors should normally be posted as a hearing protection zone.

Pressurized air can do the same type of damage as pressurized water. Treat all operations on compressed air systems with the same care taken on liquid systems. Closed valves should be slowly cracked open and both sides should be allowed to equalize prior to opening the valve further. Systems being opened for maintenance should always be depressurized before work begins.

Great care should be taken to keep contaminants from entering air systems. This is especially true for oil. Oil introduced in an air compressor can be compressed to the point where detonation takes place in a similar manner as that which occurs in a diesel engine. This detonation can cause equipment damage and personnel injury.

Summary

The important information in this chapter is summarized below.

Air Compressors Summary

- The three common types of air compressors are reciprocating, rotary, and centrifugal.
- The single-stage reciprocating compressor has a piston that moves downward during the suction stroke, expanding the air in the cylinder. The expanding air causes pressure in the cylinder to drop. When the pressure falls below the pressure on the other side of the inlet valve, the valve opens and allows air in until the pressure equalizes across the inlet valve. The piston bottoms out and then begins a compression stroke. The upward movement of the piston compresses the air in the cylinder, causing the pressure across the inlet valve to equalize and the inlet valve to reseat. The piston continues to compress air during the remainder of the upward stroke until the cylinder pressure is great enough to open the discharge valve against the valve spring pressure. Once the discharge valve is open, the air compressed in the cylinder is discharged until the piston completes the stroke.

Air Compressors Summary (Cont.)

- The centrifugal force utilized by the centrifugal compressors is the same force utilized by the centrifugal pumps. The air particles enter the eye of the impeller. As the impeller rotates, air is thrown against the casing of the compressor. The air becomes compressed as more and more air is thrown out to the casing by the impeller blades. The air is pushed along the path on the inner wall of the casing. The pressure of the air is increased as it is pushed along this path. There could be several stages to a centrifugal air compressor just as in the centrifugal pump, resulting in higher pressure.
- Rotary compressors are driven by a direct drive that rotates a mechanism (impellers, vanes, or lobes) that compresses the air being pumped. The actual compression of the air takes place due either to centrifugal forces or a diminishing air space as the impellers rotate.
- Cooling systems are required in compressed air systems to remove any heat added by the compression. The advantages to cooling the compressed air are that cool air takes less space and holds less moisture. This reduces corrosion and allows more air to be compressed into a given volume.
- Hazards associated with compressed air are similar to hazards of any high pressure system. Three general hazards include the following.

Small leaks or breaks can cause minute particles to be blown at speeds high enough to cause damage. Goggles or safety glasses should be worn when working around compressed gas.

The compressors, especially larger ones, can be quite noisy when running. The cycling of automatic drain valves contributes noise as well. Hearing protection should be worn around compressors.

Pressure swings may cause system damage. Closed valves in a compressed air system should be slowly cracked open and the pressure should be allowed to equalize prior to opening the valve further. Systems should be depressurized prior to opening for maintenance. Oil should be kept out of air systems to prevent possible explosions.

HYDRAULICS

Many machines and processes use a fluid for developing a force to move or hold an object, or to control an action. The term hydraulic refers to a liquid. A number of fluids can be used for developing the force. In a hydraulic system, oil, water, or other liquids can be used. Oil is the most common.

EO 1.5 **Given the appropriate information, CALCULATE the pressure or force achieved in a hydraulic piston.**

EO 1.6 **DESCRIBE the basic operation of a hydraulic system.**

Introduction

Although any liquid can be used in a hydraulic system, some liquids have advantages over others. Oil is a liquid often preferred as the working fluid. Oil helps to lubricate the various sliding parts, prevents rust, and is readily available. For practical purposes, oil does not change its volume in the hydraulic system when the pressure is changed.

Pressure and Force

The foundation of modern hydraulic powered systems was established when a scientist named Blaise Pascal discovered that pressure in a fluid acts equally in all directions. This concept is known as Pascal's Law. The application of Pascal's Law requires the understanding of the relationship between force and pressure.

Force may be defined as a push or pull exerted against the total area of a surface. It is expressed in pounds. Pressure is the amount of force on a unit area of the surface. That is, pressure is the force acting upon one square inch of a surface.

The relationship between pressure and force is expressed mathematically.

$$F = P \times A$$

where:

F = force in lbf

P = pressure in lbf/in.², (psi)

A = area in in.²

Example 1:

In a hydraulic system, the oil pressure at the inlet to the cylinder is 1500 psi, and the area of the piston over which the oil pressure acts is two square inches. Calculate the force exerted on the piston.

Solution:

Since $F = P \times A$, the force of the oil on the piston is calculated as follows.

$$\begin{aligned} F &= 1500 \text{ lbf/in.}^2 \times 2 \text{ in.}^2 \\ &= 3000 \text{ lbf} \end{aligned}$$

Example 2:

A hydraulic valve requires a force of 1848 lbf to be opened. The piston area is 3 square inches. How much pressure does the hydraulic fluid have to exert for the valve to move?

Solution:

Since $F = P \times A$, then $P = \frac{F}{A}$.

$$P = \frac{1848 \text{ lbf}}{3 \text{ in.}^2}$$

$$P = 616 \text{ lbf/in.}^2$$

Hydraulic Operation

The operation of a typical hydraulic system is illustrated in Figure 8. Oil from a tank or reservoir flows through a pipe into a pump. Often a filter is provided on the pump suction to remove impurities from the oil. The pump, usually a gear-type, positive displacement pump, can be driven by an electric motor, air motor, gas or steam turbine, or an internal combustion engine. The pump increases the pressure of the oil. The actual pressure developed depends upon the design of the system.

Most hydraulic systems have some method of preventing overpressure. As seen in Figure 8, one method of pressure control involves returning hydraulic oil to the oil reservoir. The pressure control box shown on Figure 8 is usually a relief valve that provides a means of returning oil to the reservoir upon overpressurization.

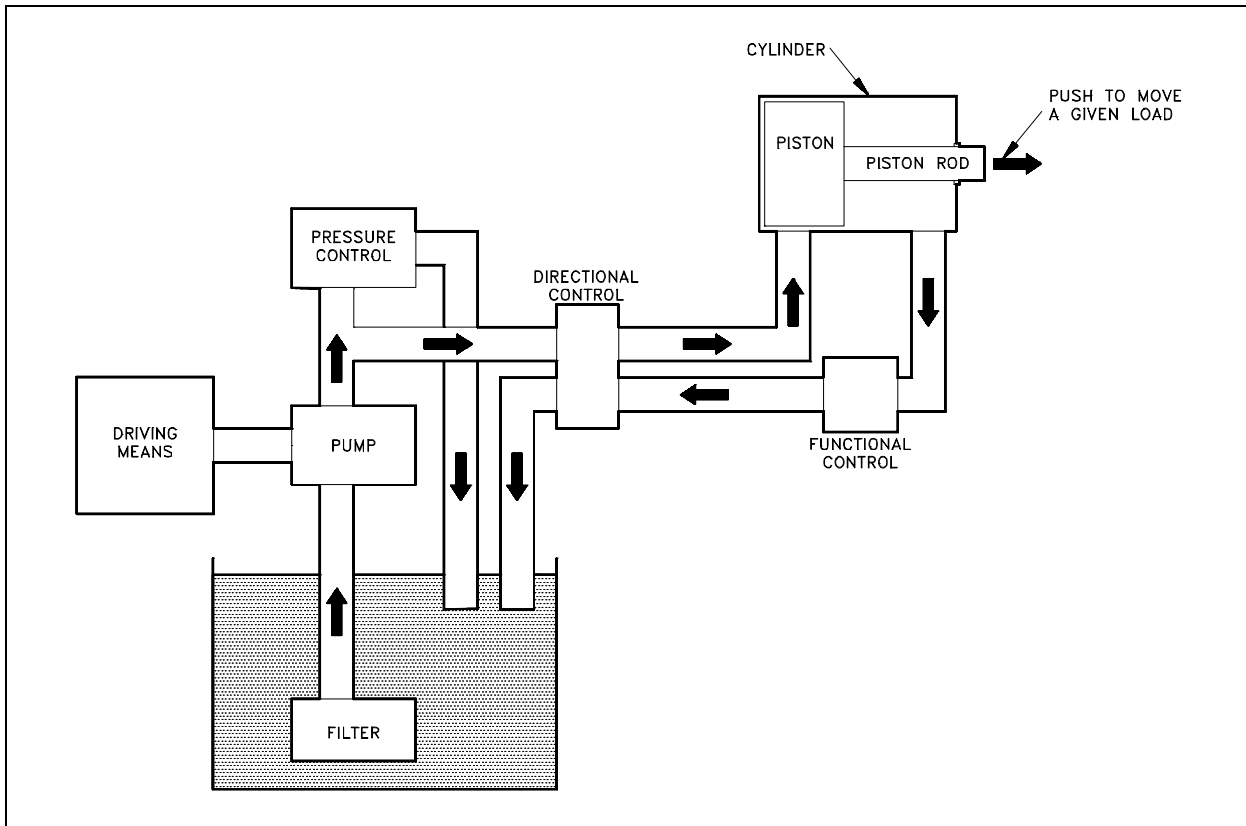


Figure 8 Basic Hydraulic System

The high pressure oil flows through a control valve (directional control). The control valve changes the direction of oil flow, depending upon the desired direction of the load. In Figure 8 the load can be moved to the left or to the right by changing the side of the piston to which the oil pressure is applied. The oil that enters the cylinder applies pressure over the area of the piston, developing a force on the piston rod. The force on the piston rod enables the movement of a load or device. The oil from the other side of the piston returns to a reservoir or tank.

Hazards

The hazards and precautions listed in the previous chapter on air compressors are applicable to hydraulic systems as well, because most of the hazards are associated with high pressure conditions. Any use of a pressurized medium can be dangerous. Hydraulic systems carry all the hazards of pressurized systems and special hazards that are related directly to the composition of the fluid used.

When using oil as a fluid in a high pressure hydraulic system, the possibility of fire or an explosion exists. A severe fire hazard is generated when a break in the high pressure piping occurs and the oil is vaporized into the atmosphere. Extra precautions against fire should be practiced in these areas.

If oil is pressurized by compressed air, an explosive hazard exists if the high pressure air comes into contact with the oil, because it may create a diesel effect and subsequent explosion. A carefully followed preventive maintenance plan is the best precaution against explosion.

Summary

The important information in this chapter is summarized below.

Hydraulics Summary

- The relationship between pressure and force in a hydraulic piston is expressed mathematically as:

$$F = P \times A$$

where:

F = force

P = pressure

A = area

- Oil from a tank or reservoir flows through a pipe into a pump. The pump can be driven by a motor, turbine, or an engine. The pump increases the pressure of the oil.

The high pressure oil flows in the piping through a control valve. The control valve changes the direction of the oil flow. A relief valve, set at a desired safe operating pressure, protects the system from an over-pressure condition. Oil entering the cylinder applies pressure to the piston, developing a force on the piston rod.

The force on the piston rod enables the movement of a load or device. The oil from the other side of the piston returns to a reservoir or tank via a filter, which removes foreign particles.

BOILERS

Boilers are commonly used at large facilities to act as primary or backup steam sources. The source of heat that generates the steam varies, but the basic operation of the boiler is the same. This chapter will summarize the operation of a boiler.

EO 1.7 DESCRIBE the basic operation of a boiler.

EO 1.8 IDENTIFY the following components of a typical boiler:

- | | |
|----------------------------------|---------------------|
| a. Steam drum | d. Downcomer |
| b. Distribution header(s) | e. Risers |
| c. Combustion chamber | |

Introduction

The primary function of a boiler is to produce steam at a given pressure and temperature. To accomplish this, the boiler serves as a furnace where air is mixed with fuel in a controlled combustion process to release large quantities of heat. The pressure-tight construction of a boiler provides a means to absorb the heat from the combustion and transfer this heat to raise water to a temperature such that the steam produced is of sufficient temperature and quality (moisture content) for steam loads.

Boilers

Two distinct heat sources used for boilers are electric probes and burned fuel (oil, coal, etc.) This chapter will use fuel boilers to illustrate the typical design of boilers. Refer to Figure 9 during the following discussion.

