PUMPS AND WELLS
OPERATIONS AND
TROUBLESHOOTING
MANUAL

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**PUMPS AND WELLS**  
**OPERATIONS AND MAINTENANCE MANUAL**

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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.

<table>
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<th>TYPE OF PUMP</th>
<th>PRESSURE/FLOW RATING</th>
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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.

End suction centrifugal pumps were designed to take up less floor space. The suction piping entered at the end of the pump and discharged at a 90° 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.
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 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.
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.

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.
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.

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:

1. **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 limits 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.

\[
\text{Total Head} = \text{Discharge Head} - \text{Positive Suction Head}
\]

\[
\text{Total Head} = \text{Discharge Head} + \text{Negative Suction Head}
\]

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.

\[
\text{T.D.H.} = \text{Discharge Head} \pm \text{Suction Head} + \text{Friction Loss}
\]
**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. 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 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.

**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.

   \[
   \text{SHUT-OFF HEAD} = \text{DYNAMIC DISCHARGE PRESS.} - \text{DYNAMIC SUCTION PRESS.}
   \]

   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 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 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 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 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 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.
**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 NPSH?

**SAMPLE TEST QUESTIONS**

1. If the pressure against a centrifugal pump increases:
   - A. The flow increases
   - B. The flow decreases
   - C. The flow stays the same

2. Pump packing must leak a little.
   - A. True
   - B. False

3. Priming a pump means:
   - A. Starting it slowly
   - B. Draining it
   - C. Filling the volute with water
   - D. None of the above

4. Which of the following will **not** cause cavitation:
   - A. Low discharge pressure
   - B. Throttling the suction valve
   - C. Low water level in the wet well
   - D. Throttling the discharge valve

5. The maximum pressure a centrifugal pump can generate is called:
   - A. Shutoff head
   - B. Total dynamic head
   - C. Total head

6. Negative suction head should never exceed:
   - A. 10 feet
   - B. 20 feet
   - C. 30 feet
   - D. 40 feet

7. 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
Pumps Operations
PUMP MAINTENANCE

Like any other business, a water system spends a great deal of money on infrastructure and capital improvements. These expenses include piping, storage and all of the mechanical equipment required to produce, treat, and deliver water. A maintenance program is essential to insuring that the mechanical components of the system stay in good working order and provide the longest possible service life. A preventive maintenance schedule should be utilized to make sure that each piece of equipment gets the proper attention. Most preventive maintenance consists of inspecting, cleaning, and lubricating the equipment. The equipment operators can usually complete these tasks. Specially trained personnel that possess the necessary mechanical skills should handle major maintenance, including component replacement and overhaul.

PUMP MAINTENANCE

The most common piece of equipment in a water system is the centrifugal pump. There are several maintenance procedures that must be performed periodically for any centrifugal pump. Pump packing wears out, bearings must be lubricated or replaced, mechanical seals need replacing, couplings must be maintained, and motor and pump shafts must be aligned. These procedures are not difficult to learn. Some of the procedures may require the use of a few special tools. Once an operator understands the basic procedures and has a chance to put the theories into practice, it doesn't take long to become proficient at each task.

PUMP PACKING

Pump packing is one of the biggest problem areas for operators in charge of pump maintenance. Poor maintenance of pump packing is responsible for more pump damage than any other maintenance item. Improperly maintained packing can cause several problems including:

- Loss of prime or suction due to an air leak
- Shaft and sleeve damage
- Water contamination of bearings

There are many different types of pump packing available for use in today's pumps. The most common type of packing comes in a square braided stock. There are a number of different kinds of braided packing. It can be manufactured from jute, asbestos, nylon, Teflon or other synthetics. It can be lubricated with graphite, grease, or other synthetic lubricants such as Teflon. Prices for packing range from several dollars a pound for graphite-impregnated jute to hundreds of dollars a pound for pure Teflon and other synthetics.

A rule of thumb is to buy the most expensive packing that you can afford, provided that you are taking care of the rest of the pump properly. If scored or damaged shaft sleeves and out of round or bent shafts are not going to be repaired, use the cheapest packing you can get. Expensive packing will not last any longer than the cheap stuff if the sleeve is scored or the shaft is bent. If the rest of the pump is properly cared for, the more expensive types of packing will last several times longer than the cheap packing and will usually pay for itself with a longer life.
REMOVING OLD PACKING

It’s time to replace the packing when there is no more adjustment left in the packing gland and there is too much leakage from the stuffing box. When this occurs, all of the packing rings must be replaced. Adding an additional ring or just replacing one or two rings will only lead to premature packing failure and damage to the shaft and sleeve. Use the following procedure to remove the old packing:

1. Tag the pump in the "OFF" position and lock it out so that it can’t be accidentally restarted.
2. Isolate the pump by closing the suction and discharge valves.
3. Drain the pump by opening the drain cock or removing the drain plug in the bottom of the volute.
4. Remove the packing gland. If it is not split for removal from the shaft, it should be tied off so that it is out of the way.
5. Remove the packing rings with a packing puller (corkscrew on the end of flexible T-handle) taking care not to score the shaft sleeve.
6. Measure the distance to the lantern ring and then remove it with the packing puller. It may take a puller on each side of the lantern ring to pull it out without getting it cocked sideways. If the lantern ring is split, it can be removed from the shaft. If you’re not sure the lantern ring was in the right placed to begin with, measure the distance from the face of the stuffing box to the seal water port or refer to the vendor’s engineering drawing of the stuffing box for the correct position.
7. Remove the remaining packing rings and clean the stuffing box and shaft.
8. Disconnect, inspect, and clean the seal water line and seal water port.
9. Inspect the shaft or shaft sleeve. If it is scored or grooved, the pump should be dismantled and the shaft dressed or repaired by a machine shop.

REPACKING THE PUMP

Before new rings are cut, it is important to determine the size and number of packing rings that are needed for the stuffing box. This information should be available in the vendor’s engineering drawings. If these drawings are not available, measurements of the stuffing box and shaft can be used to make the determination. The correct packing size is determined using the following procedure:

1. Measure the inside diameter of the stuffing box and the outside diameter of the shaft.
2. Subtract the shaft diameter from the stuffing box diameter.
3. Divide the difference by two. (See illustration on page 2-4)
The correct number of rings can be determined using the following procedure:

1. Measure the depth of the stuffing box.

2. Divide the depth of the stuffing box by the size of the packing to get the total number of rings.

3. Subtract one from this total if a lantern ring is used in the stuffing box.

Once the size and number of rings has been determined, the new packing can be cut and installed. Great care should be taken to keep the packing material clean and free from dirt. Packing spools should be stored in plastic bags to prevent contamination. Dirt and grit in the packing rings will lead to serious shaft and sleeve damage. The two most important aspects of cutting packing rings involves cutting them the right length and cutting them so the ends will butt together squarely. Cutting rings the same length with ends that butt together squarely can be accomplished using the following procedure:

1. Cut the packing to the proper length and shape using a very sharp knife or carton cutter. Wrap the packing material around the shaft, an old sleeve, or even a piece of hardwood turned to the proper diameter. Cut all of the rings at once with the packing on the shaft to insure that the ends will butt together squarely.

2. Wrap each ring of packing around the shaft and seat it in the stuffing box completely before adding the next ring. Open the ring by twisting it instead of pulling the ends apart. A light coat of grease on the outside of the ring will make it much easier to push into the stuffing box. Stagger the joints of the rings so that they are 90 degrees apart. Make sure the lantern ring lines up with the seal water port when it is installed.

3. Install the packing gland. Make sure the gland tightened down evenly. It is usually made out of cast material and will break easily if it gets in a bind.

**ADJUSTING THE PACKING GLAND**

The final adjustment of the packing gland is made while the pump is running. The pump can be restarted once the locks and tags have been removed, the discharge and suction valves are completely opened, and the pump has been primed. More packing jobs have been ruined by improper gland adjustment than any other single reason. Adjust the packing gland using the following procedure:

1. Tighten the gland one half turn a time on each side until it just begins to put pressure on the packing.

2. Start the pump and tighten the gland until the flow of water is reduced just enough to prevent flooding the drain line. Allow the pump to run for at least five minutes while the packing rings seat. Never allow the packing to get hot during this "breaking in" period. If the packing heats up and lubricant is seen oozing from the gland, the packing is already ruined and should be removed and replaced immediately.

3. After five minutes, adjust the packing slowly until the leakage is reduced to the desired level. The appropriate amount of leakage will vary with the size of the pump and type of packing, but a general rule of thumb is 20-60 drips per minute. Tighten the gland and checking the water temperature periodically. When the water turns lukewarm there is not enough flow to cool the packing properly. Loosen the packing gland just enough to cool the water back down to room temperature. The packing gland will probably need to be checked again, as the packing rings get properly seated. This may have to be done several times over the next 24 hours of run time.
Pump Maintenance

1. **Remove Old Packing**
   - **Formula**: \( \frac{x - y}{2} = \text{Packing Size} \)

2. **Cut and Flatten Packing**

3. **Make Sure Ends Are Square**

4. **Install New Packing**

5. **Stagger Packing Rings**

6. **Position Lantern Ring Properly**
**Bearings**

The bearings in the pump and motor support the rotating equipment and protect it from radial and thrust loads. Some bearings are designed specifically for thrust load applications and will fail if they are subjected to radial loads or thrust loads in the wrong direction. Others are designed to handle radial loads and will fail if thrust loading occurs. Bearings are also made to accept both thrust and radial loads in varying degrees. The design of the bearing races will determine what type of loads a bearing can handle.

