Pumps serve many purposes in wastewater collection systems and treatment plants. They are classified by the character of the material handled; raw wastewater, grit, effluent, activated sludge, raw sludge, or digested sludge. Or, they may relate to the conditions of pumping: high lift, low lift, recirculation, or high capacity. They may be further classified by principle of operation, such as centrifugal, propeller, reciprocating and turbine. The operation and maintenance of these pumps are some of the most important duties for many wastewater utility operators. The two most common type of pump are the centrifugal pump and the positive displacement pump.

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 pressure in excess of 2500 feet of head 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 between 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.

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 the center, or suction 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.

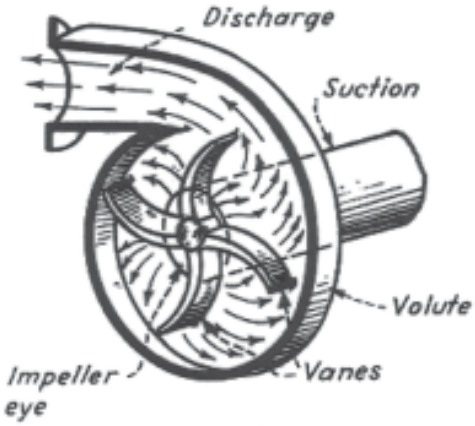


Figure 8.1 - ***Centrifugal Pump Crossection***

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.

Table 8.1 - ***Pump Characteristics***

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 pressurechanges

Centrifugal Pumps

Centrifugal pumps designed for pumping wastewater usually have smooth channels and impellers with large openings to prevent clogging.

Impellers may be of the open or closed type. Submersible pumps usually have open impellers and are frequently used to pump wastewater from wet wells in lift stations.

Propeller Pumps

There are two basic types of propeller pumps, axial-flow and mixed-flow impellers. The axial-flow propeller pump is one having a flow parallel to the axis of the impeller. The mixed-flow propeller pump is one having a flow that is both axial and radial to the impeller.

Vertical Wet Well Pumps

A vertical wet well pump is a vertical shaft, diffuser type centrifugal pump with the pumping element suspended from the discharge piping. The needs of a given installation determine the length of discharge column. The pumping bowl assembly may connect directly to the discharge head for shallow sumps, or may be suspended several hundred feet for raising water from wells. 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.

