WELL PUMPS

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PUMPING GEOTHERMAL FLUIDS

Introduction

Pumping is often necessary in order to bring geothermal fluid to the surface. For direct-use applications, there are primarily two types of production well pumps; (a) lineshaft turbine pumps and (b) submersible pumps - the difference being the location of the driver. In a lineshaft pump, the driver, usually a vertical shaft electric motor, is mounted above the wellhead and drives the pump, which may be located as much as 2,000 ft below the ground surface, by means of a lineshaft. In a submersible pump, the driver (a long, small diameter electric motor) is usually located below the pump itself and drives the pump through a relatively short shaft with a seal section to protect the motor from the well fluid.

Lineshaft pumps have two definite limitations: (a) they must be installed in relatively straight wells and (b) they are economically limited to settings of #2000 ft. For direct heat applications, the economic setting depth limit is probably closer to 800 ft. A general comparison of lineshaft and submersible pumps appears below in Table 1.

Table 1. Comparison of Lineshaft and Submersible Pumps

Lineshaft	Submersible
Pump stage efficiencies of 68 to 78%. Lower head/stage and flow/unit diameter. Higher motor efficiency. Little loss in power cable. Mechanical losses in shaft bearings.	Pump stage efficiencies of 68 to 78%. Generally, higher flow/unit diameter. Lower motor efficiency--operates in oil at elevated temperature. Higher losses in power cable. Cable at least partially submerged and attached to hot tubing.
Motor, thrust bearing and seal accessible at surface.	Motor, thrust bearings, seal, and power cable in well--less accessible.
Usually lower speed (1,750 rpm or less). Usually lower wear rate.	Usually higher speeds (3,600 rpm). Usually higher wear rate.
Higher temperature capability, up to 400ºF+.	Lower temperature capability but sufficient for most direct heat and some binary power applications, assuming the use of special high-temperature motors.
Shallower settings, 2,000 ft maximum.	Deeper settings. Up to 12,000 ft in oil wells.
Longer installation and pump pull time.	Less installation and pump pull time.
Well must be relatively straight or oversized to accommodate stiff pump and column.	Can be installed in crooked wells up to 4 degrees deviation per 100 ft. Up to 75 degrees off vertical. If it can be cased, it can be pumped.
Impeller position must be adjusted at initial startup.	Impeller position set.
Generally lower purchase price at direct use temperatures and depths	Generally higher purchase price at direct use temperatures and depths.

In some installations, selection of a pump type will be dictated by setting depth, well size, well deviation, or temperature. If not restricted by these, the engineer or developer should select a pump based on lowest life cycle costs, including important factors such as expected life, repair costs, availability of parts, and downtime costs. Power consumption costs and wire-to-water efficiency, although certainly worth evaluating, may not be nearly as important as others factors, such as those above. For most direct heat applications, the lineshaft pump has been the preferred selection.

There are many factors that can affect the relative efficiencies of lineshaft versus submersible pumps: i.e. temperature, power cable length, specific design of impeller and bowl, column length and friction losses. The wire-to-water efficiency in the particular application is the import-ant factor. The bowl efficiency of a pump with extra lateral will be less than for standard lateral (discussed in the subsection on Relative Elongation) and clearances. The bowl efficiency of a submersible will be higher than a line-shaft of similar design because extra lateral is not required in the submersible. Motor efficiency generally favors the lineshaft design.

Lineshaft Turbine Pump

To understand the potential problems and solutions in lineshaft pumping, it is necessary to understand how the pumps are constructed. Figure 1 shows a typical lineshaft turbine pump with an enclosed oil-lubricated shaft. Enclosed shaft water lubricated pumps are also manufactured. The discharge head supports the column and shaft enclosing tube which, in turn, supports the multi-stage pump bowls and intake arrangement. The column is usually in 20 ft sections with either screwed or flanged connections. A shaft enclosing tube support “spider” is provided at intervals along the column. The enclosing tube is usually in 5 ft sections with a shaft bearing at each joint, although high speed pumps may have closer spacing. The lineshaft sections are the same length as the corresponding column. The enclosing tube is connected at the top of the bowl assembly to the discharge bowl where lubricating oil outlet ports are located. At the surface, it is connected to the discharge head with a tube tensioning assembly. The en-closing tube is tensioned after installation to help maintain bearing alignment. The enclosing tube provides a water-proof enclosure for the shaft and a path for gravity feed or pressure lubrication.