**Bearing Identification**

Every bearing should have an identification number on its face that identifies the type and size of the bearing. This identification system is standard for bearings made by the major European manufacturers, i.e., FAG, SKF, NKG. Some bearings that are made by lesser-known manufacturers may not follow the same system. Most bearing suppliers can identify an equivalent for these situations.
There are four rules for identifying bearings by number. As with most rules, there are also some exceptions for certain sizes and applications. Bearings that follow this system will be identified by four numbers, i.e., 7311, 6207, etc. Here are the rules for bearing identification:

**RULE #1** - The first number identifies the type of bearing.

- **1210** - SELF-ALIGNING DOUBLE ROW BALL TYPE
- **2210**
- **210** - DOUBLE ROW BALL TYPE
- **5210**
- **6210** - DEEP GROOVE BALL TYPE
- **7210** - ANGULAR CONTACT BALL TYPE

**Exceptions:**

- **22210** - SPHERICAL SELF-ALIGNING
- **N210** - CYLINDRICAL ROLLER TYPE
- **_210** - MAX BEARING (DEEP GROOVE BALL W/ 12 BALLS)

**RULE #2** - The second digit from the left identifies the bearing housing size. It represents the amount of load the bearing can carry. The possible ratings are:

- **9** - Extra-Extra Light
- **0-1** - Extra Light
- **2** - Light
- **3** - Medium
- **4** - Heavy

As an example, a 6310 bearing is a Deep Groove Ball bearing with a Medium duty housing. The illustration on the following page shows some of the different housing sizes for the bearings with the same bore size.
RULE #3 - Bores or inside diameters of bearings are measured in millimeters.

**EXCEPTIONS:**

Pillow block bearings and American tapered roller bearings have ID's measured in inches.

**EXCEPTION TO THE EXCEPTIONS:**

Tapered roller bearings on foreign equipment will be measured in millimeters.

RULE #4 - The last two digits of the bearing number (when multiplied by 5) identify the bore or inside diameter of the bearing in millimeters. As an example, a 6210 bearing has a bore of 50 millimeters (10 X 5 = 50mm)

**EXCEPTIONS:**

- **XX00** - 10mm
- **XX01** - 12mm
- **XX02** - 15mm
- **XX03** - 17mm
**TANDEM BEARINGS**

Pumps sometimes have bearings installed in tandem or side-by-side. This is usually an angular contact thrust bearing application. Because they touch each other, it is very important that the housings be machined to special tolerances to insure that the loading is the same on both bearings. **NEVER use bearings from different manufacturers in tandem.** There will usually be some letters at the end of the bearing model number. Bearings that are made for tandem installation will be identified with the following letters at the end of the model number:

- FAG Bearings: 7210 BMP UA or UO
- SKF Bearings: 7210 BMP G
- FAFNIR Bearings: 7210 YO SU

**NEVER install bearings in tandem if they are not machined for tandem use.**

**EFFECTS OF SPEED AND LOAD ON BEARING LIFE**

When an engineer decides what type and size of bearing to use in a given application, the decision is based on the calculated speed and load at which the bearing will have to operate. The life of the bearing will be affected by changes in speed and loading on the bearing. Changes in speed will impact bearing life proportionally. If the speed of the bearing doubles, the expected life of the bearing will be reduced by 50%. Changes in load do not have a proportional impact on the bearing life. If the load on a bearing is doubled, the expected life of the bearing will be reduced by 90%.

**BEARING LUBRICATION**

Proper bearing lubrication is an important part of getting the designed life out of pump bearings. As strange as it may sound, more bearings have failed from over-lubrication than from lack of lubrication. In fact, some bearings never require lubrication and may fail if they are greased. Shielded and sealed bearings come factory-lubricated and have sufficient lubricant to last the life of the bearing. Shielded bearings have a metal skirt that is attached to the outer race. It covers the rollers but doesn't touch the inner race. Sealed bearings have a rubber skirt that does touch the inner race.

Bearings that do require periodic grease lubrication use a surprisingly small amount of grease when compared to the bearing housing size. A properly greased bearing will have a bearing housing that is never more than 25-30% full. The grease is responsible for lubricating AND cooling the bearing.

Grease that is inside the bearing will get hot as the bearing heats up. When the grease gets hot it becomes more fluid and is thrown out of the bearing and onto the wall of the bearing housing, where it cools. Grease that is outside the bearing is drawn into the race, where it again heats up and is thrown out. This process keeps the bearing lubricated and removes heat from the bearing. If the bearing housing is full of grease there is no way for the hot grease to get out of the bearing. The lubricant inside the bearing overheats and breaks down. The bearing overheats and fails.
Lubrication schedules for low-speed (under 2500 rpm) anti-friction bearing applications are based on the operating temperature of the bearing. Always refer to the vendor recommendations for the proper lubricant and lubrication frequency. If vendor data is not available, the following table represents a good rule of thumb for lubrication schedules:

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>once a year</td>
</tr>
<tr>
<td>150</td>
<td>once every 6 months</td>
</tr>
<tr>
<td>170</td>
<td>once every 3 months</td>
</tr>
<tr>
<td>190</td>
<td>once every 6 weeks</td>
</tr>
</tbody>
</table>

**Grease Lubrication Procedures**

The following procedure should be used for any grease lubricated anti-friction bearing that is not shielded or sealed:

1) Remove the drain plug from the bearing housing. This is usually located on the side opposite the grease fitting.

2) Run the pump for 5-10 minutes prior to adding new grease. Then stop the pump and lock and tag it for maintenance.

3) Waste the first shot of grease from the grease gun to remove contaminated grease from the tip. Add new grease to force the old grease out the drain. Continue until new grease comes out of the drain.

4) Restart the pump and allow it to run for 5-10 minutes while excess grease is expelled from the housing.

5) When no more grease comes out of the drain, stop the pump, re-tag it, and replace the drain plug.

6) Start the pump and allow it to run for 10-15 minutes. Check the bearing temperature. If it is too warm, remove the drain plug and allow the excess grease to be expelled again.

**Handling Bearings**

The most important thing to remember when handling bearings is to keep them **CLEAN**. Dirt in a bearing means damage and reduced bearing life. Always leave a new bearing in its protective wrapping until you are ready to install it. When you are ready to install it, keep the work area **CLEAN**! Clean hands, clean tools, and a clean work area are critical if contamination is to be kept out of the bearing.
The bearing is a precision instrument. It is manufactured to exacting tolerances. It does not take much to damage a bearing. The simple act of spinning a dry or dirty bearing can damage the polished races in the bearing and greatly reduce bearing life. NEVER spin a bearing with compressed air. If you drop a bearing on the floor or a table, the impact will probably cause scratches on the race. A bearing that has been dropped should not be put back into a pump. It is very likely to fail early. NEVER strike a bearing directly with a hammer! Most bearing suppliers will tell you when you strike a bearing you've ruined it. Many a bearing has been ruined before it ever saw any service because of improper handling and mounting techniques.

**REMOVING BEARINGS**

The extreme caution recommended in the removal and re inspection of bearings applies only when it is economically advantageous to consider re-using the bearings. **In most cases it is economically wiser to replace the bearings if they must be removed.** If bearings are to be re-use it is imperative that you use the right tools and use them correctly. There are several ways to remove a bearing from a shaft. An arbor press is the preferred method, but in the field a bearing puller is more commonly used. Here are some guidelines to follow to properly remove a bearing:

- A) Always clean the housing before disassembling it. Never allow loose dirt to get in the housing.
- B) Always press or pull the inner ring only. NEVER apply pressure or force to the outer race.
- C) NEVER press or pull against shields or cages.
- D) Block the press or adjust the puller so that it will pull or push square and straight.
- E) When using a puller, make sure not to damage shoulders, keyways, or threads on the shaft.
- F) When using a press, provide some means of catching the shaft so it doesn't hit the floor. Make sure the blocks are supporting the inner race.
- G) If a vise and drift are used, make sure the vise has brass jaws and never strike the shaft directly with a hammer.
INSTALLING NEW BEARINGS

Bearings in most pumps are designed to press onto the shaft instead of into the bearing housing. They can be mounted by force (pressed or driven) or they can be heated and mounted without force. Most small bore bearings (2" and smaller) can be pressed or driven on fairly easily. Larger bearings must be heated when installed.

Before installing a bearing make sure that the shaft and keyways are cleaned and polished with emery cloth to remove burrs and slivers. The bearing seats should be cleaned any oiled. The bearing shoulder should be cleaned and checked for runout using a dial indicator (see mechanical seals). If the runout is more than 0.003" the shaft should be reworked to square up the bearing shoulder. Misalignment of the bearing by 0.003" will reduce the bearing life by 90%.

HEATING THE BEARING

Bearings are heat stabilized to 250°F. This means that even though the metal expands when it gets hot, it will rerun to its original shape if the temperature does not exceed 250°F. When the bearing is heated to 190-220°F the inner race will expand enough to allow the bearing to slide on the shaft without the use of force.

Bearings can be heated using a small oven to supply dry heat, an oil bath similar to a deep fryer, or a light bulb placed under a steel funnel. The oven supplies a fairly constant temperature that can be monitored, but may not be practical in a field setting. The oil bath heater is messy and may contaminate the bearing if the oil gets dirty. The light and funnel heat the inner race directly, but temperature must be monitored closely.

One way to monitor the bearing temperature is with the use of a welder's temperature stick. This is a waxy substance that melts at a specific temperature. Marking the outside of the inner race with a "temp stick" that melts at 200°F allows you to quickly check to see if the bearing is hot enough to mount. Be sure to hold the bearing firmly against the shaft shoulder until it cools. If the heated bearing won't easily slide on the shaft, the shaft can be made smaller by packing it in dry ice to cool and shrink it.

Induction heaters that use magnet fields to heat the bearing can also be used. They are fairly expensive, but worth the cost if you have to replace many large bearings.
**PRESSING BEARINGS**

Many of the considerations for removing bearings are also true for installing them using force:

A) Pressure or impact must NEVER be transmitted through the rolling elements.

B) Always make sure the bearing is pressed onto the shaft straight and square.

C) NEVER strike the bearing directly with a hammer.

D) NEVER allow any force to be applied to the shields or cage.

E) If the shaft is held in a vise, make sure to use brass jaws.

F) Make sure the bearing is securely seated against the shaft shoulder.