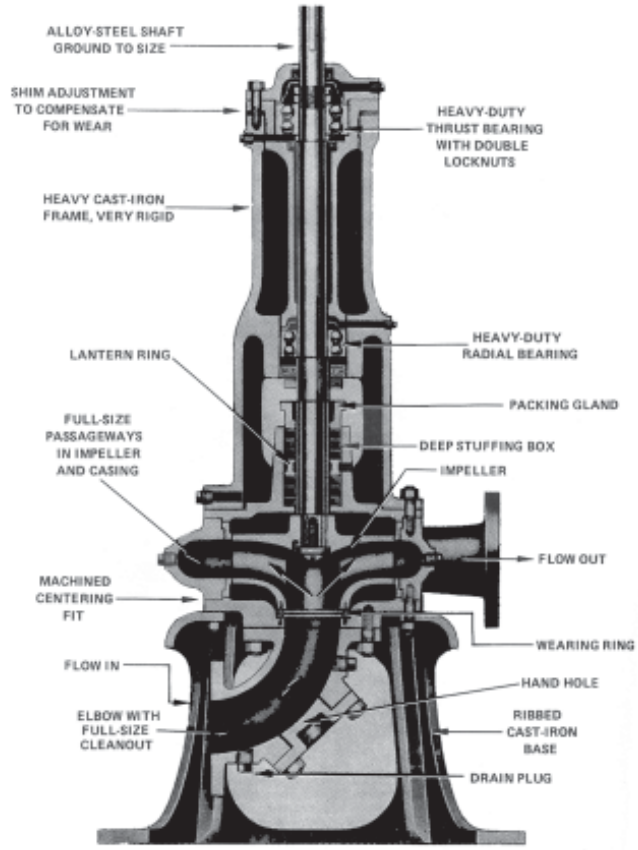


Figure 8.3
Vertical Ball Bearing Type Wastewater Pump

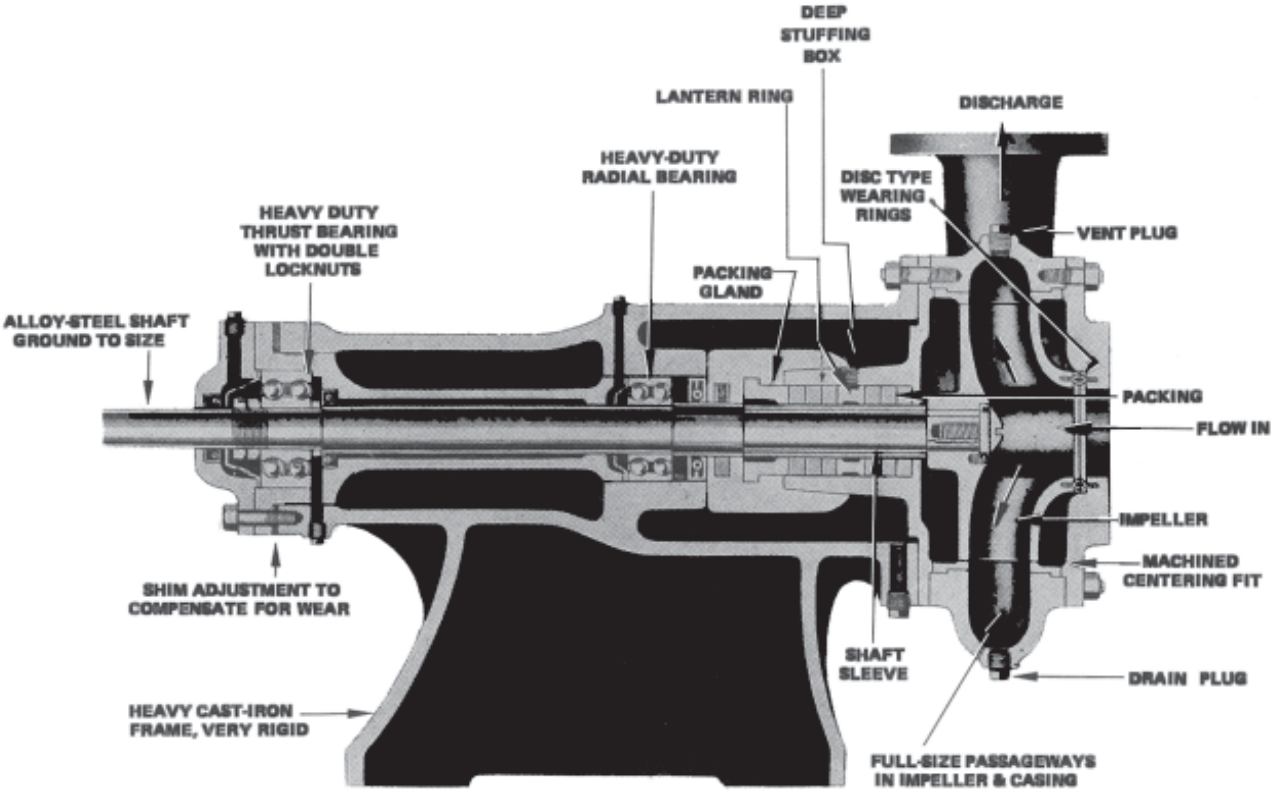


Figure 8.2 - ***Horizontal Nonclog Wastewater Pump with Open Impeller***

1. LIFTING HANDLE
2. JUNCTION CHAMBER WITH WATERTIGHT CABLE ENTRIES
3. ANTIFRICTION BEARINGS
4. SHAFT
5. STATOR WITH TEMPERATURE SENSING THERMISTORS
6. ROTOR
7. STATOR HOUSING LEAKAGE SENSOR
8. BEARING TEMPERATURE THERMISTOR
9. SHAFT SEAL
10. OIL CHAMBER
11. VOLUTE
12. NONCLOG IMPELLER
13. COOLING JACKET
14. SLIDING BRACKET
15. AUTOMATIC DISCHARGE CONNECTION

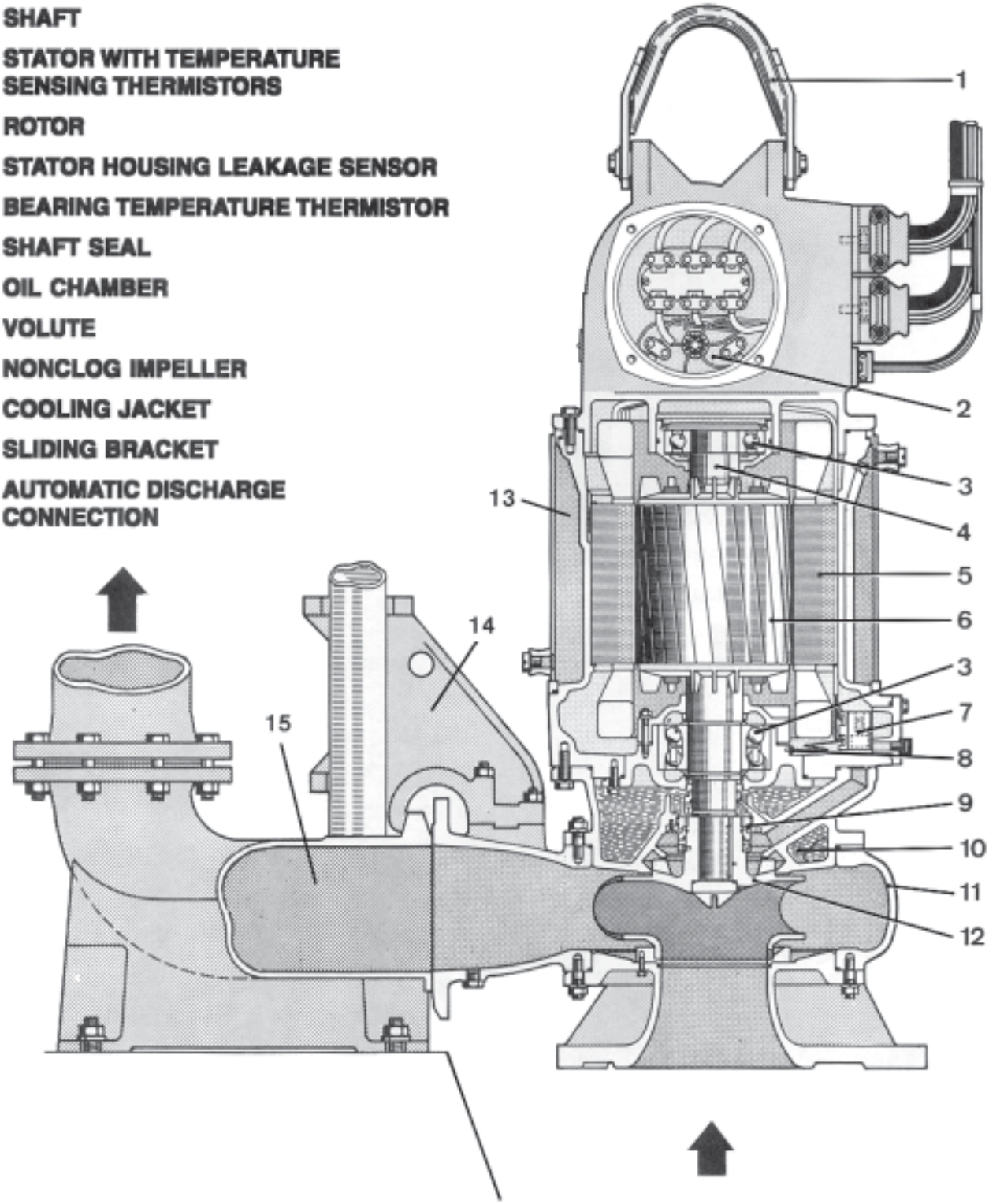
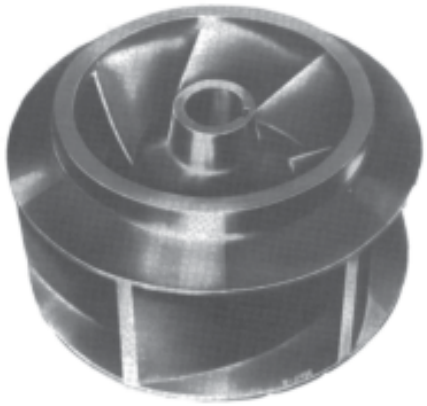
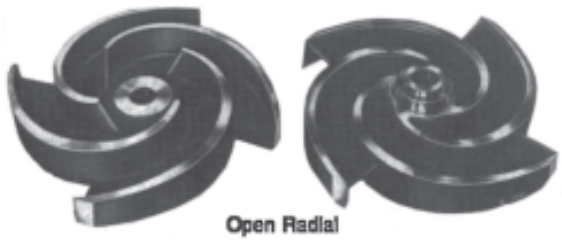