In an enclosed lineshaft oil lubricated pump, only the shaft bearings are oil lubricated. The pump shaft bearings (in the bowls between each impeller) are water lubricated. The oil is discharged into the well fluid outside the pump through the pump discharge case.

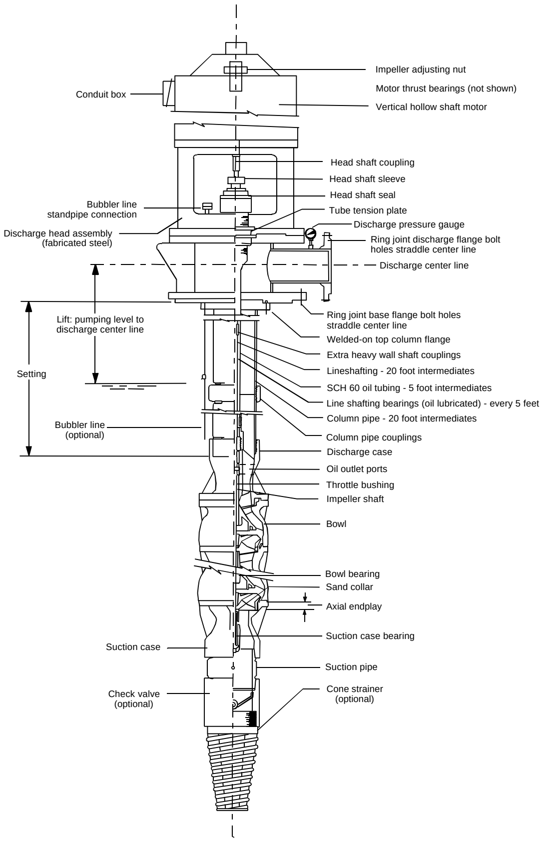

Figure 1. **Typical lineshaft turbine pump with an enclosed oil-lubricated shaft.**

Open lineshaft pumps have seen limited success in geothermal applications. Most successful applications have been characterized by very high static water levels or flowing artesian conditions. Because the bearings are lubricated by geothermal hot water, bearings tend to heat and wear faster. Many of the more common bearing materials are subject to corrosion or de-alloying by geothermal water and special bearing materials increase costs. If an open lineshaft design is used, the shaft should be of stainless steel to resist corrosion, again at a higher cost. As a result of the added costs for special materials and, likely shorter service life, the enclosed shaft design is preferred except for very clean, relatively cool (<140ºF) fluid.

The pump impellers are connected to the shaft by a collet or collet and key with locking screws. The shaft and all rotating parts are supported by the thrust bearings of the hollow shaft motor or a separate thrust bearing assembly. There is an impeller adjusting nut at the top in hollow shaft motor assemblies, or a coupling with adjusting nut for solid shaft driver arrangements.

When a vertical turbine pump stops, water flowing back down the column causes the pump to back spin. Because the pump is acting as the driver, there is very little danger of unscrewing shafting, but if the pump is started during back spin, it is likely to break shafting, loosen collets, or damage the motor. This could occur during momentary power failure or when a control signals a pump to start before the column fully drains. Foot valves, non-reversing ratchets, time delay switches, and rotation sensing switches can prevent this. Of these, non-reversing ratchet and time delays are the most common.

There are some advantages in allowing back spin. The free back spin indicates that nothing is dragging or binding and gives an indication of bearing conditions. It also permits the pump to be started with low load, reducing shock loads on shafting and bearings. A non-reversing ratchet also permits the column to drain, but it takes more time because the water flows backward through the bowls and impellers that are not rotating.

Foot valves prevent back spin and keep the column full of water, reducing the entrance of air and associated corrosion and scaling. They are, however, difficult to maintain in good condition because of scaling and corrosion properties of many geothermal fluids. Also, the pump always starts under a high load condition. Foot valves are recommended only for pumping levels <50 ft and when exclusion of air is mandatory.

Relative Elongation and Axial End Play or Lateral

A vertical turbine pump can be thought of as two concentric systems. The outer system consists of the column, impeller housings (bowls) and shaft enclosing tube. The inner system consists of the shaft and impellers. Forces resulting from dead weight, hydraulic thrust and thermal expansion result in different changes in length of these two systems. If not adequately allowed for in the design and operation of the pump, interference can occur resulting in damage to the pump.