The boiler has an enclosed space where the fuel combustion takes place, usually referred to as the furnace or combustion chamber. Air is supplied to combine with the fuel, resulting in combustion. The heat of combustion is absorbed by the water in the risers or circulating tubes. The density difference between hot and cold water is the driving force to circulate the water back to the steam drum. Eventually the water will absorb sufficient heat to produce steam.

Steam leaves the steam drum via a baffle, which causes any water droplets being carried by the steam to drop out and drain back to the steam drum. If superheated steam is required, the steam may then travel through a superheater. The hot combustion gasses from the furnace will heat the steam through the superheater's thin tube walls. The steam then goes to the steam supply system and the various steam loads.

Some boilers have economizers to improve cycle efficiency by preheating inlet feedwater to the boiler. The economizer uses heat from the boiler exhaust gasses to raise the temperature of the inlet feedwater.

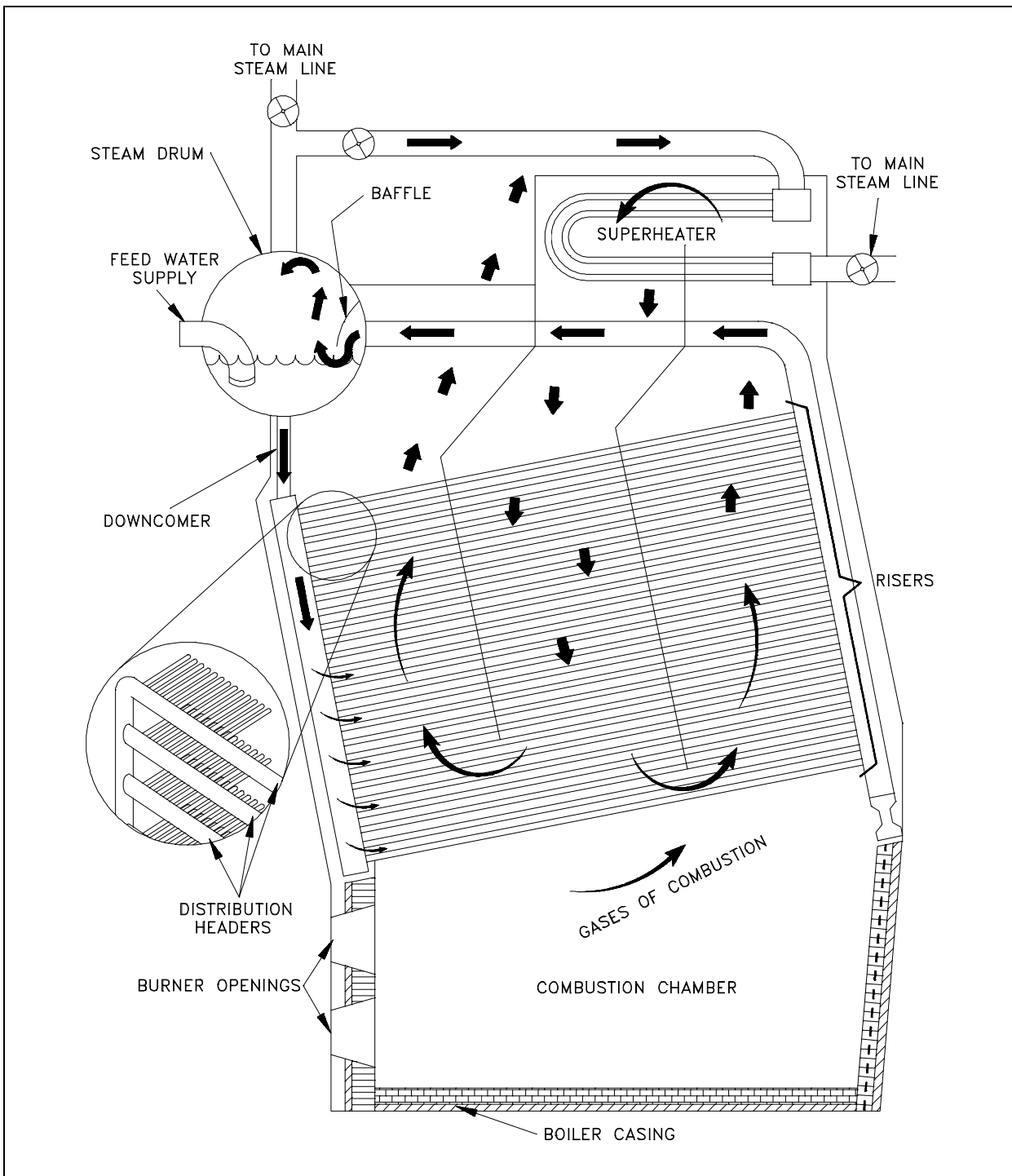


Figure 9 Typical Fuel Boiler

Fuel Boiler Components

Figure 9 illustrates a typical fuel boiler. Some of the components are explained below.

- Steam drum - The steam drum separates the steam from the heated water. The water droplets fall to the bottom of the tank to be cycled again, and the steam leaves the drum and enters the steam system. Feedwater enters at the bottom of the drum to start the heating cycle.
- Downcomers - Downcomers are the pipes in which the water from the steam drum travels in order to reach the bottom of the boiler where the water can enter the distribution headers.
- Distribution headers - The distribution headers are large pipe headers that carry the water from the downcomers to the risers.
- Risers - The piping or tubes that form the combustion chamber enclosure are called risers. Water and steam run through these to be heated. The term risers refers to the fact that the water flow direction is from the bottom to the top of the boiler. From the risers, the water and steam enter the steam drum and the cycle starts again.
- Combustion chamber - Located at the bottom of a boiler, the combustion chamber is where the air and fuel mix and burn. It is lined with the risers.

Summary

The important information in this chapter is summarized below.

Boilers Summary

- Boilers are vessels that allow water in contained piping to be heated to steam by a heat source internal to the vessel. The water is heated to the boiling point. The resulting steam separates, and the water is heated again. Some boilers use the heat from combustion off-gasses to further heat the steam (superheat) and/or to preheat the feedwater.
- The following components were discussed:

The steam drum is where the steam is separated from the heated water.

Downcomers are the pipes in which the water from the steam drum travels to reach the bottom of the boiler.

Distribution headers are large pipe headers that carry the water from the downcomers to the risers.

Risers are the piping or tubes that form the combustion chamber enclosure. Water and steam run through the risers to be heated.

The combustion chamber is located at the bottom of the boiler and is where the air and fuel mix and burn.

COOLING TOWERS

In an effort to lower costs and meet new environmental regulations, companies are developing new ways to do things. One of the developments which meets both cost decrease and environmental awareness is the cooling tower. This chapter will summarize the advantages of cooling towers and how they function.

EO 1.9 STATE the purpose of cooling towers.

EO 1.10 DESCRIBE the operation of the following types of cooling towers:

- a. **Forced draft**
- b. **Natural convection**

Purpose

Before the development of cooling towers, rivers, lakes, and cooling ponds were required to supply cooling. Through the development of the mechanical draft cooling tower, as little as one square foot of area is needed for every 1000 square feet required for a cooling pond or lake. Cooling towers minimize the thermal pollution of the natural water heat sinks and allow the reuse of circulating water. An example of the manner in which a cooling tower can fit into a system is shown in Figure 10.

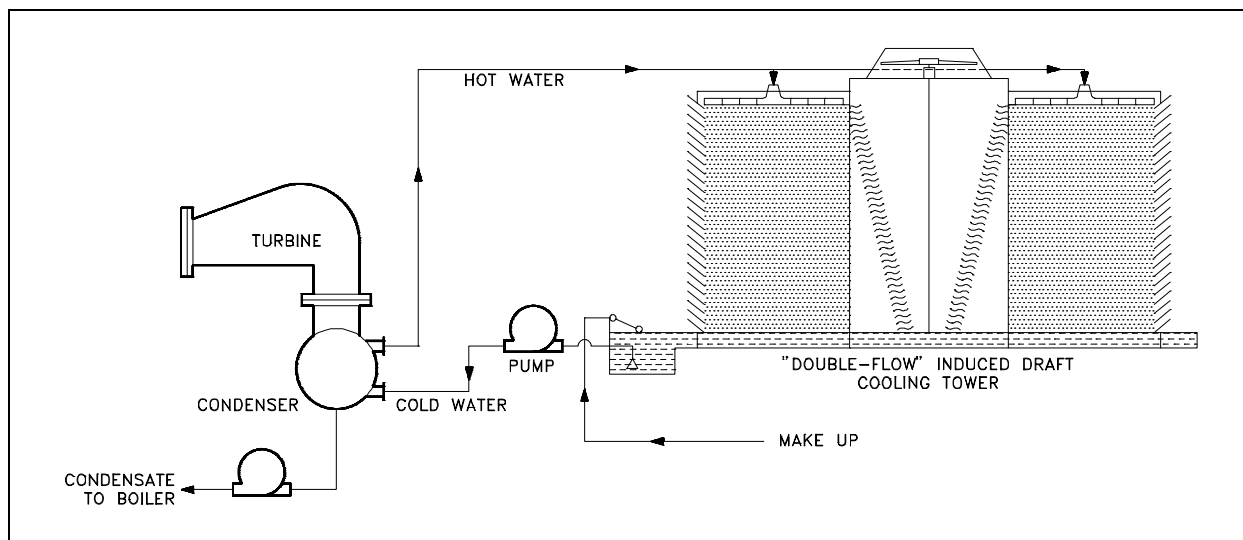


Figure 10 Cooling System Containing Cooling Tower

The cooling of the water in a cooling tower is accomplished by the direct contact of water and air. This cooling effect is provided primarily by an exchange of latent heat of vaporization resulting from evaporation of a small amount of water and by a transfer of sensible heat, which raises the temperature of the air. The heat transferred from the water to the air is dissipated to the atmosphere.

Induced Draft Cooling Towers

Induced draft cooling towers, illustrated in Figure 11, are constructed such that the incoming circulating water is dispersed throughout the cooling tower via a spray header. The spray is directed down over baffles that are designed to maximize the contact between water and air. The air is drawn through the baffled area by large circulating fans and causes the evaporation and the cooling of the water.

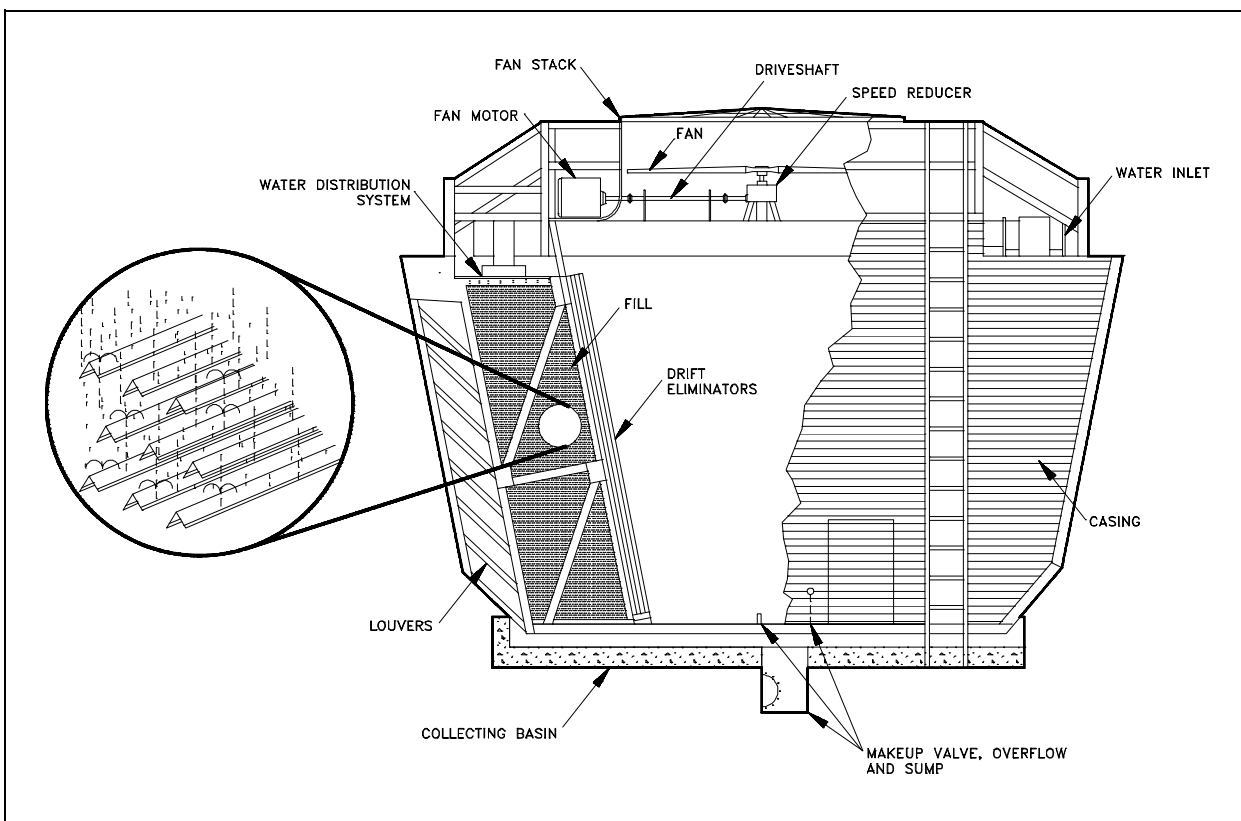


Figure 11 Induced Draft Cooling Tower

The nomenclature for induced draft cooling towers, including some items not illustrated in Figure 11 is summarized below.