Figure 8.4 - ***Submersible Wastewater Pump***

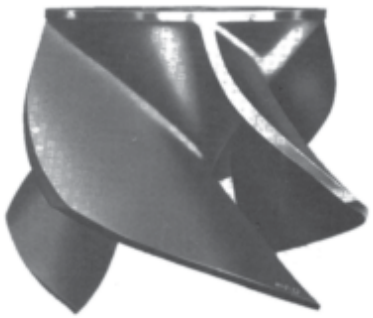


Closed Radial
(Closed radial impellers are used in wastewater treatment plants.)

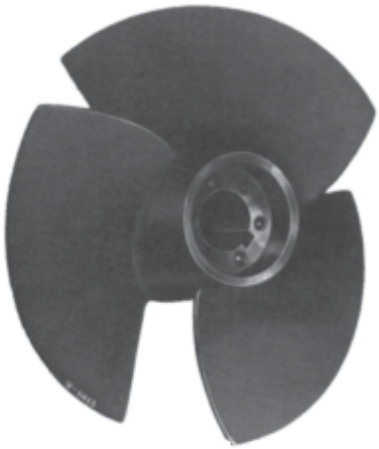


Open Radial

Figure 8.5 - ***Impellers***



Mixed-Flow



Axial-Flow

Figure 8.6
Propeller-type Impellers

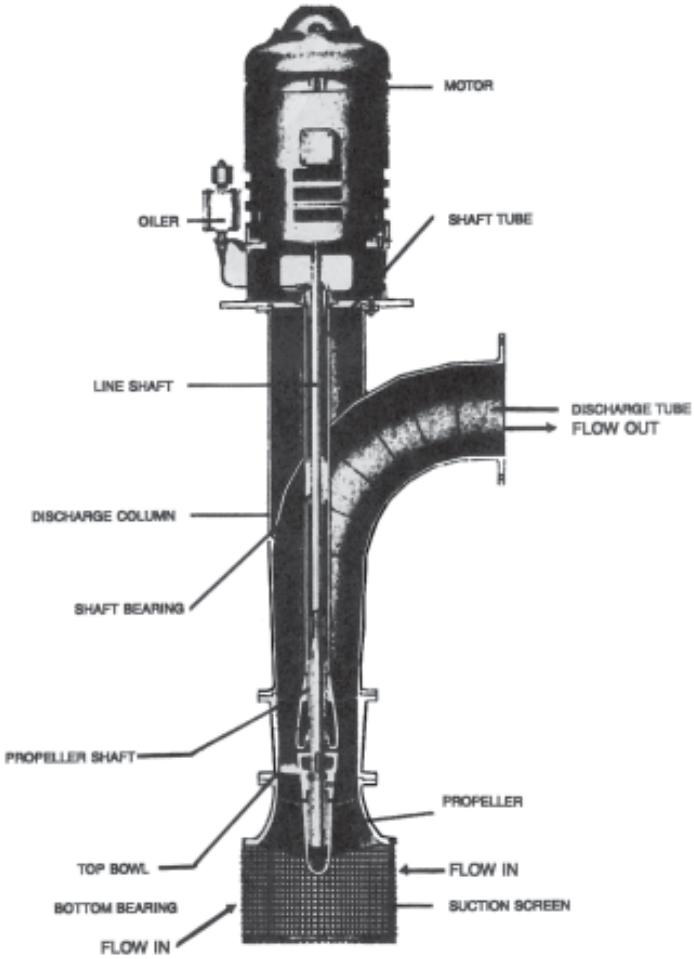


Figure 8.7 - ***Propeller Pump***

Positive Displacement Pumps

Reciprocating or Piston Pumps

The word "reciprocating" means moving back and forth, so a reciprocating pump is one that moves water or sludge by a piston that moves back and forth. A simple reciprocating pump is shown below. If the piston is pulled to the left, check valve A will be open and sludge will enter the pump and fill the casing.

When the piston reaches the end of its travel to the left and is pushed back to the right, Check Valve A will close, Check Valve B will open, and wastewater will be forced out the exit line.

A reciprocating or piston pump is a positive-displacement pump. Never operate it against a closed discharge valve or the pump, valve, and/or pipe could be damaged by excessive pressures. Also, the suction valve should be open when the pump is started. Otherwise an excessive suction or vacuum could develop and cause problems

Incline Screw Pumps

Incline screw pumps consist of a screw operating at a constant speed within a housing or trough. When the screw rotates, it moves the wastewater up the trough to a discharge point. Two bearings, one on top and one at the bottom, support the screw.