In geothermal applications, an additional consideration is thermal expansion. Because of their differences in thickness, material and mass, the column, shaft enclosing tube, and shaft will all expand at different rates and reach thermal equilibrium at different times after initial startup. Additionally, the shaft in an enclosed lineshaft pump is somewhat thermally isolated from the water in the column by the space between the shaft and the inside diameter of the tube. Once thermal equilibrium is reached, thermal expansion has no direct affect on relative shaft elongation, but it must be compensated for as it occurs, either by adjusting the impellers or by allowing extra lateral. Obviously, in a system that cycles on and off, it must be allowed for in extra lateral.

Axial end play or lateral is accommodated through the vertical seal betwen the impeller and the bowl (shown in Figure 2). This is a kind of extended skirt on the bottom of the impeller and matching bore in the lower end of each bowl. These areas may have wear rings on the bowls, impeller or both. Standard cold water axial end play typically varies from 3/16 in. in a 4-in. diameter pump to 1-3/8 in. in a 30-in. diameter high head/stage pump. Corresponding maximum axial end play using standard castings is 1/4 to 1-3/4 in. This is obtained by additional matching of the bowls. Thermal expansion alone for a 400-ft static water level, 20°F well could be 4-3/4 in., which far surpasses the maximum axial end play for standard pumps. This illustrates why standard pumps are sometimes unsuitable for geothermal service, especially in a cycling situation. Failure to consider this has led to premature wear of impellers, bowls and bearings, broken lineshafts, and burned out electric motors. Proper end play and lineshaft sizing requires experience and understanding of relative shaft stretch, and knowledge of the range of operation on the lead versus flow curves.

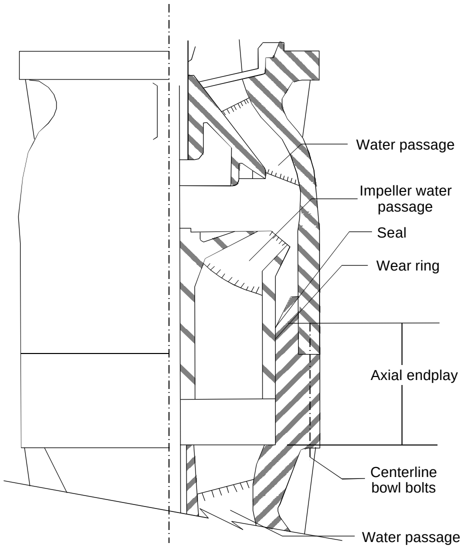

Figure 2. **Cross-sectional of a pump bowl (Johnston Pump Company).**

Extra lateral is accomplished by modifying the patterns from which the impeller and bowl castings are made and approximately matching the increased length. This entails extra cost and some manufacturers may not offer this option.

There is no real temperature break point for lineshaft pumps. For many applications up to 140°F, standard pumps, perhaps with machining up to maximum axial end play, will operate satisfactorily, particularly where the pump is operated continuously. For intermittent operation, thermal expansion and relative shaft elongation should be carefully checked.

A regular maintenance schedule is highly recommended. This includes lubrication of motor bearings (and thrust bearing if separate) and pump packing glands at specified intervals. Oil for shaft lubrication is usually gravity flow with a valve and sight glass to check the required number of drops per minute. This should be checked daily. Turbine oil 68 is the normally recommended lubricant.

Pump manufacturers can suggest a reasonable inspection frequency. It is usually more economic to pull a pump, inspect it and repair or replace parts as needed in the off season than to wait until it fails.

Submersible Pumps

A submersible pump is one in which the driver, or electric motor, is located in the well below the surface of the fluid being pumped and is usually below the pump itself. Submersible pumps, therefore, do not have the problems related to relative shaft elongation that lineshaft pumps do.

Submersible pumps can be separated into low temperature or standard pumps and high temperature pumps. The temperature limit is set primarily by the allowable temperature of the motor.

Low-Temperature Submersibles

Almost without exception, standard submersible pump motors are warranted to 90ºF or below. The allowable temperature is limited by the motor winding insulation and the heat dissipation available. Many standard submersible pump motors can be operated at 120 to 130ºF if proper allowances are made.

There are three basic types of submersible pump motors: wet winding, oil filled, and hermetically sealed.

In the wet winding motor, the motor is filled with water. Water proofing is achieved by special insulation on the stator winding wire, usually plastic, and because the wire and its insulation are bulkier, the motors are larger for a given rating. The motor is carefully filled at the surface to ensure there are no air bubbles and a filter installed in the fill port to ensure that the motor operates in clean water. Some brands are pre-filled and have an expansion diaphragm to allow for expansion and contraction of the filling solution and motor. Rotating seals and a sand slinger at the upper end prevent free circulation of well fluid in and out of the motor and reduce seal and spline wear by abrasive particles. Bearings are water lubricated.