G) Once the bearing is on the shaft, cover it to protect it until the unit is completely assembled.
MECHANICAL SEALS

Mechanical seals are sometimes used instead of packing to prevent leakage where the shaft enters the stuffing box. The most common type of mechanical seal has two faces, which mate to prevent water from passing through them. One of the seal faces, the insert, is mounted stationary in the gland ring that bolts to the stuffing box. The gland ring replaces the packing gland that is used in packed pumps. The other seal face, the seal ring, is mounted on the shaft and rotates. The face of the seal ring is held against the insert face by a spring, or set of springs, that is compressed and positioned by a locking collar.

As we mentioned earlier, the spring forces the seal faces together when the pump is not running. Seal water is used to force the seal faces apart when the pump runs. This prevents the seals from rubbing and overheating. Failure of the seal water system can quickly cause a seal failure. The life of a mechanical seal is also dependent on the tolerances and condition of the shaft, pump bearings, and the stuffing box. A shaft that is bent, bearings that are worn, or a stuffing box face that is not square will result in a premature seal failure. And it doesn't take much to cause a seal failure. As we will see later, being off by as little as 0.002"-0.010" can cause a seal to fail early. The same rule of thumb that applies to using expensive packing materials also applies to the use of mechanical seals. Don't use a mechanical seal if you are not going to check and maintain the tolerances in the rest of the pump.
MECHANICAL SEAL COMPONENTS

Some older pumps may use a single spring mechanical seal like the one described on the previous page. Many newer pumps will use a multiple spring mechanical seal. There are several advantages that a multiple spring seal has over a single spring unit. The small springs are not as susceptible to distortion at high speeds as are the larger single springs. As a result, they will exert a more even closing pressure on the seal ring at all times. The same size spring can also be used on a wider range of shaft sizes.

The components of a multiple spring seal should be broken into two groups. One group forms the stationary unit of the seal and the other group forms the rotary unit.

THE STATIONARY UNIT

The stationary unit consists of the gland ring, the seal insert, the insert mounting ring, and the gland gasket. The gland ring holds the seal insert. The seal insert is held in place and positioned by an Insert mounting ring (usually an O-ring). The O-ring also prevents leakage between the insert and the seal gland plate. The gland gasket prevents leakage between the gland plate and the stuffing box face.

THE ROTATING UNIT

The rotating unit of the seal consists of a locking collar, springs and spring pins, a compression ring, drive pins, shaft packing O-ring, and the seal.

The collar of a multiple spring seal is usually secured to the shaft with set screws. The springs and spring pins link the compression ring to the collar. The compression ring presses against and seals the shaft-packing ring to prevent leakage around the shaft. The shaft seal presses against the seal ring to hold it against the insert. The drive pins extend from the compression ring into the seal ring and are used to spin the seal ring.

SEALING POINTS

There are four main sealing points inside the mechanical seal. The primary seal is at the seal face, Point A. If a seal leaks from this point it will need repair or, more likely replacement. The shaft packing and insert mounting rings seal leakage at Points B&D. Point C is sealed by the gland gasket. Anytime a mechanical seal leaks, there is a problem that will require some work to correct. However, there is only one point, the point at the seal faces that will likely require replacing the seal. Leakage at any of the other points can be fixed by replacing an inexpensive O-ring instead of a $500 seal. The labor required to replace the O-ring will vary depending on whether it's the gland gasket or the shaft packing ring that must be replaced.
SEALING POINTS ON A MECHANICAL SEAL
MECHANICAL SEAL INSTALLATION

A mechanical seal installed in a pump that meets all original manufacturer specs may last 20-25 years. This is the reason that systems choose a pump with a $500 mechanical seal instead of one that uses $15 worth of pump packing. However, when the condition of a pump is allowed to deteriorate, a mechanical seal may not last as long as a packing would in a new pump.

CHECKING PUMP TOLERANCES

If mechanical seals are used, the pump must be maintained to some very strict tolerances with regard to the shaft and stuffing box. Before checking these measurements, the shaft and stuffing box should be cleaned and buffed. All burrs and sharp edges on keyways should also be removed. Every time a seal is replaced, the procedure should include checking the following shaft and stuffing box tolerances:

MAXIMUM ENDPLAY - 0.010"

Endplay is the axial or lateral (end-to-end) movement of the shaft. A dial indicator is placed against the shaft shoulder. The shaft is tapped on both ends with a soft mallet and the results are read on the dial indicator. This reading should not exceed 0.010".

MAXIMUM SHAFT DEFLECTION - 0.002"

The maximum shaft deflection or whip (side-to-side) movement should not exceed 0.002". The shaft deflection is measured by placing the dial indicator as close to the stuffing box face as possible and lifting the shaft at the impeller end to check the side-to-side movement. Excessive movement is usually due to damaged bearings.
CHECKING FOR SHAFT DEFLECTION OR WHIP

MAXIMUM SHAFT RUN-OUT - 0.003"

Shaft run-out is caused by the wobble of a bent shaft. Run-out should be checked by taking readings on at least two points on the shaft. First, place the dial indicator on the shaft in the area of the stuffing box face and turn the shaft. Then move the dial indicator to the coupling end of the shaft and repeat the measurement. Excessive run-out will result in bearing damage, which will cause vibration. The vibration will cause a premature seal failure.
MAXIMUM STUFFING BOX FACE RUN-OUT - 0.005"

If the stuffing box face is not perpendicular to the shaft, the seal insert will not mate squarely with the rotating seal. This misalignment will cause the seal to wobble as it spins, again resulting in premature seal failure. This is measured by attaching the dial indicator to the shaft with the stuffing box bolted in place. The instrument is then placed against the face of the stuffing box and the run-out is measured as the shaft is turned.

CHECKING FOR STUFFING BOX FACE RUN-OUT

MAXIMUM STUFFING BOX ECCENTRICITY - 0.005"

When the stuffing box is concentric to the shaft, the distance from the outside of the shaft to the inside of the stuffing box is the same all the way around the stuffing box. If it is closer on one side than the other it is said to be eccentric to the shaft. This condition places the seal faces off-center and alters the hydraulic loading of the seal faces which will reduce the seal life. This is measured by attaching the dial indicator to the shaft, as with stuffing box face run-out, and measuring either the bore (inside) and register (outside) of the stuffing box.

CHECKING FOR STUFFING BOX BORE ECCENTRICITY
INSTALLING SEALS

Before attempting to install a mechanical seal, be sure to look at the engineering drawing that comes with it. There are a number of dimensions shown on these drawings, but one of them is very important to the proper installation of the seal. On the drawing you will find a dimension that identifies the distance from the face of the stuffing box to the back edge of the locking collar on the rotating element. This is known as the location dimension. It will allow the locking collar to be positioned at a point on the shaft that will give the seal the proper compression when the gland ring is installed. The location dimension for the seal shown below is distance "E".

Once the location dimension has been determined and the shaft and stuffing box have been dressed, the following procedure should be followed to properly install the seal:

1) Scribe a reference mark (also called the witness mark) on the shaft that will line up with the stuffing box face.

2) Remove the shaft and scribe another mark, the location mark, on the shaft that is the same distance from the reference mark as the location dimension on the drawing.
3) Lubricate the shaft with a silicone lubricant (usually supplied with the seal.)

4) Mount the insert in the gland ring. Lightly lubricate the insert mounting O-ring and position it in the gland ring. Gently press the insert into the gland ring and seat it. Always try to avoid direct contact with the seal face. Make sure your hands are clean in case you do have to apply pressure directly to the seal face as you seat it.

5) If the seal is being installed from the impeller end of the shaft, slide the gland ring over the shaft and past the reference mark. Avoid bumping the insert against the shaft. If the seal is installed from the coupling end of the shaft, the gland ring will go on last.

6) Install the rotary unit parts on the shaft in the proper order. Lubricate the shaft packing O-ring and take care not to roll or pinch it as it slides into place. Again, try to avoid contact with the seal face.

7) Set the back of the locking collar on the location mark and tighten the set screws firmly and evenly.

8) Reassemble the pump, making sure to clean and flush the stuffing box.

9) Seat the gland ring and ring gasket to the stuffing box face by tightening the gland nuts/bolts evenly and firmly. Check manufacturer's specs for proper torque.
STARTUP PROCEDURES

The following recommendations cover startup procedures for most mechanical seals:

A) **Never run a seal dry!** It probably won't hurt to bump the motor to check rotation, but running the seal dry for even a few seconds can seriously damage it.

B) Vent the stuffing box before starting the pump. Even if the pump has a flooded suction, air can still get trapped in the upper portion of the stuffing box. This is especially important in vertical installations.

C) New seals may leak somewhat during initial startup. Allow a reasonable amount of time (30-60 minutes should do it) for the seal faces to "wear-in" to each other.

D) Do not open the seal faces for inspection unless absolutely necessary. Seals establish a wear pattern which micro-scopically matches the two faces. When the insert is removed it cannot be put back together with any hope of matching the original wear pattern.

E) Outside seals on vertical turbine pumps can be set by raising and lowering the shaft with the adjusting nut on top of the motor. Raise the shaft the distance equal to the compression distance for the spring. Lock the rotating assembly on the shaft and then lower the shaft to compress the spring. **ALWAYS free the rotating assembly on a vertical turbine pump before attempting to adjust the impeller clearance or damage to the seal may result.**

CARTRIDGE MECHANICAL SEALS

Cartridge mechanical seals are being used to replace the outside seal assemblies on a vertical turbine pump. A cartridge mechanical seal consists of a pre-loaded and pre-set mechanical seal that is mounted to a seal gland plate. The seal assembly simply slides over the end of the shaft and mounts to the stuffing box. The rotating seal assembly is then secured to the shaft with setscrews. The seal water line is attached to the seal gland.