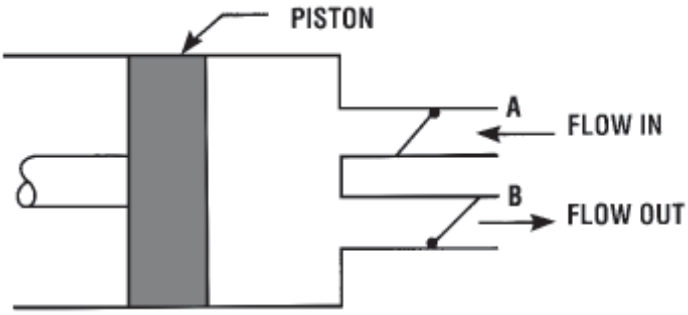


Figure 8.8 - ***Simple Reciprocating Pump***

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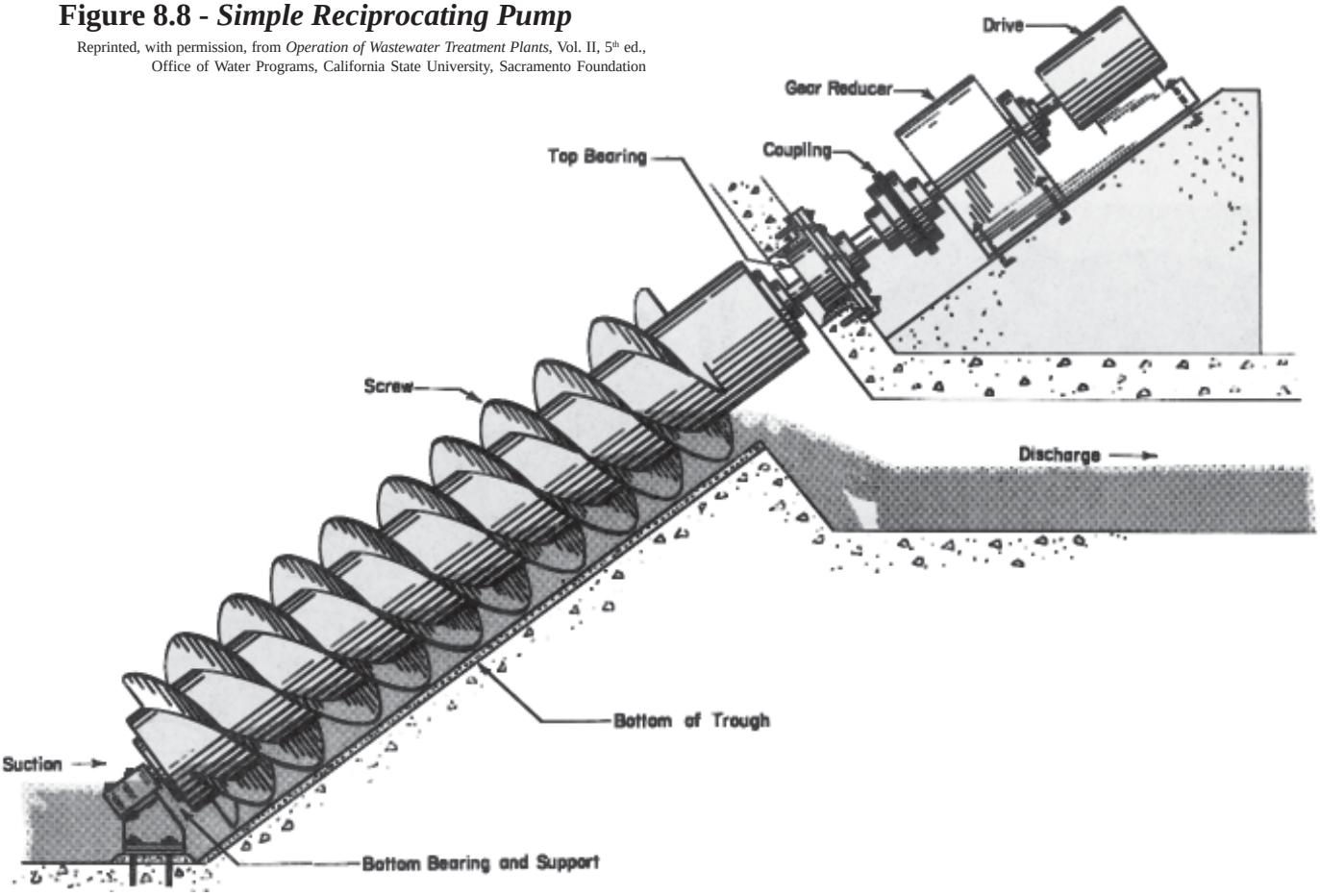

