Pumps and Pumping Systems

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PUMPS AND PUMPING SYSTEMS

I. DESIGN PARAMETERS

A. PURPOSE

The purpose of this course is to provide practitioners with some of the latest procedures for improving water and wastewater systems design and operation. The design process for water systems has been simplified and improved as a result of the new and sophisticated computer programs which are currently available. The amount of time saved by using electronic design enables the engineers to evaluate a system under a number of different design conditions and constraints and achieve an optimum design that will produce a highly efficient system.

B. THE IMPACT OF DIGITAL ELECTRONICS

The emergence of digital electronics has greatly impacted the water system industry in the following areas:

1. **Enhanced System Modeling.** As a result of the speed and accuracy at which computer software is able to analyze networks, system performance can be evaluated under a number of flow, pressure, and pumping scenarios that would have been previously virtually impossible to duplicate with manual systems of calculation.

2. **Recall of Information.** The engineer can search elements of past designs for use on current projects using data basing. This rapid recall of information can allow information on completed designs to be used on a current design having the same defining elements and thereby result in a significant savings of design hours.

3. **Communication**. With the use of electronic mail, rapid communication is available between a firm's offices, their clients, material and pump suppliers, and others involved in a project design. Interoffice communication is also enhanced. This enables a project to be designed in multi-offices, provides for project documentation and maintains a file on correspondence. It has greatly reduced the time required for receiving responses to design related questions.

4. **Design of Water Pumping Equipment.** The selection of pumps for a water system is a major component of system design. Technical catalogs that were once utilized to furnish the technical information necessary to provide proper pump selection have been replaced by CD-ROM discs and on-line data services that provide current information and rapid selection of pumps meeting design conditions. Concurrent with the changes in mechanical design, electronic control of water systems in the form of direct, digital control or programmable logic controllers, has virtually eliminated older mechanical control systems. Digital electronics has created greater design accuracy that guarantees better pump selection. The use of electronic design aids has improved the chances of selecting an efficient pumping system for each application.

5. Variable Speed Pump Drivers. Digital electronics has resulted in a continuing decline in pumping systems having constant speed pumps with their fixed head capacity curves and the emergence of pumps having variable speed drivers which can adjust more easily to system conditions while using less energy. The variable frequency drive with electronic speed control and pump programming match the flow and head developed by the pumps to the flow and head required by the system without the use of mechanical devices.

6. Commissioning. Electronic instrumentation and recording devices have accelerated the start-up of water systems by enhancing verification of compliance of both the total system and system components.

C. PHYSICAL DATA

1. Standards. It is important for the designer to be cognizant of the standards to be used in the particular water pumping system which he or she is designing. These standards may be established by technical societies, governmental agencies, trade associations, and as codes by local, state or federal governing bodies. In some instances, the engineering firm doing the design might establish the standards and criteria to be used.

2. Standard Operating Conditions. This sub-section will discuss technical data relating to water with the exception of pipe friction, which will be covered in Section I. D. All equipment and piping in a water system is based on certain operating conditions relating to temperature and/or pressure. Usually the designer specifies these conditions and then verifies that the products to be furnished conform to the specifications.

a. Operating Pressures. The basic equation for pressure is: psia = psig + p_A
where psia = absolute pressure in pounds per square inch

psig = gauge pressure in pounds per square inch as measured by a gauge on pumping equipment or piping and represents the hydraulic gradient at any point in a water system.

P_A = atmospheric pressure in pounds per square inch. It is 14.7 psi at sea level and decreases as the altitude above mean seal level increases.

b. Standard Air Conditions. Ambient air is the surrounding air in which all water pumping equipment must operate. Standard ambient air is generally specified as 70^{o} F and maximum ambient air temperature is normally specified as 104^{o} F. This temperature is the industry standard for electrical and electronic equipment. It is incumbent on the designer to insure that the equipment which he or she specifies is compatible with the ambient air conditions prevalent at the site. Ventilation air is the air that is used to cool the operating equipment and provide ventilation for the pump enclosure (building). The designer must insure that pump equipment rooms are not affected by surrounding processes that contain harmful substances, such as hydrogen sulfide, which is generated in wastewater pumping and treatment operations. He or she must be cognizant of all ambient air conditions at the site and also the ventilation and or mechanical cooling which might be required to abate heat generation in the equipment rooms to protect both the pumping and electrical equipment and insure that the design standards of the equipment are not exceeded. A situation that deserves mentioning involves the application of variable-speed drives to pumps for wastewater operations. Due to the corrosive nature of ambient air at these installations, experience has shown that 1.) wet wells be properly ventilated and 2.) pump and equipment rooms be air conditioned. This will protect both the electrical switchgear and the pumps and drivers from corrosion that would otherwise occur.

D. SYSTEM FRICTION

Because the sizing of pumps is determined principally by flow and head, it is imperative that system calculations be as accurate as possible. Since flows and static heads can readily be determined, the remaining variable, system friction, is the most critical issue facing water system designers. A poor computation of system friction will have an adverse effect on pump selection and operation. Two references which are essential for water systems designers involved in pipe friction analyses are:

1. Hydraulic Institute's "Engineering Data Book", 2nd Ed.

2. "Cameron Hydraulic Data", latest issue, published by Ingersoll-Dresser Pumps, Flowserve Corporation.

This Section is based on water and sewage which are considered to be Newtonian liquids which means they do not have a change of viscosity caused by any motion of the liquid when the temperature of the liquid is constant. Non-Newtonian liquids are sludges that will be discussed in another Section.

1. Total Pipe Owning Cost

Good piping design balances initial cost against operating cost, taking into consideration all factors that exist for each installation. Piping costs increase and power costs decrease with increases in pipe diameter for the same design flow. First cost is the primary reason for increased cost with corresponding increases in pipe size; maintenance costs may or may not increase with pipe size. Power costs will decrease with an increase in pipe size. The economic pipe size is at the minimum point of the overall costs of owning the pipe. Figure 1.1 illustrates this concept of economic pipe sizing.
The total owning costs of the piping system should be generated for each installation, particularly where large diameters of pipe are involved.

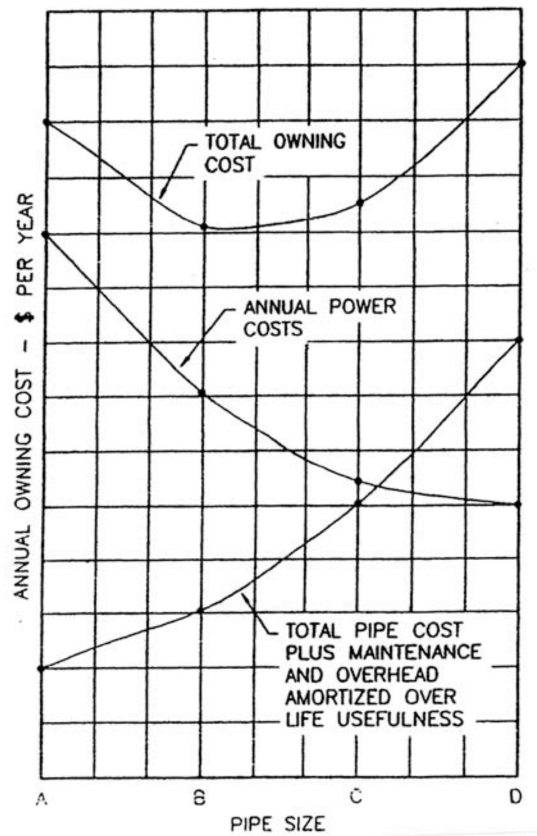


FIGURE 1.1 Economic pipe sizing

2. Capacities and Velocities of Piping

Most pipeline designers have their own parameters for velocities and corresponding head loss in pipelines. In many instances, these parameters are based on many years of experience in pipeline design. While there are guidelines within the industry regarding maximum velocities in various types of pipe materials, it is the designers' responsibility to determine pipe size and maximum velocity to achieve a cost effective system. This is an excellent opportunity for the designer to use computer capability in sizing the piping. He or she can make several computer runs at different pipe sizes to achieve the economically desirable pipe size.

3. Pipe Friction Analysis

As water flows through pipe, friction is generated that resists the flow. Energy is required to overcome this friction and must be derived from pumps, a reduction in system pressure, or changes in static head. In practice, the Bernoulli Theorem is used to determine the total energy at any point in a piping system. The formula is:

$$H_S = Z + Hp + \frac{V^2}{2g}$$

Where

H_S	=	total system head (feet)
Z	=	static head (feet)
Hp	=	system pressure (ft. of head)
$\frac{V^2}{2g}$	=	velocity head (feet)

The velocity head $\left(\frac{V^2}{2g}\right)$ is so small that is seldom used in water distribution calculations. However, it should not be ignored totally, as it is of importance when determining the flow in pipes around pumps.

a. Pipe Friction Formulas.

There are two principle formulas for determining pipe friction, the Darcy-Weisbach and the Hazen-Williams. Both of these formulas develop friction loss in pipes taking into account pipe diameter and friction factors. In actual practice, pipe friction losses are almost never calculated using formulas. Tables have been developed which give velocity, velocity head and head loss (ft/100 ft.) for various flow rates and types and diameter of pipe. The tables shown in "Cameron Hydraulic Data" are based on the Darcy-Weisbach formula. Similar tables have been developed using the Hazen-Williams formula.

Plastic pipe offers a lower resistance to water flow than steel pipe. It is the plastic pipe industry's standard to use the Hazen-Williams formula for calculating pipe friction losses using a C factor (design factor) of 150. Accordingly, data for steel, cast iron, and copper pipe is based on the Darcy-Weisbach formula while data for plastic pipe is generally based on the Hazen-Williams formula.

b. Pipe Fitting Loses

A significant part of the friction loss for water piping can be caused by the various fittings, valves and appurtenances that are contained in the piping network. The proper method of computing fitting loss is to determine as closely as possible the loss for every fitting. Sometimes a contingency factor may be added to recognize the variation in manufacture of fittings. Flow coefficients or K factors have been developed for various fittings, pipe diameters and types of pipe. These fitting losses are referenced to the velocity head of water flowing in the pipe ($V^2/2g$) to obtain this head loss thru the fitting. This is expressed by the formula: $H_F = K\left(\frac{V^2}{2g}\right)$ The use of equivalent feet of pipe as a means of calculating friction in fittings and valves does not seem to provide as accurate results as the K factors of the above equation.

E. HYDRAULIC GRADIENT DIAGRAMS

The hydraulic gradient diagram provides a visual description of the changes in total pressure in a water system. The hydraulic gradient includes only the static and pressure heads in a system. The energy gradient includes the velocity head of the water system ($V^2/2g$). This is usually a low number (less than 5 feet) and is not used to move water through pipes as are static and pressure heads. The hydraulic gradient diagram is an excellent method of checking energy transformations in a water system. It should be developed with no flow on the water system with the pumps running at shutoff head or no-flow condition. The second condition for the diagram should be at the full flow or design situation for the system. Computer programs have been developed to facilitate the development of hydraulic gradient diagrams. Figure 1.2 is a representative diagram for a hypothetical situation. The pump design head is the static head plus the friction head and the difference between the minimum delivery and supply pressures. In this example, the pump head at design flow is 200 + 6 + 23 + (30-25) 2.3 or 241 feet. If the shutoff head for the pump is 305 feet, the maximum pressure

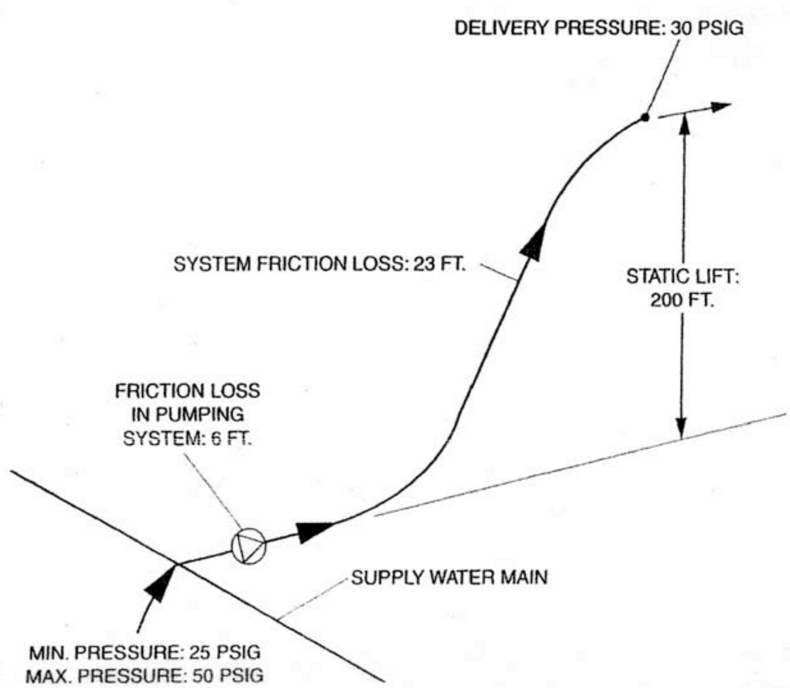


FIGURE 1.2 System configuration for calculating maximum system pressure

that can be exerted on any part of the system is the maximum supply pressure plus the pump head at the no flow condition or 50 + 305/2.31 or 182 psig.

