# PUMPS

Pumps provide the means for moving water through the system at usable working pressures. The operation and maintenance of these pumps are some of the most important duties for many water utility operators. There are two basic types of pumps used in water and wastewater systems. The most common type of pump is the centrifugal pump. The other type is the positive displacement pump.

All pumps are rated by the flow they produce and the pressure they must work against. Centrifugal pumps are used for high flow and low head pressure applications. Booster pumps or primary service pumps are required to move high volumes of water and usually operated at low head pressures (200-300 feet of head for water and as little as 50 feet of head for wastewater applications). Centrifugal pumps are ideally suited to these types of applications and are much more efficient than positive displacement pumps of comparable size.

Positive displacement pumps are used for low flow and high-pressure applications. High pressure water jet systems like those used for well screen or sewer line cleaning use positive displacement pumps since pressures in excess of 2000 psi are needed and the flows seldom exceed 100 gpm. Sludge pumps and chemical feed pumps are also likely to be positive displacement pumps. Piston pumps, diaphragm pumps, and progressive cavity screw pumps are the most common types of positive displacement pumps.

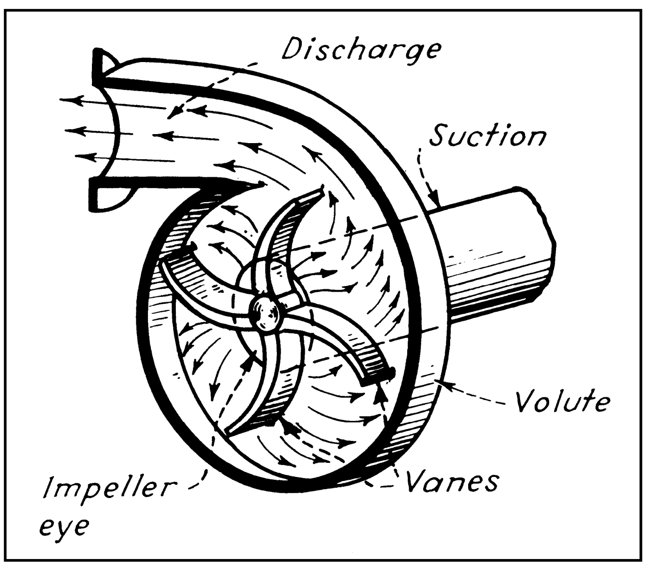
Another difference in centrifugal and positive displacement pumps has to do with how they react to changes in discharge pressure. When the pressure that a centrifugal pump has to work against changes, the flow from the pump changes. As the pressure increases, the flow from the pump will decrease, and when the pressure drops the flow will increase. Positive displacement pumps do not react this way. The flow does not change when the discharge pressure changes. This is the main reason that positive displacement pumps are used for chemical feeding and sludge pumping. The operator knows that every time the pump strokes, it is pumping the same amount of fluid. This is important if accurate records are to be kept of chemical dosages and pounds of solids that are moving through the system. The most common positive-displacement pump is the reciprocating pump. These pumps are also called piston or diaphragm pumps.

| TYPE OF PUMP | PRESSURE/FLOW RATING | CHARACTERISTICS |
|---|---|---|
| Centrifugal | Low Pressure/High Flow | Flow changes when pressure changes |
| Positive-Displacement | High Pressure/Low Flow | Flow doesn't change when pressure changes |

## CENTRIFUGAL PUMPS

A centrifugal pump moves water by the use of centrifugal force. Any time an object moves in a circular motion there is a force exerted against the object in the direction opposite the center of the circle. This would be easier to explain if we use an example consisting of a person with a bucket full of water. If the person swings the bucket in a circle fast enough, the water will stay in the bucket even when it is upside down. The force that holds the water in the bucket is called centrifugal force. If a hole is made in the bottom of the bucket, and it is swung in a circular motion, the centrifugal force will push the water out of the bucket through the hole. The same principle applies when water is moved through a centrifugal pump.

An impeller spins inside a centrifugal pump. It is the heart of the pump. Water enters at the center, known as the eye of the impeller. As the impeller rotates, the veins pick up the water and sling it out into the pump body under pressure. It is the pressure exerted by the vanes that moves the water out of the pump and into the system. The suction created as the water leaves the impeller draws more water into the impeller through the suction eye.

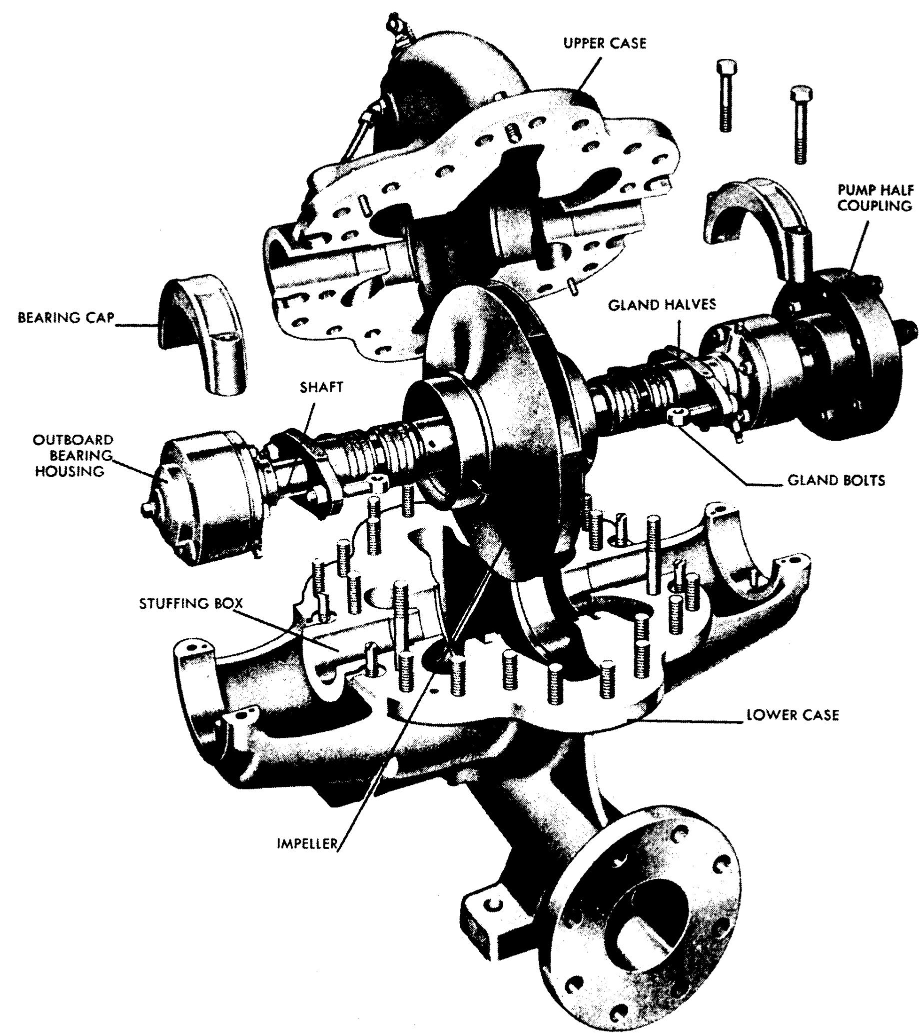



**IMPELLER ROTATION AND CENTRIFUGAL FORCE**

The number of vanes and the sweep of the veins determine the performance characteristics of the impeller. As vanes are added, the impeller will produce higher discharge pressures and lower flows. The same situation applies to increasing the length or sweep of the vanes. Reducing the number of vanes or the sweep of the vanes will increase the flow and reduce the pressure.