Oil filled motors are prefilled with a dielectric oil. A rotating shaft seal (with sand slinger) is utilized to keep the oil in and water out. Because water has a higher density than oil, the motors have an oil reservoir with expansion bladder at the bottom. Any water that leaks through the seal in time migrates to the bottom of the reservoir. However, if the seal leaks there is probably always a small amount of water mixed with the oil surrounding the windings. Bearings are oil lubricated giving them higher capacity.

Hermetically sealed motors have the winding encased in a welded can, usually stainless steel. The windings may be similar to a surface motor with air inside the can but usually are embedded in a thermo-setting resin to provide better heat dissipation and reduce the possibility of water leaking in. The rest of the motor is similar to the wet type described above with the bearings water lubricated.

All small submersible motors have a thrust bearing at the lower end to carry pump downthrust and a small thrust bearing at the upper end to carry the momentary upthrust during pump startup. Some larger motors intended primarily for deep settings have a separate seal section providing for sealing and expansion. The seal section is located between the motor and the pump and contains the main thrust bearings.

High-Temperature Submersibles

High-temperature submersible pumps were developed for deep settings in oil fields. They are almost universally rated in barrels per day (bpd) rather than gallons per minute (gpm = bpd/34.3). For elevated temper-atures in both geothermal and oil fields, better elastomers for seals, higher temperature insulating materials for cable, and improved oils and bearings have been developed. Satisfactory operation has been attained in oil wells up to 290ºF. Figure 3 shows a submersible installa-tion. The gas separator shown is primarily used in oil field production. The function of the separator is to remove free gas from the fluid before it enters the pump where it would expand in the low-pressure suction area, possibly cause cavitation, and prevent proper pump operation.

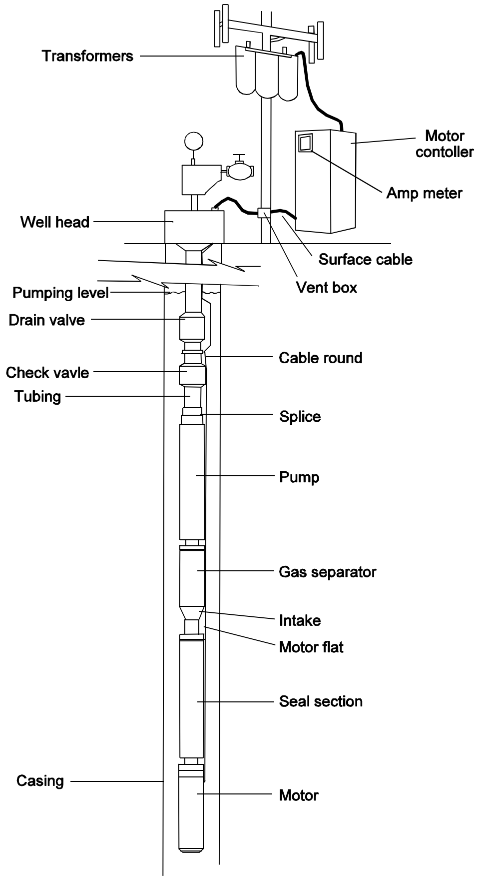

Figure 3. **Submersible pump installation (Centrilift Hughes).**

The pump section of a submersible is similar to a lineshaft in that it is a multi-stage centrifugal. Pump rpm is usually 3,475, which is higher than most lineshafts. Impellers are usually of the balanced or floating type to offset hydraulic thrust, because space for thrust bearings is limited

The seal section between the pump and motor provides for equalization of well fluid and internal motor pressure, allows for expansion and contraction of dielectric motor oil, provides a seal between the well fluid and motor oil and houses the thrust bearings. Separation of the well fluid and motor oil is accomplished by two or more mechanical shaft seals, elastomer expansion chamber and backup labyrinth.

Impellers are designed for balancing at peak efficiency. Operation at higher than design capacity results in upthrust, and lower than design capacity results in downthrust. Bearings are usually of the multiple tilting pad type; there are two, one for upthrust and one for downthrust.

Motors used in high-temperature submersibles are oil-filled, two-pole, three-phase, squirrel cage, induction type. Design voltages range from 230 to 5000 V.

In deep setting applications, motors are run at high voltages in order to reduce current flow. Voltages often are not the common values used in aboveground motors. In deep settings, there can be significant voltage drops in the downhole power cable. Submersibles, therefore, can require special above ground equipment, transformers and controllers, which are supplied by the manufacturers to match existing conditions.