F. PIPING NETWORK ANALYSES

The hydraulic analysis of complex water systems, such as municipal water distribution systems, can be problematical due to the variable flows that can occur in parallel and series loops. The earlier analyses utilized a methodology known as the Hardy Cross Method which calculated friction in piping networks using trial and error hand calculations. With the advent of computers, special software has been developed to compute friction losses in complex water systems. A method in extensive use is the KYPIPE method developed at the University of Kentucky. This piping network modeling software involves the solution of many simultaneous equations, depending on the magnitude of the network, to determine the pressure at each node. A simplified piping network is shown as Figure 1.3.

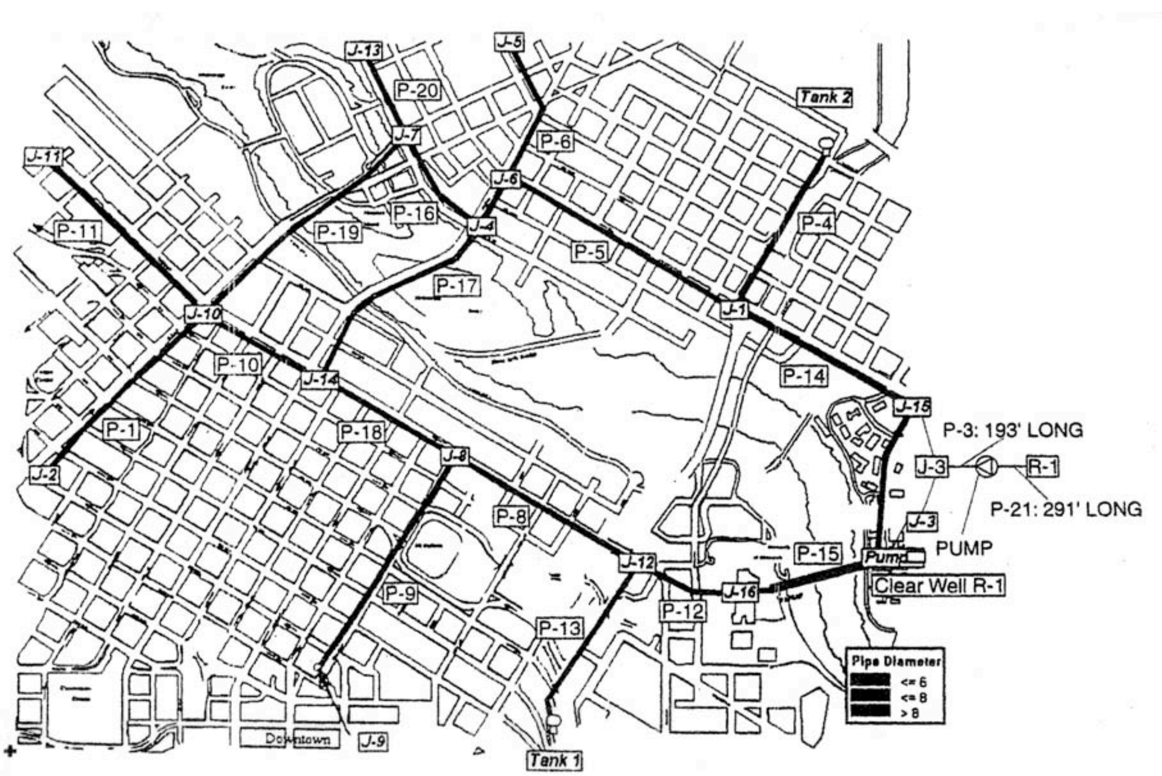


FIGURE 1.3 System arrangement for networking

This system consists of loops, branches, elevated storage, distribution pumps, valves and hydrants. The data required for this network analysis is listed in Table 1.1 and includes pipe diameters, lengths, roughness co-efficients (based on Hazen-Williams), supply reservoir and tank levels and head-capacity data of pumps.

TABLE 1.1 Data for Piping Network Analysis

Piping Names and Information

Pipe name	Node names #1	Node names #2	Length (ft)	Diameter (in)	Roughness coeff.	Minor loss coeff.
P-1	J-2	J-10	2844.00	6.00	130.0000	0.00
P-10	J-10	J-14	1649.00	8.00	140.0000	0.00
P-11	J-10	J-11	2800.00	6.00	130.0000	0.00
P-12	J-12	J-16	1370.00	8.00	140.0000	0.00
P-13	J-12	T-1	2428.00	8.00	140.0000	3.40
P-14	J-15	J-1	2547.00	8.00	140.0000	0.00
P-15	J-16	J-3	1764.00	10.00	120.0000	0.00
P-16	J-4	J-7	1550.00	8.00	140.0000	0.00
P-17	J-4	J-14	2948.00	8.00	140.0000	0.00
P-18	J-14	J-8	1940.00	8.00	140.0000	0.00
P-19	J-7	J-10	3408.00	8.00	140.0000	0.00
P-2	J-3	J-15	2072.00	10.00	120.0000	0.00
P-20	J-7	J-13	1221.00	6.00	130.0000	0.00
P-21	Pump-1	R-1	291.00	12.00	120.0000	7.50
P-3	J-3	Pump-1	193.00	12.00	120.0000	6.40
P-4	J-1	T-2	2321.00	8.00	140.0000	1.90
P-5	J-1	J-6	3298.00	8.00	140.0000	0.00
P-6	J-6	J-5	1983.00	6.00	130.0000	0.00
P-7	J-6	J-4	678.00	8.00	140.0000	0.00
P-8	J-8	J-12	2632.00	8.00	140.0000	0.00
P-9	J-8	J-9	3124.00	6.00	130.0000	0.00

For this example, consisting of 21 pipes, the computer solves 21 simultaneous equations to determine the pipeline flows and node pressures, balance the energy equation for all loops and between tanks and supply reservoirs and satisfy flow continuity at all nodes. From this information selected flows can be set up in the system and simulation runs can be made to determine the pressures at the pumps and at each node. The selected flows might include average daily flow, peak daily flow, fire flow at a given node and various scenarios of pumping/reservoir operation. Any conceivable load distribution can be imposed on the water system and the resulting pressures will be calculated for all parts of the system.

II. PUMP PERFORMANCE

A. CENTRIFUGAL PUMPS

The two broad classes of water pumps are centrifugal and positive displacement. Centrifugal pumps use centrifugal force to move the liquid while positive displacement pumps use some type of mechanical device to force the liquid through the pump. Generally, higher-capacity pumps are of the centrifugal type while smaller-capacity pumps can be either centrifugal or positive displacement.

Centrifugal pumps are the type used in the water, wastewater, stormwater and other water industries for most pump applications. Positive displacement pumps are used for chemical feed and sludges with higher viscosities. An exception to these classifications is the screw type pump used for large capacities of very low static heads. They are positive displacement type pumps. All pumps have some type of a rotating or reciprocating member that causes pressure on the liquid inside the pump. That liquid is then directed to an opening in the pump body or casing that allows it to flow from the pump into a discharge pipe or the atmosphere.

1. Design of Centrifugal Pumps.

Centrifugal pumps use centrifugal force to move water through them and into a water system. There are two basic types of centrifugal pumps: (1) volute and (2) axial flow. Volute type pumps use a casing called the volute that collects water from the pump impeller and directs it around to the pump discharge and into a pipe or the atmosphere. A typical example of this type of pump can be found in water plant pumping stations where the treated water is pumped to the water distribution system. Axial type centrifugal pumps are so named because the water flows axially along the pump shaft to its discharge. They consist of a casing or bowl or a number of bowls, depending on the head condition, where the vanes in the impeller diffuses the water through the bowl assembly to its point of discharge.

A typical example of this type of pump can be found in well fields where the pumps are used to lift the raw water out of the ground and direct it to the water treatment plant. Centrifugal pumps operate under radial and lateral thrusts, are subject to suction conditions, and require energy from a driver to produce the desired flow and head.

A centrifugal pump creates pressure on a water stream that can be used to move that water through a system of piping and equipment. The amount of pressure that the pump can create depends on the flow rate through it. Its fundamental performance curve is called a head capacity curve and is shown in Figure 2.1. The flow in gallons per minute (gpm) is plotted horizontally while the head, in feet, is plotted vertically. Pump head is always show in feet of liquid rather than pounds of pressure. The formula for conversion is:

$$\text{Feet of head (h)} = \frac{144}{\gamma} \text{ where } \gamma$$

equals the specific weight of the liquid in lb/ft^3 at the actual water temperature. Water at 60^o F has a specific weight of 62.34 lb/ft^3. Therefore, h for 60^o F water, is $\frac{144}{62.34}$ = 2.31 feet per lb. of pressure.

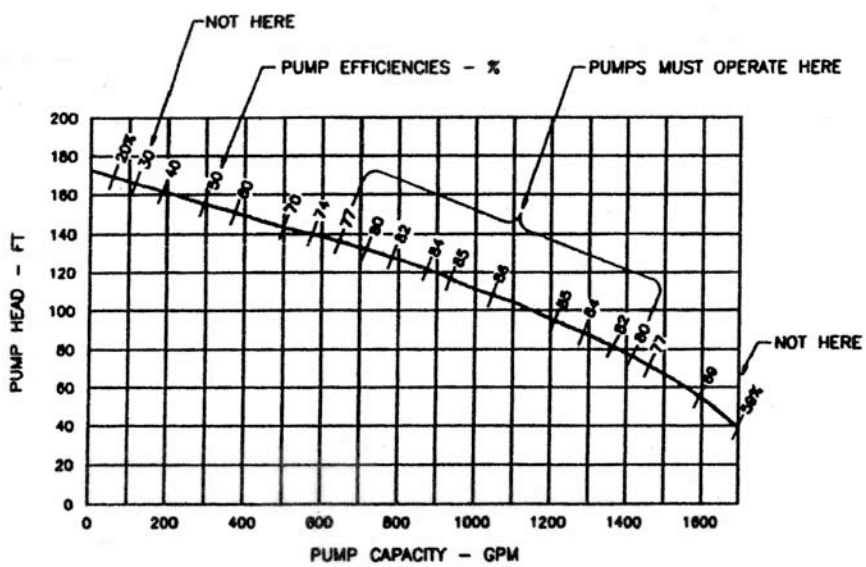


FIGURE 2.1 Typical pump head-capacity curve

It should be noted that pump efficiency is zero at zero flow and then increases to a point called the best efficiency point for the pump regardless of the characteristic of the pumps head-flow curve. As flow increases through the pump beyond this point, friction increases in the pumping system and the efficiency starts to fall again.

The efficiency of a pump is dependent upon the losses therein and include the following:

Mechanical – losses incurred in the bearing and mechanical seals or packing
Leakage – losses caused by water flowing past the case wear rings from the impeller discharge back to the impeller suction.
Recirculation – losses caused by circulation of the water within the volute or bowl.
Hydraulic – losses that are caused by the friction developed by the water flowing through the impeller and volute or bowl.

The pump designer works with vector diagrams and discharge connection sizes to produce a number of pumps that will cover a broad range of flows and heads. The result is a number of head-flow curves as shown in Figure 2.2. This area of flow versus head is called the hydraulic coverage that is provided by a specific class or model of pump and is used by designers as a quick guide to determine the suitability of a pump for a particular application.