Casing -	The casing encloses the walls of the cooling tower, exclusive of fan deck and louvers.
Collecting basin -	The collecting basin is a receptacle beneath the cooling tower for collecting the water cooled by the cooling tower. It can be made of concrete, wood, metal, or an alternative material. Certain necessary accessories are required such as sump, strainers, overflow, drain, and a makeup system.
Drift eliminators -	The drift eliminators are parallel blades of PVC, wood, metal, or an alternative material arranged on the air discharge side of the fill to remove entrained water droplets from the leaving air stream.
Driver -	The driver is a device that supplies power to turn the fan. It is usually an electric motor, but turbines and internal combustion engines are occasionally used.
Drive shaft -	The drive shaft is a device, including couplings, which transmits power from the driver to the speed reducer.
Fan -	The fan is a device used to induce air flow through the cooling tower.
Fan deck -	The fan deck is a horizontal surface enclosing the top of the cooling tower above the plenum that serves as a working platform for inspection and maintenance.
Fan stack -	The fan stack is a cylinder enclosing the fan, usually with an eased inlet and an expanding discharge for increased fan efficiency.
Fill -	The fill is PVC, wood, metal, or an alternative material that provides extended water surface exposure for evaporative heat transfer.
Intake louvers -	The intake louvers are an arrangement of horizontal blades at the air inlets that prevent escape of falling water while allowing the entry of air.

Makeup valve -	The makeup valve is a valve that introduces fresh water into the collection basin to maintain the desired collecting basin water level.
Overflow -	The overflow is a drain that prevents the collecting basin from overflowing.
Partition -	The partition is a baffle within a multicell cooling tower that is used to prevent air and/or water flow between adjacent cells.
Plenum -	The plenum is the internal cooling tower area between the drift eliminators and the fans.
Speed reducer -	The speed reducer is a right-angle gear box that transmits power to the fan while reducing the driver speed to that required for optimal fan performance.
Sump -	The sump is a depressed portion of the collecting basin from which cold water is drawn to be returned to the connected system. The sump usually contains strainer screens, antivortex devices, and a drain or cleanout connection.
Distribution system -	The distribution system is that portion of a cooling tower that distributes water over the fill area. It usually consists of one or more flanged inlets, flow control valves, internal headers, distribution basins, spray branches, metering orifices, and other related components.

Forced Draft Cooling Towers

Forced draft cooling towers are very similar to induced draft cooling towers. The primary difference is that the air is blown in at the bottom of the tower and exits at the top. Forced draft cooling towers are the forerunner to induced draft cooling towers. Water distribution problems and recirculation difficulties discourage the use of forced draft cooling towers.

Natural Convection Cooling Towers

Natural convection cooling towers, illustrated in Figure 12, use the principle of convective flow to provide air circulation. As the air inside the tower is heated, it rises through the tower. This process draws more air in, creating a natural air flow to provide cooling of the water. The basin at the bottom of the tower is open to the atmosphere. The cooler, more dense air outside the

tower will flow in at the bottom and contribute to the air circulation within the tower. The air circulation will be self-perpetuating due to the density difference between the warmer air inside and the cooler air outside.

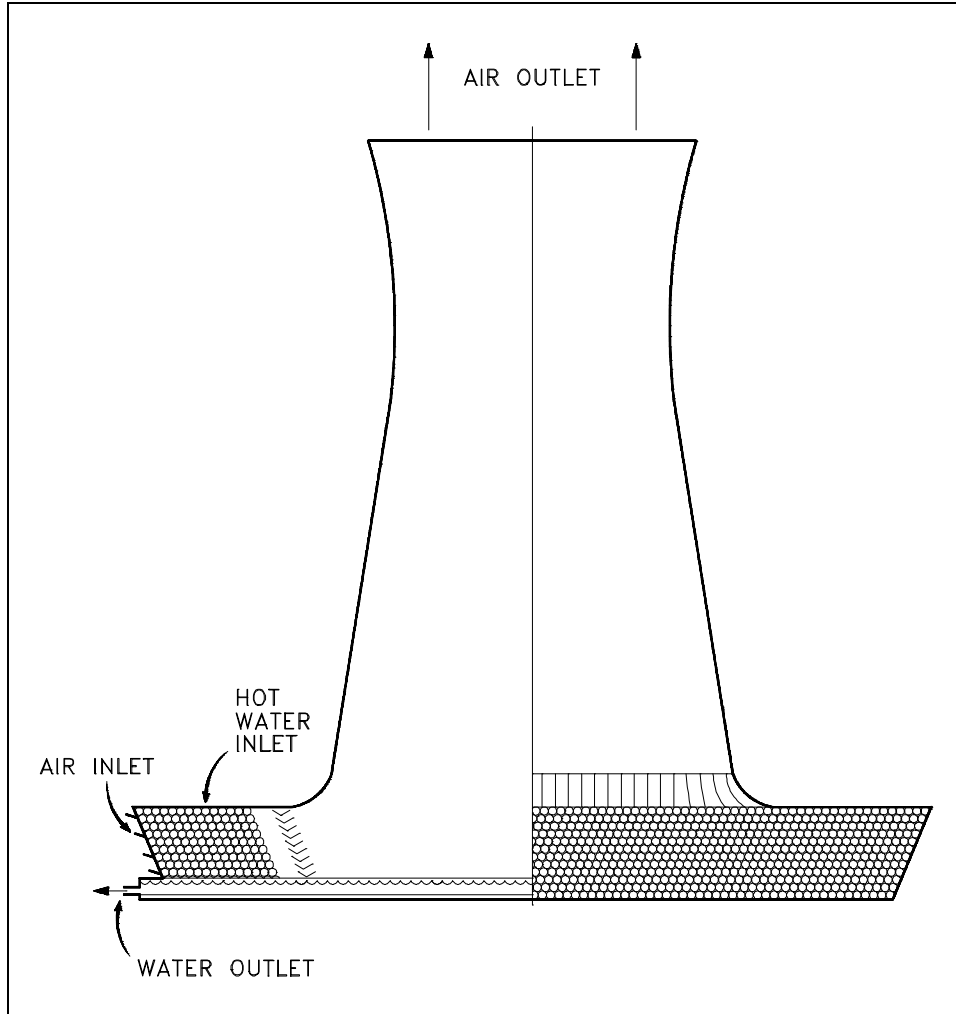


Figure 12 Natural Convection Cooling Tower

The incoming water is sprayed around the circumference of the tower and cascades to the bottom. The natural convection cooling towers are much larger than the forced draft cooling towers and cost much more to construct. Because of space considerations and cost, natural convection cooling towers are built less frequently than other types.

Summary

The important information in this chapter is summarized below.

Cooling Towers Summary

- The cooling tower removes heat from water used in cooling systems within the plant. The heat is released to the air rather than to a lake or stream. This allows facilities to locate in areas with less water available because the cooled water can be recycled. It also aids environmental efforts by not contributing to thermal pollution.
- Induced draft cooling towers use fans to create a draft that pulls air through the cooling tower fill. Because the water to be cooled is distributed such that it cascades over the baffles, the air blows through the water, cooling it.
- Forced draft cooling towers blow air in at the bottom of the tower. The air exits at the top of the tower. Water distribution and recirculation difficulties limit their use.
- Natural convection cooling towers function on the basic principle that hot air rises. As the air inside the tower is heated, it rises through the tower. This process draws more air in, creating a natural air flow to provide cooling of the water.

DEMINERALIZERS

The cost of corrosion and radioactive contamination caused by poor water quality in nuclear facilities is enormous. Demineralizers are an intricate part of water quality control. The chemical theory of demineralizers is detailed in the Chemistry Fundamentals Handbook. This chapter will address the mechanics of how demineralizers operate.

EO 1.11 STATE the purpose of a demineralizer.

Purpose of Demineralizers

Dissolved impurities in power plant fluid systems generate corrosion problems and decrease efficiency due to fouled heat transfer surfaces. Demineralization of the water is one of the most practical and common methods available to remove these dissolved impurities.

In the plant, demineralizers (also called ion-exchangers) are used to hold ion exchange resins and transport water through them. Ion exchangers are generally classified into two groups: single-bed ion exchangers and mixed-bed ion exchangers.

Demineralizers

A demineralizer is basically a cylindrical tank with connections at the top for water inlet and resin addition, and connections at the bottom for the water outlet. The resin can usually be changed through a connection at the bottom of the tank. The resin beads are kept in the demineralizer by upper and lower retention elements, which are strainers with a mesh size smaller than the resin beads. The water to be purified enters the top at a set flow rate and flows down through the resin beads, where the flow path causes a physical filter effect as well as a chemical ion exchange.

Single-Bed Demineralizers

A single-bed demineralizer contains either cation or anion resin beads. In most cases, there are two, single-bed ion exchangers in series; the first is a cation bed and the second is an anion bed. Impurities in plant water are replaced with hydrogen ions in the cation bed and hydroxyl ions in the anion bed. The hydrogen ions and the hydroxyl ions then combine to form pure water. The Chemistry Handbook, Module 4, Principles of Water Treatment, addresses the chemistry of demineralizers in more detail.

Figure 13 illustrates a single-bed demineralizer. When in use, water flows in through the inlet to a distributor at the top of the tank. The water flows down through the resin bed and exits out through the outlet. A support screen at the bottom prevents the resin from being forced out of the demineralizer tank.