Figure 8.9 - ***Incline Screw Pump***

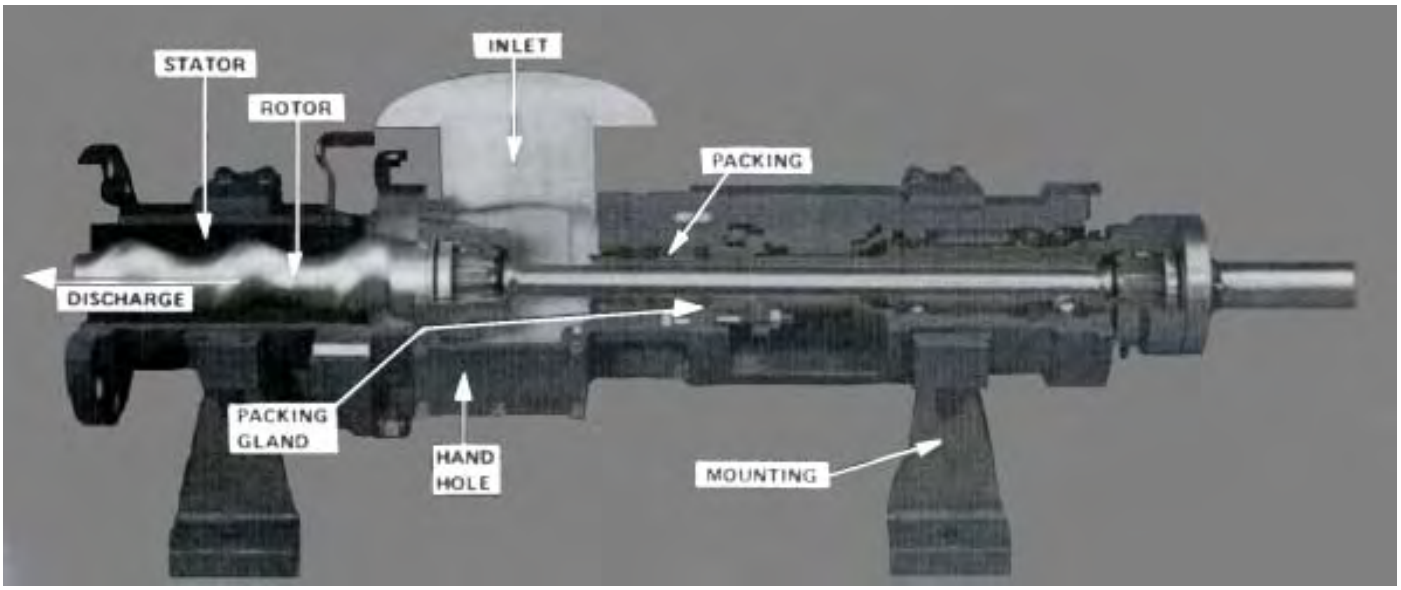

Figure 8.10 - ***Progressive Cavity (screw-flow) Pump***

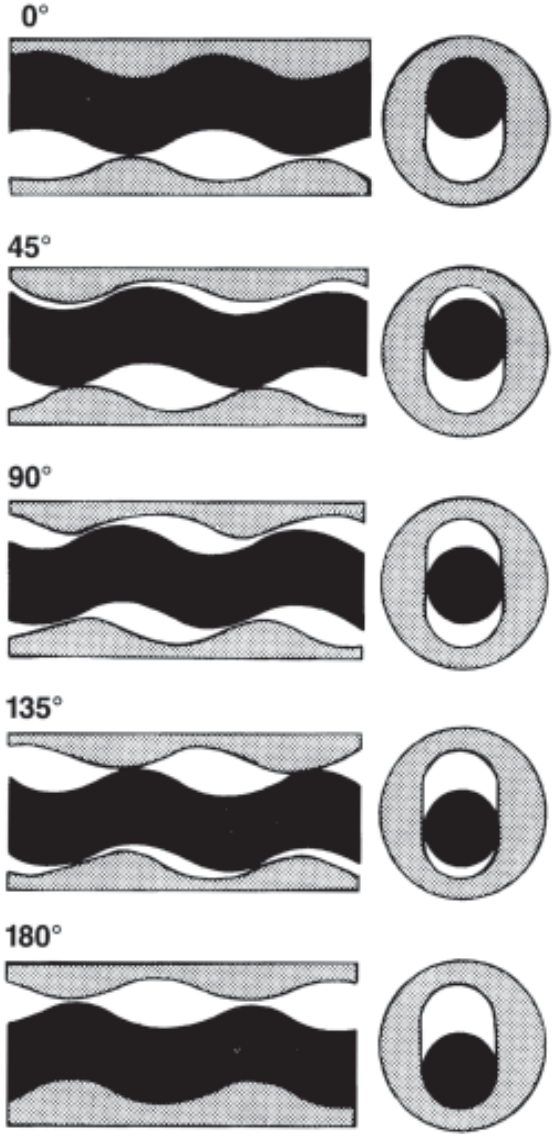

Figure 8.11 - ***Pumping Principle of a Progressive Cavity Pump***

PROGRESSIVE CAVITY PUMPS

Operation of a progressive cavity pump is similar to that of a precision incline screw pump. The progressive cavity pump consists of a screw-shaped rotor snugly enclosed in a non-moving stator or housing. The threads of the screw-like rotor make contact along the walls of the stator (usually made of synthetic rubber). The gaps between the rotor threads are called "cavities." When wastewater is pumped through an inlet valve, it enters the cavity. As the rotor turns, the waste material is moved along until it leaves the conveyor (rotor) at the discharge end of the pump. The size of the cavities along the rotor determines the capacity of the pump.

These pumps are recommended for materials that contain higher concentrations of suspended solids. They are commonly used to pump sludges. Progressive cavity pumps should NEVER be operated dry (without liquid in the cavities), nor should they be run against a closed discharge valve.

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.

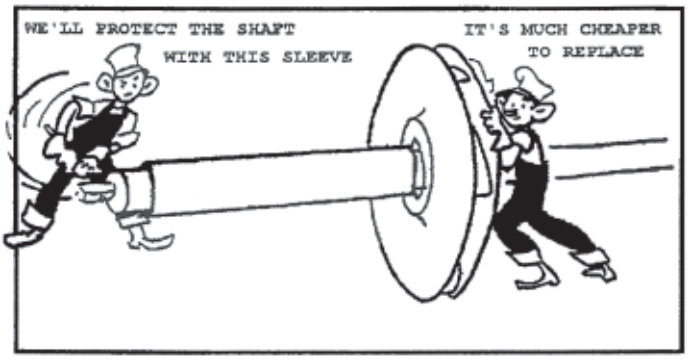

Figure 8.12 - *Protecting the Shaft*

The 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.

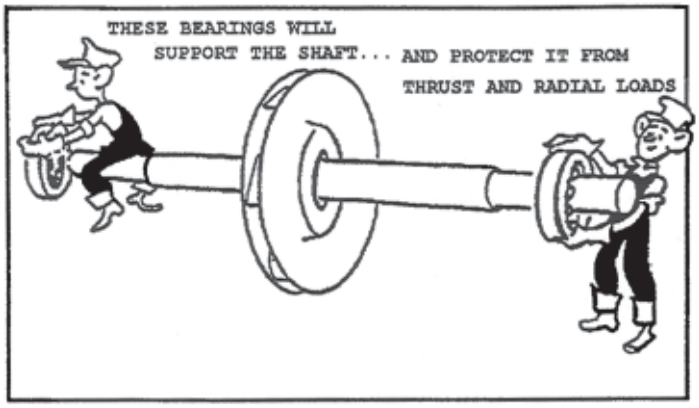

Figure 8.13 - *Bearings*

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 up thrust. The pressure developed inside the pump also pushes against the impeller in the opposite direction. This downward force is referred to as down thrust. 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.

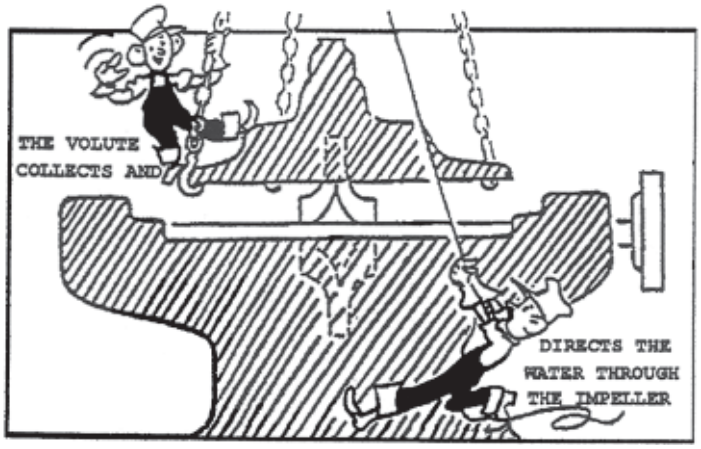

Figure 8.14 - *Volute*

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.