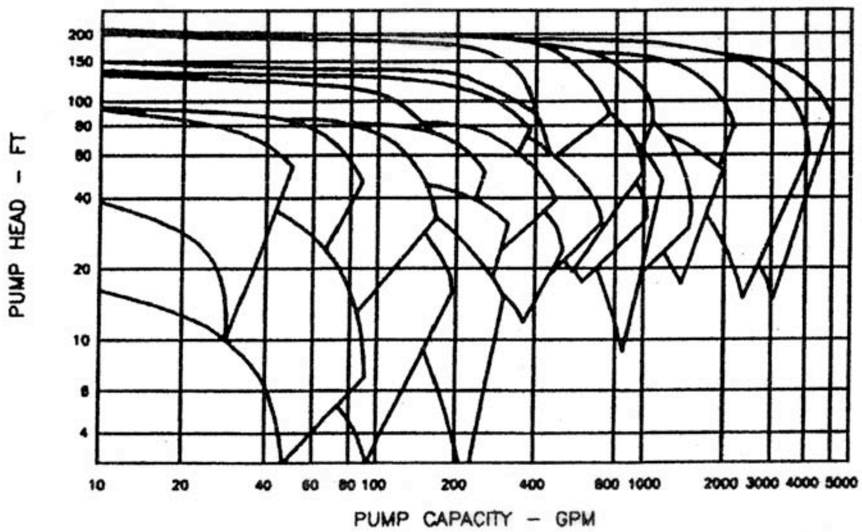


FIGURE 2.2 Family of head-capacity curves

Centrifugal pumps operate on water, a liquid stream that can change its state under certain pressure/temperature relationships. When the temperature of the water reaches the evaporation temperature for the absolute pressure of that stream, part of the water in the stream changes from a liquid to a gas and a term called cavitation can occur. The specific gravity of the gas is much less than that of the liquid water so the result is hammering, as dense water and the "light" steam alternatively hit the internal parts of the water system. It is incumbent on the designer of the system to determine the minimum allowable pressure at the inlet at the pumps (pump suction is most often the point of lowest pressure in a water system) known as the net positive suction head required (NPSHR) in order to eliminate cavitation. Pump manufacturers test centrifugal pumps carefully to determine the net positive suction pressure that must be placed on the pump suction at various flows through the pump in order to eliminate cavitation. From this testing, NPSHR curves are developed for the pump(s) to assist water system designers.

The formula for calculating net positive suction pressure available is:

$$NPSHA = P_a + Z - P_v - H_F$$

Where P_a = atmospheric pressure in feet at the installation altitude

Z = static head of water above pump impeller

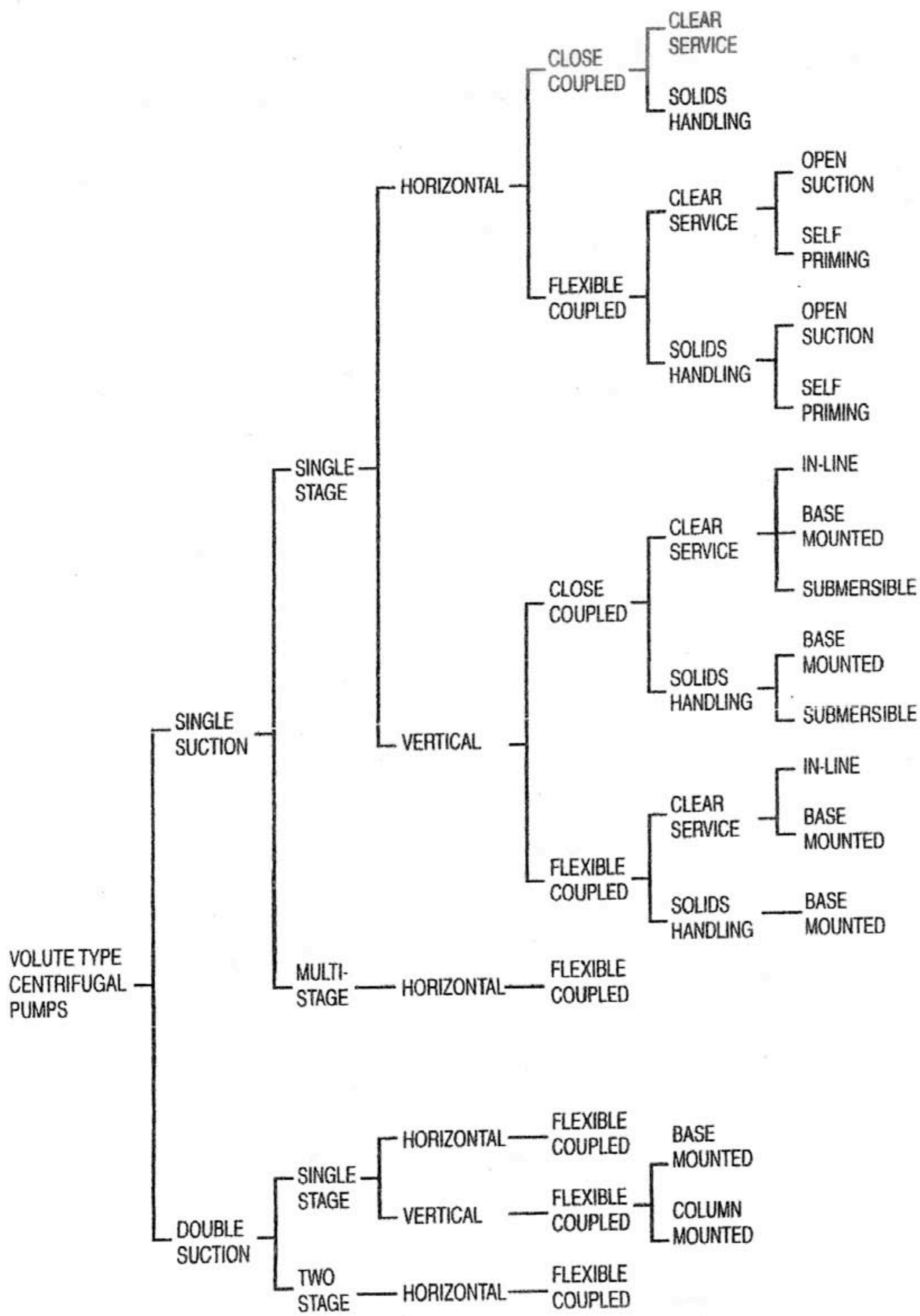
P_v = vapor pressure of water in feet at operating temperature

H_F = friction of suction pipe, fittings and valves in feet of head

2. Types of Centrifugal Pumps.

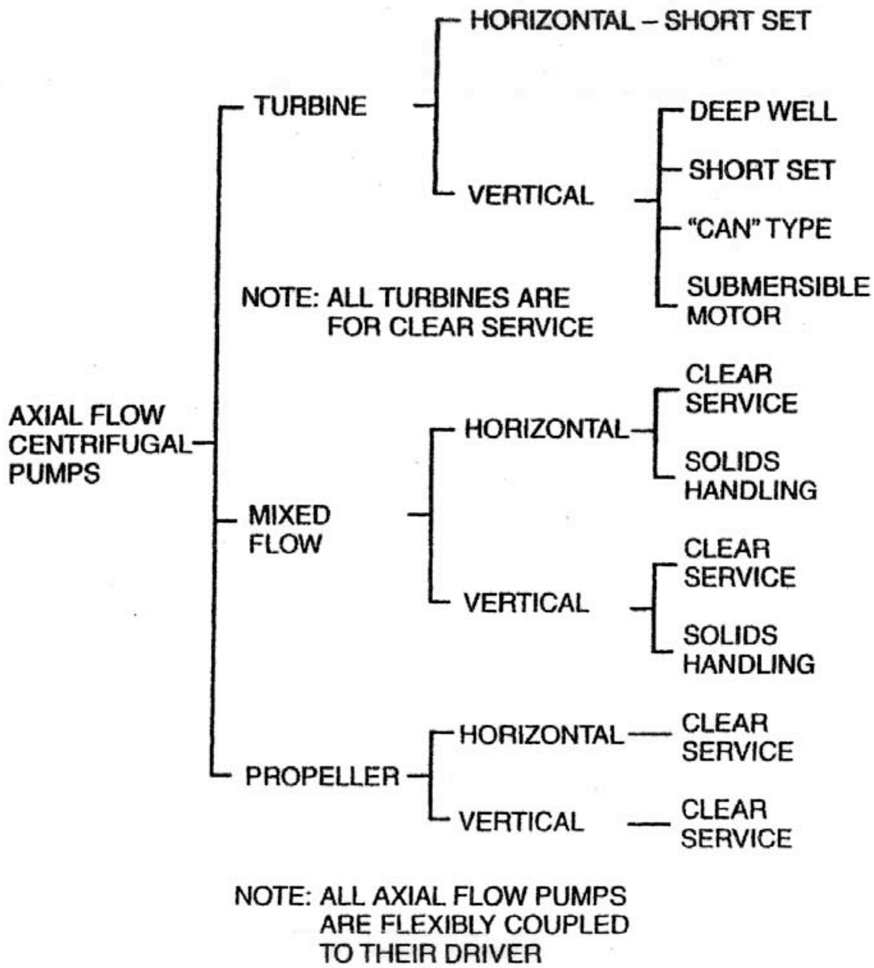
There are two principal types of centrifugal pumps for water systems; these are volute and axial flow types. From an application standpoint, there are clear service and solids handling pumps. Tables. 2.1 and 2.2 provide charts that describe the various types of centrifugal pumps found in the water industry. While there is not universal agreement on the classification of centrifugal pumps, the nomenclature shown in these tables seem to have the greatest degree of acceptance in the industry.

TABLE 2.1 Classification of Volute Type Centrifugal Pump



NOTE: MULTI-STAGE, SINGLE SUCTION AND ALL DOUBLE SUCTION PUMPS ARE CLEAR SERVICE.

TABLE 2.2 Classification of Axial Flow Pumps



3. Centrifugal Pump Performance.

The pressure or head that is developed depends on the flow through that pump. This head-flow relationship is termed the pump's head-flow curve. Figure 2.3 depicts the head-flow curves for a medium-sized, constant-speed pump in the form normally found in pump manufacturers' catalogs. Included in this figure are the efficiency curves, brake horsepower curves, and a net positive suction head required curve.

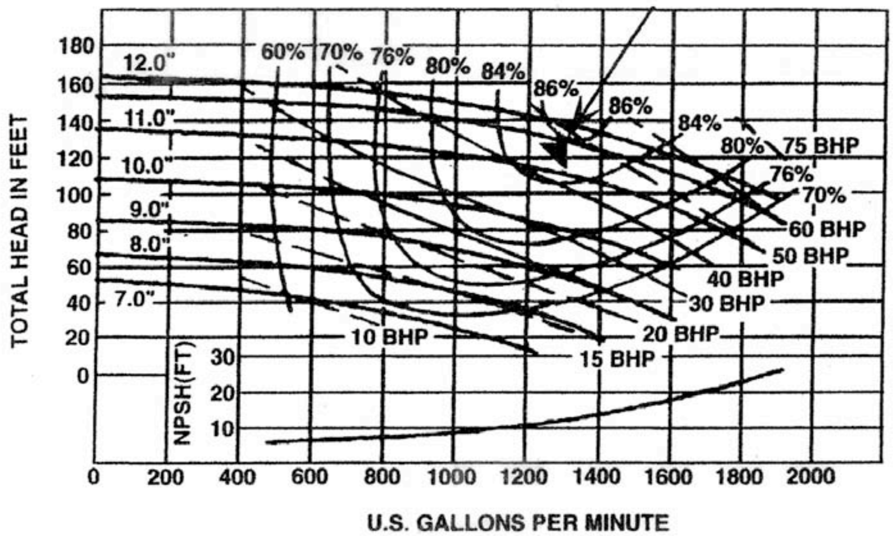


FIGURE 2.3 Typical head-flow curve for centrifugal pumps

a. Affinity Laws. The basic laws for centrifugal pump performances that pertain to speed and impeller diameter changes are called the affinity laws or the relationship between the various elements of pump performance. For a constant speed pump the following relationships pertain to impeller diameter changes:

1. The pump capacity varies directly with the impeller diameter.
2. The pump head varies as the square of the impeller diameter.
3. The pump brake horsepower required varies as the cube of the impeller diameter.

The affinity laws that govern pump performance with variable speed are, for a fixed diameter impeller:

1. The pump capacity varies directly with the speed.
2. The pump head varies as the square of the speed.
3. The pump brake horsepower required varies as the cube of the speed.