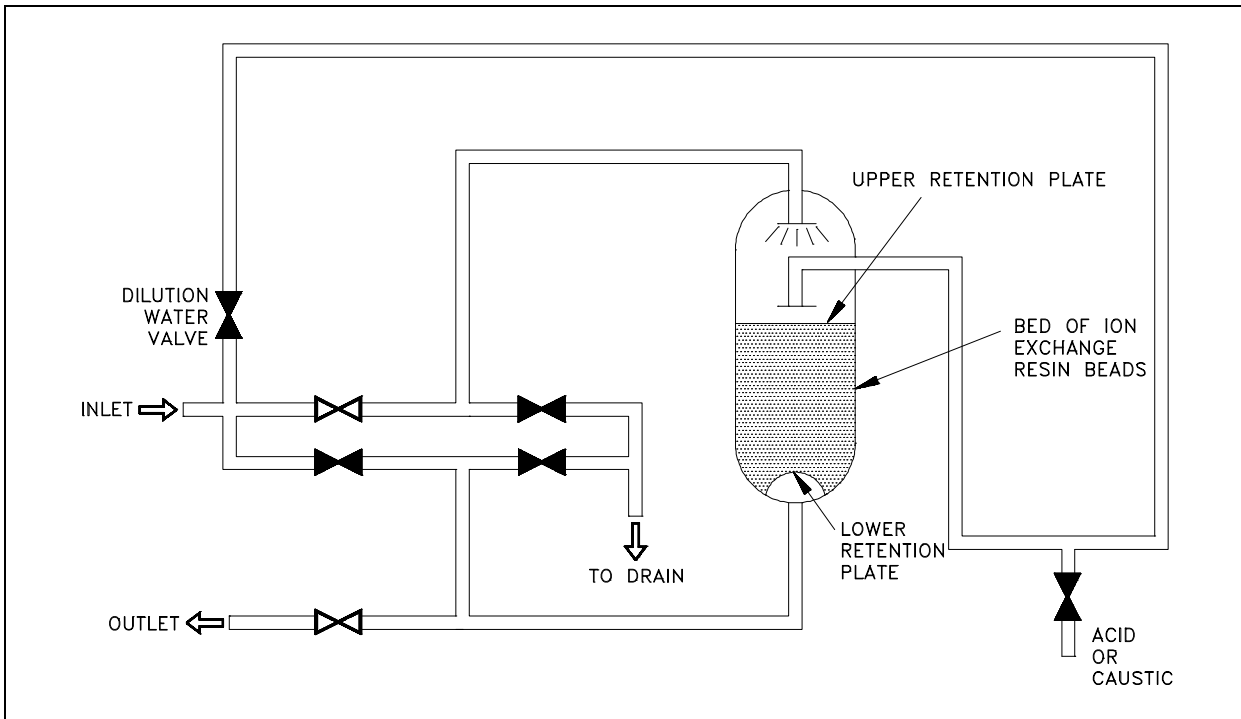


Figure 13 Single-Bed Demineralizer

Single-Bed Regeneration

The regeneration of a single-bed ion exchanger is a three-step process. The first step is a backwash, in which water is pumped into the bottom of the ion exchanger and up through the resin. This fluffs the resin and washes out any entrained particles. The backwash water goes out through the normal inlet distributor piping at the top of the tank, but the valves are set to direct the stream to a drain so that the backwashed particles can be pumped to a container for waste disposal.

The second step is the actual regeneration step, which uses an acid solution for cation units and caustic solution for anion units. The concentrated acid or caustic is diluted to approximately 10% with water by opening the dilution water valve, and is then introduced through a distribution system immediately above the resin bed. The regenerating solution flows through the resin and out the bottom of the tank to the waste drain.

The final step is a rinsing process, which removes any excess regenerating solution. Water is pumped into the top of the tank, flows down through the resin bed and out at the bottom drain.

To return the ion exchanger to service, the drain valve is closed, the outlet valve is opened, and the ion exchanger is ready for service.

Single-bed demineralizers are usually regenerated "in place." The resins are not pumped out to another location for regeneration. The regeneration process is the same for cation beds and for anion beds; only the regenerating solution is different. It is important to realize that if the ion exchanger has been exposed to radioactive materials, the backwash, regeneration, and rinse solutions may be highly radioactive and must be treated as a radioactive waste.

Mixed-Bed Demineralizer

A mixed-bed demineralizer is a demineralizer in which the cation and anion resin beads are mixed together. In effect, it is equivalent to a number of two-step demineralizers in series. In a mixed-bed demineralizer, more impurities are replaced by hydrogen and hydroxyl ions, and the water that is produced is extremely pure. The conductivity of this water can often be less than 0.06 micromhos per centimeter.

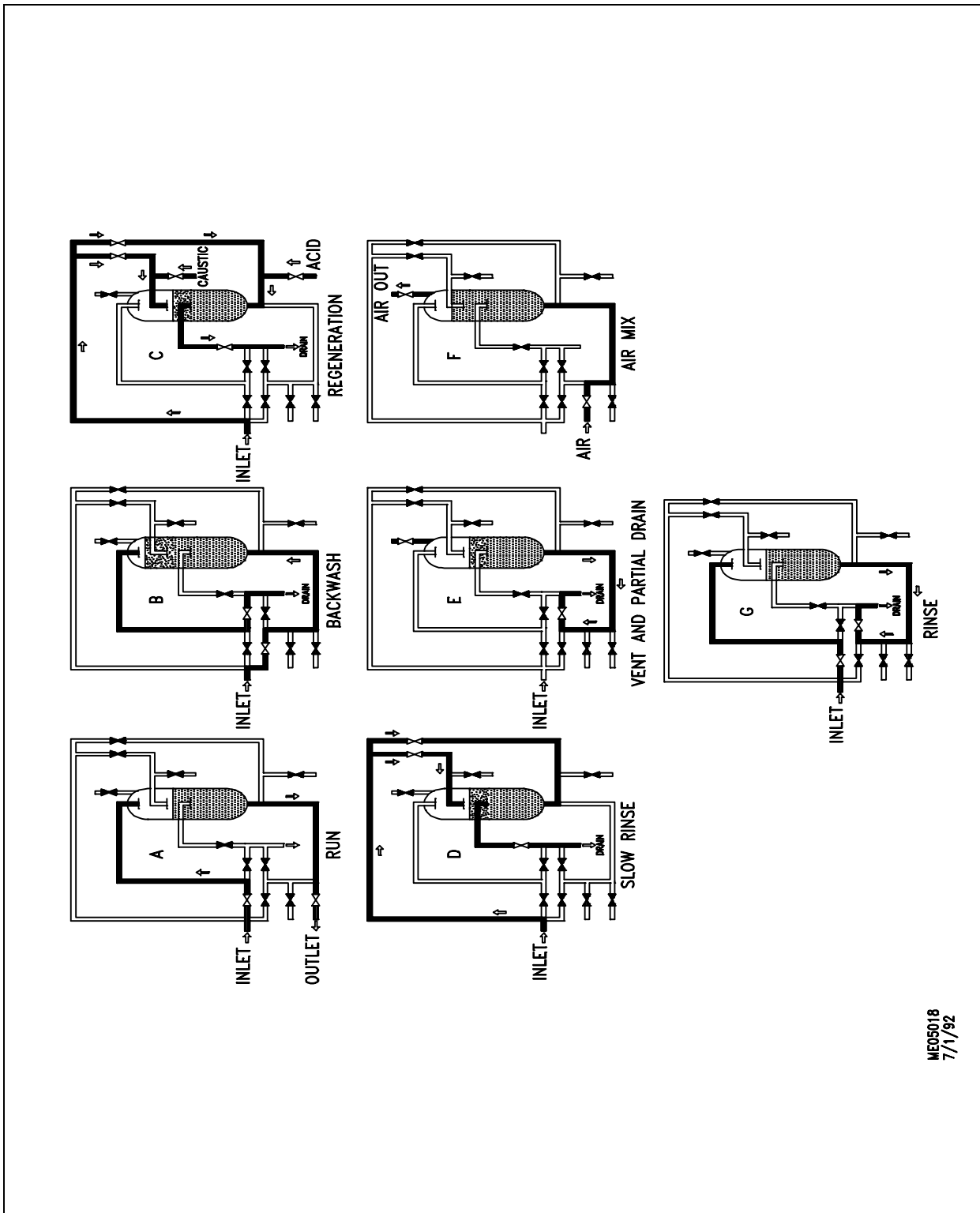
Mixed-Bed Regeneration

The mixed-bed demineralizer shown in Figure 14 is designed to be regenerated in place, but the process is more complicated than the regeneration of a single-bed ion exchanger. The steps in the regeneration are shown in Figure 14.

Figure 14a shows the mixed-bed ion exchanger in the operating, or on-line mode. Water enters through a distribution header at the top and exits through the line at the bottom of the vessel. Regeneration causes the effluent water to increase in electrical conductivity.

The first regeneration step is backwash, as shown in Figure 14b. As in a single-bed unit, backwash water enters the vessel at the bottom and exits through the top to a drain. In addition to washing out entrained particles, the backwash water in a mixed-bed unit must also separate the resins into cation and anion beds. The anion resin has a lower specific gravity than the cation resin; therefore, as the water flows through the bed, the lighter anion resin beads float upward to the top. Thus, the mixed-bed becomes a split bed. The separation line between the anion bed at the top and the cation bed at the bottom is called the resin interface. Some resins can be separated only when they are in the depleted state; other resins separate in either the depleted form or the regenerated form.

The actual regeneration step is shown in Figure 14c. Dilution water is mixed with caustic solution and introduced at the top of the vessel, just above the anion bed. At the same time, dilution water is mixed with acid and introduced at the bottom of the vessel, below the cation bed. The flow rate of the caustic solution down to the resin interface is the same as the flow rate of the acid solution up to the resin interface. Both solutions are removed at the interface and dumped to a drain.



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Figure 14 Regeneration of a Mixed-Bed Demineralizer

During the regeneration step, it is important to maintain the cation and anion resins at their proper volume. If this is not done, the resin interface will not occur at the proper place in the vessel, and some resin will be exposed to the wrong regenerating solution. It is also important to realize that if the ion exchanger has been involved with radioactive materials, both the backwash and the regenerating solutions may be highly radioactive and must be treated as liquid radioactive waste.

The next step is the slow rinse step, shown in Figure 14d, in which the flow of dilution water is continued, but the caustic and acid supplies are cut off. During this two-direction rinse, the last of the regenerating solutions are flushed out of the two beds and into the interface drain. Rinsing from two directions at equal flow rates keeps the caustic solution from flowing down into the cation resin and depleting it.

In the vent and partial drain step, illustrated in Figure 14e, the drain valve is opened, and some of the water is drained out of the vessel so that there will be space for the air that is needed to re-mix the resins. In the air mix step, (Figure 14f) air is usually supplied by a blower, which forces air in through the line entering the bottom of the ion exchanger. The air mixes the resin beads and then leaves through the vent in the top of the vessel. When the resin is mixed, it is dropped into position by slowly draining the water out of the interface drain while the air mix continues.

In the final rinse step, shown in Figure 14g, the air is turned off and the vessel is refilled with water that is pumped in through the top. The resin is rinsed by running water through the vessel from top to bottom and out the drain, until a low conductivity reading indicates that the ion exchanger is ready to return to service.

External Regeneration

Some mixed-bed demineralizers are designed to be regenerated externally, with the resins being removed from the vessel, regenerated, and then replaced. With this type of demineralizer, the first step is to sluice the mixed bed with water (sometimes assisted by air pressure) to a cation tank in a regeneration facility. The resins are backwashed in this tank to remove suspended solids and to separate the resins. The anion resins are then sluiced to an anion tank. The two batches of separated resins are regenerated by the same techniques used for single-bed ion exchangers. They are then sluiced into a holding tank where air is used to remix them. The mixed, regenerated, resins are then sluiced back to the demineralizer.

External regeneration is typically used for groups of condensate demineralizers. Having one central regeneration facility reduces the complexity and cost of installing several demineralizers. External regeneration also allows keeping a spare bed of resins in a holding tank. Then, when a demineralizer needs to be regenerated, it is out of service only for the time required to sluice out the depleted bed and sluice a fresh bed in from the holding tank. A central regeneration facility may also include an ultrasonic cleaner that can remove the tightly adherent coating of dirt or iron oxide that often forms on resin beads. This ultrasonic cleaning reduces the need for chemical regeneration.

Summary

The important information in this chapter is summarized below.

Demineralizers Summary

- Demineralization of water is one of the most practical and common methods used to remove dissolved contaminants. Dissolved impurities in power plant fluid systems can generate corrosion problems and decrease efficiency due to fouled heat transfer surfaces. Demineralizers (also called ion-exchangers) are used to hold ion exchange resins and transport water through them. Ion exchangers are generally classified into two groups: single-bed ion exchangers and mixed-bed ion exchangers.
- A demineralizer is basically a cylindrical tank with connections at the top for water inlet and resin addition, and connections at the bottom for the water outlet. The resin can usually be changed out through a connection at the bottom of the tank. The resin beads are kept in the demineralizer by upper and lower retention elements, which are strainers with a mesh size smaller than the resin beads.
- The water to be purified enters the top at a set flow rate, flows down through the resin beads where the flow path causes a physical filter effect as well as a chemical ion exchange. The chemistry of the resin exchange is explained in detail in the Chemistry Fundamentals Handbook.
- There are two types of demineralizers, single-bed and mixed-bed. Single-bed demineralizers have resin of either cation or anion exchange sites. Mixed-bed demineralizers contain both anion and cation resin.
- All demineralizers will eventually be exhausted from use. To regenerate the resin and increase the demineralizer's efficiency, the demineralizers are regenerated. The regeneration process is slightly different for a mixed-bed demineralizer compared to the single-bed demineralizer. Both methods were explained in this chapter.