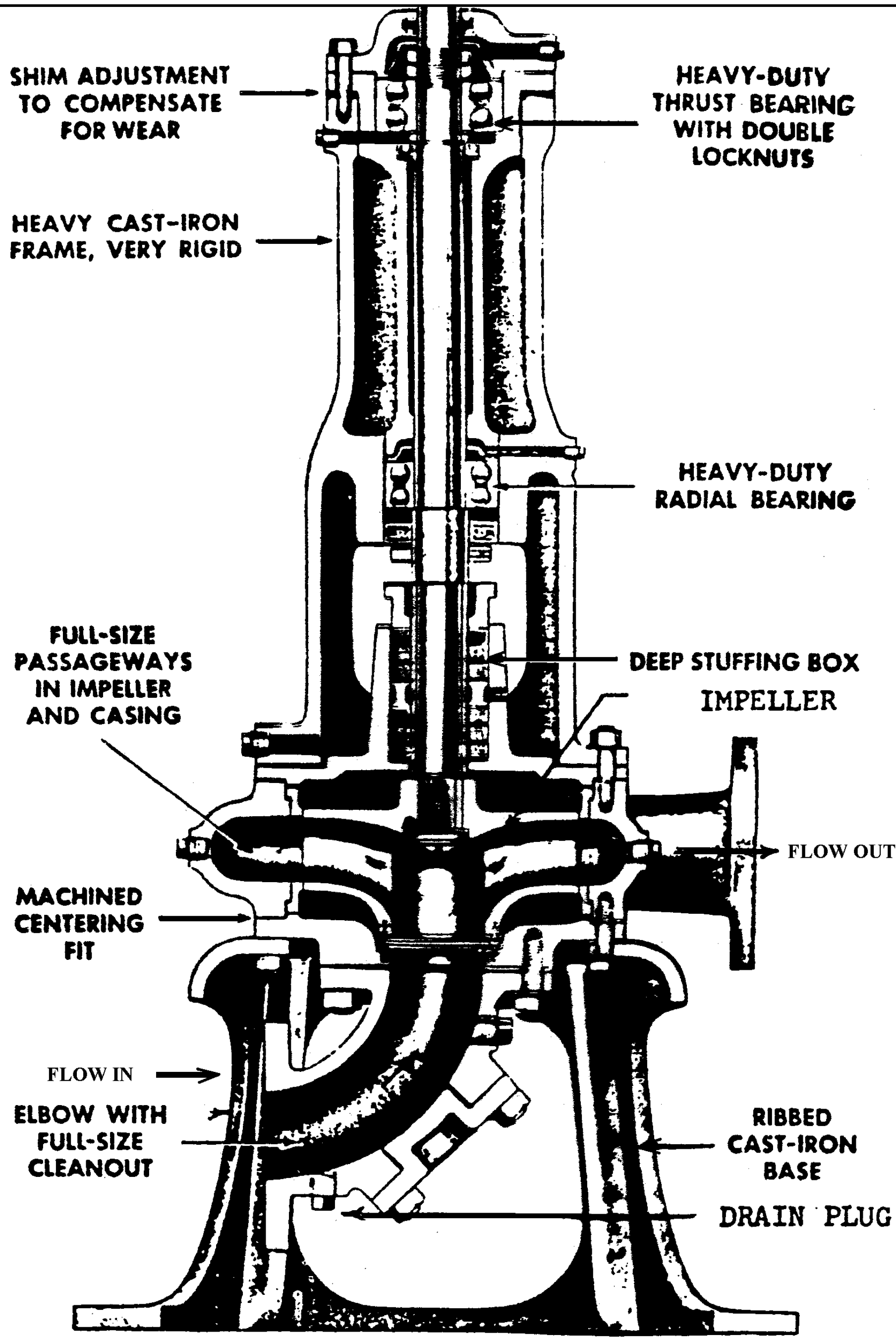
## TYPES OF CENTRIFUGAL PUMPS

There are three basic types of centrifugal pumps. Although they differ in design, all three have the same basic components. The first centrifugal pumps were called horizontal split case pumps. The shaft was horizontal and the casing was split in half. With the top half of the casing removed, the entire rotating assembly can be removed for maintenance. The problem with horizontal pumps is the floor space they require.



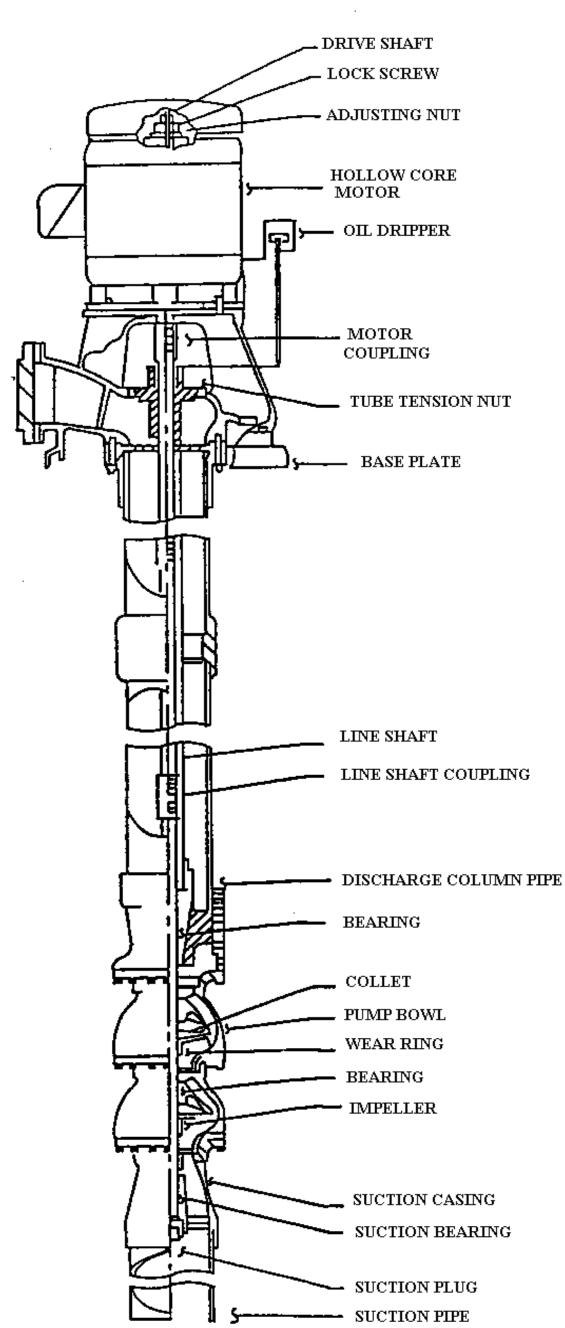

**HORIZONTAL SPLIT CASE CENTRIFUGAL PUMP**

End suction centrifugal pumps were designed to take up less floor space. The suction piping enters at the end of the pump and discharges at a 90$^{o}$ angle to the suction. This allowed more flexibility in installation and, since the pump could be mounted vertically, more pumps in a given floor space.