The main advantage of the cartridge mechanical seal is that the lateral adjustment process is easier to accomplish because the shaft can slide up and down in the seal without affecting the seal setting. Simply loosen the shaft setscrews, move the shaft, and re-tighten the screws.
STUDY QUESTIONS

1. What does the bearing first identification number represent?

2. Where should the lantern ring be located in the stuffing box?

3. Which part of the mechanical seal attaches to the shaft?

4. What is the term for the measurement of the circularity of a rotating shaft?

5. What is the advantage of a cartridge mechanical seal?

SAMPLE TEST QUESTIONS

1. What is the function of grease in a bearing?
   A. Lubrication
   B. Prevents corrosion
   C. Cooling
   D. All of the above

2. The packing gland should be tightened until the leakage has stopped.
   A. True
   B. False

3. Always apply force to the outer race when pressing a bearing on a shaft:
   A. True
   B. False

4. The stationary seal face is located:
   A. On the shaft
   B. In the seal gland
   C. On the motor coupling
   D. Next to the wear rings

5. Before working on a pump, you should first:
   A. Log it on a work order
   B. Remove the coupling shield
   C. Lock and tag it out

6. If you double the load on a bearing the bearing life is reduced by:
   A. 10%
   B. 20%
   C. 50%
   D. 90%

7. How many sealing points are there on a mechanical seal?
   A. 1
   B. 2
   C. 4
   D. 6
GROUNDWATER AND WELLS

HYDROLOGIC CYCLE

Water is being exchanged between the earth and the atmosphere all the time. This exchange is accomplished with energy supplied by the heat of the sun and the pull of gravity. Water that enters the atmosphere from wet ground, lakes, rivers and the ocean is known as evaporation. Plants also release water to the atmosphere. This process is known as transpiration. It is carried in the air as water vapor. When the water vapor cools and condenses, it changes from a gas to a liquid and falls back to earth as precipitation in the form of rain, sleet, snow, or hail. Evaporation from land and ocean puts water back in the atmosphere, and the exchange goes on continually as water goes from earth to atmosphere to earth. For this reason the exchange of water between earth and atmosphere is called the Hydrologic Cycle.

When precipitation falls, part of the water runs off into natural channels, part of it evaporates, and the remainder seeps or infiltrates into the ground. The amount of water that percolates farther into the ground water supply depends on the type of soil it must pass through and how much water is retained in the root zone. Plants retain the water in the root zone and release it back to the atmosphere as transpiration. Percolation is the most common means of recharging ground water supplies.
GROUND WATER SUPPLIES

Water will continue to percolate down through the earth until an impervious stratum is reached. An impervious stratum is a layer of material in the earth that will not allow water to pass through it. This material is usually made of rock formation or clay. As the water reaches the impervious stratum it will begin to collect and saturate the surrounding soil, forming an aquifer. It is a common belief that the water quality of an aquifer is constant throughout the aquifer. In fact, the water quality can change dramatically within the confines of a given aquifer. This can be attributed to changes in the medium or mineral deposits in the zone of saturation. Aquifers are generally classified as Water Table (unconfined) and Artesian (confined).

WATER TABLE AQUIFER

An aquifer that is formed from a single impervious stratum and has an upper surface that is free to rise and fall with seasonal changes of recharge rate is known as a water table or unconfined aquifer. This condition allows the free flow of water in the aquifer generally in the same direction as surface water. The water level in a well located in a water table aquifer will not rise above the initial point of encounter. A perched aquifer is a very small, unconfined aquifer that doesn't contain much water and is only recharged by local precipitation.

ARTESIAN WELLS

Artesian wells originate from ground water that is trapped between two impervious strata. As the water flows between these strata it becomes confined and as recharge continues, the water backs up, creating pressurized conditions in the aquifer. Water in a well located in an artesian aquifer will rise above the point at which it is first located. If the water rises to the surface it is a free-flowing artesian well. If not, it is called a non-flowing artesian well.

TYPES OF GROUND WATER FORMATIONS

The saturation zone of an aquifer may be any one of several different materials. Most aquifers occur in formations of sand or gravel. Others may be found in limestone, sandstone, shale, clay, or even silt. The type of formation will influence the water quality and yield of a well.

WATER WELL LOCATION

Several factors are involved in selecting a site for a new well. The most important of these is finding adequate quantities of water that will meet SDWA drinking standards with the minimum amount of treatment. Potential pollution of the water supply is another major concern. Economics related to purchasing easement and connecting to the system, and population or demand within the system will also be factored into the decision. Finally, politics can become an issue in some cases.

Consulting engineers will rely on well logs from other wells in the area, geological data, and test holes to determine where the best chance of finding the appropriate quantity and quality of water exists. But even then, drilling a water well is still a hit or miss proposition.
SANITARY CONSIDERATIONS

Sanitary hazards must be considered when locating a well. NMED should be consulted regarding requirements concerning well location, especially with regards to potential sources of pollution. The minimum distance from a well to a potential pollution source should be at least 200 feet. Potentially hazardous conditions such as petroleum storage areas, chemical or radioactive disposal sites, and industrial waste treatment facilities may require special consideration as far as well location is concerned. Wells should never be located in a 100-year flood plain.

WATER WELL CONSTRUCTION

Water wells may be classified according to the method of construction. The type of construction will depend on the depth of the well, the geological formations to be encountered, and the amount of water needed for the system.

Small wells, particularly private wells, may be dug or driven. Public water systems usually require more water than either dug or driven well can produce. The most common method of construction used by public water systems is the drilled well. These wells are ideally suited to deep water bearing formations where larger yields are available. This type of well, when properly constructed offers good protection against contamination from the surface. Two different methods of constructing drilled wells are the cable tool or percussion method and the rotary drilling method.

CABLE TOOL METHOD

The impact created by raising and dropping a heavy drill bit and stem crushes and dislodges pieces of the formation as the well is drilled. The up and down motion of the drill bit mixes the cuttings with water to form slurry and a bailer is used periodically to remove the slurry. A bailer is made of a 10 to 20 foot section of pipe with a foot or check valve at the bottom. The casing is usually put in place as the well is drilled, especially in loose formations such as sand and sandy loam. Wells drilled by the cable tool method are more likely to have problems with vertical alignment than those drilled by the rotary method.

ROTARY DRILLED WELLS

These types of wells use power driven drill stems, which in most cases are hollow. The drill bit is attached to the lower end of the drill stem and breaks up the material as it advances. Water or drilling mud is pumped down the drill stem to cool the bit. It also picks up the cuttings or drilling fines and carries them to the surface. The mixture of mud cuttings is discharged to a settling pit where the cuttings are removed and the drilling mud is recirculated. When the well hole is completed, the drill stem is withdrawn and the casing is put in place.

VERTICAL CASING ALIGNMENT

It is important that the casing is in proper vertical alignment when it is installed. Even a slight misalignment may create stress on the pump shaft and bearings that can lead to mechanical failures. If a casing is misaligned, it may be necessary to install a submersible well pump instead of a line shaft pump. This may be the only solution to chronic line shaft failures in a misaligned casing. There are several ways to check casing alignment. Down hole TV inspection is popular because the condition of the casing and screen can be checked at the same time.
SANITARY PROTECTION OF THE WELL

After a well has been drilled, care must be taken to prevent any surface contamination from entering the water supply. First, the casing is set to prevent the well from caving in or becoming contaminated from undesirable water sources located above the aquifer. The casing should be grouted with concrete on the outside to a depth of at least 50 feet or until an impervious layer of clay or rock is encountered. It may be necessary to grout deeper than this to seal any undesirable water formations off the well. The depth of grout is determined by NMED on a case-by-case basis. In most instances, grouting will be required to extend to the water table. The grout must be pumped into the well from the bottom to the top. Otherwise, air will be trapped and prevent proper sealing of the cavity.

The casing should extend at least 6 to 12 inches above the well pad, depending on whether the well is located in a well house or out in the open, to prevent standing water from entering the well. The well pad should be sloped away from the casing. A sanitary well seal must be used to connect the well head and motor to the casing. Well seals are usually made of rubber or neoprene. A welded seal is also approved and used in some cases.

Well casing and discharge column pipe vents should extend at least 18" above grade. The outlets should be turned down to prevent rainwater from entering and screened to keep bugs out. Well housings should never be located in a pit. Abandoned wells should be plugged to a depth of at least 10 feet. In some states they must be completely cemented.
DEVELOPING A WELL

Once construction is complete, the well is developed to remove the very small sand, shavings, and drilling mud from the surrounding aquifer. Two methods used to develop the well are surging and backwashing. Water is forced in and out through the screen as it flushes out the drilling mud and fine sand. Usually a pump much larger than the actual production pump is used. The well is pumped at the highest rate possible. This is done not only to remove the loosened mud but also to determine the well log data such as the yield, static and pumping levels, and specific capacity. The development of this data may require that this pumping rate be maintained for at least 8 hours.
It may take much longer to clear the well of drilling mud prior to disinfection. It is also important to determine the well recovery rate after the test is completed. The pump used to develop the well should never be the pump that is to be installed upon completion.

**Gravel Pack Wells**

Wells that are located in fine sand formations, where sand pumping presents a problem, are usually gravel packed. If gravel packing is not used, the screen openings may have to be so small that the yield of the well is dramatically reduced. A layer of gravel is placed around the screen to hold the sand back and allow a larger well screen to be installed. The gravel packing is usually three times the diameter of the well screen or a minimum of 4" thick. The selection of the size of the gravel to be used depends upon the type of sand formation that is encountered and the type of screen that is being installed.

The gravel does not filter the sand. It is the increasing velocity, as the water gets closer and closer to the screen, which draws the sand into the well. The gravel pack holds the sand out away from the screen where the velocities are significantly lower than they are at the point where the water enters the screen. This minimizes the amount of sand that enters the well.

As sand is pumped out of the well, the gravel will fill in the cavity that is created and the gravel level will drop. This can result in exposing the well screen if gravel is not added periodically. The gravel is usually added to the well through a gravel packing pipe. This pipe is usually 4 inches in diameter. The level of the gravel pack should be checked at least yearly.

Gravel should be cleaned and disinfected with a strong chlorine solution before it is added to the well. The level should be rechecked as the new gravel is added. Gravel should never be allowed to stand in the packing pipe. The vibration that is created when the pump is running can cause the gravel to compact and block the pipe.
DISINFECTING WATER WELLS

The final step, prior to putting any new well, or old well that has had major cleaning or repair, in service, is disinfection and testing for bacteriological quality. The well should be flushed or redeveloped to remove drilling mud and debris prior to disinfection.