PRESSURIZERS

Pressurizers are used for reactor system pressure control. The pressurizer is the component that allows a water system, such as the reactor coolant system in a PWR facility, to maintain high temperatures without boiling. The function of pressurizers is discussed in this chapter.

EO 1.12 STATE the four purposes of a pressurizer.

EO 1.13 DEFINE the following terms attributable to a dynamic pressurizer system:

- | | |
|------------------------|------------------------|
| a. Spray nozzle | c. Outsurge |
| b. Insurge | d. Surge volume |

Introduction

There are two types of pressurizers: static and dynamic. A static pressurizer is a partially filled tank with a required amount of gas pressure trapped in the void area. A dynamic pressurizer is a tank in which its saturated environment is controlled through use of heaters (to control temperature) and sprays (to control pressure).

This chapter focuses on the dynamic pressurizer. A dynamic pressurizer utilizes a controlled pressure containment to keep high temperature fluids from boiling, even when the system undergoes abnormal fluctuations.

Before discussing the purpose, construction, and operation of a pressurizer, some preliminary information about fluids will prove helpful.

The evaporation process is one in which a liquid is converted into a vapor at temperatures below the boiling point. All the molecules in the liquid are continuously in motion. The molecules that move most quickly possess the greatest amount of energy. This energy occasionally escapes from the surface of the liquid and moves into the atmosphere. When molecules move into the atmosphere, the molecules are in the gaseous, or vapor, state.

Liquids at a high temperature have more molecules escaping to the vapor state, because the molecules can escape only at higher speeds. If the liquid is in a closed container, the space above the liquid becomes saturated with vapor molecules, although some of the molecules return to the liquid state as they slow down. The return of a vapor to a liquid state is called condensation. When the amount of molecules that condense is equal to the amount of molecules that evaporate, there is a dynamic equilibrium between the liquid and the vapor.

Pressure exerted on the surface of a liquid by a vapor is called vapor pressure. Vapor pressure increases with the temperature of the liquid until it reaches saturation pressure, at which time the liquid boils. When a liquid evaporates, it loses its most energetic molecules, and the average energy per molecule in the system is lowered. This causes a reduction in the temperature of the liquid.

Boiling is the activity observed in a liquid when it changes from the liquid phase to the vapor phase through the addition of heat. The term saturated liquid is used for a liquid that exists at its boiling point. Water at 212°F and standard atmospheric pressure is an example of a saturated liquid.

Saturated steam is steam at the same temperature and pressure as the water from which it was formed. It is water, in the form of a saturated liquid, to which the latent heat of vaporization has been added. When heat is added to a saturated steam that is not in contact with liquid, its temperature is increased and the steam is superheated. The temperature of superheated steam, expressed as degrees above saturation, is called degrees of superheat.

General Description

The pressurizer provides a point in the reactor system where liquid and vapor can be maintained in equilibrium under saturated conditions, for control purposes. Although designs differ from facility to facility, a typical pressurizer is designed for a maximum of about 2500 psi and 680°F.

Dynamic Pressurizers

A dynamic pressurizer serves to:

- maintain a system's pressure above its saturation point,
- provide a means of controlling system fluid expansion and contraction,
- provide a means of controlling a system's pressure, and
- provide a means of removing dissolved gasses from the system by venting the vapor space of the pressurizer.

Construction

A dynamic pressurizer is constructed from a tank equipped with a heat source such as electric heaters at its base, a source of cool water, and a spray nozzle. A *spray nozzle* is a device located in the top of the pressurizer that is used to atomize the incoming water.

A dynamic pressurizer must be connected in the system to allow a differential pressure to exist across it. The bottom connection, also called the surge line, is the lower of the two pressure lines. The top connection, referred to as the spray line, is the higher pressure line. Differential pressure is obtained by connecting the pressurizer to the suction and discharge sides of the pump servicing the particular system. Specifically, the surge (bottom connection) is connected to the pump's suction side; the spray line (top connection) is connected to the pump's discharge side. A basic pressurizer is illustrated in Figure 15.

The hemispherical top and bottom heads are usually constructed of carbon steel, with austenitic stainless steel cladding on all surfaces exposed to the reactor system water.

The pressurizer can be activated in two ways. Partially filling the pressurizer with system water is the first. After the water reaches a predetermined level, the heaters are engaged to increase water temperature. When the water reaches saturation temperature, it begins to boil. Boiling water fills the void above the water level, creating a saturated environment of water and steam. The other method involves filling the pressurizer completely, heating the water to the desired temperature, then partially draining the water and steam mixture to create a steam void at the top of the vessel.

Water temperature determines the amount of pressure developed in the steam space, and the greater the amount of time the heaters are engaged, the hotter the environment becomes. The hotter the environment, the greater the amount of pressure.

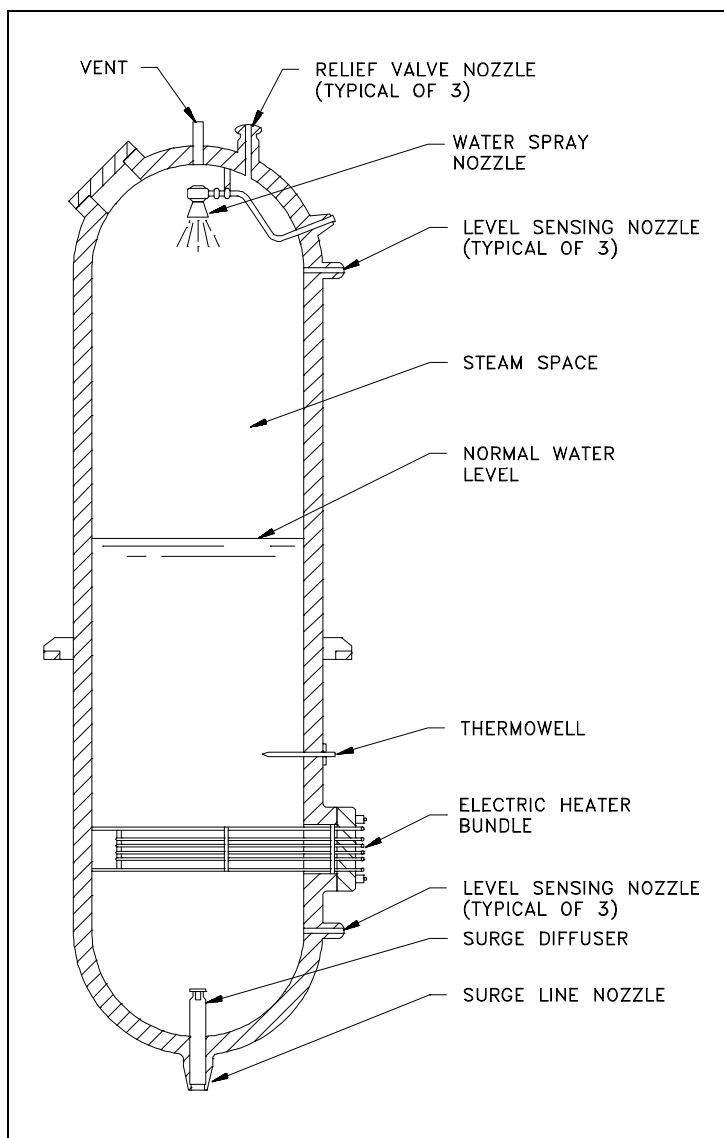


Figure 15 Basic Pressurizer

Installing a control valve in the spray line makes it possible to admit cooler water from the top of the pressurizer through the spray nozzle. Adding cooler water condenses the steam bubble, lowers the existing water temperature, and reduces the amount of system pressure.

Operation

The level of water within a pressurizer is directly dependant upon the temperature, and thus the density, of the water in the system to which the pressurizer is connected. An increase in system temperature causes the density of the water to decrease. This decreased density causes the water to expand, causing the level of water to increase in the vessel. The increased level of water in a pressurizer is referred to as an *insurge*. An insurge compresses the vapor space, which in turn causes the system pressure to rise. This results in slightly superheated steam in contact with the subcooled pressurizer liquid. The superheated steam transfers heat to the liquid and to the pressurizer walls. This re-establishes and maintains the saturated condition.

A decrease in system temperature causes the density to increase which causes the system water volume to contract. The contraction (drop) in pressurizer water level and increase in vapor space is referred to as an *outsurge*. The increase in vapor space causes the pressure to drop, flashing the heated water volume and creating more steam. The increased amount of steam re-establishes the saturated state. Flashing continues until the decrease in water level ceases and saturated conditions are restored at a somewhat lower pressure.

In each case, the final conditions place the pressurizer level at a new value. The system pressure remains at approximately its previous value, with relatively small pressure variations during the level change, provided that the level changes are not too extreme.

In actual application, relying on saturation to handle all variations in pressure is not practical. In conditions where the system water is surging into the pressurizer faster than the pressurizer can accommodate for example, additional control is obtained by activating the spray. This spray causes the steam to condense more rapidly, thereby controlling the magnitude of the pressure rise.

When a large outsurge occurs, the level can drop rapidly and the water cannot flash to steam fast enough. This results in a pressure drop. The installed heaters add energy to the water and cause it to flash to steam faster, thereby reducing the pressure drop. The heaters can also be left on to re-establish the original saturation temperature and pressure. In certain designs, pressurizer heaters are energized continuously to make up for heat losses to the environment.

The pressurizer's heater and spray capabilities are designed to compensate for the expected surge volume. The *surge volume* is the volume that accommodates the expansion and contraction of the system, and is designed to be typical of normal pressurizer performance. Plant transients may result in larger than normal insurges and outsurges. When the surge volume is exceeded, the pressurizer may fail to maintain pressure within normal operating pressures.

Pressurizer operation, including spray and heater operation, is usually automatically controlled. Monitoring is required in the event the control features fail, because the effect on the system could be disastrous without operator action.

Summary

The important information in this chapter is summarized below.

Pressurizer Summary

- Two types of pressurizers -- static and dynamic
- Purposes of a pressurizer:
 - Maintains system pressure above saturation
 - Provides a surge volume for system expansion and contraction
 - Provides a means of controlling system pressure
 - Provides a means of removing dissolved gases
- A spray nozzle is a device located in the top of the pressurizer, used to atomize incoming water to increase the effects of spraying water into the top of the pressurizer to reduce pressure by condensing steam.
- Insurge is the volume absorbed within the pressurizer during a level increase to compensate for a rise in the system's temperature.
- Outsurge is the volume released from the pressurizer during a level decrease to compensate for a reduction in the system's temperature.
- The surge volume is the volume of water that accommodates the expansion and contraction of the system, and is designed to be typical of normal pressurizer performance.

STEAM TRAPS

Steam traps are installed in steam lines to drain condensate from the lines without allowing the escape of steam. There are many designs of steam traps for high and low pressure use.

EO 1.14 STATE the purpose and general operation of a steam trap.

EO 1.15 IDENTIFY the following types of steam traps:

- | | |
|---------------------------------|------------------------------|
| a. Ball float steam trap | c. Bucket steam trap |
| b. Bellow steam trap | d. Impulse steam trap |

General Operation

In general, a steam trap consists of a valve and a device or arrangement that causes the valve to open and close as necessary to drain the condensate from piping without allowing the escape of steam. Steam traps are installed at low points in the system or machinery to be drained. Some types of steam traps that are used in DOE facilities are described in this chapter.

Ball Float Steam Trap

A ball float steam trap is illustrated in Figure 16. The valve of this trap is connected to the float in such a way that the valve opens when the float rises. When the trap is in operation, the steam and any water that may be mixed with it flows into the float chamber. The water, being heavier than the steam, falls to the bottom of the trap, causing the water level to rise. As the water level rises, it lifts the float; thus lifting the valve plug and opening the valve. The condensate drains out and the float moves down to a lower position, closing the valve before the condensate level gets low enough to allow steam to escape. The condensate that passes out of the trap is returned to the feed system.