Motors are built in 3-1/2 in. to 7-1/2 in. outside diameters to fit inside standard American Petroleum Institute (API) casing sizes. Rotors are generally 12 to 24 in. long and hp is increased by adding rotors. Single-motor lengths may reach 30 ft producing 400 hp and tandem motors 90 ft producing 750 hp. Motors have bearings designed to carry the rotor loads but not any additional pump loads.

Motor cooling is critical, and at least 1 ft/s flow past the motor is recommended. Flow inducer sleeves can increase flow velocity as described above for standard submersibles, and centralizers are often used to ensure even flows completely around the motors. Centralizers are required in deviated wells.

The cable providing electrical connection between the pump and surface is an important part of a submersible system. The cable is connected to the motor at a waterproof pothead that is usually a plug in type. Waterproof integrity is essential, and special EPDM elastomers are used for sealing. Pothead leaks were a continuing source of trouble in early submersibles for geothermal use, but the new designs have somewhat alleviated the problems. A flat motor lead extension cable is usually installed from the pothead to above the pumps. A cable guard is installed over the cable along the seal and pump sections to prevent mechanical damage during installation and removal. Either round or flat cable is spliced above the pump and run to the surface through the wellhead and to a junction box. Cable is available for several operating temperatures. Up to 180 to 200°F polypropylene insulation with nitrile jacket is used. At temperatures above 200°F, insulation and jacket are EPDM. Various configurations with or without tape and braid and lead sheathing are available for temperatures up to 450°F. Most cable has an interlocking armor of galvanized steel or monel. Galvanized steel will have a very short life in most geothermal fluids. Monel metals generally have longer expected life depending on the alloy and amount of hydrogen sulfide (H_2S) present.

Because all the submersible equipment is in the well, there is no maintenance that can be performed except scheduled pulling and inspection. Large submersibles may be equipped with recording ammeters that can help determine causes of failures and give an indication of pump and well performance. Pump wear, for instance, is indicated by decreasing motor output and current draw.

Excessive current in one or more legs might indicate motor or cable problems. If recording ammeters are installed, they should be checked regularly and the records analyzed.

VARIABLE-SPEED DRIVES FOR GEOTHERMAL APPLICATION

Introduction

Energy costs associated with the operation of production well pumps constitute a large expense for many geothermal systems. In direct use systems, particularly those serving predominantly space heating loads, there is a wide variation in flow requirements. As a result, an efficient means of controlling flow should be an integral part of these systems.

Because most systems utilize centrifugal lineshaft-driven or submersible well pumps, there are three methods available for controlling flow:

1. Throttling pump output
2. Varying the speed of the pump
3. Intermittent pump operation with storage tank.

Throttling the output of any fluid handling device is simply dissipating energy through the addition of friction. This is an inherently inefficient approach to flow control.

Intermittent pump operation can impose serious shock loads in the pumping system, particularly at bearings and impeller connections. This has, in several projects, led to pump failures. Storage tanks can serve as a point of entrance for oxygen, thus aggravating corrosion problems. The results of these combined effects has been unreasonably high maintenance costs.

Use of variable speed drives can significantly increase pump life. A slow speed pump will outlive a faster pump with identical installations and pump construction. The wear rate is proportional to somewhere between the square and cube of the speed ratio; as a result, a pump rotating twice as fast will wear at four to eight times the rate (Frost, 1988).

A review of the response of a basic pumping system suggests that pump speed control is a much more energy efficient approach to controlling flow rate. In a closed piping loop, flow varies directly with pump speed, pressure drop with the square of the pump speed and horsepower requirement with the cube of the pump speed.

One must realize that the above relationships are based upon a situation in which the pump head is composed entirely of friction head. In a geothermal system, much of the pump head may be composed of static head. Static head is, of course, independent of flow. As a result, for a pump operating against a 100% static head, the system response is one in which flow is directly related to speed, pressure drop is in-dependent of speed and horsepower varies directly with speed.

The savings to be achieved through speed control of a centrifugal fluid handling device under a 100% static head situation are then significantly less than the savings achieved in a 100% friction head situation over the same speed range. In addition, there is a limit imposed by a large static head upon the minimum pump speed. This minimum speed is a function of the ability of the pump to develop sufficient head to move the water out of the well.

Geothermal systems will fall somewhere between these two extremes (100% static head and 100% friction head) depending upon static level, drawdown and surface head requirements.