END-SUCTION CENTRIFUGAL PUMP

A vertical turbine centrifugal pump consists of multiple impellers that are staged on a vertical shaft. The impellers are designed to bring water in the bottom and discharge it out the top. This results in axial flow as water is discharged up through the column pipe. Staging the impellers in these pumps can create very high discharge pressures, since the pressure increases as the water moves through each stage.

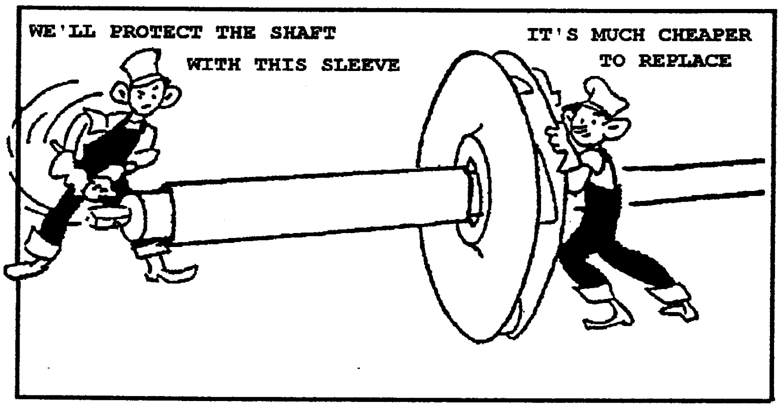



VERTICAL TURBINE CENTRIFUGAL PUMP

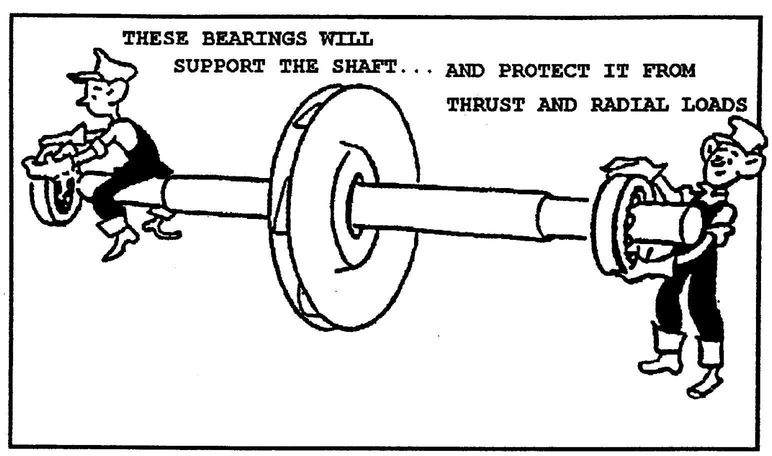
## CENTRIFUGAL PUMP COMPONENTS

Before we can discuss operations and maintenance of a centrifugal pump, it is important to understand how a pump is put together and what the role is of each of the pump components. A centrifugal pump is constructed from about a dozen major components. Let's take a look at how these pieces fit together to make a pump.

The impeller is attached to the pump shaft. The shaft must be straight and true so that it will not cause vibration when it rotates. The shaft should be protected from potential damage caused by the failure of other pump parts. A shaft sleeve is used to protect the shaft in the area where the shaft passes through the pump casing.

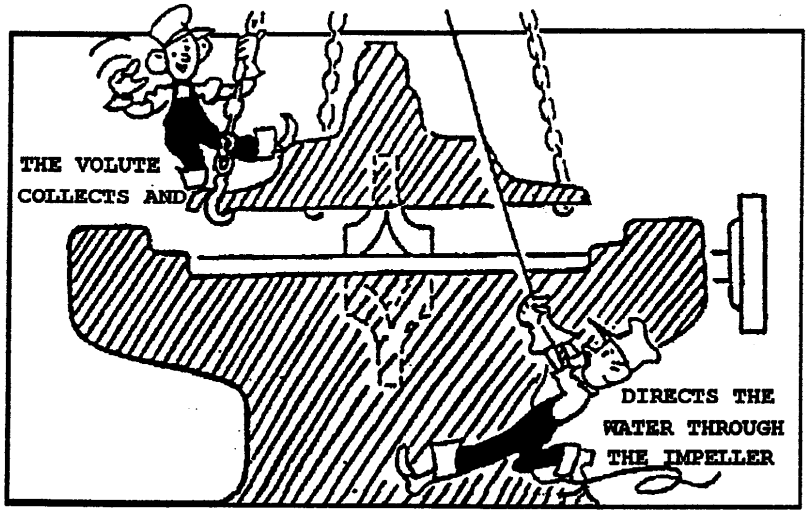



This rotating assembly must be supported as it spins in the pump. Bearings hold the spinning shaft in place. There are two types of anti-friction bearings normally found in centrifugal pumps. One type of bearing is designed to keep the shaft from wobbling from side-to-side as it spins. This side-to-side motion is referred to as radial movement. The bearings used to prevent radial movement of the shaft are called radial bearings. The most common variety of radial bearing is the standard ball-type roller bearing

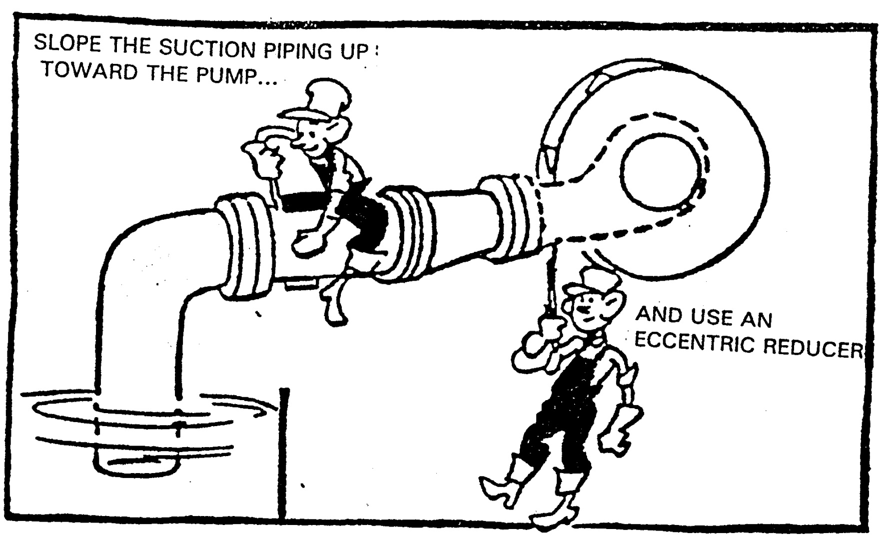


As the impeller spins, water entering the suction eye pushes against the top of the impeller exerting force in the same axis as the pump shaft. This is referred to as upthrust. The pressure developed inside the pump also pushes against the impeller in the opposite direction. This downward force is referred to as downthrust. Bearings designed to support the shaft against this type of force are called thrust bearings. The most common variety of thrust bearing is an angular contact ball bearing.