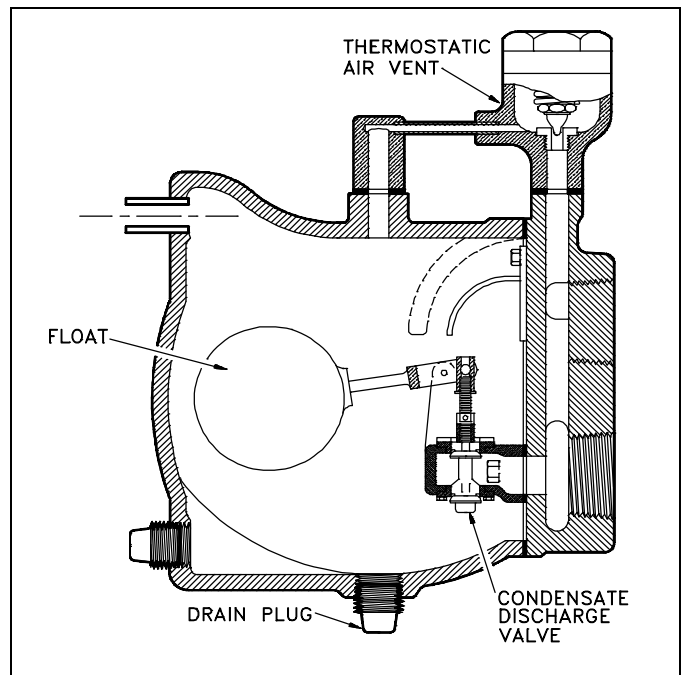


Figure 16 Ball Float Steam Trap

Bucket Steam Trap

A bucket steam trap is illustrated in Figure 17. As condensate enters the trap body, the bucket floats. The valve is connected to the bucket in such a way that the valve closes as the bucket rises. As condensate continues to flow into the trap body, the valve remains closed until the bucket is full. When the bucket is full, it sinks and thus opens the valve. The valve remains open until enough condensate has passed out to allow the bucket to float, and closing the valve.

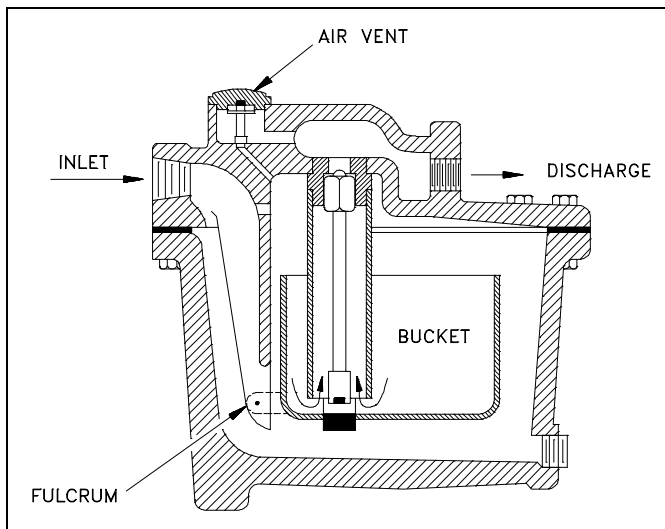


Figure 17 Bucket Steam Trap

Thermostatic Steam Traps

There are several kinds of thermostatic steam traps in use. In general, these traps are more compact and have fewer moving parts than most mechanical steam traps.

Bellows-Type Steam Trap

A bellows-type steam trap is illustrated in Figure 18. The operation of this trap is controlled by the expansion of the vapor of a volatile liquid, which is enclosed in a bellows-type element. Steam enters the trap body and heats the volatile liquid in the sealed bellows, causing expansion of the bellows.

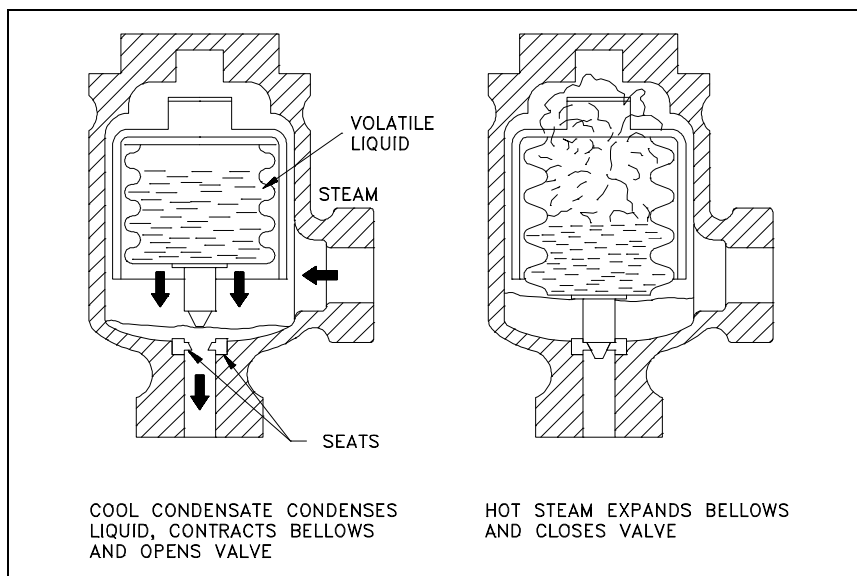


Figure 18 Bellows-Type Steam Trap

The valve is attached to the bellows in such a way that the valve closes when the bellows expands. The valve remains closed, trapping steam in the valve body. As the steam cools and condenses, the bellows cools and contracts, thereby opening the valve and allowing the condensate to drain.

Impulse Steam Trap

Impulse steam traps, illustrated in Figure 19, pass steam and condensate through a strainer before entering the trap. A circular baffle keeps the entering steam and condensate from impinging on the cylinder or on the disk. The impulse type of steam trap is dependent on the principle that hot water under pressure tends to flash into steam when the pressure is reduced.

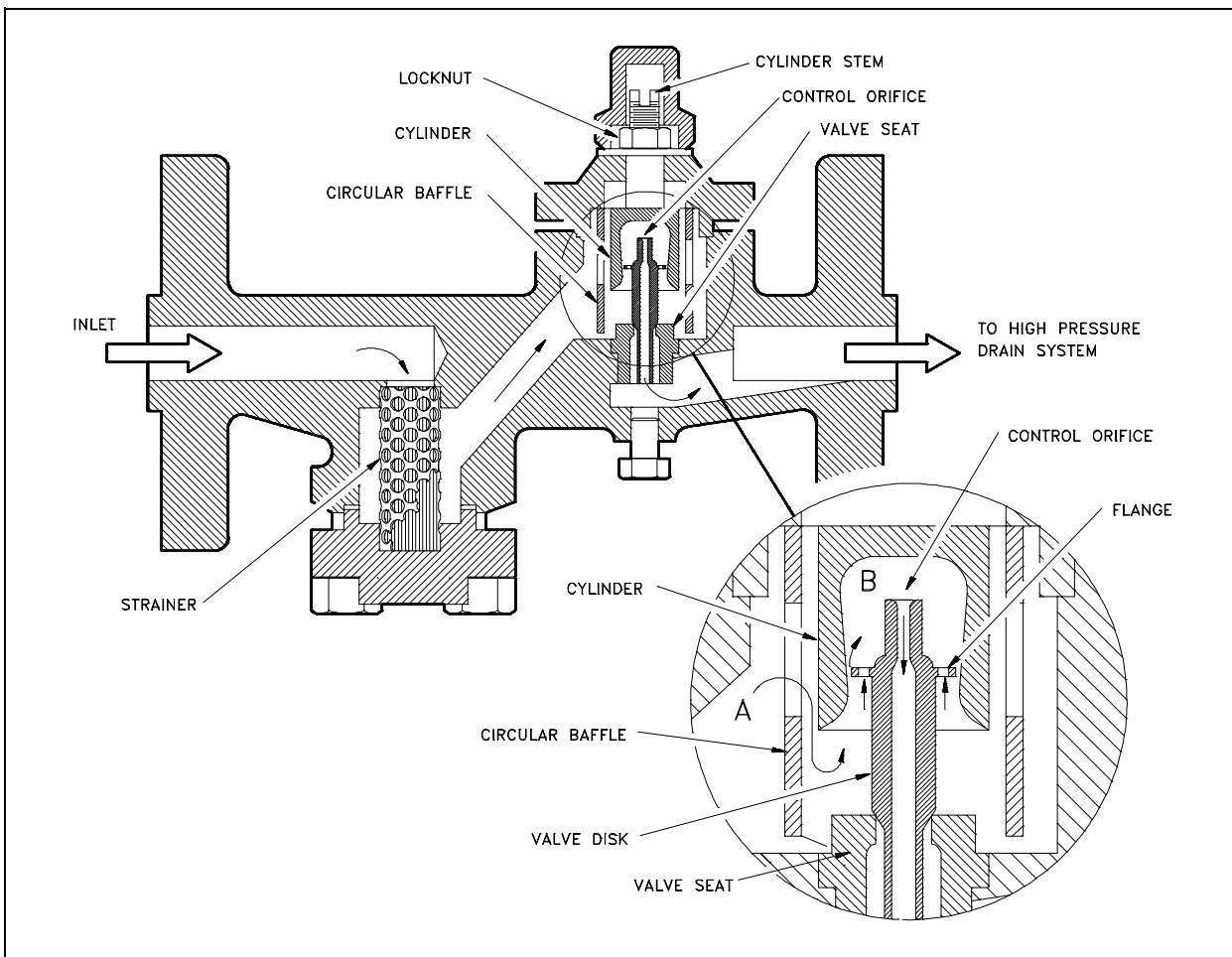


Figure 19 Impulse Steam Trap

The only moving part in the steam trap is the disk. A flange near the top of the disk acts as a piston. As demonstrated in Figure 19, the working surface above the flange is larger than the working surface below the flange.

A control orifice runs through the disk from top to bottom, which is considerably smaller at the top than at the bottom. The bottom part of the disk extends through and beyond the orifice in the seat. The upper part of the disk (including the flange) is inside a cylinder. The cylinder tapers inward, so the amount of clearance between the flange and the cylinder varies according to the position of the valve. When the valve is open, the clearance is greater than when the valve is closed.

When the trap is first placed in service, pressure from the inlet (chamber A) acts against the underside of the flange and lifts the disk off the valve seat. Condensate is thus allowed to pass out through the orifice in the seat; and, at the same time, a small amount of condensate (called control flow) flows up past the flange and into chamber B. The control flow discharges through the control orifice, into the outlet side of the trap, and the pressure in chamber B remains lower than the pressure in chamber A.

As the line warms up, the temperature of the condensate flowing through the trap increases. The reverse taper of the cylinder varies the amount of flow around the flange until a balanced position is reached in which the total force exerted above the flange is equal to the total force exerted below the flange. It is important to note that there is still a pressure difference between chamber A and chamber B. The force is equalized because the effective area above the flange is larger than the effective area below the flange. The difference in working area is such that the valve maintains at an open, balanced, position when the pressure in chamber B is approximately 86% of the pressure in chamber A.

As the temperature of the condensate approaches its boiling point, some of the control flow going to chamber B flashes into steam as it enters the low pressure area. Because the steam has a much greater volume than the water from which it is generated, pressure builds up in the space above the flange (chamber B). When the pressure in this space is 86% of the inlet pressure (chamber A), the force exerted on the top of the flange pushes the entire disk downward and closes the valve. With the valve closed, the only flow through the trap is past the flange and through the control orifice. When the temperature of the condensate entering the trap drops slightly, condensate enters chamber B without flashing into steam. Pressure in chamber B is thus reduced to the point where the valve opens and allows condensate to flow through the orifice in the valve seat. The cycle is repeated continuously.

With a normal condensate load, the valve opens and closes at frequent intervals, discharging a small amount of condensate at each opening. With a heavy condensate load, the valve remains open and allows a continuous discharge of condensate.

Orifice-Type Steam Trap

DOE facilities may use continuous-flow steam traps of the orifice type in some constant service steam systems, oil-heating steam systems, ventilation preheaters, and other systems or services in which condensate forms at a fairly constant rate. Orifice-type steam traps are not suitable for services in which the condensate formation is not continuous.

Although there are several variations of the orifice-type steam trap, each has one thing in common; it contains no moving parts. One or more restricted passageways or orifices allow condensate to trickle through, but do not allow steam to flow through. Some orifice-type steam traps have baffles in addition to orifices.

Summary

The following important information in this chapter is summarized below.