Disinfection is achieved by the addition of a strong solution of chlorine to the well. The chlorine dosage should be at least 50 mg/l. If dosages in the range of 200-400 mg/l are added, less contact time will be required. The well should then be agitated periodically by surging. The contact time at a dosage of 50 mg/l should be 18 to 24 hours but at 200 mg/l only about 2 hours is needed. However, with longer contact times, the chlorine will move farther out into the surrounding aquifer.

The well should be flushed to remove the remaining chlorine once disinfection is completed. The bacteriological (Bac-T) samples should then be taken from the well and submitted for testing. These samples must be taken daily until they are negative on two consecutive days.

REFERENCES:

Groundwater and Wells, 2nd Edition, 1986, Chapter 4

WELL PUMPS

Most well pumps that are installed in public water systems are vertical turbine centrifugal pumps. The main difference between vertical turbines and other types of centrifugal pumps is that the vertical turbine impeller discharges water out of the top of the impeller. This water flows upward along the pump shaft, instead of at a right angle to the shaft. These pumps can generate the high discharge pressures needed to pump water several hundred feet out of the ground.

"Staging", or stacking several impellers on the shaft, is how the high pressures are generated. As the water passes from the discharge of one impeller to the suction of the impeller above it, the pressure that the pump develops is increased. If five impellers that each generate 100 feet of head are staged in a pump, the pump will generate 500 feet of head pressure. Anytime pumps are operated in series, where one pump or impeller discharges to the suction of another pump; the pressure will increase while the flow remains constant.

In some very small, shallow wells airlift pumps may be used. These are normally not suitable for wells supplying most public water systems.

VERTICAL TURBINE INSTALLATIONS

There are two kinds of vertical turbine pumps installed in wells. One of these is known as a submersible pump. A submersible pump will have the motor located beneath the pump. In a small well, it is the least expensive centrifugal well pump to purchase and install. Because there is no pump shaft running to the surface, the submersible is also the ideal pump installation in wells where vertical casing alignment problems exist. The biggest disadvantage of submersible pump installations is that the pump must be pulled from the well when the motor needs repair. Since this is usually the most common type of repair for water wells, the cost of maintenance for submersible pumps is very high.

The other type of vertical turbine well pump is known as a line shaft pump. Line shaft pumps have the motor located on the well head. A line shaft runs down the discharge column pipe to the pump. The shaft is supported by line shaft bearings that center and stabilize the shaft in the column pipe. Line shaft pumps will cost more than submersible installations.
VERTICAL TURBINE CENTRIFUGAL PUMP
Vertical casing misalignment may make a line shaft pump installation impractical. The stress placed on the shaft and bearings can lead to chronic maintenance problems. The biggest advantage of a line shaft installation is that the motor can be repaired without pulling the pump and column pipe from the well.

**LINE SHAFT PUMPS**

The line shaft must be supported to minimize vibration and radial (side-to-side) movement when the shaft spins. A line shaft bearing, also known as spider support or spider bearing, will be located in every section of discharge column pipe. Since column pipe sections vary in length from 12 to 20 feet, there are 5-8 bearings for every 100 feet of shaft. These bearings must be lubricated. There are two methods of lubricating line shaft bearings. One method utilizes water to lubricate the bearings while the other uses an oil-lubricated system.

**LINE SHAFT BEARINGS**

Water lubricated line shaft bearings rely on the water that is pumped through the column pipe for cooling and lubrication. When the water table is very shallow, water in the column pipe will reach the bearing almost immediately. If the water table is deeper it can take several seconds for water to reach the uppermost bearings. If these brass or rubber bearings are allowed to spin for even a few seconds without lubrication they will fail prematurely. This type of installation will normally have some type of pre-lubrication system that allows water to run down the shaft and lubricate the top bearings before the pump starts. It may be set on a timer or it may drip continuously. Even with this type of pre-lubrication system, it is difficult to guarantee that all of the bearings that are located above the water table are properly lubricated before the pump starts.

Oil lubricated line shaft pumps are normally installed when water table depths exceed 100 feet. In an oil-lubricated system, the shaft spins inside a tube that is kept full of oil. The oil used in these systems must be EPA approved. These oils can be either vegetable or mineral based. Line shaft bearings are located inside the tube. Spider supports stabilize the tube inside the discharge column pipe.

**OIL Dripper Systems**

Oil lubricated line shafts will usually be supplied with a dripper system to keep the shaft tube full of oil. The dripper system will consist of two dripper assemblies. One dripper will be setup to drip constantly and the other will be activated by a solenoid and will drip only when the pump is running. The solenoid-activated dripper will normally be supplied with a cooling water jacket that helps to maintain a constant oil temperature in the dripper.

The cooling water is needed because temperature fluctuations will cause the viscosity or thickness of the oil to change. As the viscosity changes the drip rate will also change. The effect that these changes will have on the drip rate must be taken into consideration when the drip rate is adjusted. The drippers should be checked and adjusted at least twice a year, in the early summer and early winter.

Peristaltic pumps can be used in oil dripper systems. They will always feed at a constant drip rate regardless of the viscosity of the oil. They can provide a higher degree of protection and reduce line shaft failures.
WATER LUBRICATED

1 - Line Shaft
2 - Shaft Coupling
3 - Column Pipe
4 - Column Pipe Coupling
5 - Stabilizer Support (Spider)
6 - Rubber Shaft Bearing

7 - Snap Ring
8 - Shaft Sleeve
9 - Column Pipe Spacer Ring
10 - Oil Tube
11 - Line Shaft Bearing
12 - Tube Stabilizer (Spider)

OIL LUBRICATED

SHAFT LUBRICATION SYSTEMS
**ADJUSTING DRIPPER SYSTEMS**

The constant dripper should be adjusted when the well has not been running for several hours. The oil temperature will be about the same as the ambient air temperature. This is the situation most of the time that the constant dripper is needed. If it is set in the summer and not checked again when it turns cold in the winter, the drip rate will be much lower as the oil temperature drops and the oil becomes thicker. The constant drip rate should be set at 1 drip/minute.

The automatic dripper should be set after the well, and dripper-cooling water, has been running for an hour or so. If the drip rate is set when the well is not running and the oil temperature is higher, the drip rate may be too low when the cooling water lowers the oil temperature. In most wells, the automatic drip rate should be set at 6-10 drips/minute. Wells over 500 feet deep may require drip rates of up to 18 drips/minute. If wells are only run at night, to take advantage of lower electric rates, then the drippers should be adjusted at night. Otherwise the drip rate will be lower when the evening temperatures drop.

**WELL SCREENS**

There are several types of well screens that can be installed in most wells. They range from well casing that is perforated on-site with a cutting torch to continuous-slot well screens made of steel, or sometimes plastic, strips that are wrapped around a wire cage. Louvered or perforated casing is also used in many installations. Continuous-slot screens are the most expensive and generally considered to be the best choice because of the low friction loss encountered as the water enters the well. These screens typically have openings that are equal to 40-50% of the total surface of the screen.

**REFERENCES:**

WELL HYDRAULICS

The amount of water a well will produce depends mainly on the type of aquifer, well construction, and the depth of the zone of saturation. The annual recharge rate from percolation, along with the ability of the water bearing formation to transmit water to any given point, will also influence well production. The performance of a well can be determined by taking readings of the hydraulic conditions. An operator must be familiar with these terms and definitions, in order to accurately troubleshoot problems that may be discovered.
**Static level** is the water level in a well when the pump is not operating.

**Pumping level** is the water level in the well when it is producing.

**Drawdown** is the difference in elevations between the static level and the pumping level. The amount of water produced is approximately proportional to the drawdown. For example, increasing the yield by 10% will increase the drawdown by 10%. The drawdown that occurs when a well is running is roughly equal to the head loss encountered in moving the water into the well. Water bearing formations of gravel, limestone and coarse sand will usually provide more water with less drawdown than formations containing fine sand or clay.

**Specific capacity** is the relationship between the yield of a well and the amount of drawdown in the well. It can be expressed as a ratio of the yield, in terms of gallons per minute, to the drawdown in feet. A well producing 100 gpm with a drawdown of 20 feet would have a specific capacity of 5 gpm per foot of drawdown.

\[
\frac{100 \text{ gpm}}{20 \text{ feet}} = 5 \text{ gpm/foot}
\]

In this particular case every time the yield is increased by 5 gpm the drawdown will increase by one foot. This relationship will exist until the yield exceeds the aquifer's ability to deliver water to any single point. When this limit is reached, the drawdown increases dramatically with little or no increase in the yield.

**Cone of depression** is directly related to the drawdown in the well. As the pump draws down the water level, a portion of the aquifer surrounding the well is drained of water. A cone shaped depression is formed in the water table around the well. The shape of the cone will vary depending on the type of formation in which the well is located. A fine sand formation will usually create a steep cone of depression, while a shallow cone is usually found in coarse sand and gravel formations.

**Radius of influence** is the farthest distance from the well that the cone of depression affects the water table. This distance can be determined by sinking test holes around the well and monitoring the water levels in them while the well is pumping.

**Recovery time** is the amount of time required for the aquifer to stabilize at its static water level once pumping has stopped. This can also be determined by monitoring the water levels in the test holes used to determine the radius of influence.

**MEASURING STATIC AND PUMPING LEVELS**

Several methods can be used to determine the elevation of water in the well. This can be accomplished by lowering some type of measuring device, that can locate the water level, into the well casing through a sounding tube (sometimes called a drawdown tube). A chalk line can be used if the approximate level is known. The bottom five to ten feet of the line is chalked and then lowered into the well to the estimated water level. The amount of line that is wet (easily identified by the wet chalk) is subtracted from the total amount lowered into the well to accurately locate the water level.

Another device that is used to determine water levels consists of an electrode attached to a cable and connected to a DC power supply. This type of device is sometimes referred to as an "M-scope." The electrode is lowered into the well casing until it contacts the water surface. Contact with water closes the electrical circuit and lights an indicator lamp on the power supply. The length of the cable that is in the casing is measured to determine the water level. The biggest disadvantage to
using this type of "sounding" device is that the cable may wrap itself around the column pipe, making removal a real problem.