Under certain conditions, the affinity laws for impeller diameter changes may not be completely accurate and aberrations may occur. This makes it difficult to use impeller change in computer programs for predicting pump performance without a careful evaluation of the actual pump curves.

b. Head-flow Curves. Previously there has been much discussion in the pump industry regarding the gradient of the pump head-flow curve. If a pump head-flow curve rises more than 25 percent from the design point to the shutoff head, it is considered to be steep; it is considered flat if this rise is less than 25 percent.

The shape of the pump curve was of some concern when mechanical control systems for pumps were popular. It was desired to have relatively steep pump curves so that a minor change in system head would not make a great change in system flow. With the advent of electronic controls, there is very little need to be concerned about the shape of the pump curve. Peak efficiency is what is sought, not the shape of the pump curve. In fact, flat-curved pumps are desired in order to eliminate the rise to shutoff head for constant-speed pumps that are operating on variable-flow systems provided they are equipped with electronic pressure controllers.

The broad variations in flows and pressures in most water systems usually requires multiple pumps to handle all of the system flow-head requirements. Most of these pump applications consist of multiple pumps operating in parallel with fewer of them in series operation. Figure 2.4 describes the various resulting head-flow curves when operating pumps in parallel and in series. Parallel operation enables designers to select a number of pumps that will produce efficient operation from minimum to maximum system flow.

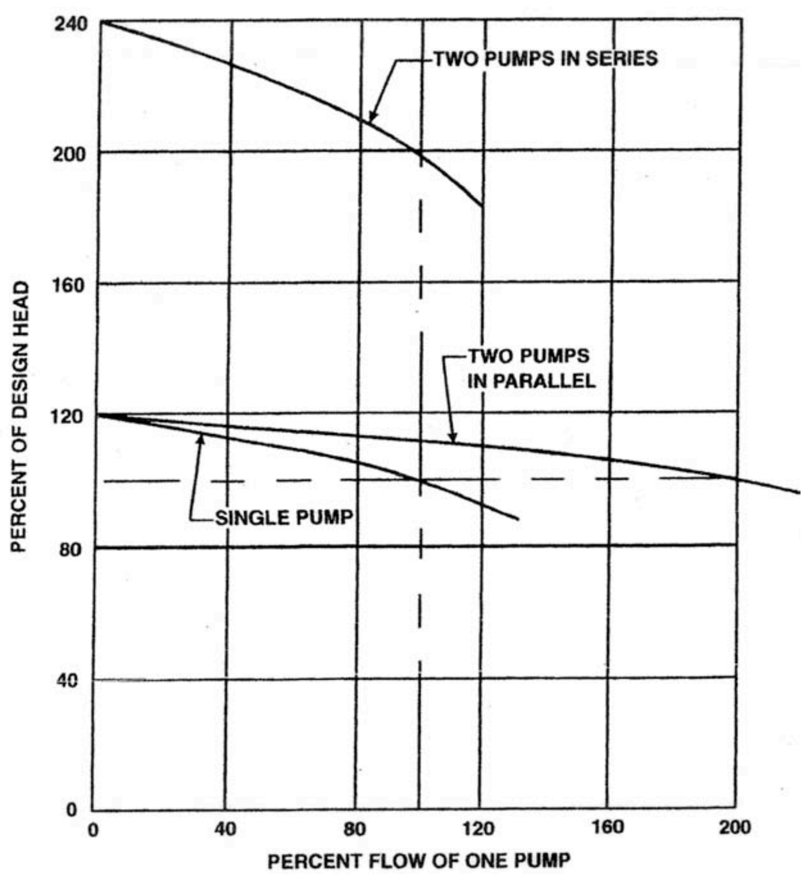
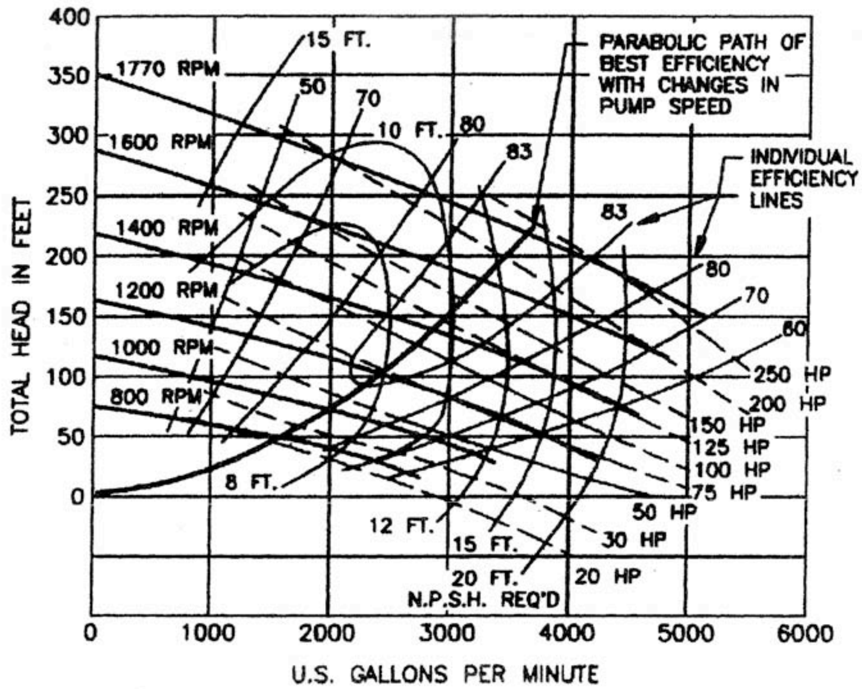


FIGURE 2.4 Series-parallel pumping.

Highly efficient means of moving water can be achieved with variable speed pumping. Figure 2.5 provides a diagram of classical variation of pump speed with a particular size of impeller. Due to the number of variable-speed pumps that are now used in the water industry, it is important that designers become familiar with pump performance when the speed of the driver is varied from minimum to maximum.



b. Head – capacity curves for a variable speed pump.

FIGURE 2.5 Variable-speed curves for one pump diameter

In Figure 2.5 the speed variation shown is from around 45 to 100 percent speed, which is the range that most pump manufacturers feel comfortable in certifying pump performance. In Figure 2.5, note the curve describing the parabolic path of the best efficiency points as the pump driver changes its speed. The figure is also a graphic representation of the pump affinity laws since it shows the variation of pump performance with speed changes with a constant impeller diameter.

Pump performance can be affected drastically by air entrainment in the suction of centrifugal pumps. Air can enter the water system of at any of the following points:

As a result of vortexing when water is taken from a tank.
Through connections
Air generated as a result of chemical reactions

Dissolved oxygen in the system
Through valve stem packing
Air unintentionally injected into the system.

Every effort should be made to insure that the water in a pump is free of gases since their presence will result in a reduction of head, efficiency, and flow.

In summary, centrifugal pumps should be evaluated on the basis of efficiency of operation, ease of pump maintenance, first cost, and space requirements. Variable speed pumps should be efficient throughout their operating range. Technical data on pumps that was previously furnished by pump manufacturers in pump catalogs can now be furnished in software form, such as diskettes or CD-ROM. Most of the pump manufacturers are furnishing computer selection programs where the required pumping head and flow are inserted and the pump selection is made for the designer. This selection can be on the basis of (1) the most efficient or (2) the most economical in first cost.

B. POSITIVE DISPLACEMENT PUMPS.

Positive displacement pumps are used to move water containing solids such as sludges and in feeding chemicals required for the treatment of water and wastewater.

The selection of a particular type of positive displacement pump is based on ease of maintenance, first cost, and user preference. Efficiency is not an important factor due to the relatively low volumes being pumped. An exception is the Archimedes spiral pump that moves large volumes of water and operates at a very high efficiency.

The two general classifications of positive displacement pumps are (1) rotary and (2) reciprocating. Rotary pumps use a pump shaft and rotor to move the liquid through the pump to the receiving system. They include a cavity in which vanes, rollers, lobes, buckets, gears or similar mechanical devices are connected to a rotating shaft to accomplish a positive movement of liquid. Reciprocating power pumps derive their pumping action from a piston or plunger that is connected to a crankshaft rotated by the pump driver that is, usually, an electric motor. The pumps can be installed vertically or horizontally and can be either single or double acting.

A positive displacement pump that is totally unlike other pumps in this category are the screw pumps with very high volumes and relatively low heads. They are used principally to pump stormwater and wastewater.

These larger screw pumps are available in either open or closed construction. They consist of a rotating element equipped with one, two or three flights that move the water upward as the pump rotates in a semicircular concrete or steel trough that is formed or installed at the jobsite. The pumps are driven by standard electric motors that operate the pumps through V-belt drives that result in pump speeds of from 20 to 70 rpm. Some of the advantages of screw pumps are:

Variable-volume pumping at constant speed.
Higher efficiencies at reduced capacities.
Ability to pump liquids with little or no screening.
Relatively low maintenance.

C. PUMP DRIVERS.

Water pumps are driven by electric motors, steam turbines and either gasoline or oil-fueled engines. The great majority of pumps are operated by electric motors. Pumps driven by engines are used in the construction industry for dewatering, for standby service for fire pumps, or where emergency pump operation is required due to power outages. Variable-speed water pump drivers have become very common due to their great advantages and the significant reduction in initial cost. Variable-frequency drives (VFDs) are used in most cases due to their high efficiencies.

Almost all electric motor-driven pumps in the United States water industries are single or three phase, 60 hertz and of the induction type. Ratings shown on the motor nameplate are for 40^{o} C (104^{o} F) ambient air and for motors installed between sea level and 3300 feet elevation. Motor operation at altitudes higher than 3300 feet should be referred to the motor manufacturer for guidance. Most water pump motors are NEMA design B with a maximum allowable slip of 5 percent and a service factor of 1.15 up to 200 hp and 1.0 over 200 hp. The service factor is the permissible overload beyond nameplate rating with standard voltage and frequency. Most horizontally mounted, and some vertically mounted, electric motors for water pumps are manufactured in three different enclosures: drip proof; totally enclosed, fan cooled; and explosion proof. It is incumbent on the designer to know the particular atmosphere in which the pump will operate so that the proper motor enclosure can be specified. Most designers will select the size (horsepower) of the motor directly from the head-capacity curve. In some instances, the pump can carry out to capacities greater than the design point and the motor becomes overloaded.

Accordingly, it is recommended that the specifications for electric motors for pumps include the statement that the motor will not be overloaded beyond its nameplate rating when the pump operates at any point on it head-capacity curve.

Due to the significant advancements that have been made in the electronics industry in the last few decades, variable frequency drives (VFD's) have become increasingly popular with designers in the selection of pump drivers. The VFD is a drive that varies the motor speed by changing the frequency of the power applied to an electric motor. The speed of the motor is directly proportional to the frequency of this power. VFDs are available for nearly any water pump application and have been the preferred means of varying the speed of a pump. They have become the drive of choice for new applications for many reasons, which include:

Lower first cost in most sizes
All are air cooled
Much higher wire-to-shaft efficiency than any slip-type drive. Wire-to-shaft efficiency is determined by the speed/load relationship of the drive and motor.
Very easy to integrate drive control software into the control software of pumping Systems

The application of VFDs requires some care to insure proper operation and reasonable useful life. Some of the more pertinent considerations for their installation include:

Adequate ventilation in the pumping area
Cleanliness of the pumping area
Insuring environments that are not conducive to chemical attack
Insuring that maximum ambient air temperatures do not exceed 140^{o} F
Proper location of pumping equipment and controls (VFDs should never be exposed to direct sunlight
Reliable power supply
Provide one VFD for each pump. Do not try to operate multiple pumps on a single drive.

The selection of motors and drives for water pumps is critical for the realization of a cost-effective and efficient installation. There are a number of decisions that must be made by the designer to achieve this end. Care should be taken in the selection of electric motors, insuring that the best type, rating, and enclosure has been selected for each application.

III. PUMPING DYNAMICS

A. WATER DISTRIBUTION

With the higher energy costs experienced in current markets, it is incumbent on the designers of water systems to produce energy efficient designs and achieve the efficient use of pumping energy in them. Some of the tools available to accomplish this include:

The use of digital electronics to achieve higher efficiencies in the movement of water
The elimination of energy consuming mechanical devices
The use of variable-speed pumps
The use of newer pipe materials which are available
The development of better information on pipe friction

Designs should encourage systems that result in useful energy consumptions and avoid the inefficient use of energy.