The rotating assembly is placed in a pump casing. Part of the pump casing is specially designed to collect and direct the flow of water as it enters and leaves the impeller. This part of the pump casing is called the volute.



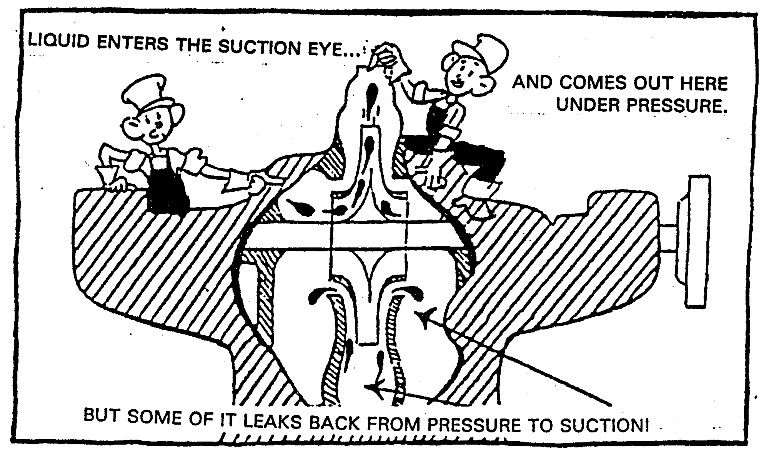

The suction and discharge piping are attached to the pump casing. The suction piping will always be larger than the discharge piping. Suction piping is designed to bring water into the pump at 4 ft/sec in order to minimize the friction loss on the suction side of the pump. The discharge piping is designed to carry water away from the pump at 7 ft/sec.

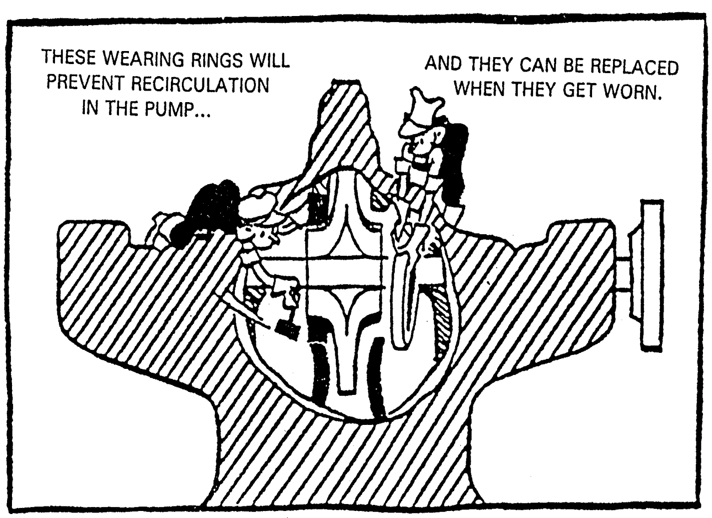


There are several important aspects to suction piping installation. Horizontal runs of piping should slope upward toward the pump. Any reducers on the line should be horizontal across the top instead of tapered. A reducer that is flat on one side is known as an eccentric reducer. A reducer that is tapered on both sides is called a concentric reducer.

These installation features are used to prevent the formation of air pockets in the suction piping. Air trapped in the suction piping can create restriction of flow into the pump. It is also important to make sure there are no leaks in the suction piping that might allow air to be drawn into the pump. The pump must never support the piping. Placing that kind of stress on the casing can cause it to crack or become sprung enough to cause damage to the rotating assembly.

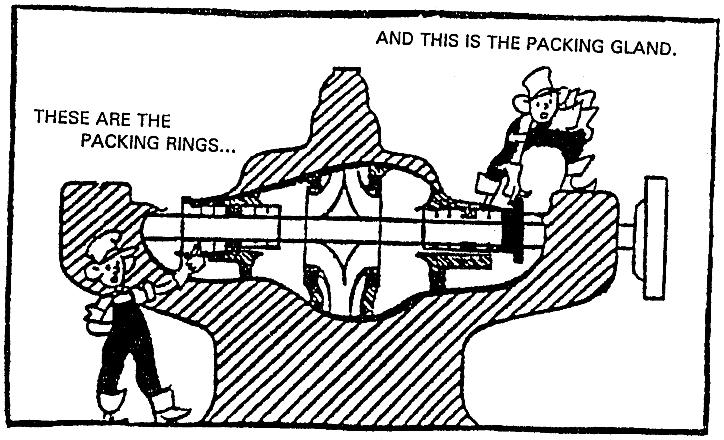
Now that the casing is assembled and the piping is in place, we can spin the impeller and begin moving water. Water will enter from the suction side of the volute and will be slung out of the impeller into the discharge side of the volute. Unfortunately, the water will try to pass from the high-pressure side back to the suction side and recirculate through the impeller again.




The pump casing could have been machined to close this gap, but the fit would become worn and widened over time. To prevent this internal recirculation, rings are installed between the pump and the impeller that reduce the clearance between them to as little as 0.010". Unlike the casing, these rings are removable and can be replaced when they become worn. Because they wear out and get replaced, they are called wear rings or wearing ring.

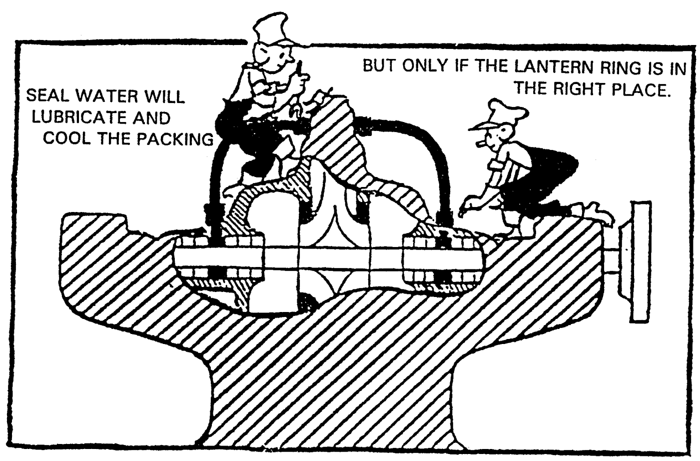
There is another area of the pump that will require some attention. Something must be done to plug the hole where the shaft enters the pump casing. This is a place where water can leak out and air can leak into the pump. Neither of these situations is acceptable. The part of the pump casing that the shaft passes through is called the stuffing box. It's called the stuffing box because we are going to stuff something in the box to keep the water in and the air out.