Another effective method of determining these levels involves using an air line. The air line is installed inside the casing and extends down to a point just above the bowls of the pump. A pressure gauge, installed at ground level, and an air pump (bicycle or hand pump) are all the equipment that is needed. The length of the air line must also be known in order to use this method.

As air is pumped into the line, the pressure gauge reading will begin to increase. When the pressure reading no longer rises, all of the water has been forced out of the pipe by the air. This gauge reading will represent a column of water the same height as the distance the line extends below the surface of the water. Subtracting this distance from the total length of the line will locate the elevation of the water in the well. The gauge reading may be used directly if the gauge is calibrated in feet of head. If the gauge reading is in pounds per square inch (psi), it must be multiplied by a factor of 2.31 ft/psi before being subtracted from the length of the air line. As an example, the air line is 300 feet long and the gauge reading is 100 feet of head when the pump is not running:

\[
300 \text{ ft.(air line)} - 100 \text{ ft.(head)} = 200 \text{ ft. to the water}
\]

The static level is determined after the pump has not been running for several hours or overnight. The pumping level should not be determined until the well has been pumping long enough to insure that the pumping level has stabilized. It could take from 30 minutes to several hours to stabilize the pumping level.
THE WELL LOG

When the contractor is developing the well, information about the well is being recorded for the well log. A well log will contain information that includes:

<table>
<thead>
<tr>
<th>WELL LOG DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Depth of the Well</td>
</tr>
<tr>
<td>- Length of Screen</td>
</tr>
<tr>
<td>- Pump Setting</td>
</tr>
<tr>
<td>- Yield</td>
</tr>
<tr>
<td>- Static Water Level</td>
</tr>
<tr>
<td>- Pumping Water Level</td>
</tr>
<tr>
<td>- Drawdown</td>
</tr>
<tr>
<td>- Specific Capacity</td>
</tr>
<tr>
<td>- Other Geological Data Regarding the Aquifer</td>
</tr>
</tbody>
</table>

The well log is essential for troubleshooting well operational problems. It represents how the well should perform when everything is working right. Without this data it is very difficult to determine what, if anything, is wrong with current the well performance. If a well is over 20 years old, there is a good possibility that the well log can't be located. This is no reason to panic yet. Contractors are responsible for filing a copy of every public water supply well log with the State Engineer's Office. Copies of well logs can be obtained by contacting the State Engineer. Information on surrounding wells may also be obtained to assist in gathering data used to locate new wells.

REFERENCES:

*Groundwater and Wells, 2nd Edition, 1986, Chapter 9*
TROUBLESHOOTING WELL PROBLEMS

There is little information that can be gathered that will indicate how a well is performing. Changes in the static level, the pumping level or the yield of a particular well will generally indicate a problem has developed. In addition to this information, the amps on the motor is the only other indicator poor of well performance. It is important to check static and pumping levels periodically to prevent any problems that may develop from becoming serious. The well log is used as a reference for each set of readings. Anytime there is a well problem, both the yield, and the specific capacity will be reduced.

WELL RELATED PROBLEMS

Let's take as look at the example illustrated below. From the well log and current measurements it has been determined that the static level has remained the same but the pumping level has dropped several feet.

Under these conditions it should be noted that the drawdown has increased. The drawdown is equal to the head loss encountered in moving water into the well. Since the drawdown has increased, there is more head loss now than when the well was new. It is unlikely that the conditions in the aquifer have changed. Therefore, the well screen must be getting clogged.

CLOGGED WELL SCREENS

There are several ways that a well screen can become clogged. The most common cause is chemical scaling or lime encrustation on the screen. Newer wells may develop a condition called "sand bridging." Another possibility is clogging due to iron bacteria colonies that are growing on the screen.
**SAND BRIDGING**

Sand bridging is a condition that is normally only found in new wells. It occurs when sand, drawn toward the well, blocks the screen by forming an arch across the openings.

Sand bridging is usually a result of improper development of the well or inadequate gravel packing. Surging water through the screen may break up the bridging. If surging doesn't work, it may be necessary to pull the pump and mechanically clean the screen with high-pressure jets to correct the condition. The well should be re-developed before replacing the well pump.

**IRON BACTERIA**

Clogging caused by iron bacteria is a problem for many wells in the Southwest. If the well has been in service for several years, and the water supply is low in alkalinity and corrosive, there is a good possibility that the clogging is a result of the build up of iron bacteria colonies on the screen. Iron bacteria feed on the iron that is naturally present in some supplies. They will attach themselves to iron and steel screens and a colony of the bacteria will begin to grow. Clogging caused by iron bacteria is very difficult to remove. Chemical treatment with massive doses of chlorine (200-300 mg/l) followed by surging or even mechanical cleaning may be the only means of clearing clogged screen openings. Even then, it is unlikely that the entire colony has been removed. The remaining bacteria will begin to grow, causing a recurrence of the problem. Wells with iron bacteria should be treated with chlorine periodically to inhibit the regrowth for as long as possible.

**LIME SCALING**

Lime scaling is most likely to occur when the water contains high amounts of alkalinity and hardness. Like iron bacteria, lime scaling will tend to be a chronic problem where the conditions that promote its formation exist. There are several ways to clean a screen of lime scale.
CLEANING SCALED WELL SCREENS

Well screens that are clogged with scale can be cleaned using one of several techniques. The four most commonly used methods are listed below:

1. **Surging** water through the screen may break up loose scale that is just beginning to form. This is accomplished by starting and stopping the pump to allow water in the column pipe to fall back into the well and create a surge out through the screen. This is sometimes taken a step further by holding the check valve open when the pump is stopped so that more water will rush down the well and out into the surrounding aquifer. In order for this method to be effective, the condition must be identified before the scaling becomes very severe.

2. The **percussion** method may be the most dangerous method of cleaning a well screen. It involves the detonation of some type of explosive within the well casing. The theory behind this process is that the explosion will create shock waves that will vibrate the screen enough to shake the scale loose. This is sometimes accomplished by firing a blank down the well. This is only effective in very small, shallow wells where there is not much water standing above the clogged screen.

   In most public supply wells a larger charge is needed, and it is usually placed down the well in the vicinity of the screen. Blasting caps and primer cord are the most common explosives used in these situations. In addition to the obvious dangers involved in handling these types of explosives, the possibility for damaging the well screen also exists.

3. The **acidizing** method will clean all but the most severely scaled screens. Acid is poured down the well casing and allowed to stand for 8 to 12 hours. The acid will react with the lime and dissolve the deposits on the screen. The well is then surged to help loosen the remaining scale and flushed.

   **Always use inhibited acid!** Inhibited acid is chemically weakened. In this weakened state it will dissolve the lime without attacking the screen or pump parts. There are inhibited acids available in solid forms, sulphamic acid for example, that can make the acidizing process much easier and more effective. The pelletized acid can be poured into casing where it will sink to the bottom of the well and dissolve in the area of the screen.

4. **Mechanical cleaning** may be the only method that is effective in situations where severe clogging exists. Mechanical cleaning will require the removal of the pump from the well. The screen will be cleaned using a larger wire brush or high-pressure water jets and then bailed to remove the debris that is knocked loose. In extreme cases, the screen may have to be pulled and cleaned or replaced. Not only is this very expensive, but it can also result in the collapse of the gravel pack around the screen. Anytime the pump is pulled from the well and maintenance is performed, the well must be disinfected prior to being put back into service.
**PUMP RELATED PROBLEMS**

From the well log and current measurements, it is determined that the static level is the same, but the pumping level has risen several feet. Water production from the pump has also decreased. This reduced drawdown and yield from the well indicates a problem with the pump.

![Well Log and Current Data Diagram](image)

When the drawdown and pump production have both decreased, it usually means the pump efficiency is reduced. The most common cause of this problem results from the clearance between the impeller and the pump bowls being too wide. Water will begin to slip around the impeller instead of being pumped out of the well.

If the impeller clearance is properly set, the only other cause of this type of condition is some type of mechanical problem with the pump or line shaft. Mechanical problems will require pulling the pump, so the first step in troubleshooting this situation is to adjust the impeller clearance. Adjusting the impeller clearance is also referred to as adjusting the "lateral setting" or "setting the stretch" on the pump.

**ADJUSTING IMPELLER CLEARANCE (LATERAL SETTING)**

When the pump is operating, the proper clearance between the wear rings and the impeller should be between 1/32-1/4" (depending on the impeller design). Wear rings, as the name implies, are designed to eventually wear out. The clearance between the impeller will increase as wear occurs. Specific adjustments can be made to raise or lower the impellers and bring the clearance back within acceptable tolerances.

Line shaft stretch must also be taken into account. Even though the shaft is made of hardened steel, it will stretch under load. There are several factors that will impact the shaft stretch.

**FORCES THAT CAUSE SHAFT STRETCH**

1. The weight of the shaft
2. The weight of the impellers
3. The downthrust exerted against the impellers
The most common means of raising and lowering the shaft is by adjusting the top shaft nut or adjusting nut, located on the top of a hollow core motor. The rotor in a hollow core motor is hollow and the pump shaft can slide up and down through the rotor. The adjusting nut prevents the shaft from slipping down through the motor. Tightening and loosening the top shaft nut will then raise and lower the pump impellers. Smaller shallow wells may not have hollow core motors. If this is the case, the adjustment is made at a special motor coupling or by shimming the motor. After a lateral adjustment is complete, motor amps can be used as a tool to check the adjustment.

![WELL TROUBLESHOOTING FLOW CHART](image-url)
TROUBLESHOOTING WELL PUMPS

Check TDH

DECREASE
Change in TDH?

INCREASE

Pump Mechanical Problem

Motors Amps?

HIGH

Erratic Motor Amps

LOW

Impeller Wear/Damage or Too Much Clearance

Bearing Damage or Not Enough Clearance

NPSH Low?

YES

Reduced Flow and Cavitation

NO

Reduced Flow No Cavitation

REFERENCES:
BASIC STUDY QUESTIONS

1. What is meant by the term percolation?
2. What is the primary reason for grouting a well casing?
3. What is the drawdown in a well?
4. What are the requirements for disinfecting a well?
5. Which type of well pump will help minimize the problems caused by well casing misalignment?