There are two commonly used methodologies for calculating the efficiency of a water system. The first compares useful energy versus energy input. This can be done at both full flow and partial load conditions.

Useful energy can be calculated in KW by the formula:

$$P_s = \frac{\text{Useful frictions (ft) x system flow (gpm) x 0.746}}{3960}$$

Which reduces to $P_s = \frac{\text{useful friction x Q}}{5308}$ in KW

Energy input = $P_c = \frac{\text{Total system head x system flow}}{5308 \text{ x } e_m \text{ or } e_{ws} \text{ x } e_p}$

Where e_m = motor efficiency
e_{ws} = wire to shaft eff. of the motor and VFD
e_p = pump efficiency

In these equations the useful friction and total system head are not necessarily the same value.

The efficiency of the system = $\frac{P_s}{P_c}$

System efficiencies at partial load conditions will be less (sometimes much less) than those for full load conditions.

A second method for determining system efficiency involves the comparison between energy consumption (P_{kw}) and flow (Q)

The equation is: $K_w/MGD = \dfrac{24/hr/day \times P_{kw}}{\dfrac{1440\ min/day \times Q}{1,000,000\ gal}} = \dfrac{16,667 \times P_{kw}}{Q}$

Since this formula includes the pump head required there is little advantage in comparing the K_w/MGD of one water system with another; it is a useful value in evaluating the performance of a water system under similar pumping head conditions.

Following are some recommendations to maximize energy conservation in the design of water systems.

1. The design should fit the specific requirements of the owner and achieve the most efficient system possible within budgetary constraints.
2. The system should be configured to distribute the water efficiently with a minimum use of energy-wasting devices.
3. The piping should be designed with fittings that will minimize head loss.
4. The friction for the piping should be calculated for all pipe runs, fittings and valves.
5. Pumps should be selected for maximum efficiency at the design condition.
6. Pumps should be added and subtracted to avoid operation of pumps at points of high thrust and poor efficiency. Pump sequencing should achieve maximum possible system efficiency.

B. SYSTEM CONFIGURATION

In reviewing the basic equation for pumping energy, it is apparent that the energy required by a pump rises with increases in system flow or head and with decreases in pump and/or driver efficiency. Accordingly, it is incumbent on designers to develop a system network having minimum flow and head for a particular application. Water systems are categorized as either open or closed. Open systems deliver the water from source to discharge and closed or looped systems are circulatory, where most of the water is returned to the source.

One of the most difficult tasks confronting designers is to accurately compute flow and head conditions in a water system. Very few water systems are uniformly loaded due to variations in water consumption in various parts of the system. As the flows vary, head conditions will also vary. Recognizing that systems are not loaded uniformly and that diversity does exist is an important element in evaluation and modeling of a water system.

With the aid of computers and special software designers are able to simulate system characteristics under several loading scenarios in very rapid fashion. They can then select the design that most closely fits the economic parameters of the proposed system and facilitate energy efficient pump(s) selection.

Water systems may consist of various types of pressure characteristics such as: all friction, high static, combination of friction and static, varying supply pressures and combinations of supply pressures versus static head versus friction head. Most municipal systems, because of their magnitude and complexity, include all types of the above components in their various sub-systems.

These municipal systems utilized N.V.G.D. (National Vertical Geodetic Datum) (standard sea level) as a reference point for their hydraulic gradients. Simpler systems can use the ground floor of a building or bottom of a suction tank for reference. Sewage lift stations can use the bottom of the wet well. The reference point used for the system being evaluated should be whatever is most convenient for the designer. The hydraulic gradient is a useful tool for calculating operating pressures and also in determining system over pressure that may occur due to incorrect piping or pumping design.

Water systems with multiple loads and networks of pipes create friction analysis problems due to the various flow rates that can occur in parallel and series piping loops. Accordingly, water system analysis can be a difficult and tedious effort. Any time spent toward calculating system flows and heads carefully will be rewarded in energy and first cost savings.

C. CENTRIFUGAL PUMP APPLICATIONS

The actual application of pumps to water systems should be carefully evaluated to achieve optimum energy consumption. This evaluation begins with making a decision regarding constant speed versus variable speed pump selection. As a general rule, constant speed pumps should be used for constant volume-constant head systems and variable speed pumps should be used for variable volume-variable head systems. Often, it is difficult to classify water systems as candidates for constant or variable speed pumps. If a water system has a large variation in flow, say from less than 50 percent to 100 percent of design and in its corresponding head requirements, it is probably a candidate for variable speed pumps. Likewise, if the flow rarely changes and there is little variation in pump head, it is a constant speed pump application.

In selecting constant-speed pumps, the pump should operate at peak efficiency at or near its design point. Generally, constant speed pumps should operate at no greater flow range than ± 25 percent of the flow at the best efficiency point. Constant speed pumps operating at less than desirable flow ranges will not only have poor efficiencies, but are subject to excessive wear due to hydraulic imbalance within the pump. In an attempt to avoid poor pump operation, and recognizing the inability to accurately compute system head, the usual practice with constant speed pumps has been to add a conservation factor to the design pump head and then select the pump to the left of the best efficiency point to insure that the pump will operate without damage at the higher flows and lower heads. The other practice has been to install a balancing valve on the pump discharge that will induce enough friction to prevent the operation at higher flows.

Selection of a variable speed pump must take into account the efficiencies of the motor, the variable speed drive, and the pump itself. The point of selection is less critical since the pump controls will not allow the pump to "runout" to an undesirable point on the pump curve. Variable speed pumps should be selected slightly to the right of the best efficiency point since, as the pump speed is reduced to minimum speed, the pump passes closer to the parabolic curve for best efficiency, from maximum to minimum speed. This is illustrated by Figure 3.1

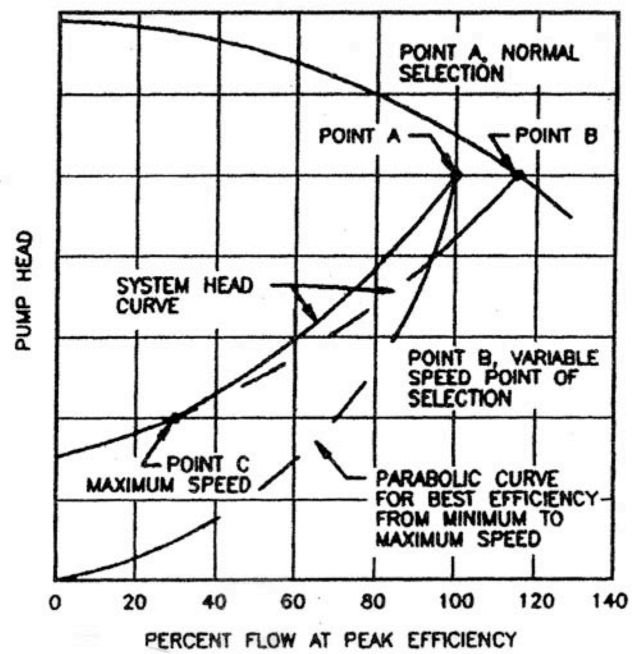


FIGURE 3.1 Point pump selection for variable-speed pumps

Generally, it is not good practice to mix constant and variable speed pumps in parallel in multiple pump installations. Usually, more energy is consumed with a mixture of constant and variable speed pumps and control and sequencing of pumps becomes complex.

Many water systems have a broad range of operation due to the variations in flow and head. They can also have more than one pump due (1) to the broad range of loads and (2) to provide some redundancy in case of pump failure. Water systems can range from one pump on small systems with a specific flow range and little need for standby pump capability up to a number of pumps operating in parallel to accommodate load range and reliability. Designers must make decisions early in the system design to insure that the desired levels of efficiency and reliability are achieved. The consequences of system failure should be determined to develop the redundancy needed on each system. Potable water systems, sewage lift stations, and other critical operations obviously should have standby pump capability to insure that there is continuous service.

On critical installations, there are sometimes decisions to be made concerning the amount of standby-by flows to be provided. This may be determined by local or state codes that stipulate the amount of standby flow. The two most frequent selections are two 100-percent flow pumps or three 50-percent flow pumps. The three 50-percent flow pumps is usually the best selection since they offer three chances before total failure, and the pumps and motors are smaller. The designer must make a final decision after an energy consumption of KW input evaluation is made.

The overall efficiency of a pumping system is known as the wire to water efficiency, a term that has been used for many years in the pumping industry. It is the energy imparted to the water divided by the electrical energy applied – work done divided by work applied. It is the only known method of determining the overall efficiency of a pumping system and enables both engineers and operators to evaluate the total pumping installation. Computer programs have been developed to calculate the wire to water efficiency of a pumping system, from minimum to maximum flow.

With the advent of variable speed pumps, there are two aspects to pump control, (1) pump start-stop procedures and (2) pump speed control. These procedures must be evaluated when designing a pumping system. Pumps are started or stopped in response to physical events such as low system pressure and to programming procedures that provide more efficient or reliable pumping. The latter includes alteration of operating pumps, adding and subtracting variable-speed pumps to achieve optimum energy use, and varying the speed of pumps to maintain desired system conditions. Pump start-stop procedures consist of a number of control techniques which are:

with system activation or shut-down
by system demands such as flow, level, or pressure
by emergencies caused by pump failure

There are several methods for sequencing pumps in multiple pump systems. The goal is to achieve maximum pumping efficiency, from minimum to maximum system flow. Popular methods of sequencing pumps are:

1. Maximum Flow. An older method of sequencing constant-speed pumps was to let one pump run until it could no longer handle the system requirements. The controls then started the next pump in the pumping sequence. This can be wasteful in energy if the pump operates too far to the right of the design point at a poor efficiency. Generally, maximum flow should be used as a backup control system to maintain system flow upon failure of more efficient control systems.

2. **Percent of Maximum Speed**. For variable speed pumps, arbitrarily selecting a percent of the maximum speed to add and/or subtract pumps, does not achieve peak efficiency.

3. **Specific Flow Control**. This method has been called best efficiency control or end-of-curve protection, as the pumps are sequenced so that they operate closer to their best efficiency on the curve. This is achieved by evaluating the system head for the proposed system and selecting pump sequencing so the pumps do not "run out" but operate near their best efficiency point. This requires a system flow meter to detect the selected point of addition.

4. **Use of total KW for Pump Programming**. An efficient method for controlling multiple, variable speed pumps is by total KW input for the pumping system. It requires a minimum of instrumentation, provides precise control of the pumps, and enables the operator to verify that the pumps are operating efficiently.

5. **Wire-to-Water Efficiency Control**. This method is essentially the same, efficiency wise, as the KW input control, but offers the advantage of providing the actual wire-to water efficiency of a pumping system at any point in its operation. It requires an accurate flow meter and a differential pressure transmitter across the pump headers.

Over the years of automatic control of pumps, almost every conceivable method of alternating the lead or operating pumps has been used in the pump industry. In most cases, the purpose was to provide equal wear on all of the pumps. Two negative facts have resulted from this practice. (1) Equal wear is not necessarily the best procedure since there is a greater probability that all of the pumps will wear out at the same time. (2) Automatic alteration encourages the operator to neglect the pumps. An additional factor is that the use of variable speed pumps and factory assembled pumping systems where pumps are programmed correctly has resulted in the elimination of the need for alternation cycles. If it is determined that there is a need to alternate pumps, the simplest and most economical method is manual alternation by the operator. Each motor should be equipped with an elapsed time meter to enable the operator to maintain the selected operating hours between pumps.

Sometimes, it is necessary to use non-self priming pumps on a suction lift, usually for clear service applications. There are three basic methods for priming centrifugal pumps. These are:

by use of vacuum pumps
use of a priming tank and foot valve
by use of water pressure

Any of these systems require servicing to insure that they are operable.

D. INTAKE DESIGN

The design of intake structures for both volute and axial flow pumps involves two categories, that for clear service and that for solids handling applications. Intakes for clear service require configurations that will serve to avoid surface or underwater vortexes, as well as crosscurrents. Solids handling installations require design parameters similar to those for clear service but must also be arranged to maintain control of sludge build-up.

The primary source of information on intake structures is the pump manufacturers. They have tested their pumps with specific types of intakes and can provide necessary data such as submergence and floor and wall clearances. Many have done research on new types of intake structures and can provide modeling for specific applications of their pumps.

The Hydraulic Institute has summarized the subject of intake design in their "American National Standard ANSI/HI 9.8-1998 on Pump Intake Design." This document should be referred to when the design for pump intakes is initiated.