Steam Traps Summary

- A steam trap consists of a valve and a device or arrangement that causes the valve to open and close as necessary to drain the condensate from the lines without allowing the escape of steam. Steam traps are installed at low points in the system or machinery to be drained.
- The type of steam trap used depends primarily on its application. Types include ball float, bucket traps, thermostatic traps, bellows-type traps, impulse traps, and orifice-type traps.
- Impulse steam traps pass steam and condensate through a strainer before entering the trap. A circular baffle keeps the entering steam and condensate from impinging on the cylinder or on the disk. The impulse type of steam trap is dependent on the fact that hot water under pressure tends to flash into steam when the pressure is reduced.

FILTERS AND STRAINERS

When it is necessary to remove suspended solids from a liquid, the usual method is to filter or strain the liquid. The two methods differ only in the size of the mesh being used. Filtering removes the very small solids, and straining removes the larger solids. Because filtering and straining are for all practical purposes the same, this chapter will differentiate the two terms on the basis of application of the filter or strainer.

EO 1.16 DESCRIBE each of the following types of strainers and filters, including an example of typical use.

- | | |
|--|---|
| <p>a. Cartridge filters</p> <p>b. Precoated filters</p> <p>c. Deep-bed filters</p> | <p>d. Bucket strainer</p> <p>e. Duplex strainer</p> |
|--|---|

EO 1.17 EXPLAIN the application and operation of a strainer or filter backwash.

Introduction

Filtration is a process used to remove suspended solids from a solution. Other processes such as demineralization remove ions or dissolved ions. Different filters and strainers are used for different applications. In general, the filter passage must be small enough to catch the suspended solids but large enough that the system can operate at normal system pressures and flows. Filters and strainers are used throughout most DOE facilities. They are used in hydraulic systems, oil systems, cooling systems, liquid waste disposal, water purification, and reactor coolant systems.

Cartridge Filters

Figure 20 illustrates a typical multi-cartridge filter. The cartridges are cylinders and usually consist of a fiber yarn wound around a perforated metal core. The liquid being filtered is forced through the yarn, which is approximately 1/2 inch thick, and then through the perforations in the metal core to the filter outlet, which can be at either end. A cartridge filter may include several cartridges, the exact number depending on the liquid flow rate that must be handled.

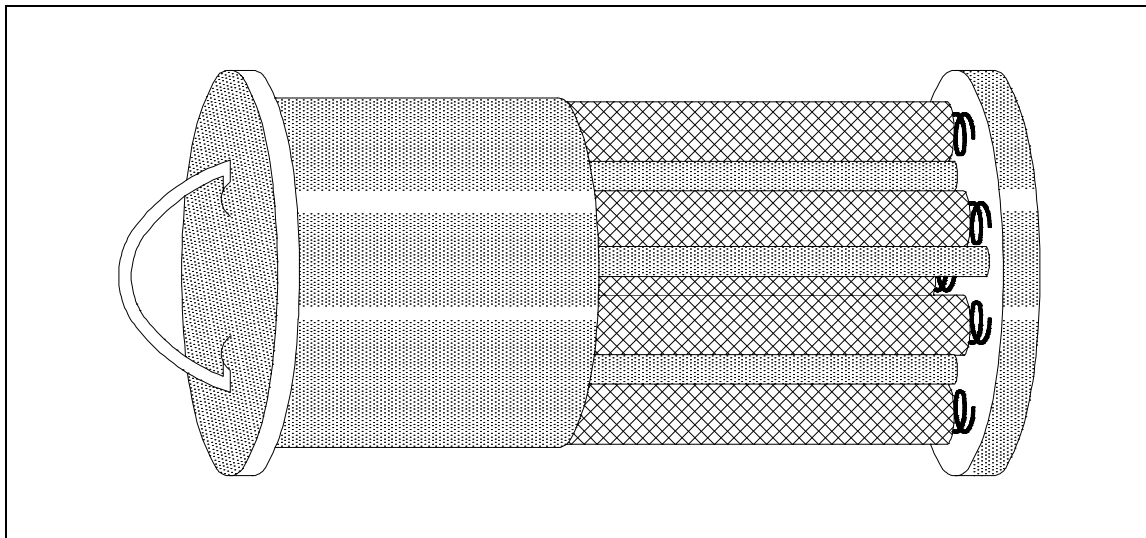


Figure 20 Typical Multi-Cartridge Filter

In the filter assembly illustrated in Figure 21, the cartridges are held between plates so that the water must pass through the layer of yarn to reach the filter outlet. The type of yarn that is used depends on the application. Some of the fibers commonly used include resin-impregnated wool or cellulose, cotton-viscose, polypropylene, nylon, and glass. In some applications that involve high temperatures or pressures, porous metal cartridges are used. These cartridges are usually made of 316 stainless steel, but inconel, monel, and nickel are also used.

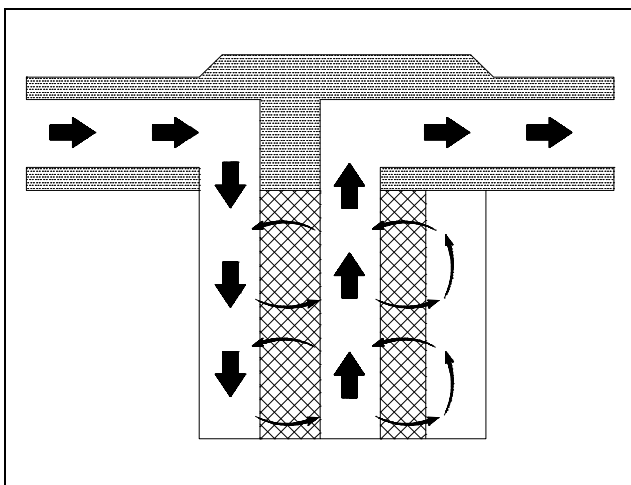


Figure 21 Cartridge Filter

Depending on the fiber or metal that is used, cartridges are available that will filter out all particle matter down to a specified size. For example, a certain cartridge might be designed to remove all particles larger than 10 microns, one micron, or even 0.1 micron. (A micron is 10^{-3} millimeters.)

Cartridge filters have the advantage of being relatively inexpensive to install and operate. Instruments measure the differential pressure across these filters to let the operator know when a filter is plugged and must be replaced. When the cartridges are removed from radioactive systems, the radiation levels can be very high. For this reason, the

cartridges may be withdrawn into a shielded cask for moving to a storage area or a solid waste processing area. When the porous metal cartridges become plugged, they can be cleaned ultrasonically and reused. When this is done, the cleaning solution becomes contaminated and must be processed as liquid radioactive waste.

Another type of cartridge filter is the wafer, or disk filter. In this filter, disks are stacked to form a cartridge and placed down over a central perforated pipe. Each disk is typically 1/8 inch to 1/4 inch thick and made of cellulose or asbestos fibers.

Liquid that enters the disk filter moves up around the outside of the stack of disks, is forced between the disks, travels through the perforations in the central pipe, and then leaves the filter. The filtering action takes place as the liquid is forced between the disks.

As with the smaller cartridges, if a disk filter is used to filter radioactive water, it may be very radioactive when it is removed, and must be handled very carefully. One way to remove a disk filter is by means of a crane, which lifts the filter out of its housing and moves it to a shielded container. The disposal problem is one of the major disadvantages of cartridge and disk-cartridge filters.

Precoat Filters

A precoat filter eliminates the problem of physically handling radioactive materials, because the filter material (called the medium) can be installed and removed remotely. Inside the filter housing is a bundle of septums (vertical tubes, on which the filter medium is deposited). The septums in some filters are approximately 1 inch in diameter and 3 feet long and are usually made of perforated or porous metal (normally stainless steel). There may be several hundred of these septums in a filter. Septums in other filters are approximately 3 inches in diameter and 3 feet long and are made of porous stone or porous ceramic material. There are usually less than 100 of these larger septums in a filter.

The filtering medium fibers may be finely divided diatomite, perlite, asbestos, or cellulose. Diatomite, the least expensive medium, is used to filter liquid waste that will be discharged from the plant. Cellulose is generally used for processing water that will be returned to a reactor, because diatomite can allow silica leaching.

When a precoat filter is in use, water that enters the filter vessel passes through the filter medium that is deposited on the septums and then leaves through the outlet. Before the filter can be placed into operation, however, the filter medium must be installed; that is, the filter must be precoated.

The first step in precoating the filter is to close the inlet and outlet valves to the filter. The filter medium used is mixed with demineralized water in an external mixing tank to form a slurry, which is pumped through the filter. Some of the filter medium deposits on the septums and is held there by the pressure of water on the outside of the septums. At the beginning of the precoating process, some of the fibers of the filter medium pass through the septums, either because they are smaller than the openings or because they pass through lengthwise. Thus, there is still some filter medium in the water as it leaves the filter, so the slurry is recirculated again and again until the water is clear. Clear water indicates that all of the filter medium is deposited on the septums, and the filter is precoated.

One characteristic of the precoating process is that a very even layer of filter medium (approximately 1/8 inch thick) is deposited on the septums. This occurs because the circulating slurry follows the path of least resistance. When the coating at one point reaches a certain thickness, the slurry takes the fibers to another point, and this process continues until precoating is complete.

Because water pressure holds the filter in place, flow must be maintained through the recirculating loop to keep the medium from falling off. This is called a holding flow. As the inlet and outlet valves are opened for normal usage, called service flow, the holding flow is gradually cut off.

Backwashing Precoat Filters

After a filter has been precoated, it is put into service and kept on line until the pressure differential indicates that the filter medium is becoming plugged. When this occurs, the old filter medium is removed and the filter is precoated again. Filters are usually installed in pairs, so that one filter can remain in service while the other is undergoing the filter backwashing and precoating process.

Since water pressure helps to hold the filter medium against the septums, some of the old filter medium will fall off as soon as this pressure is removed. Backwashing is used to remove the filter medium that does not fall off. Backwashing is usually done in one of two ways. With some filters, demineralized water is pumped backwards through the center of the septums, and the filter medium coating is knocked off by the water as it comes out through the septums.

Most filters use a multi-step backwashing procedure. First, the inlet valve and the outlet valve are closed, and the drain valve and the top vent are opened to allow the water to drain. Then the drain valve and the vent are closed, and the inlet water valve is opened to raise the water level. The filter is equipped with a special high-domed top to trap and compress air. When the water inlet valve is closed and the drain valve is opened quickly, the compressed air forces water down through the center of the septums. This water knocks the filter medium off of the septums.

With both types of backwashing, the filter medium coating that is removed is sluiced out through a drain line to a filter sludge tank, where it is stored for further processing. The filter is then precoated again and put back into service.

With precoat filters, the type and quantity of filter medium is critical. If too little material or too coarse a material is used, some of the finely divided crud in the water may get into the openings of the septums. When the filter is backwashed, this crud is usually not removed. It continues to build up during subsequent use of the filter until the septums become so plugged that they have to be replaced.

If too much filter medium is used, the layer that builds up on the septums will bridge the area between the septums. When the filter is backwashed, these bridges are usually not removed. Therefore the bridging continues, and the filter runs become progressively shorter. Eventually, the filter must be opened and the filter medium must be removed manually.

Precoat filters are much more complicated than cartridge filters, and the equipment required is much more expensive to install and maintain. The major advantage of precoat filters is the remote operation, which eliminates the physical handling of highly radioactive filter cartridges.

Deep-Bed Filters

Deep-bed filters are usually found only in makeup water systems, where they are used to filter water after it has been treated in a clarifier. They are used to remove organic matter, chlorine, and very fine particulate matter.

A deep-bed filter is based on a support screen (decking), which is mounted a few inches above the bottom of the tank. The screen is perforated to allow water to flow through it. A coarse, aggregate layer of crushed rock or large lumps of charcoal is placed on top of the screen, and the deep bed itself (2 to 4 feet of granular anthracite or charcoal) is placed on top of the aggregate. The filter is sized so that there is 1 to 2 feet of "free board" above the deep bed.

When the filter is in service, raw water is pumped in through a pipe that feeds a distribution pipe above the deep bed. The water is filtered as it percolates down through the granules. (Charcoal granules will filter out organic matter, chlorine, and fine particulates, while anthracite granules remove only the particulates.) The water collects in the bottom of the tank, below the support screen, and leaves the filter through a pipe in the bottom of the filter vessel.