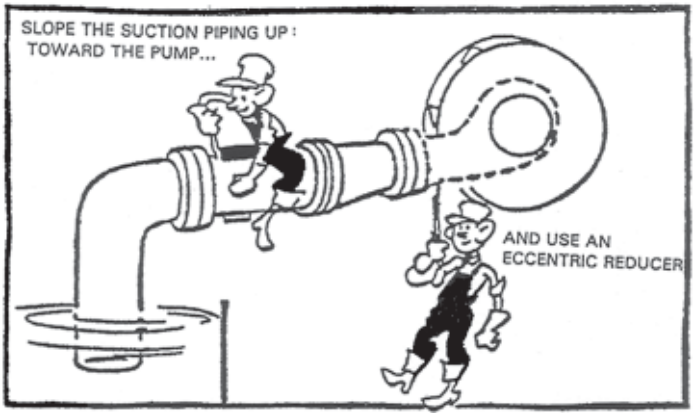

Figure 8.15 - *Suction Piping Installation*

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.

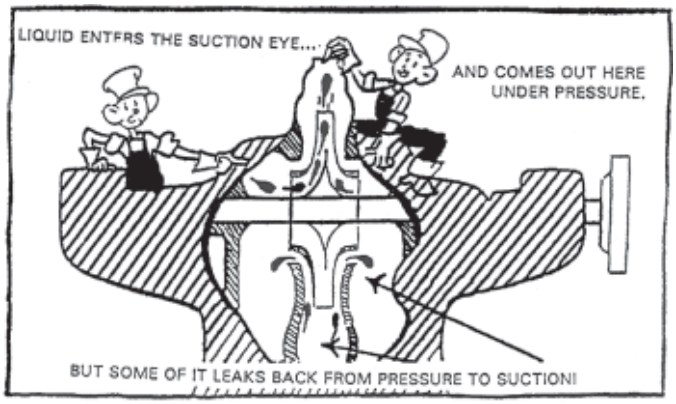

Figure 8.16 - ***Recirculation through the Impeller***

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 wearing rings.

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.

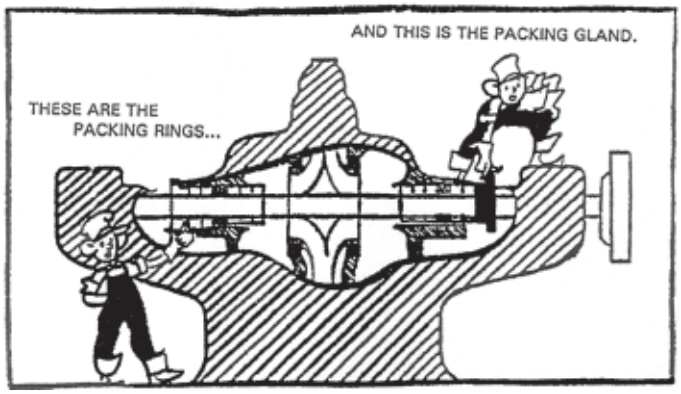

Figure 8.17 - ***Packing Rings***

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 to 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.

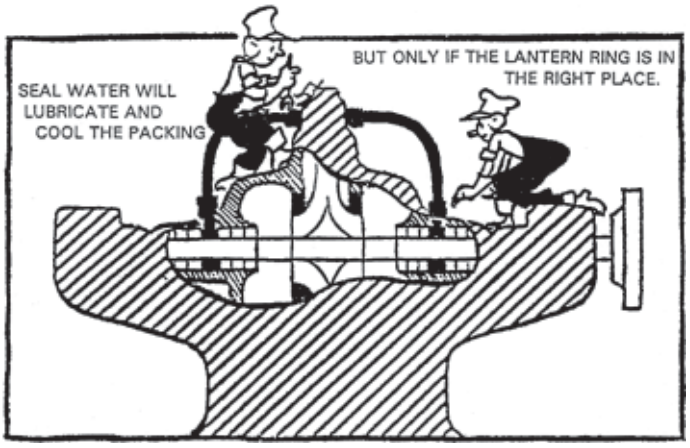

Figure 8.18 - ***Lantern Ring***

This water must 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 is 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 between the packing and the shaft.

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 device must be used to prevent a possible cross-connection.

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 damage shaft sleeve.

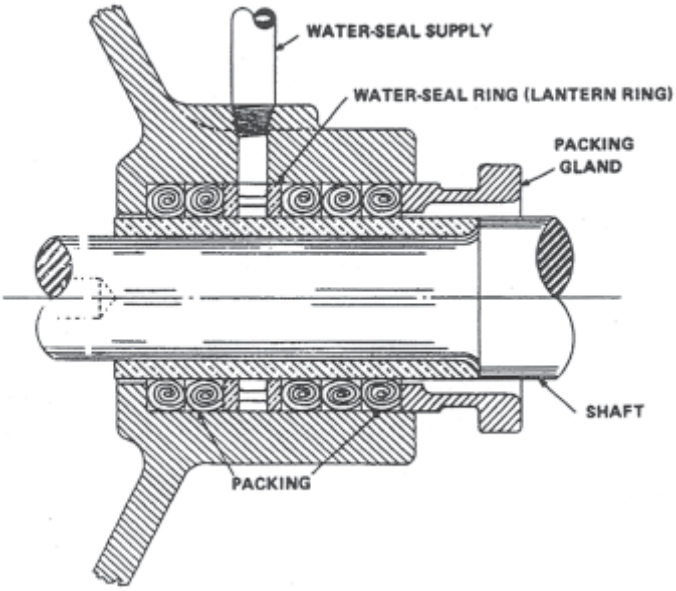

Figure 8.19 - ***Stuffing Box with Lantern Ring***

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.

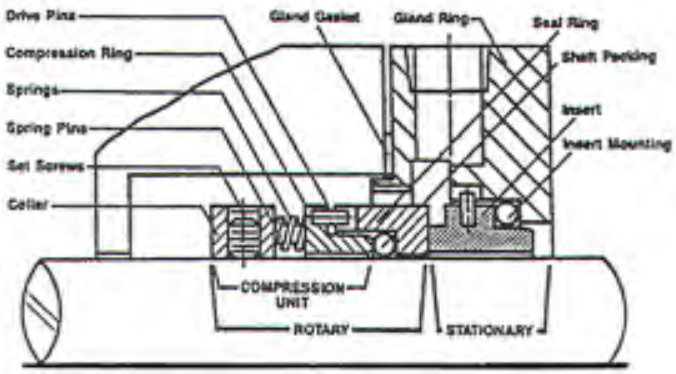

Figure 8.20 - ***Mechanical Seal Components***

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.