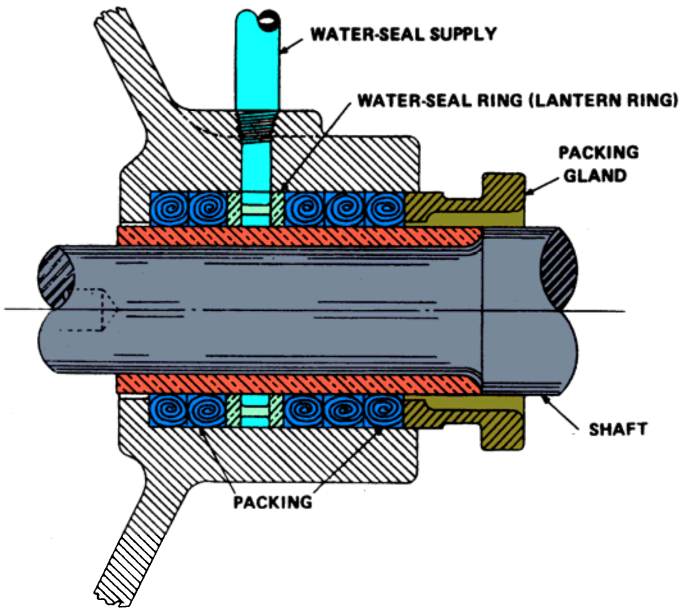

This "stuffing" will usually be rings of pump packing. Several rings of packing are placed in the stuffing box. A metal insert ring fits on top of the stuffing box and is used adjust or tighten the packing down to minimize water leakage. It is called a packing gland.

Since the packing rings touch the shaft sleeve as it rotates, friction and heat are generated in the stuffing box when the pump is running. Water is generally used to cool the packing rings during operation. This means that some water must leak out of the stuffing box when the pump is running. Water may simply be allowed to leak through the packing rings from inside the pump to cool them.

This water may be come from the low-pressure side of the pump and may not be under enough pressure to leak past the packing rings when the packing gland it properly adjusted. If this is the case, high-pressure water from the discharge side of the pump may have to be piped into the stuffing box. Seal water piping is used to supply this water to the packing. The seal water enters the stuffing box from the outside, but it's needed on the inside.

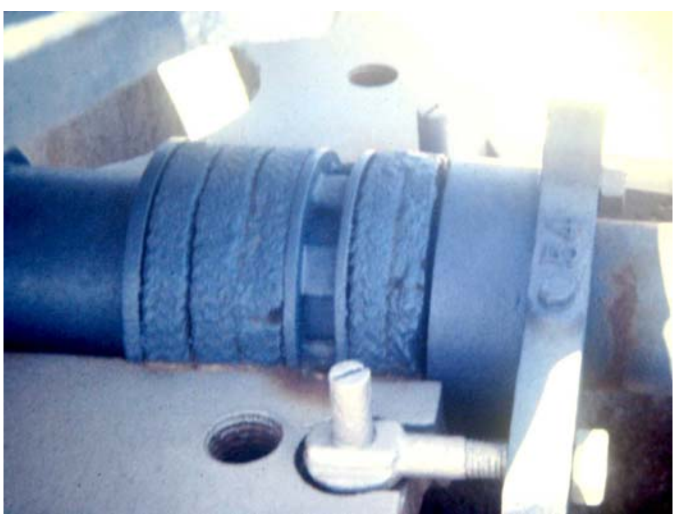


A lantern ring is used to get the water to the inside of the packing rings where the heat is being generated. The lantern ring is a metal ring that has holes in it. Water circulates around the outside of the lantern ring and passes through the holes to get to the inside of the packing rings. The lantern ring must be aligned with the seal water port on the stuffing box to make sure that water will get to the center of the stuffing box. Whenever a potable supply is used for a pump that is pumping non-potable water, an air gap or reduced pressure backflow preventer must be used to prevent a possible cross-connection.



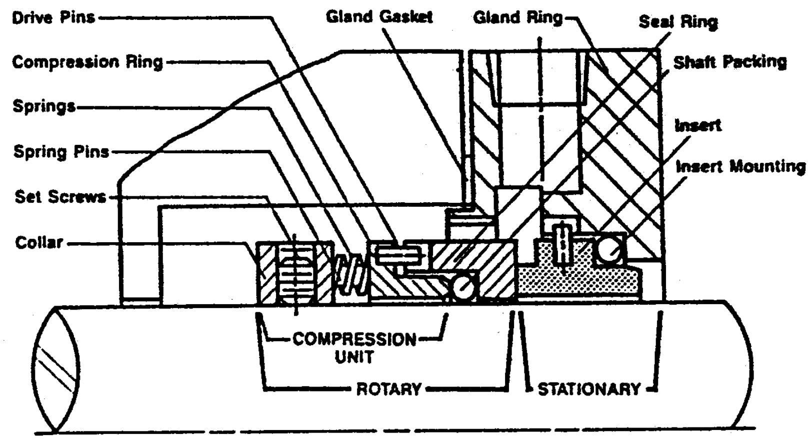

STUFFING BOX WITH LANTERN RING

If there isn't enough seal water moving past the packing and rotating pump shaft to cool them properly, the packing will overheat. If the packing is allowed to overheat, the lubricant in the packing will be driven away from the shaft and the packing will become glazed, much like nylon cord that has been burned at the end. The glazed packing will then start cutting into the shaft sleeve, creating more friction and heat. The result will be packing failure and a severely damaged shaft sleeve.