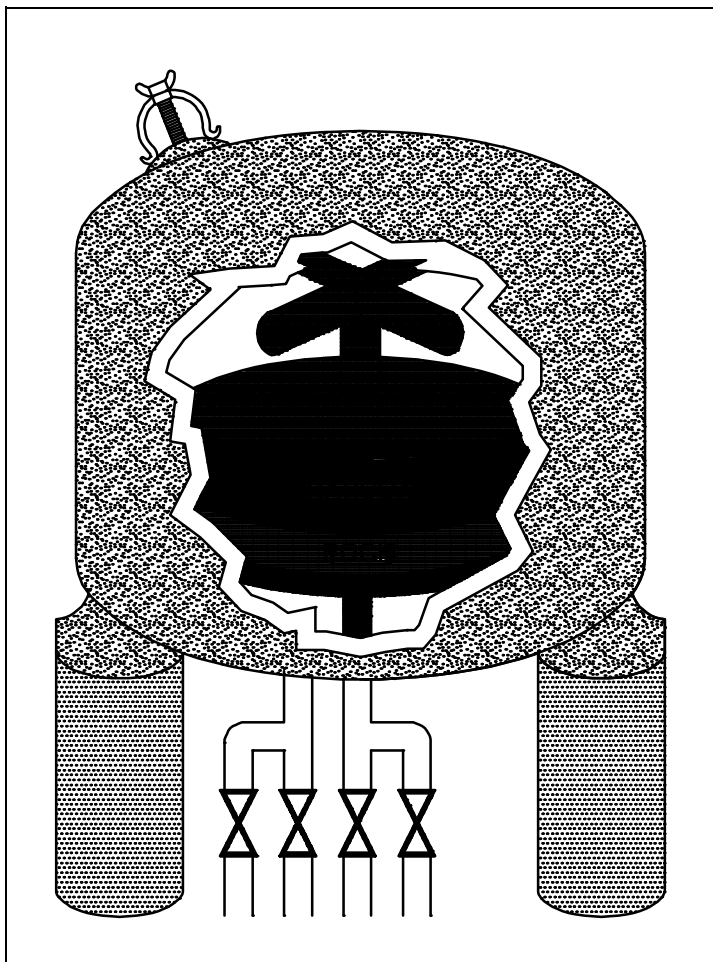


Figure 22 Deep-Bed Filter

Deep-bed filters, like precoat filters, are cleaned by backwashing. Water is pumped through the distribution piping near the top of the filter. The flow rate of the water is kept high enough to lift the granulated charcoal or anthracite up into the free space. The water washes away the deposits that have accumulated. When the backwash cycle is completed, the flow is stopped, and the granules settle back down into the filter bed. The filter can then be put back into service.

Metal-Edged Filters

Metal-edged filters are used in the lubrication (oil) systems of many auxiliary units. A metal-edged filter consists of a series of metal plates or disks. Turning a handle moves the plates or disks across each other in a manner that removes any particles that have collected on the metal surfaces. Some metal-edged type filters have magnets to aid in removing fine particles of magnetic materials.

Strainers

Strainers are fitted in many piping lines to prevent the passage of grit, scale, dirt, and other foreign matter, which could obstruct pump suction valves, throttle valves, or other machinery parts. One of the simplest and most common types of strainers found in piping systems is the Y-strainer, which is illustrated in Figure 23.

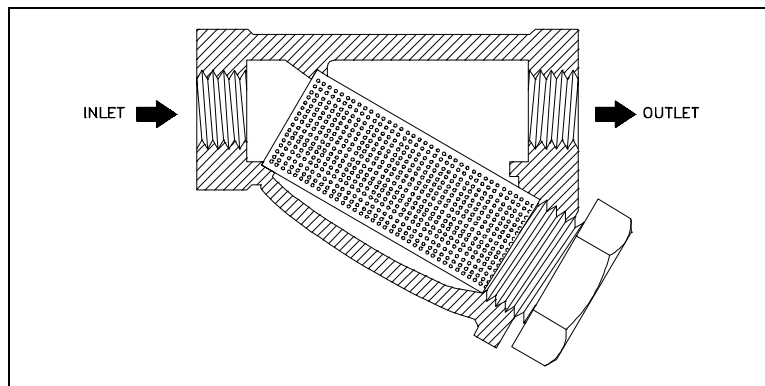


Figure 23 Y-strainer

Figure 24 illustrates three additional common types of strainers. Part A shows a typical sump pump suction bucket strainer located in the sump pump suction line between the suction manifold and the pump. Any debris that enters the piping is collected in the strainer basket. The basket can be removed for cleaning by loosening the strongback screws, removing the cover, and lifting the basket out by its handle.

Part B of Figure 24 shows a duplex oil strainer commonly used in fuel oil and lubricating oil lines, where it is essential to maintain an uninterrupted flow of oil. The flow may be diverted from one basket to the other, while one is being cleaned.

Part C of Figure 24 shows a manifold steam strainer. This type of strainer is desirable where space is limited, because it eliminates the use of separate strainers and their fittings. The cover is located so that the strainer basket can be removed for cleaning.

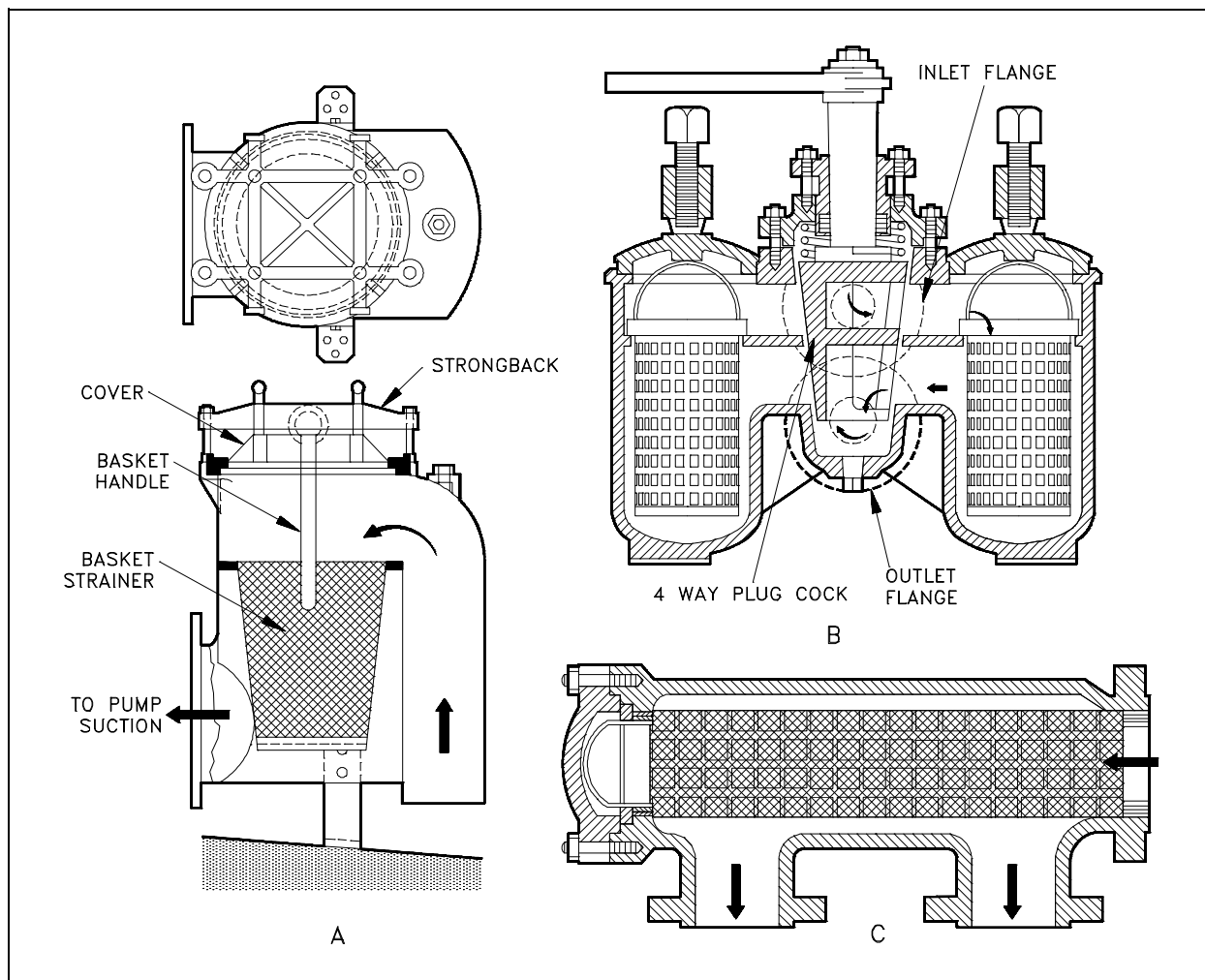


Figure 24 Common Strainers

Backwashing

If the filter or strainer cannot be easily removed for cleaning, the system design will usually include a flowpath for backwashing. The backwashing of precoated filters has already been explained because it is more complex than a typical backwash. The intent of a backwash is to flow liquid in the opposite direction of normal flow, creating a pressure that pushes the debris off the strainer or filter. The debris is flushed to a waste tank or drain.

Normally, to establish a backwash lineup, the flowpath upstream of the inlet to the strainer or filter is closed, the flow path downstream of the outlet is closed, and a drain flowpath is opened.

The flush source is then opened and the flow goes into the outlet of the strainer or filter, through the strainer or filter, and exits the inlet to the backwash drain or waste tank, carrying the debris with it.

Summary

The important information in this chapter is summarized below.

Filters and Strainers Summary

- A cartridge filter may be a single cartridge or multi-cartridge filter. The cartridges are cylinders that usually consist of a fiber yarn wound around a perforated metal core. The liquid being filtered is forced through the yarn and then through the perforations in the metal core to the filter outlet, which can be at either end. This type of filter is used to remove fine particles in any flow condition. Radioactive systems may use these because they are inexpensive and easy to replace.
- Precoat filters consists of a filter housing that contains a bundle of septums, (vertical tubes, on which the filter medium is deposited) usually made of perforated or porous metal (normally stainless steel), porous stone, or porous ceramic material. The filtering medium fibers may be finely divided diatomite, perlite, asbestos, or cellulose. Diatomite, the least expensive medium, is used to filter liquid waste that will be discharged from the plant. Cellulose is generally used for processing water that will be returned to the reactor, because diatomite can allow silica leaching.
- A deep-bed filter is based on a support screen (decking), which is mounted a few inches above the bottom of the tank. The screen is perforated to allow water to flow through it. A coarse, aggregate layer of crushed rock or large lumps of charcoal is placed on top of the screen, and the deep bed itself (2 to 4 feet of granular anthracite or charcoal) is placed on top of the aggregate. This type of filter is frequently used in raw water treatment.
- The bucket strainer is literally a bucket to catch debris. The bucket can be removed for cleaning by loosening the strongback screws, removing the cover, and lifting the bucket out by its handle. It is usually used in systems expected to have larger debris.

Filters and Strainers Summary (Cont.)

- A duplex strainer is a strainer consisting of two sides with a basket in each side. Only one side is placed in service at a time. These are commonly used in fuel oil and lubricating oil lines, where it is essential to maintain an uninterrupted flow of oil. The flow may be diverted from one basket to the other, while one is being cleaned.
- If the filter or strainer cannot be easily removed for cleaning, the system design will usually include a flowpath for backwashing. The intent of a backwash is to flow liquid in the opposite direction of normal flow, creating a pressure that pushes the debris off the strainer or filter. The debris is flushed to a waste tank or drain.

Normally, to establish a backwash lineup, the flowpath upstream of the inlet to the strainer or filter is closed, the flow path down stream of the outlet is closed, and a drain flowpath is opened. The flush source is then opened and the flow goes into the outlet of the strainer or filter, through the strainer or filter, and exits the inlet to the backwash drain or waste tank, carrying the debris with it.

end of text.

CONCLUDING MATERIAL

Review activities:

DOE - ANL-W, BNL, EG&G Idaho,
EG&G Mound, EG&G Rocky Flats,
LLNL, LANL, MMES, ORAU, REEC_o,
WHC, WINCO, WEMCO, and WSRC.

Preparing activity:

DOE - NE-73
Project Number 6910-0024