ALIGNMENT

Whenever two pieces of rotating equipment such as a pump and motor are used, there must be some means of transmitting the torque from the motor to the pump. Couplings are designed to do this. To function as intended, the equipment must be properly aligned at the couplings. Misalignment of the pump and the motor can seriously damage the equipment and shorten the life of both the pump and the motor. Misalignment can cause excessive bearing loading as well as shaft bending which will cause premature bearing failure, excessive vibration, or permanent damage to the shaft. Remember that the purpose of the coupling is to transmit power and unless the coupling is of special design, it is not to be used to compensate for misalignment between the motor and the pump.

When connecting a pump and a motor, there are two important types of misalignment, (1) parallel and (2) angular. Parallel misalignment occurs when the centerlines of the pump shaft and the motor shaft are offset. The pump and the motor shafts remain parallel to each other but are offset by some degree.

Angular misalignments occur when the shaft centerlines are not parallels, but instead form an angle, which represents the amount of angular misalignment.
In reality, misalignment usually includes both parallel and angular misalignment. The goal when aligning machines is to reduce the angular and parallel misalignment to a minimum. Toward this end it is recommended that the use of a dial indicator be employed.

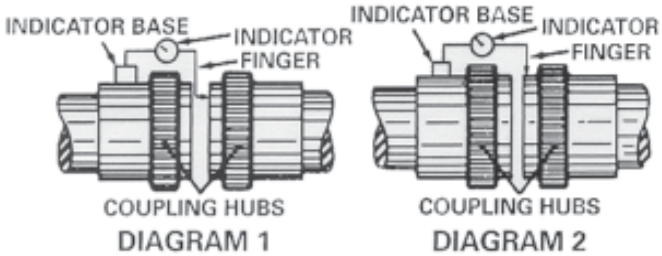

Figure 8.21 - ***Use of Dial Indicator to Check for Shaft Angular Alignment and Trueness***

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The two types of misalignment and end float, which is an in-and-out movement of the shaft along the axis of the shaft, are shown below.

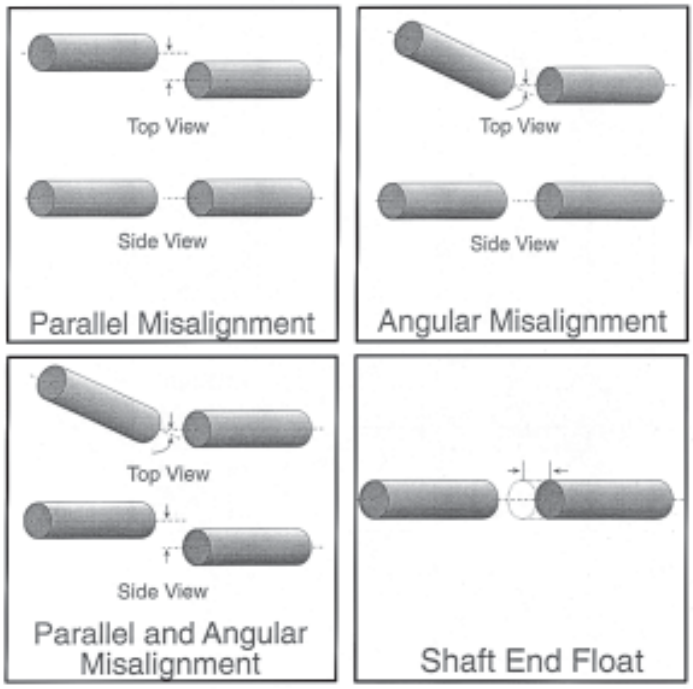


Figure 8.22 - ***Types of Shaft Misalginment and End Float***

Bearings

Pump bearings usually should last for years if serviced properly and used in their proper application. There are several types of bearings used in pumps such as ball bearings, roller bearings, and sleeve bearings. Each bearing has a special purpose such as thrust load, radial load, and speed. The type of bearing used in each pump depends on the manufacturer's design and application. Whenever a bearing failure occurs, the bearing should be examined to determine the cause and if possible, to eliminate the problem. Many bearings are ruined during installation or start-up. Bearing failures may be caused by:

1. Fatigue failure,
2. Contamination,
3. Brinelling,
4. False brinelling
5. Thrust failures
6. Misalignment,
7. Electric arching,
8. Lubrication failure,
9. Cam failure

Lubrication

Pumps, motors, and drives should be oiled and greased in strict accordance with the recommendations of the manufacturer. For additional information read section 15.4 of the Operations of Wastewater Treatment Plants Vol. II.

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. NPSH represents the minimum dynamic suction head that is required to keep the pump from cavitating.

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 tarting 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 NSPH 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.

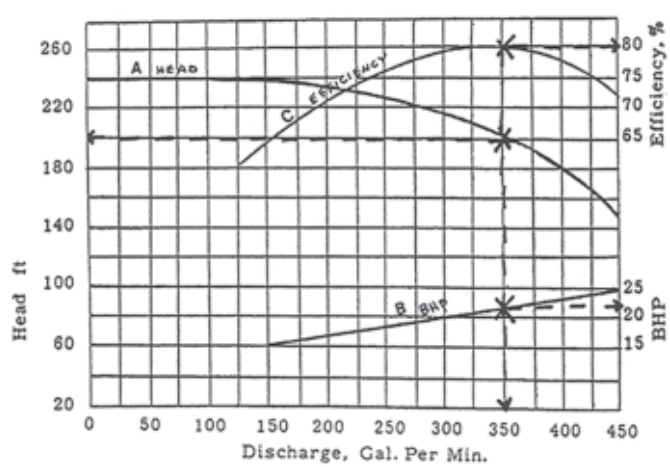


Figure 8.23 - ***Pump Curve***

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 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 designed to spin at 1750 rpm and it is only turning at 1700 rpm, the shut off head will also be lower than the pump curve. 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 Shutoff 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.

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.