Wet well volumes should be determined on the basis of pump cycle time if constant speed pumps are used or controlling the speed of variable speed pumps. Digital controls provide new procedures for improving level control in wet wells. Since the points of pump start and stop can be compressed or expanded easily to eliminate pump cycling, closer control of wet-well levels can be achieved resulting in an overall reduction in total volume. Wet-well design and control should focus on the final depth of the wet well and the range of level required by the control itself. Either of these factors can affect both the first cost and the operating cost.

Intake structures for solids handling pumps must be designed to direct the settling solids to the pump intakes where they can be pumped from the structure. Vertical or steeply sloped surfaces should replace flat surfaces. Wet wells for solids bearing liquids should be properly vented and located where they are not a nuisance. They should be separated from electrical switchgear and VFD's. Due to the toxicity of the solids bearing liquid it may be necessary to place the electrical switchgear and/or VFD's in either well ventilated or air conditioned enclosures. Intake structures for solids bearing liquids may include strainers, bar screens and trash racks. Bar screens may be manual or mechanically cleaned. Many factors must be considered when installing equipment that cleans the pump station influent and the pump intake equipment should be designed by experienced engineers.

IV. CLEAR WATER PUMPING

There are five main categories of clear water pumping activities. These are pumps for:

(1) Water Treatment Plants
(2) Water Distribution Systems
(3) Plumbing Systems
(4) Fire Protection
(5) Agriculture

Each of these applications will be discussed briefly in the following paragraphs.

A. Water Treatment Plants

Potable water originates from rainfall that falls into the surface water bodies. Some of this water seeps into underground sand and rock strata and develops aquifers. Drinking water standards are established by the United States Environmental Protection Agency (EPA). In Florida, rules for drinking water are also promulgated by the Florida Department of Environmental Protection. The degree of treatment of the raw water depends upon its source. Generally, the need of chemical treatment of surface water is far greater than that required from water originating in the underground aquifer. Most of the potable water in Florida comes from deep wells developed into the Floridan aquifer. Sometimes treatment consists simply of aeration and chlorination.

The most common types of water pumps found in water treatment plants are volute type, both single suction and double suction, and axial-flow pumps of the turbine type for high head applications and mixed-flow and propeller types for low head applications. As with any treatment plant, the basic pump duties are:

(1) raw water pumps
(2) filter pumps
(3) filter backwash pumps and,
(4) water uses in the plant.

Effluent pumps, in most cases, are considered to be part of the water distribution system.

The increased demand for potable water has resulted in greater production from seawater. The method of choice for desalinization is by reverse osmosis using membrane technology. Florida already has several desalinization water plants, either in service or in the planning stage, and it is probable that, as the population increases and demands rise, the number of desalinization plants will also increase.

Due to projected shortfall in the supply of potable water, new procedures have emerged for reclamation and/or reuse of water. Possibly the largest project ever undertaken in this regard is the Comprehensive Everglades Restoration Plan. It is projected that wells and pumps will be installed that will redirect 1.7 billion gallons per day back into the Everglades rather than allowing it to be flushed out to sea.

Recharge is the name given a method that introduces water into an underground aquifer rather than letting it run into a lake, stream, or river. In Florida, stormwater management practices require retention and recharge both for pollution abatement of surface waters and for recharge of the aquifer.

B. WATER DISTRIBUTION PUMPS

All water treatment plants require a relatively constant production of potable water and rely on water storage to smooth out a variable demand rate that changes appreciably during each day or during a fire event. Water distribution systems utilize both ground storage and elevated tanks to secure adequate storage of water.

The primary pumping station delivers water from the treatment plant to the water storage facilities or directly into the distribution system. The primary pumps can be vertical turbine pumps in the treatment plant clear well or horizontal double-suction pumps installed at elevations sufficient to maintain net positive suction pressure. The latter is preferred based on the fact that they are so easy to service compared to vertical pumps. The top half of the casing can be lifted to inspect the interior of the pump or to remove the pump-rotating element. This is contrasted to the need for a sizable crane to pull a vertical pump from a clear well.

Large municipal water systems consist of primary and/or secondary pumping facilities as necessary to maintain water levels in the storage tanks and satisfactory pressures throughout the distribution system. In Florida, with its relatively flat terrain, it is possible to maintain balance in distribution systems without the need for pressure regulating stations as would be the case in hilly terrain. Most municipal water systems do not have simple system head curves or areas. Water is transported through parallel mains and often from more than one source. Calculation of system friction loss must incorporate the use of networking to develop reasonable friction losses for each part of the system.

Hydraulic shock or "water hammer" is an important design issue in long discharge lines that are found in municipal water distribution systems. Hydraulic shock is caused by three significant operations in water systems, namely valve operation, pump start-stop operations and pump driver failure. Valve operation creates hydraulic shock when a valve is opened or closed rapidly. When a valve closes rapidly on a flowing water system, separation occurs at the discharge of the valve, causing a drop in system pressure. This creates a pressure wave, the intensity of which depends on a number of conditions in the system, such as the velocity of the water, the length of the discharge pipe, and the amount of static head. Similar actions occur when pumps are started or stopped either by control or by driver failure. Most municipal water systems are equipped with a safety relief system of valves and/or expansion tanks that control hydraulic shock. Designers need to be cognizant of the conditions when hydraulic shock can occur and incorporate abatement measures into their designs.

C. FIRE PUMPS

An important use of clear service-type water pumps is fire protection. They are provided for buildings and other occupied areas where the local domestic water pressure is inadequate for fire demands. That National Fire Protection Association (NFPA) has established a number of standards for protecting people from the hazards of fire. The basic standard for fire pumps is NFPA 20, "Standard for the Installation of Stationary Pumps for Fire Protection." This is the only design guide for fire pumps and their installation in the United States and Canada. Designers should insure that the most current issue of the standard is being used.

The standard is divided into two principal sections, the standard itself and the appendices that provide detailed information on the chapters in the standard.

Other local codes may apply to a specific type of installation. Also, insurance underwriters may use the requirements of approval agencies such as underwriter's laboratories (UL) or Factory Mutual (FM) for a particular installation.

Information on pumps for foam and water mist systems is also included in NFPA 20. Both of these systems utilize rotary type positive-displacement pumps.

Traditionally, stationary fire pumps have been double-suction volute or vertical turbine. The need for smaller rate of flow pumps has resulted in the use of single-suction volute pumps. Both the double-suction and vertical turbine pumps range in capacities from 500 gpm up to 5000 gpm. Both single and double-volute pumps can be installed horizontally or vertically. Stationary fire pumps have flow rates from 25 to 5000 gpm. These flow ratings are for a pump head of 40 psi minimum or more as required by the fire protection system. NFPA 20, Table 2-3 provides these rated flows.

Fire pump drivers are either electric motors or diesel engines. Gasoline or natural gas engines are not approved for fire pump duty. All fire pump motors must be specifically listed for fire pump service. Two independent electric power sources are required for an electric motor-driven fire pump with an approved transfer switch for operating the pump on either power source. A standby generator and automatic transfer switch satisfies this requirement.

Water system designers involved in the design of a fire pump system should be thoroughly familiar with the design and installation criteria of NFPA 20.

D. PUMPS FOR AGRICULTURE

The major use of pumps in this field is for irrigation. The basic methods of irrigation are open flow in channels (ditches) or closed flow in pipes. Pumps are used when there is no gravity head available to move the water from wells, lakes, rivers, or streams. The types of pumps used vary from single-or double-suction volute pumps to axial flow pumps. Axial flow pumps can be turbine, mixed flow, or propeller, depending on the flow-head requirements. Pump drivers are either electric motors or engine driven for stationary installations and are usually engine driven on portable installations.

Pumps are required in open-channel irrigation when it is necessary to lift the water from a wet well or underground aquifer or to repump the water from one channel to another. This is a popular method of irrigation in relatively flat terrain. The power cost of distributing the water is usually much lower than that for closed pipe irrigation. Generally, the pumps used for this application are designed for relatively low heads and very high flow rates, hence they are almost always constant speed.

Closed-pipe irrigation can be with a fixed piping system similar to that often seen in citrus groves, golf courses, and nurseries, or it can be center pivot where the water is taken from a well and fed into a pipe assembly mounted on wheels that rotates around the center pivot. Center pivot irrigation works very well on rolling terrain with certain types of soil. Center pivot sprinkler systems are classified by the water pressure at the pivot that is used to distribute the water and range from 15 up to 80 psig depending on the type of nozzles and/or sprinkler heads that are used. The rate of delivery of the water is determined in inches of water per hour and varies according to the type of soil receiving the water.

The source of water for golf course irrigation may be municipal (potable) water, surface waters resulting from rainwater runoff, or treated wastewater effluent (reuse). Potable water is seldom used due to its cost. The intent of most golf course management is to use surface water wherever possible. The construction of lakes on the golf course provides a source for the water as well as hazards for the golf holes. The use of treated wastewater effluent is popular because it serves a dual purpose – the disposal of effluent and irrigation of the golf course with water enriched in nutrients. Both constant and variable speed pumps are used for golf course irrigation. They can be both single-and double-suction volute pumps as well as vertical turbine pumps. Golf course pumping stations should be installed in environmentally suitable enclosures to prevent their deterioration from the elements.

Water wells developed in connection with irrigation projects should follow the same procedures that apply to wells developed for potable water. This includes locating the well, establishing the well design criteria, drilling the well, testing it with a developing pump and equipping it with a permanent, deep well turbine pump and driver.

V. SOLIDS HANDLING PUMPING

A. PERFORMANCE OF POSITIVE DISPLACEMENT PUMPS

As mentioned in Section II B, positive displacement pumps can be divided into two categories, rotary pumps and reciprocating pumps. All positive displacement pumps provide a volume of liquid with each rotation or stroke. Unlike a centrifugal pump, these pumps do not create any pressure themselves. The discharge piping and valves develop the pressure imposed upon the discharge of the positive displacement pumps. The positive displacement pumps have one affinity law in common with centrifugal pumps and that is that flow varies directly with speed taking into account the compressibility of the liquid and any slip that can occur in the pump liquid end. Since these are constant torque machines, generally, the horsepower varies directly with the speed when the pressure is constant.

A rotary pump is a positive displacement pump whose pumping device rotates around the pump shaft. Major classifications are sliding vane, flexible element, lobe, gear, progressive cavity, and screw pumps. Figure 5.1 compares the performance of rotary pumps with centrifugal pumps at a constant shaft speed.

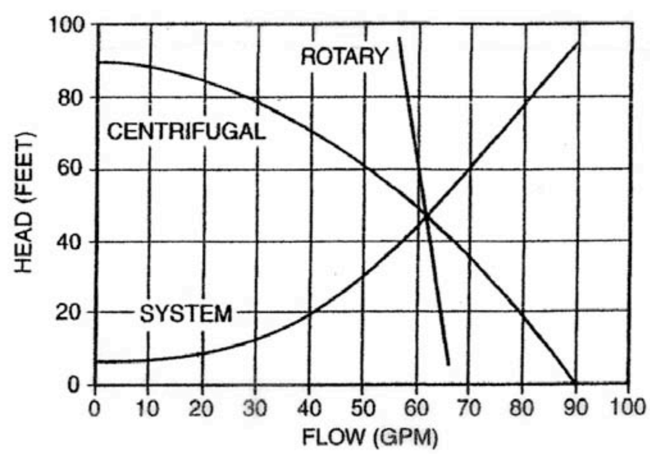


FIGURE 5.1 Comparison of head-flow curves for rotary and centrifugal pumps

There is a small change in the flow in a rotary pump with variation in system pressure (head) compared to the great variation in flow for a centrifugal pump. Since viscosity is of great concern in a rotary pump, pump performance curves have the flow plotted vertically against the pump differential pressure plotted horizontally, as shown in Figure 5.2. Pump horsepower required is also plotted vertically.