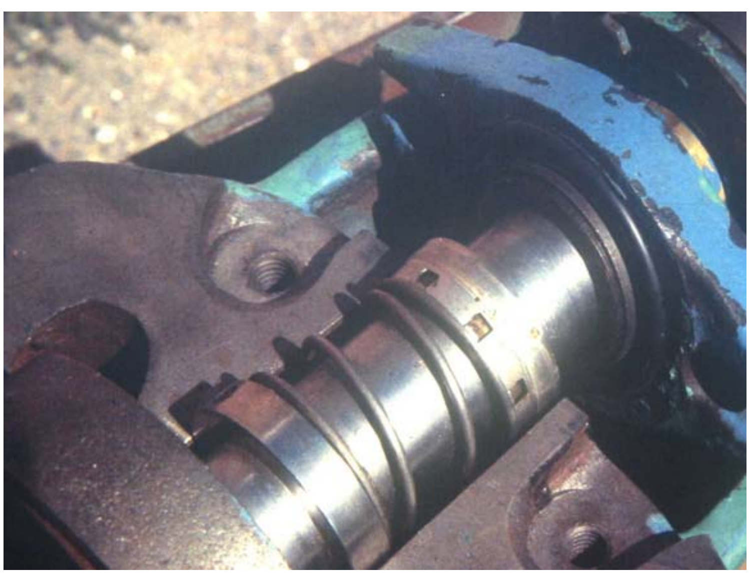


**Stuffing Box on a Horizontal Split Case Pump**

Pumps that do not have packing in the stuffing box will be equipped with a mechanical seal. Mechanical seals are comprised of two highly polished seal faces. One seal face is inserted in a gland ring that replaces the packing gland on the stuffing box. The other seal face is attached to the rotating shaft. It is held in place with a locking collar and is spring loaded so that there is constant pressure pushing the two seal faces together.




**MECHANICAL SEAL COMPONENTS**



**Mechanical Seal on a Horizontal Split Case Pump**

When the pump runs, seal water is piped into the stuffing box under enough pressure to force the seal faces apart. The seal faces don't touch when the pump is running, but the friction loss created as the water pushes them apart prevents any leakage from the gland plate. Failure of the seal water system will result in the seal faces rubbing against each other. The friction that is generated when this happens can destroy a mechanical seal in a matter of seconds.

## PUMP HYDRAULICS

When a pump is installed, it is important to make sure that it is designed to pump the proper amount of water against the correct head pressure. Pumps that are not properly sized for a specific application will fail to give satisfactory performance. The majority of complaints regarding pump performance usually result from placing a pump in an application that requires it to operate outside its designed flow or pressure ratings.

In order to get the right pump for the job, you must know not only how much water must be moved, but also how much pressure it is going to have to pump against. Determining how much water needs to be pumped is the easy part. A pump dealer may have fifteen different pumps that are rated for 500 gpm. Some of them will pump 500 gpm against 500 feet of head and some will only pump 500 gpm against 50 feet of head pressure. The trick is figuring out how much pressure the pump will have to work against.

The following steps should be taken when sizing a pump:

**l. Determine the gpm**:

The pump should be able to meet the peak daily demand that will be encountered.

**2. Determine the suction head**:

The suction head is the vertical distance from the surface of the water supply to the centerline of the pump. If the water supply is below the centerline of the pump, the distance is negative suction head, or suction lift. If the water supply is above the centerline of the pump, it is known as positive suction head. The illustration shows both positive and negative suction heads of 20 feet. Atmospheric pressure and the ability of the pump to pull a vacuum limit negative suction head. At sea level the absolute maximum negative suction head is 33.8 feet. For most pumping applications negative suction heads should never exceed 20 feet.

**3. Determine the discharge head:**

The discharge head is the vertical distance from the centerline of the pump to the overflow of the storage tank. The illustration shows a discharge head of 60 feet.

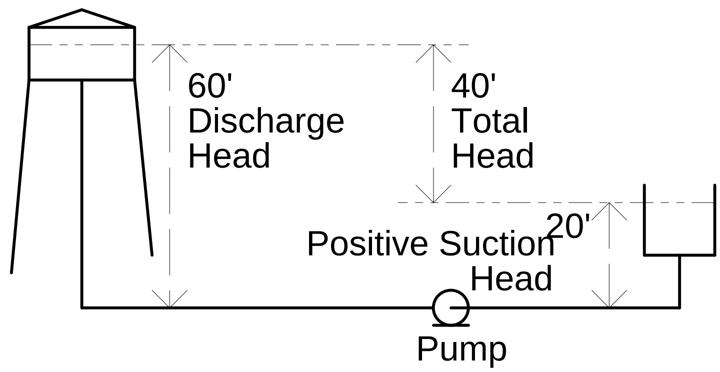
**4. Determine the total head**:

The total head can be determined by **adding** a **negative suction head** to the discharge head or by **subtracting** a **positive suction head** from the discharge head.

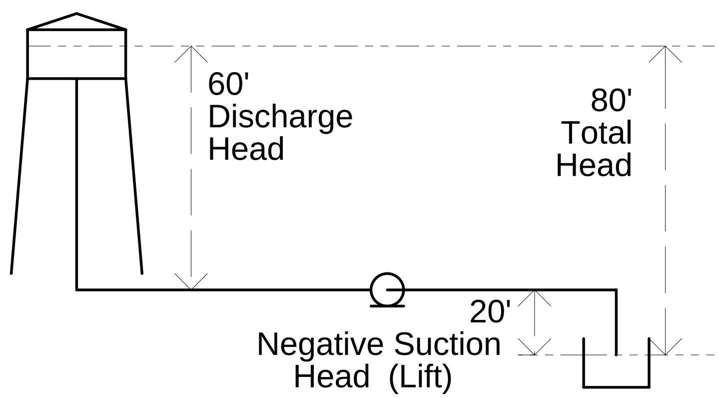
**5. Determine the friction loss**:

The total head represents the vertical distance that the pump must lift the water. The horizontal distance the water must move will also impact the pressure against the pump. As water moves through a pipe, it rubs against the inside of the pipe. This creates friction that will reduce the available pressure at the end of the pipe.

A pump must produce a pressure higher than total head to overcome this friction loss and still move the required amount of water. There are four factors to consider when determining friction loss. They are the size of the pipe, the flow through the pipe, the length of the pipe, and the "C factor". The "C factor" is also known as the coefficient of friction. It represents the roughness of the inside of the pipe wall.




**Total Head = Discharge Head - Positive Suction Head**




**Total Head = Discharge Head + Negative Suction Head**

**6. Determine the Total Dynamic Head**

Once the friction loss has been determined, it is **added** to the total head to calculate the total dynamic head. The total dynamic head (TDH) is the head at which the pump should be rated. The pump can now be sized according to the gpm demand and the total dynamic head that it must work against.