Common Operational Problems

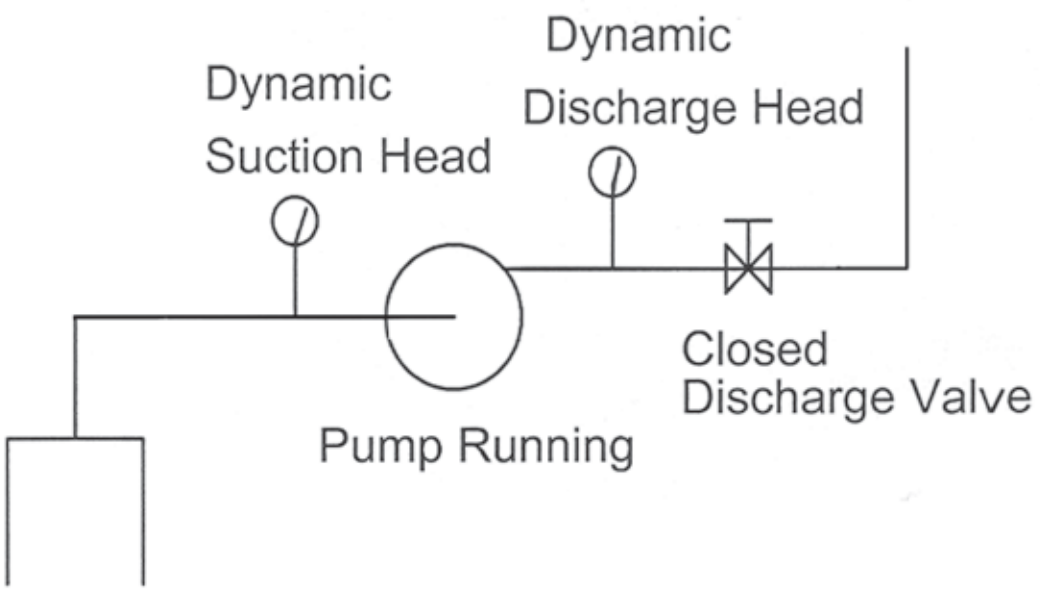
The operator should check all pumps and motors every day to insure proper operation. After spending a certain amount of time with these pumps and motors an operator should be able to tell just by listening to them whether they are work-ing properly. The vast majority of pumping problems are either a 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 may be chipped away.

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



Shut off Head = Dynamic Discharge Pressure – Dynamic Suction Pressure

Figure 8.24 - *Shut Off Head*

corrected. Remember that the discharge 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 is isolated for maintenance.

Table 8.2 - *Causes of Cavitation*

- Loss of discharge pressure due to open hydrants or line breaks
- Closed suction valve
- Obstruction in the suction line
- Low suction head due to drop in water level

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 condition means 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.

Electricity

Very few operators do electrical repairs or trouble shooting because this is a highly specialized field and unqualified operators can seriously injure themselves or damage costly equipment. For these reasons the operator must be familiar with electricity, know the hazards, and recognize his/her own limitations when working with electrical equipment.

Most municipalities employ electricians or contract with a "commercial electrical company" that they call when major problems occur. However, the operator should be able to explain how the equipment is supposed to work and what it is doing or not doing when it fails.

The need for safety should be apparent. If proper safe procedures are not followed in operating and maintaining electrical equipment, accidents can happen that cause injuries, permanent disability, or loss of life. Serious accidents that could have been avoided have happened because machinery was not shut off, locked out, and tagged properly.

Due to the nature of electricity it is suggested you read and understand the chapter on electricity in the Small Wastewater System Operation and Maintenance By California State University, Sacramento or the Operation of Wastewater Treatment Plants Vol. II.

Electric Motors

Electric motors are commonly used to convert electrical energy into mechanical energy. A motor generally consists of a stator, rotor, end bells, and windings. The rotor has an extending shaft, which allows a machine to be coupled to it. Most large motors will be three phase motors rated from 220 or 4160 volts.

Phases

The term "phase" applies to alternating current (AC) systems and describes how many external winding connections are available from a generator, transformer, or motor for actual load connections. Motors are either single-phase or three-phase.

Single Phase Motors

Single-phase motors are normally operated on 110-220 volt A.C. single-phase systems. A straight single-phase winding has no starting torque so it must incorporate some other means of spinning the shaft. A single-phase motor requires a special start circuit within the motor to make sure it runs in the right direction. Several different types of starter windings are available in these motors. Single-phase power leads will have three wires, like a three-prong extension cord.

Three Phase Motors

Three-phase systems refer to the fact that there are three sets of windings in the motor and three legs of power coming in from the distribution system. This type of motor is used where loads become larger than single-phase circuits can handle. With three legs to carry power, more amps can

be delivered to the motor. Three phase motors are the most common types used in water and wastewater systems. Three major types of three phase motors are the squirrel cage induction motor, synchronous motors, and wound rotor induction motors.

Squirrel cage induction motors are widely used because of its simple construction and relative low maintenance requirements. The windings are stationary and are built into the frame of the motor. The power supply is connected to the windings in the stator, which creates a rotating magnetic field. The rotor is made up of bars arranged in the shape of a cylinder and joined to form a "squirrel cage." Squirrel cage induction motors make up approximately 90% of all motors used in industry today.

Three-phase motors do not use a start circuit. The direction of rotation is determined by how the three leads are wired to the motor. If any two of the leads are switched, the motor rotation will be reversed.

Single Phasing

Anytime a lead becomes grounded, a dead short develops, or one of the contacts opens in a three-phase motor, single phasing will result. When this occurs, the speed of the motor will drop and it will begin to overheat. The single phase will draw too many amps and it will quickly burn up. When single phasing occurs while the motor is not running, it simply will not start up again. Special circuit protection is available that will shut the motor off if single phasing occurs.

Circuit Protection

Motors need to be protected from power surges and overloads. Fuses and circuit breakers are designed to open the circuit when the current load threatens to damage the motor. Fuses are generally sized at 120-150% of motor capacity. Circuit breakers can be reset when they trip, instead of being replaced like a fuse. Circuit breakers can react faster than fuses and are usually sized closer to the current rating of the motor.

References

Office of Water Programs, California State University, Sacramento, *Operation of Wastewater Treatment Plants*, Volume II, 5^{5h} ed., Chapter 15