ADVANCED STUDY QUESTIONS

1. What are the limitations for water lubricated line shafts?
2. Why is a gravel pack used in wells?
3. What is specific capacity?
4. Public wells should be located how many feet from potential pollution sources?
5. What should be done when treating a well for iron bacteria?

BASIC SAMPLE TEST QUESTIONS

1. The distance from the well to the edge of the cone of depression is:
   A. Drawdown
   B. Radius of influence
   C. Infiltration
   D. Zone of saturation
2. If the drawdown increases, the screen is becoming clogged.
   A. True
   B. False

ADVANCED SAMPLE TEST QUESTIONS

1. If the pressure gauge on an air line reads 25 psi and the air line is 400 feet long, how far is it to the water level?
   A. 25 feet
   B. 58 feet
   C. 342 feet
   D. 375 feet
2. The friction loss on the suction side of the well pump is equal to:
   A. The drawdown
   B. The specific capacity
   C. The pumping level
   D. The lateral setting
3. When the drawdown in a well increases:
   A. The screen is clogged
   B. The pump impellers may be worn
   C. The specific capacity increases
4. The drawdown in a well has decreased and the motor amps are high. The most likely problem is:
   A. The screen is clogged
   B. The pump impellers are worn
   C. The line shaft bearings are failing
   D. The TDH has increased
WATER WELL MAINTENANCE

CHECKING GRAVEL PACKING

As sand is pumped out of the well, the gravel will fill in the cavity that is created and the gravel level will drop. This can result in exposing the well screen if gravel is not added periodically. The gravel is usually added to the well through a gravel packing pipe. This pipe is about usually 4" in diameter and is sunk beside the casing. The level of the gravel pack should be checked at least yearly. This can be accomplished using the following procedure:

1) Tie a small weight and a paper clip "fish hook" to the end of a string.

2) Drop the string down the packing pipe until it hits the top of the gravel and then mark it.

3) Pull the string out until the "fish hook" catches on the bottom of the gravel pipe and mark it again.

4) Measure the distance between the marks and pull the string out (straightening the paper clip "hook").

Gravel should be cleaned by flushing with water and disinfected with a strong chlorine solution before it is added to the well. The gravel level should be rechecked as the new gravel is added. Gravel should never be allowed to stand in the packing pipe. The vibration that is created when the pump is running can compact the gravel and block the pipe.

DISINFECTING WATER WELLS

The final step before putting a well in service is disinfection and testing for bacteriological quality. The completed well should be cleared as thoroughly as possible of drilling mud and debris prior to disinfection. (It is always easier to flush dirt out of the system than it is to burn it up with chlorine.) Disinfection is achieved by the addition of a strong solution of chlorine to the well. The chlorine dosage should be at least 50 mg/l, however, if higher dosages (100-200 mg/l) are added, less contact time will be required. The contents of the well should be agitated by surging and allowed to stand for several hours, preferably overnight. The contact time at a dosage of 50 mg/l should be 18 to 24 hours but at 200 mg/l only about 2 hours is needed. However, with longer contact times, the chlorine will move farther out into the surrounding aquifer.

The proper dosage can be determined from the tables from the tables on the following page, provided the number of feet of casing below the water line is known. First, multiply the number of feet by the gallons in each foot using the top table on page 2. After the total number of gallons to be treated is determined, the bottom table is used to figure the proper dosage.
The well should be flushed out to remove the remaining chlorine once disinfection is completed. The bacteriological (Bac-T) samples should then be taken from the well and submitted for testing. These samples must be taken daily until they are total coliform negative on two consecutive days.

**Example:**
A well has a 6" casing and it is 200 feet from the water level to the bottom of the well screen. From the tables it is determined that a 6" well casing holds 1.5 gallons/foot. Multiplying 1.5 by 200 ft. of water, the total amount of water to be treated is 300 gallons.

\[
1.5 \text{ gal/ft} \times 200 \text{ ft. of water} = 300 \text{ gallons}
\]

For a dosage of 100ppm (mg/l) the table shows 2 ounces (4 tablespoons) of HTH per 100 gallons. Multiplying 2 ounces by 300/100 (or 3.0), it will require 6 ounces (12 tablespoons) of HTH to dose at 100 ppm.

### Volumes of Well Casings

<table>
<thead>
<tr>
<th>Diameter in inches</th>
<th>Gallons per Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>4&quot;</td>
<td>0.7</td>
</tr>
<tr>
<td>5&quot;</td>
<td>1.0</td>
</tr>
<tr>
<td>6&quot;</td>
<td>1.5</td>
</tr>
<tr>
<td>7&quot;</td>
<td>2.0</td>
</tr>
<tr>
<td>8&quot;</td>
<td>2.6</td>
</tr>
<tr>
<td>9&quot;</td>
<td>3.3</td>
</tr>
<tr>
<td>10&quot;</td>
<td>4.1</td>
</tr>
</tbody>
</table>

### Dosage per 100 Gallons of Water in the Casing

<table>
<thead>
<tr>
<th>Dosage</th>
<th>HTH - 70%</th>
<th>Bleach - 5.25%</th>
<th>Contact time</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mg/l</td>
<td>2 oz. or 4 Tablespoons</td>
<td>1 quart</td>
<td>12 hours</td>
</tr>
<tr>
<td>200 mg/l</td>
<td>4 oz. or 8 tablespoons</td>
<td>2 quarts</td>
<td>2 hours</td>
</tr>
</tbody>
</table>

**Example:**
A well has a 6" casing and it is 200 feet from the water level to the bottom of the well screen. From the tables it is determined that a 6" well casing holds 1.5 gallons/foot. Multiplying 1.5 by 200 ft. of water, the total amount of water to be treated is 300 gallons.

\[
1.5 \text{ gal/ft} \times 200 \text{ ft. of water} = 300 \text{ gallons}
\]

For a dosage of 100ppm (mg/l) the table shows 2 ounces (4 tablespoons) of HTH per 100 gallons. Multiplying 2 ounces by 300/100 (or 3.0), it will require 6 ounces (12 tablespoons) of HTH to dose at 100 ppm.
ADJUSTING IMPELLER CLEARANCE (LATERAL SETTING)

When the pump is operating, the proper clearance between the wear rings and the impeller should be between 1/32-1/4" (depending on the impeller design). Wear rings, as the name implies, are designed to eventually wear out. The clearance between the impeller will increase as wear occurs. Specific adjustments can be made to raise or lower the impellers and bring the clearance back within acceptable tolerances.

Line shaft stretch must also be taken into account. Even though the shaft is made of hardened steel, it will stretch under load. There are several factors that will determine how much the shaft will stretch. They are:

- The weight of the shaft
- The weight of the impellers
- The downthrust exerted against the impellers

The most common means of raising and lowering the shaft is by adjusting the top shaft nut or adjusting nut, located on the top of a hollow core motor. The rotor in a hollow core motor is hollow and the pump shaft can slide up and down through the motor core. The adjusting nut prevents the shaft from slipping down through the motor. Tightening and loosening the top shaft nut will then raise and lower the pump impellers. Smaller shallow wells may not have hollow core motors. If this is the case, the adjustment is made at a special motor coupling or by shimming the base of the motor.

DETERMINING SHAFT STRETCH (ELONGATION)

The shaft stretch can be determined if information on the number and type of impellers, size and length of the shaft, and discharge head on the pump are available. This information should be available on the engineering drawings that were supplied by the design engineer or contractor as part of the well log. When this information is available, the following procedure can be used to calculate the stretch:

1) Determine the weight of the shaft by multiplying the weight per foot (Table 1) and multiplying by the length of the shaft.
2) Determine the weight of the impellers by multiplying the weight of each impeller (Table 2) by the number of stages on the pump.
3) Determine the down thrust by multiplying the thrust, in pounds per foot of head (Table 2), by the discharge head on the pump.

NOTE: If the designed discharge head for the pump is not available, it can calculated by taking the discharge pressure from the well head (in feet of head) and adding it to the length of shaft (i.e. 150 feet of head and 300 feet of shaft equals 450 feet of discharge head on the pump.)

4) Determine the total weight on the shaft (shaft weight + impeller weight + down thrust).
5) Use this number to determine the shaft stretch, in inches per 100 feet of shaft, from Table 3. Then multiply that number by the length of shaft divided by 100 (i.e., 350 feet of shaft will equal a factor of 3.5).
6) Add the stretch to the recommended impeller clearance from Table 4. This number represents the total distance the impellers must be raised off the pump bowls in order to have the correct clearance when the shaft stretches.

Tables 1-4 are supplied by and printed with permission of Peerless Pumps. Check with your pump dealer for this information on other brands of pumps. Although the numbers may change, the procedure described above can still be used.