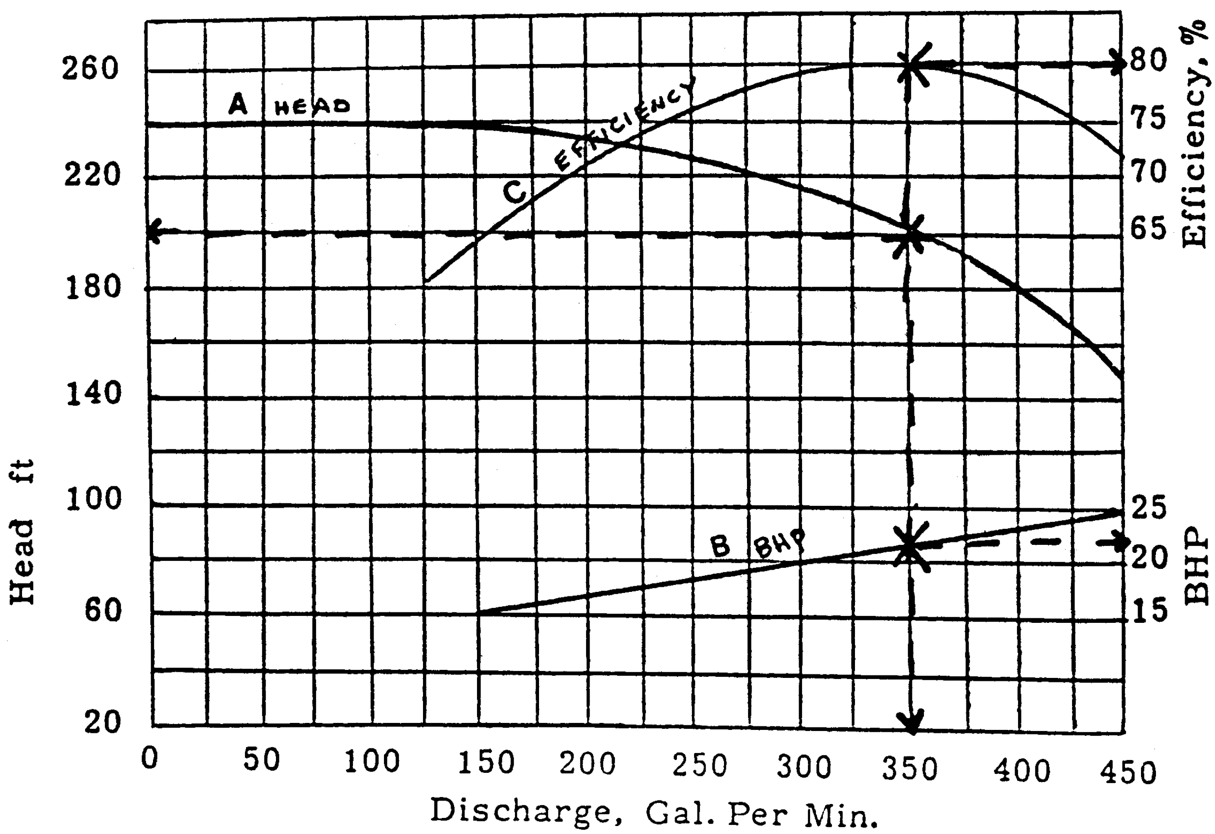
**T.D.H. = Discharge Head +/- Suction Head + Friction Loss**

## PUMP CHARACTERISTIC CURVES

Every pump has certain characteristics under which it will operate efficiently. These conditions can be illustrated with pump characteristic curves. The graph of the pump curve should show:

1) The head capacity curve (A)
2) The brake horsepower curve (B)
3) The efficiency curve (C).

The graph may contain a curve labeled "NPSH" (Net Positive Suction Head) instead of a BHp (Brake Horsepower) curve.




**PUMP CURVE**

To use the pump curve:

1. Start at the particular head pressure that is desired and then travel across the chart to the point where it crosses the head capacity curve (A).

2. Drop a straight line from this point down to the bottom of the chart to determine the gpm output at that particular head pressure.

3. The brake horsepower can be determined by starting at the point where the vertical line crosses the horsepower curve (B) and going across to the right side of the chart. Use the same procedure for NPSH if it is used instead of BHp.

4. The efficiency of the pump at this flow and pressure is determined by starting at the point where the vertical line crosses the efficiency curve (C) and going over to the right side of the chart.

When the head pressure of the pump represented by this curve is 200 feet, the output is 350 gpm. The brake horsepower under these conditions is about 22 BHp and the efficiency is 80%. If the impeller or the speed of the pump changes, all of the pump's characteristics will also change.

If the pressure is increased to 220 feet of head the flow will drop to about 275 gpm. At this point on the curve the BHp requirement drops to 19 brake horsepower and the efficiency drops to about 78%. If the pressure drops to 180 feet of head the flow goes up to 400 gpm. Now the BHp requirement goes up to about 23 brake horsepower and the efficiency again drops to about 78%.

## SHUT-OFF HEAD

The highest head pressure that the pump will develop is called the "shut-off head" of the pump. The shut-off head for the pump in this curve is 240 feet of head. When a pump reaches shut-off head, the flow from the pump also drops to 0 gpm. This is a valuable piece of information for conducting a quick check of the pump's performance. If the pump cannot generate its rated shut-off head, the pump curve is no longer of any real value to the operator. A loss of shut-off head is probably caused by an increase in recirculation inside the pump due to worn wear rings or worn impellers.

There is another factor that might affect the shut-off head of the pump. The pump curve assumes that the pump is running at design speed. If a pump that is supposed to spin at 1750 rpm and it is only turning at 1700 rpm, the shut off head will be lower than the pump curve too. However, if the pump speed is checked with a tachometer and found to be correct, the wear rings or impellers are probably in need of repair.

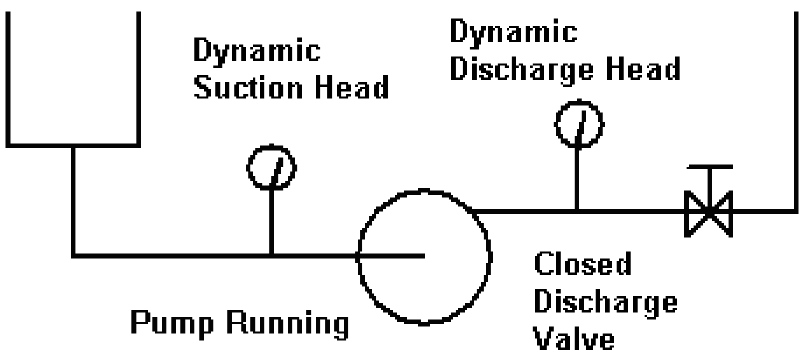
## CHECKING SHUT-OFF HEAD

It is fairly easy to check the shut-off head on a pump if it has suction and discharge pressure gauges:

1. Start the pump and close the discharge isolation valve. This will create a shut-off head condition since the flow has been reduced to 0 gpm. The pump should not operate at shut-off head for more than a minute or it will begin to overheat.

   **NOTE:** NEVER attempt to create shut-off head conditions on a multi-staged turbine well. The shut-off head may be several hundred feet higher than normal operating pressure, which can cause damage to piping.

2. With the pump running at shut-off head, read the suction and discharge pressure gauges. Subtract the suction pressure from the discharge pressure to get the shut-off head. Compare the field readings to the pump curve to see if the wear rings are in need of replacement.




**SHUT-OFF HEAD = DYNAMIC DISCHARGE HEAD - DYNAMIC SUCTION HEAD**

If the shut-off head matches the curve, the same calculation can be used, when the pump is running normally, to estimate the Total Dynamic Head (TDH) and determine the flow when a meter is not available.