If the control strategy is based upon a constant wellhead pressure, the system very nearly approaches the 100% static head situation. In general, large surface pressure requirements (which vary with flow) relative to static head requirements tend to make speed controls more cost effective.

Most geothermal applications involve the use of a squirrel cage induction motor. The results in two basic approaches to pump speed control:

1. Motor oriented control
    a. Multi-speed motor
    b. Variable frequency drive (AC).

2. Shaft oriented control through the use of a fluid coupling.

The choice among the above techniques should consider: capital cost, duty cycle, hp, speed/torque relation-ship, efficiency, and maintenance requirement.

Conclusion

Among the various drive technologies available, the choice is a function of a host of project specific parameters. The information presented here, along with pump and well information from your project, should permit an accurate analysis to be carried out. The results of this analysis can then be employed in the decision process. Table 2 summarizes the various characteristics of the speed control techniques outlined herein.

LESSONS LEARNED

Listed below are a number of factors relating to pumps that can lead to premature failure of pumps and other components. Many of these have been noted or alluded to elsewhere, but are restated here. Some seem obvious, but the obvious is often overlooked (Culver, 1994).

1. Pump suppliers/manufacturers should be provided with complete data on all foreseen operating conditions and complete chemical analyses. Standard potable water analysis is not adequate, because they do not test for important constituents, such as dissolved gases.

2. In general, continuous or nearly continuous operation of well pumps is preferred. Short cycle start/stop operation should be avoided. This is particularly true for open lineshaft pumps. When the column drains, bearings and the inside of the column are exposed to oxygen, leading to corrosion.

Table 2. Summary of Speed Control Techniques

Method	Efficiency	Capital Cost	Maint. Required	Over Speed Capacity	Effect on Motor Life[e]	Turn Down	Auto Control	Size Range
Adjustable[a] Frequency (AC)	High	Moderate	Low	Y	Lowers	Inf.	Y	Franctional to several hundred
Fluid[b] Coupling	Moderate	High	Moderate	N	None	4:1	Y	5 - 10,000 hp
Multi-speed[c] Motors	Moderate	Low	Low	N	None	2:1	Y	Fractional to several hundred
Throttling[d]	Very low	Low	Low	N	None	No limit	Y	No limit

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a. Allows motor operation in failure mode. Should use high-temperature rise motors. Minimum ambient temperature 50°F.
b. Poor efficiency at low output speeds.
c. Poor efficienty at low output speeds.
d. Stopped output speed in 2 or 4 increments, must throttle in between, possible problems with shaft and bearings.
e. Refers to older motors--depends on application.

Start/stop operations often necessitate a storage tank. This is often a source of air in-leakage. Parts per billion (ppb) of oxygen (O_2) in combination with ppb hydrogen sulfide (H_2S) can lead to early failure of copper and copper alloys, dezincification of brass and bronze and soldering alloys used in valves, fan coils, and piping.

As noted in Chapter 8, almost without exception, geothermal fluid contains some H_2S. If a start/stopmode of operation is used, air is drawn into the system when fluid drains down the column after the pump stops. This can cause a greatly accelerated rate of pitting corrosion in carbon steels, formation of cuprous sulfide films, and crevice corrosion of copper, brass and bronze (except leaded brass and bronze), de-alloying of lead/tin solders and dissolution of silver solder.

Start/stop operation imposes high shaft and coupling torque loads. It is believed this has led to early failure of lineshafts and lineshaft to motor couplings.

3. Records of pressure and flow versus rpm or power should be kept on a regular basis. Decreases in flow or pressure indicate something is wrong and is a portent of more drastic trouble that could occur later on.

4. Pumps should be pulled and inspected on a regular basis, based on experience or as recommended by the manufacturer.

5. Some minimum flow must be maintained in variable-speed applications. Relatively short periods of operation at shutoff will overheat pumps and motors.

6. Motors should be well ventilated. Although this seems obvious, several motors have been installed in below ground unventilated pits. With hot water piping in close proximity, the motor is near its upper operating temperature even when not in operation.

7. Packing glands should be well maintained. All above surface centrifugal pumps tend to in-leak air through packing glands, especially if starting at low suction pressure. Air in-leakage leads to corrosion. Leaks around lineshaft packing lead to corrosion/ scaling of the shaft, making sealing progressively more difficult.

8. Enclosed lineshaft pumps require that lubricant (water or oil) be supplied before the pump is started. It has been observed that in installations where the lubricant flow started and stopped simultaneously with the pump motor, pumps failed prematurely.

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