### TABLE 1

<table>
<thead>
<tr>
<th>Shaft Diam.</th>
<th>Weight lbs/ft</th>
<th>Size</th>
<th>Thrust lbs/ft</th>
<th>Weight lbs</th>
<th>Thrust lbs/ft</th>
<th>Weight lbs</th>
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<tbody>
<tr>
<td>3/4</td>
<td>1.50</td>
<td>4L</td>
<td>1.6</td>
<td>1.5</td>
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<td>5.5</td>
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<tr>
<td>1</td>
<td>2.67</td>
<td>4L</td>
<td>1.0</td>
<td>1.5</td>
<td>10EH</td>
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<td>1-3/16</td>
<td>3.77</td>
<td>6L</td>
<td>1.5</td>
<td>3.5</td>
<td>10KH</td>
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</tr>
<tr>
<td>1-1/2</td>
<td>6.01</td>
<td>6MA</td>
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<td>3</td>
<td>11MB</td>
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<td>3</td>
<td>12LDB</td>
<td>6.0</td>
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<td>1-15/16</td>
<td>10.02</td>
<td>7L</td>
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<td>6</td>
<td>12MB</td>
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<td>27.13</td>
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<td>11</td>
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<td>10.0</td>
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<tr>
<td>3-7/16</td>
<td>31.56</td>
<td>10L</td>
<td>4.1</td>
<td>25</td>
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### TABLE 2

<table>
<thead>
<tr>
<th>Hydraulic Thrust and Weight Data</th>
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</thead>
<tbody>
<tr>
<td>Shaft Diameter</td>
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</tr>
<tr>
<td>500</td>
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<td>1200</td>
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### TABLE 3

<table>
<thead>
<tr>
<th>Shaft Stretch: Inches per 100 Feet of Shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft Diameter</td>
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</table>

### TABLE 4

<table>
<thead>
<tr>
<th>Elongation (in inches)</th>
<th>Shaft Length (feet)</th>
<th>Modulus of Elasticity (29,000,000)</th>
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<tr>
<td>22,000</td>
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</tr>
<tr>
<td>33,000</td>
<td>34,000</td>
<td>35,000</td>
</tr>
</tbody>
</table>

**Notes:**
- **N.T.** = Hydraulic Thrust (pounds)
- **G.S.A.** = Gross Shaft Area (sq. inches)
### Table 4
**Most Efficient Impeller Clearance (Inches) - Peerless Pumps**

<table>
<thead>
<tr>
<th>PUMP SIZE</th>
<th>IMP. #</th>
<th>CLEARANCE</th>
<th>PUMP SIZE</th>
<th>IMP. #</th>
<th>CLEARANCE</th>
<th>PUMP SIZE</th>
<th>IMP. #</th>
<th>CLEARANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6LB</td>
<td>2616324</td>
<td>1/32</td>
<td>9LA</td>
<td>ALL</td>
<td>1/8</td>
<td>12MB</td>
<td>2624331</td>
<td>1/32</td>
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<tr>
<td></td>
<td>2618292</td>
<td>1/8</td>
<td>10LB</td>
<td>ALL</td>
<td>1/8</td>
<td>2623936</td>
<td>1/16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2616318</td>
<td>1/8</td>
<td>10MA</td>
<td>T84363</td>
<td>1/8</td>
<td>2624332</td>
<td>3/16</td>
<td></td>
</tr>
<tr>
<td>6MA</td>
<td>8V850B</td>
<td>1/32</td>
<td>2624288</td>
<td>1/16</td>
<td>12HXB</td>
<td>2608379</td>
<td>1/8</td>
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<tr>
<td>6HXB</td>
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<td>10HXB</td>
<td>ALL</td>
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<td>OTHERS</td>
<td>1/16</td>
<td></td>
</tr>
<tr>
<td>7LB</td>
<td>ALL</td>
<td>1/8</td>
<td>10HH</td>
<td>ALL</td>
<td>1/16</td>
<td>12HXH</td>
<td>ALL</td>
<td>1/8</td>
</tr>
<tr>
<td>7HXB</td>
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<td>1/8</td>
<td>11MB</td>
<td>ALL</td>
<td>1/16</td>
<td>14LD</td>
<td>ALL</td>
<td>1/16</td>
</tr>
<tr>
<td>8LB</td>
<td>2616464</td>
<td>1/4</td>
<td>12LB</td>
<td>2623849</td>
<td>1/32</td>
<td>14MC</td>
<td>ALL</td>
<td>1/16</td>
</tr>
<tr>
<td></td>
<td>2616465</td>
<td>1/8</td>
<td>2616025</td>
<td>1/8</td>
<td>14HXB</td>
<td>ALL</td>
<td>1/8</td>
<td></td>
</tr>
<tr>
<td>8MA</td>
<td>T84229</td>
<td>3/16</td>
<td>2616011</td>
<td>1/16</td>
<td>14HH</td>
<td>ALL</td>
<td>1/16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T84234</td>
<td>1/8</td>
<td>12LD</td>
<td>ALL</td>
<td>1/16</td>
<td>15LC</td>
<td>ALL</td>
<td>1/8</td>
</tr>
<tr>
<td>8HXB</td>
<td>ALL</td>
<td>1/16</td>
<td></td>
<td></td>
<td></td>
<td>15MA</td>
<td>ALL</td>
<td>1/8</td>
</tr>
</tbody>
</table>

**Example of a Lateral Setting Calculation**

The following example will illustrate how to determine shaft stretch:

The well pump is set at 300 feet. The shaft diameter is 1 inch. There are 7 stages of Model 8MA impellers. The discharge pressure at ground level is 120 feet of head.

1) To determine the weight of the shaft, find 1" from Table 1 and read the weight per foot next to it. In this case it is 2.67 pounds/foot. Now multiply 300 feet of shaft by 2.67 lbs/ft:

\[
300 \text{ ft} \times 2.67 \text{ lbs/ft} = 801 \text{ lbs}
\]

2) To determine the weight of the impellers, find the 8MA impeller size from Table 2. The number to the right is the down thrust and the number in the next column the weight of the impeller, which is 7 pounds in this case. Multiply 7 stages by 7 pounds/stage:

\[
7 \text{ stages} \times 7 \text{ lbs/stage} = 49 \text{ lbs}
\]

3) To determine the thrust on the impellers, find the 8MA impeller on Table 2 and read the thrust factor in the center column. There is 5.6 pounds of thrust created by every foot of head above the impellers. Since the ground level discharge pressure is 120 feet of head, it must be added to the 300-foot setting of the pump to get the total head on the impellers:

\[
120 \text{ feet} + 300 \text{ feet} = 420 \text{ feet total}
\]
Multiply 450 feet of head by 5.6 pounds of thrust/foot:

\[
420 \text{ ft} \times 5.6 \text{ lbs/ft} = 2352 \text{ lbs of thrust}
\]

4) Add the weight of the shaft and impellers from Steps 1 and 2 and the down thrust from Step 3 to get the total downward force on the shaft:

\[
801 \text{ lbs} + 49 \text{ lbs} + 2352 \text{ lbs} = 3202 \text{ lbs of downward force}
\]

5) Calculate the stretch in the shaft by finding 3200 (rounded off) on the left side of Table 3 and read the stretch factor from the 1" column. There is .169" of stretch in every 100 feet of 1" shaft at 3200 pounds of force. Multiply 3.0 (300 feet/100) by .169 to determine the total stretch in the shaft:

\[
3.0 \times 0.169" = 0.507" \text{ Total Stretch}
\]

6) Add the proper impeller clearance for the 8MA impeller (#T84234), which is 1/8" or 0.125", to the total stretch to determine the total distance the impellers have to be raised:

\[
0.507" + 0.125" = 0.632" \text{ Total Adjustment}
\]

NOTE: Ideally, these calculations are carried out to 0.001 of an inch. While it is possible to measure these distances with a micrometer; in this case, 0.507" could be rounded off to 1/2" without causing any serious problems. Then 1/2", or 4/8", plus 1/8" would equal an adjustment of 5/8".

NOTE: These calculations are appropriate for wells with under 500 feet of shaft. For longer shafts, particularly oil-lubricated shafts consult your pump manufacturer for additional information.

**ADJUSTING THE IMPELLER CLEARANCE**

The following procedure can be used to adjust impeller clearance on a vertical turbine centrifugal pump:

1) Make sure the pump is locked and tagged out.

2) Remove the cover from the top of the motor and remove the locking screws or lock nut on the adjusting nut (thrust nut.)

3) Hold the shaft with a strap wrench (NOT a pipe wrench) and loosen the adjusting nut until it spins freely. The impellers are now resting on the pump bowls and the shaft cannot be turned by hand. Tighten the nut back down until it is snug.
IMPORTANT: If the well/pump has a non-cartridge mechanical seal, the gland plate should be loosened or removed to prevent potential damage to the seals when the shaft is raised and lowered. If a cartridge seal is used, loosen the shaft setscrews before making adjustments.

4) Measure the shaft sticking out of the top of the adjusting nut and add the total adjustment distance to it.

5) Tighten the adjusting nut until the shaft has been raised the proper distance.

6) Replace the locking screws or nut, the top cover, and mechanical seal gland plate, if applicable. The seal will need to be reset if it is not a cartridge seal.

7) Remove equipment locks and tags.

8) Start the well and check motor amps for acceptable readings.

MAINTENANCE INSPECTIONS

A maintenance schedule should be established and followed as a means of preventive maintenance and identifying problem areas in the well system. A typical inspection schedule is listed below:

DAILY INSPECTIONS

1) Check for excessive noise, vibration, or high temperatures while the pump is operating.

2) Check oil in motor and drip oil storage.
   - If packing/lineshaft bearings are water lubricated, check water feed lines.

3) Check flow readings or totals from the meter.

4) Check the discharge pressure.

5) Check for leaks around packing and all fittings.

6) Check for unsanitary conditions around well.

MONTHLY INSPECTIONS

1) Check the motor amps.

2) Check the oil dripper rates on oil lubricated line shafts.

3) If well can be shut off for 24 hours, measure the water level to check recovery rate.
Semi-Annual Inspections

1) Check the static level after the well has been out of service for several days.

2) Check pumping and drawdown levels during the period of highest production.

3) Check the gravel pack level.

Log all inspection data for future reference. When this information is plotted on a chart of the well field it can aid in planning the production schedule of the different wells and help in planning for the addition of new wells.
STUDY QUESTIONS

1. What is the purpose of gravel packing in a well?

2. How often should gravel packing be checked?

3. Where is the lateral adjustment nut?

SAMPLE TEST QUESTIONS

1. Which of the following is not a factor in determining shaft stretch?
   - A. Weight of the impellers
   - B. Weight of the column pipe
   - C. Weight of the shaft
   - D. Weight of the water column

2. The minimum dosage of chlorine for well disinfection is.
   - A. 20 mg/L
   - B. 30 mg/L
   - C. 50 mg/L
   - D. 100 mg/L

3. The distance the impellers must be raised for a lateral adjustment includes the downthrust on the shaft and:
   - A. Proper impeller running clearance
   - B. Coupling gap
   - C. Depth of the pump bowls
   - D. None of the above

4. Drawdown and pumping levels should be checked:
   - A. At night
   - B. In the winter
   - C. During the period of highest production
   - D. Daily
Water Well Maintenance