## NET POSITIVE SUCTION HEAD

There is a minimum suction pressure required to move water into the pump at the rated flow. This value is known as the Net Positive Suction Head (NPSH). It is the pressure on the suction side of the pump when it's running. If a pump is allowed to run with the suction pressure below the required NPSH it will cavitate. It is important to always make sure the "Stop" level switch in the storage tank is set above the minimum NPSH requirement.

## COMMON OPERATIONAL PROBLEMS

The operator should check all pumps and motors every day to insure proper operation. After spending a certain amount of time with these pumps and motors an operator should be able to tell just by listening to them whether they are working properly. The vast majority of pumping problems are either a result of improperly sizing a pump for the job or one of the three following operational problems.

## CAVITATION

One of the most serious problems an operator will encounter is cavitation. It can be identified by a noise that sounds like marbles or rocks are being pumped. The pump may also vibrate and shake, to the point that piping is damaged, in some severe cases. Cavitation occurs when the pump starts discharging water at a rate faster than it can be drawn into the pump. This situation is normally caused by the loss of discharge head pressure or an obstruction in the suction line. When this happens, a partial vacuum is created in the impeller causing the flow to become very erratic. These vacuum-created cavities are formed on the backside of the impeller vanes.

As the water surges into the impeller, the partial vacuum is destroyed and the cavities collapse, allowing the water to slam into the impeller vanes. These cavities form and collapse several hundred times a second. As they collapse, they draw the water behind them into the impeller at about 760 mph! The impact created by the water slamming into the impeller is so great that pieces of the impeller are chipped away. The impeller on the left has been damaged by cavitation

When cavitation occurs, immediate action must be taken to prevent the impeller, pump and motor bearings, and piping from being damaged. Cavitation can be temporarily corrected by throttling the discharge valve. This action prevents damage to the pump until the cause can be found and corrected. Remember that the discharge gate valve is there to isolate the pump, not control its flow. If it is left in a throttled position the valve face may become worn to the point that it won't seal when the pump must be isolated for maintenance. Butterfly valves can be throttled, but it is still not a good idea to throttle a pump with an isolation valve.

**CAUSES OF CAVITATION**

- Loss of Discharge Pressure
- Closed Suction Valve
- Low Suction Head Due to Drop in Water Level
- Obstruction in the Suction Line

## Air Locking

Air locking is another common problem with pumps. It is caused by air or dissolved gases that become trapped in the volute of the pump. As the gas collects, it becomes compressed and creates an artificial head pressure in the pump volute. As more air collects in the pump, the pressure will continue to build until shut-off head is reached. Air locking is most often caused by leaks in the suction line. The failure of low level cut-off switches, allowing air in from the wet well, may also cause air locking.

An air locked pump will overheat in a matter of minutes. The shut-off head conditions mean that no water is moving through the pump. Vertical pumps that use internal leakage to cool packing may also experience packing ring failure, since the trapped air can prevent water from reaching the packing.

Air relief valves are used to prevent air locking. They are located on the highest point on the pump volute and automatically vent air as it accumulates in the pump. It is also a good idea to repair leaking gaskets and joints on the suction piping. If the pressure in the line drops below atmospheric pressure when the pump is running, air will leak in instead of water leaking out.

## Loss of Prime

Loss of prime happens when water drains out of the volute and impeller. The impeller can't create any suction at the impeller eye unless it is filled with fluid. This occurs only when negative suction head conditions exist. Pumps that operate with negative suction lift are usually installed with a foot valve or check valve at the bottom of the suction pipe. This valve holds the water in the suction pipe and pump when the pump is off.

When a pump loses its prime it must be shut down, reprimed, and all the air bled out of the suction line before starting the pump again. Worn packing and a defective foot valve normally cause loss of prime. The best way to prevent loss of prime is to design a pump installation so that there is positive suction head on the pump.

## Centrifugal Blowers

Centrifugal blowers used in aeration systems operate on the same principles as a centrifugal pump. They must move air to avoid overheating. The airflow drops as the pressure against the blower increases. They will also cavitate. This is why it is important to clean and replace intake filters as they get dirty. It is also why the suction valve should never be throttled. The discharge can be throttled using shims as long as the reduction in airflow does not cause overheating.

## BASIC STUDY QUESTIONS

1. What kind of load creates wobble as the shaft spins?
2. What do wear rings prevent?
3. What are the three factors that determine total dynamic head?
4. What device is used to prevent air locking in a pump?
5. What is shutoff head?
6. What happens when you increase the pressure on a centrifugal pump?
7. What are some of the possible causes of cavitation?

## ADVANCED STUDY QUESTIONS

1. What does the term "C" factor refer to?
2. What is the best way to prevent loss of prime?
3. What are four conditions that could cause cavitation in a centrifugal pump?
4. What kind of information is found on a pump curve?
5. What is NPSH?

## BASIC SAMPLE TEST QUESTIONS

1. A lantern ring:

   A. Must be located in line with the seal water port
   B. Is used to direct cooling water to the center of the stuffing box
   C. Will be found in the stuffing box
   D. All of the above

2. The discharge piping of a centrifugal pump will be larger than the suction piping.

   A. True
   B. False

3. Air trapped in the volute of the pump will cause:

   A. Cavitation
   B. Air locking
   C. Loss of prime
   D. All of the above

4. Which type of pump would be used in a well?

   A. Vertical turbine centrifugal
   B. Split case horizontal centrifugal
   C. End suction centrifugal
   D. Positive displacement

5. If the pressure against a centrifugal pump increases:

   A. The flow increases
   B. The flow decreases
   C. The flow stays the same

6. Pump packing must leak a little.

   A. True
   B. False

7. Priming a pump means:

   A. Starting it slowly
   B. Draining it
   C. Filling the volute with water
   D. None of the above

8. Pumps are usually rated to run at the most efficient point on the pump curve.

   A. True
   B. False

## ADVANCED SAMPLE TEST QUESTIONS

1. The maximum pressure a centrifugal pump can generate is called:

   A. Shutoff head
   B. Total dynamic head
   C. Total head

2. Negative suction head should never exceed:

   A. 10 feet
   B. 20 feet
   C. 30 feet
   D. 40 feet

3. Which of the following would make a centrifugal pump stop cavitating?

   A. Throttle the suction valve
   B. Throttle the discharge valve
   C. Decrease the TDH
   D. Decrease the NPSH

4. Which of the following will <u>not</u> cause cavitiation:

   A. Low discharge pressure
   B. Throttling the suction valve
   C. Low water level in the wet well
   D. High discharge pressure

5. When a pump runs at shutoff head:

   A. The flow increases
   B. It will overheat
   C. It vibrates

6. How can you prevent loss of prime?

   A. Air release valves
   B. Maintain negative suction head
   C. Replace the packing
   D. Maintain positive suction head

7. A dirty air filter on a centrifugal blower can cause:

   A. Overheating
   B. Cavitation
   C. Vibration
   D. All of the above