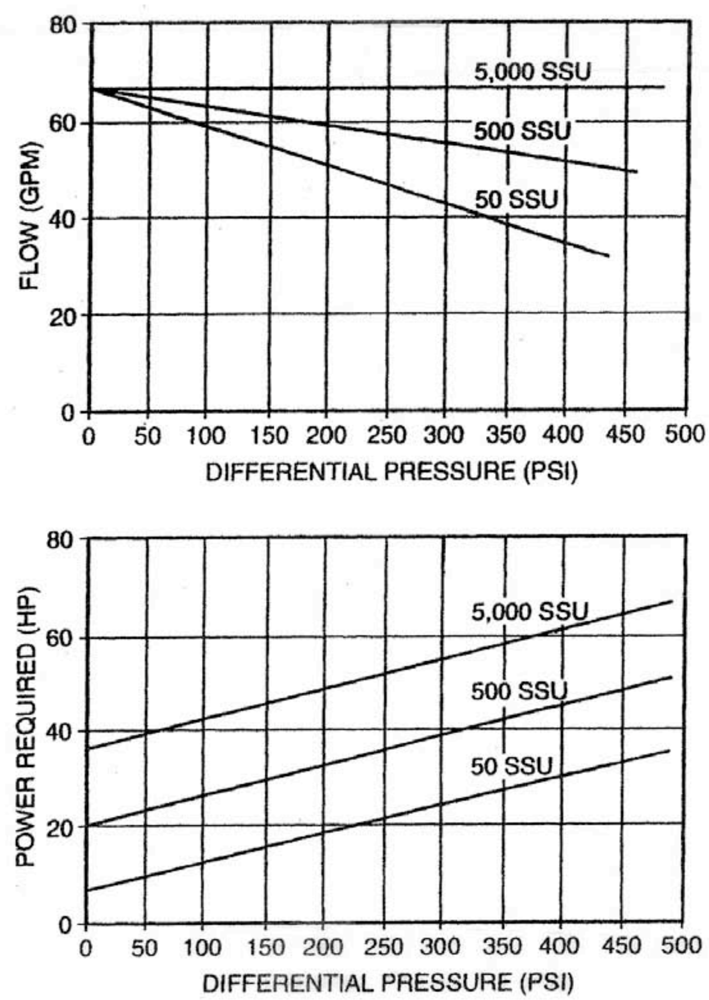


FIGURE 5.2 Rotary pump performance with respect to differential pressure and viscosity

Figure 5.3 compares efficiencies of centrifugal and rotary pumps with consideration for viscosity. There are many system and fluid conditions that must be considered in selecting the specific type of rotary pump to be used for a specific application. References are available that provide application theory and practical recommendations to assist designers in the selection of these pumps. One such reference is the "Pump Handbook", 3rd Edition published by McGraw-Hill.

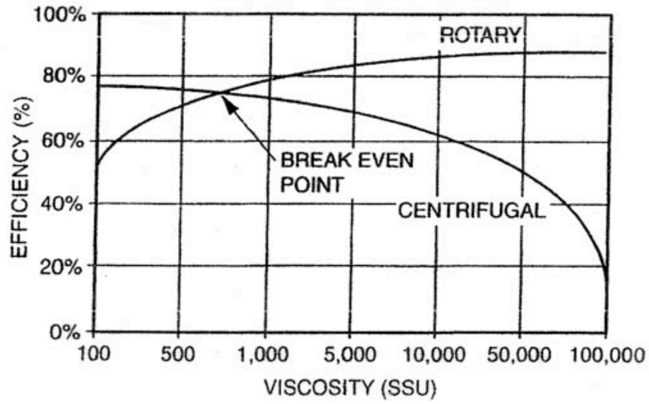


FIGURE 5.3 Comparison of efficiencies for rotary and centrifugal pumps and variations in viscosity of liquid

Reciprocating pumps are also called power pumps and depend on a linear action to move the liquid through the pump. They consist mostly of piston pumps although diaphragm pumps are included in this category. The piston pumps often have multiple pistons to increase capacity and to smooth the ripple effect on the discharge pressure. As many as nine pistons are available on these pumps. Figure 5.4 describes typical performance of these pumps without any slip. The slip that occurs in them depends on the fluid viscosity, pump speed, and discharge pressure and generally is in the range of from 1 to 4 percent.

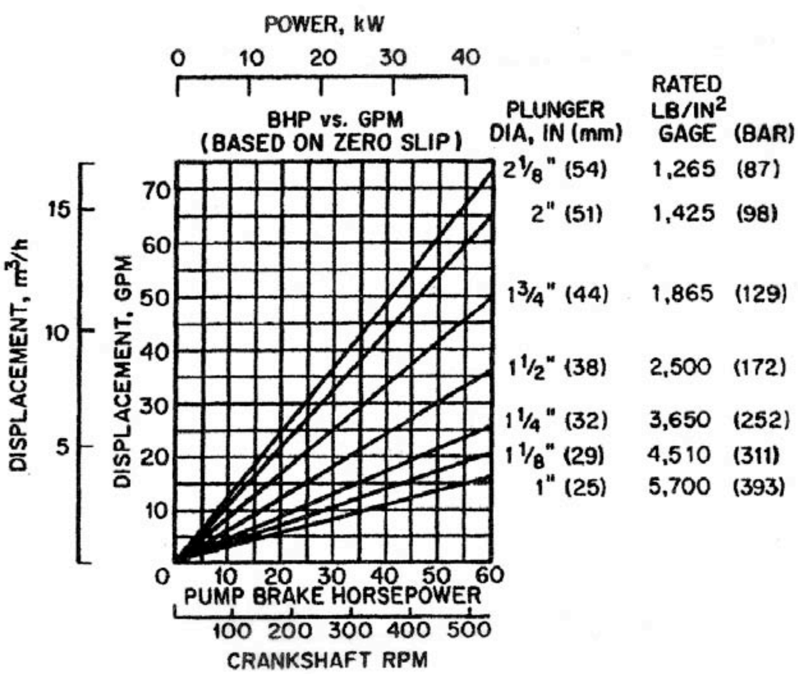


FIGURE 5.4 Typical power pump performance

There are a number of different applications of positive displacement pumps, particularly in wastewater treatment plants where they are used for pumping grit, scum and various types of sludge. Although positive displacement pumps do not consume much power in the water and wastewater industry, they perform many necessary duties to maintain the quality of potable water and wastewater effluent.

B. PUMPS FOR SEWAGE COLLECTION SYSTEMS

There are three basic types of sewage lift stations which are: (a) submersible pumps (b) dry-pit pumps, and (c) surface mounted pumps. These are shown in Figure 5.5.

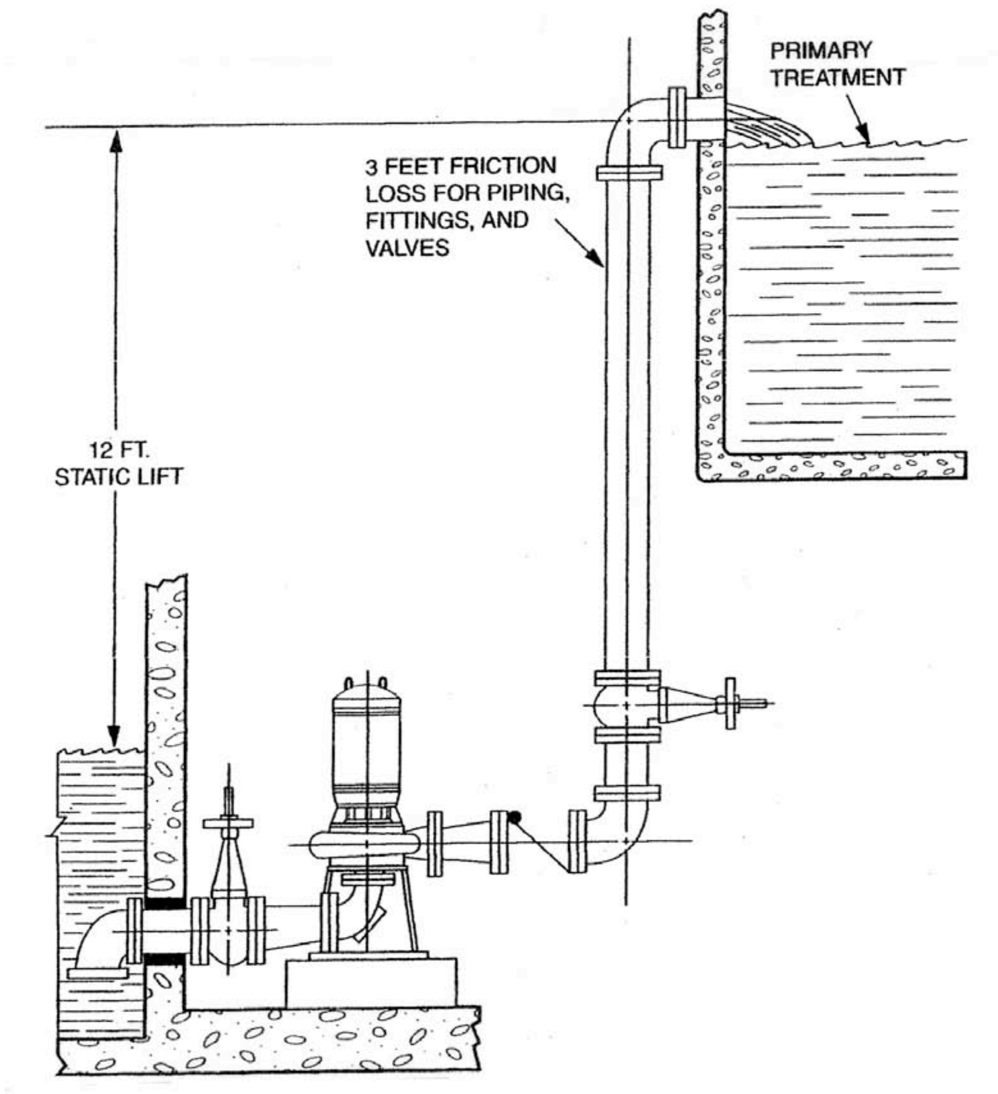


FIGURE 5.5 Sewage lift stations

Submersible pumps are usually single suction equipped with single-or double-vaned propellers. Dry-pit pumps are almost always single-suction, volute pumps of the end-suction, closed or flexible coupled type, and base mounted either horizontally or vertically. Surface pumps are vertical with mixed-flow, non clog impellers or they can be self-priming pumps with non-clog impellers. The type of pump selected for a particular station is determined by the flow and head, location, service facilities, quality of electric power, ease of maintenance, reliability, and client preference.

A sewage lift station collects sewage from a single drainage basin or sub-basin and conveys it through a system of force or gravity mains to its ultimate discharge of either a master lift state or a wastewater treatment plant. This "area" lift station usually consists of two constant-speed pumps with each pump being able to handle the design flow. The wet wells should be sized to avoid unnecessary cycling of the pumps. A pump cycle time in the range of from 5 to 7 times per hour is desirable. Level controls in the wet well should be set so that both pumps will operate during peak flows. Typically, area lift stations are not equipped with standby power. Usually provisions are made to connect portable pumps and/or for the use of trailer mounted generators to pump down wet wells during extended power outages.

A master lift station collects sewage from several area stations and/or large trunk gravity mains and conveys the sewage to a wastewater treatment facility. A master lift station has three or more pumps, of either constant or variable speed, with each pump being able to handle 50 or 67 percent of the design flow depending on the design criteria mandated by code. Wet wells for master lift stations are larger than those for area lift stations. Their depth will vary depending on whether variable-level (pump-down) or constant wet well-level control is used. Experience has shown that considerable energy savings can be realized from constant wet-well control. The points of transition for changing the number of pumps in operation is critical in securing the lowest possible KW/mgd value. It should be noted that variable-speed pumps will run out their head-flow curves just as constant-speed pumps do if they are not controlled correctly. The important control point is to operate the pumps at or near their best efficiency point. The advent of quality VFD's for sewage pumps at master lift stations has offered a great advantage in operating the pump flow to be equal to the station flow. The variable flow thus achieved has smoothed out the variation in flow being received at the wastewater treatment plant and eliminated the "slugging" that would occur with constant speed pumps. It should be reemphasized that, due to the corrosive environment at these master lift stations, pump and control rooms should be air conditioned and other areas well ventilated. Since master lift stations usually serve relatively large sections of a sewage collection system, they are almost always equipped with a stationary standby generator to enable the pump to operate in the event of a loss of commercial power.

One application of sewage pumping that deserves mention is installations that consist of multiple lift stations feeding a single force main. Since peak flows in any given sewer service area occur at approximately the same time of day, it is unlikely that a single lift station would be operating alone. Most likely, all of the lift stations would be operating simultaneously, resulting in high friction heads, reduced pumping capability, low pump efficiencies, and high energy consumption. It is possible, in a given situation for the pumps to be running at a particular lift station and the level in the wet well remains virtually unchanged. This is a poor application for constant speed pumps since there is no practical way to control them and avoid runout. With variable-speed pumps properly controlled a reasonable operation may be secured. This situation should be avoided, if at all possible, in the design of new systems. Where the situation is confronted in existing systems designers should look at methods to retrofit the system to provide more efficient and reliable operation. This could include the use of variable speed pumps at some of the lift stations, converting the common force main to a gravity interceptor, rerouting some of the flow and other solutions depending on flow and elevation. The objective is to end up with the most energy efficient system possible consistent with all of the constraints that may prevail.

Another procedure for collecting residential sewage is the use of grinder pumps. A grinder pump is a centrifugal or positive displacement pump that can handle raw sewage and has enough pump head to propel the sewage through a force main to a remote lift station or the wastewater treatment plant. Grinder pumps have cutters so they can handle raw sewage. Figure 5.6 illustrates a typical collection system for grinder pump use. The centrifugal-pump type fits systems with a relatively flat profile without appreciable static lift while the positive displacement pump is applicable to collection systems with hilly terrain and high static lift. Many times, when seweering areas served by septic systems, the grinder pumps can be installed directly in the septic tanks when permitted by local codes.

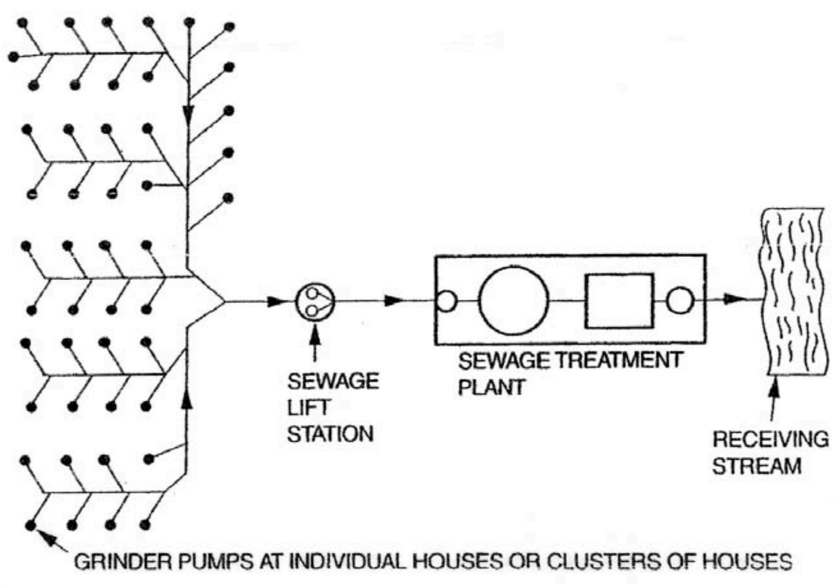


FIGURE 5.6 Typical Grinder Pump Installation

C. PUMPS FOR WASTEWATER TREATMENT FACILITIES

Wastewater treatment facilities use more types of pumps than almost any other facility due to the need to transport and process the different solids and liquids that enter them. Both centrifugal and positive displacement pumps are utilized depending on the plant hydraulics and the treatment process. There is no universal role for distinguishing between the use of centrifugal and positive displacement pumps. One breakpoint is the percent of solids in the wastewater. Centrifugals may be the preference below 8 percent solids and positive displacement pumps above it. This, however, depends on the actual content of the sludge. Another criterion is control of flow; if reasonably accurate flow is required, a positive displacement pump may be the preferred choice. The type and number of pumps is dependent on the type of treatment and the elevation of the treatment facility with respect to the incoming raw sewage and exiting treated wastewater. Typically, the incoming raw sewage is pumped by either non-clog centrifugal pumps or large screw pumps. The treated effluent is pumped to its point of ultimate disposal usually, by either horizontal double suction or vertical turbine pumps. If disposal is to spray irrigation areas, vertical turbine pumps mounted in the discharge structure of the storage reservoir work well. Pumping system first cost and energy consumption are factors that should be considered in the evaluation of pumps for wastewater treatment facilities.

D. STORMWATER PUMPS

Typically, stormwater pumping systems are low head, high volume installations designed to protect designated land areas from flooding. Stormwater pumping stations seldom run, as the flooding occurs only a few times each year. Reliability is, therefore, the basic design parameter, not energy consumption. Most of these stations use constant speed pumps with the pump motors and switchgear located above the flood plain. There are three generally recognized procedures for developing the inflow hydrograph for stormwater stations. They are:

1.) **Rational Method**. This involves the use of an empirical formula; Q = Cia to obtain the maximum runoff in cfs. The Rational Method can be used for small watersheds of less than 5 square miles.

2.) **Soil Conservation Service.** The Soil Conservation Service developed the SCS Method based on rainfall, runoff volume parameters, and time parameters. Determination of runoff volume, time of concentration, travel time, and lag, as well as peak discharge, can be determined from SCS tables.

3.) **Computerized Runoff Models**. Computer models are available for determining the inflow hydrograph for large watersheds. Software is available that can solve complex models and simulations. The U.S. EPA Storm Water Management Model is an example of a design-level model that is available.

Any centrifugal, single-stage pump can be used for stormwater. The type of pump is conditioned on the maximum flow that is generated. Large stormwater pumping stations usually have vertical axial flow pumps with motors and controls located above the maximum flood level.

VI. PUMP INSTALLATION AND OPERATION

A. INSTALLATION

A pump's useful life is determined more by its installation than its qualify of manufacture. More pumps wear out because of improper installation and operation than from any other factors. Most water pumps should not require extraordinary maintenance. The way to avoid extraordinary maintenance is to install the pumps and piping properly. Virtually all pump and pumping system manufacturers provide detailed installation instructions that should be followed carefully. The fundamental goal in installing pumps and piping is to conclude with an installation that imposes no external forces on them. This is achieved by setting the pump base properly and connecting the piping and electrical conductors so that no forces are imposed on the finished assembly. A pump assembly should be observed carefully during its first hours of operation to insure that it has been installed properly and that no vibration is present.

B. INSTRUMENTATION

The ability to operate pumping systems efficiently is dependent on the quality of the instrumentation used to control them. Efficient operation of pumping systems can be secured by means of digital electronics but, accurate instrumentation is required to determine what is being achieved in actual operation. Instrumentation includes transmitters, indicators, and controllers. Transmitters measure values such as pump speed, temperature, differential temperature, pressure, differential pressure, level, and electrical characteristics such as voltage, amperage, kilowatts, and power factor. Indicators display similar operating values such as temperature, pressure, level, and electrical values. Controllers compute pumping system values such as KW input, wire to water efficiency, start and stop pumps and control their speed if they are equipped with variable speed drives. All sensors on pumping installations where appreciable amounts of energy are consumed should be traced to the standards of National Institute of Standards and Technology (NIST).

An instrumentation device that deserves special mention is flow meters. Flow meters can be classed into:

(1) head loss instruments,
(2) propeller, and
(3) electronic measurement instruments.

Head loss-type flow meters measure the head loss through themselves to determine the flow. This class includes orifice plate, Venturi, pilot tube, insertion tube, special valves and any impact measuring type meter that uses friction or velocity head loss as a measurement of flow. This class of flow meters is acceptable for measuring flow in water systems that have a relatively steady flow with very little variation. Since the velocity head of a water stream varies with the square of the flow, this class of slow meters is not acceptable for the measurement of flow in variable water volume systems. Propeller meters use an insertion device that contains some type of rotating element that is calibrated to measure the flow. The speed of rotation of the propeller varies with the flow rate. Propeller meters have greater flow ranges than the head loss type instruments. Propeller meters can be full throated (across the entire pipe area) or insertion type. Because they have moving parts, they should be calibrated often. Electronic flow meters emit an electronic signal across the water stream and use some method of evaluating the quality or quantity of that signal when it is received to measure flow. These meters can be “full throated”, insertion type or strap-on where they are attached to the exterior surface of the pipe. Full-throated magnetic meters provide the greatest flow range, 1 to 30 ft./sec. at probably the highest accuracies. Some manufacturers quote accuracies as high as ± 0.5 percent from 1 to 30 ft./sec. velocity.

C. TESTING PUMPS

The Hydraulic Institute (HI) has produced test standards for water pumps that have been approved by the American National Standards Institute (ANSI). Standards have been developed for centrifugal, vertical, rotary, reciprocating, and submersible pump tests. These standards should be in the possession of designers of water systems and buyers of water pumps or pumping systems. Pumps should be tested for their actual performance in meeting flow, head, and efficiency specifications. HI can be contacted at their e-mail address of www.pumps.org.

EXAMINATION

PUMPS AND PUMPING SYSTEMS

December 11, 2008

(There is only one correct answer)

1. The emergence of digital electronics has

   a. enhanced system modeling.
   b. simplified the selection of pumping equipment.
   c. accelerated system start-up
   d. all of the above

2. Design standards for water pumping systems

   a. are established by the American Waterworks Association.
   b. are not fixed by any single entity.
   c. are established by code.
   d. are determined by the area in which the project lies.

3. The most critical issue facing water system designers is

   a. calculating system friction.
   b. selecting the proper pump(s).
   c. determining system flows.
   d. calculating static head.

4. Pipe friction losses

   a. are calculated using the Darcy Weisbach formula.
   b. are calculated using the Hazen-Williams formula.
   c. are selected from tables which have been developed for various flow rates and pipe diameters.
   d. take into account the velocity head.

5. The hydraulic gradient diagram includes

   a. the static heads in a system.
   b. the pressure heads in a system.
   c. the velocity head in a system.
   d. a. and b. above.

6. the efficiency of a pump is dependent upon

a. the flow rate.
b the pumping head.
c. the losses therein.
d. all of the above.

7. Maintaining a certain minimum static head of water above the pump impeller will serve to eliminate:

a. cavitation.
b. pump "runout".
c. pump "seeking".
d. low pump efficiency.

8. For variable speed pumps having a fixed diameter impeller

a. the pump capacity varies inversely with the speed.
b. the pump head varies as the cube of the speed.
c. the pump capacity varies directly with the speed.
d. the pump brake horsepower required varies as the square of the speed.

9. The gradient of a pump head-flow curve

a. should not rise more than 25 percent.
b. is of little concern with the advent of electronic controls.
c. should be as flat as possible.
d. does not matter if constant speed pumps are being used.

10. Most multiple pump systems operate

a. with variable speed pumps.
b. in a series.
c. in the range of from 45 to 100 percent speed.
d. in parallel.

11. A pump that derives its pumping action from a piston that is connected to a crankshaft rotated by a motor is called a

a. reciprocating pump.
b. screw pump.
c. single stage pump.
d. rotary pump.

12. Which of the following statements regarding variable frequency drives are true?

   a. They have a higher initial cost.
   b. They can be easily integrated into the control software of pumping systems.
   c. Special cooling is required.
   d. All of the above.

13. A method for measuring the efficiency of a water system involves

   a. measuring pump running time versus total daily flow.
   b. comparing useful energy versus energy input.
   c. comparing energy consumption and flow.
   d. either b or c

14. Variable speed pumps should be selected

   a. by adding a conservation factor to the design pump head and selecting the pump to the left of the best efficiency point.
   b. at the best efficiency point.
   c. slightly to the right of the best efficiency point.
   d. so as to not allow the pump to “runout” to an undesirable point on the pump curve.

15. The only known method (s) for determining the overall efficiency of a pumping system is:

   a. specific flow control
   b. use of total KW for pump programming
   c. wire to water efficiency control
   d. a. and b. above

16. Operations in water systems which can cause hydraulic shock are

   a. valve operation.
   b. pump start-stop operations.
   c. pump driver failure.
   d. all of the above.

17. Generally, power costs for distributing the water are lower

   a. with a fixed irrigation piping system.
   b. in open channel irrigation.
   c. with center pivot sprinkler systems.
   d. when constant speed pumps are used.

18. Pumps which depend on a linear action to move liquid through them are called

   a. rotary pumps.
   b. progressive cavity pumps.
   c. reciprocating pumps.
   d. sludge pumps.

19. Pumps used at sewage lift stations are

   a. submersible pumps.
   b. dry-pit pumps.
   d. surface mounted pumps.
   d. all of the above.

20. The primary factor in determining a pump's useful life is

   a. its installation.
   b. quality of manufacture.
   c. maintenance it receives.
   d. hours of operations.