

Selection Of Centrifugal Pumping Equipment¹

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INTRODUCTION

The pump is an essential component of an irrigation system. Proper selection of pumping equipment that will provide satisfactory performance requires good understanding of existing conditions. Design restrictions, operating conditions of the irrigation system, and required flexibility in system operation must be understood before an efficient pump can be selected for a given system.

PUMP PERFORMANCE PARAMETERS

Capacity, head, power, efficiency, required net positive suction head, and specific speed are parameters that describe a pump's performance.

Capacity

The capacity of a pump is the amount of water pumped per unit time. Capacity is also frequently called discharge or flow rate (Q). In English units it is usually expressed in gallons per minute (gpm). In metric units it is expressed as liters per minute (l/min) or cubic meters per second (m³/sec).

Head

Head is the net work done on a unit weight of water by the pump impeller. It is the amount of energy added to the water between the suction and discharge sides of the pump. Pump head is measured

as pressure difference between the discharge and suction sides of the pump.

Pressure in a liquid can be thought of as being caused by a column of the liquid that, due to its weight, exerts a certain pressure on a surface. This column of water is called the head and is usually expressed in feet (ft) or meters (m) of the liquid. Pressure and head are two different ways of expressing the same value. Usually, when the term "pressure" is used it refers to units in psi (pounds per in²) in the English system or kilopascals (kPa) in metric units, whereas "head" refers to ft in English units or meter's (m) in metric units. A column of water that is 2.31 ft high will exert a pressure of 1 psi.

Power Requirements

The power imparted to the water by the pump is called water power. To calculate water power, the flow rate and the pump head must be known. In English units water power can be calculated using the following equation:

$$WP = (Q \times H)/3960 \quad (1)$$

where:

WP	=	water power in horsepower units
Q	=	flow rate (pump capacity) in gpm
H	=	pump head in ft

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In metric units water power is expressed in kilowatts, pump capacity in liters per minute, head in meters, and the constant is 6116 instead of 3960.

In any physical process there are always losses that must be accounted for. As a result, to provide a certain amount of power to the water a larger amount of power must be provided to the pump shaft. This power is called brake power (brake horsepower in English units). The efficiency of the pump (discussed below) determines how much more power is required at the shaft.

$$BP = WP/E \tag{2}$$

where E is the efficiency of the pump expressed as a fraction, BP and WP are brake power and water power, respectively.

Efficiency

Pump efficiency is the percent of power input to the pump shaft (the brake power) that is transferred to the water. Since there are losses in the pump, the efficiency of the pump is less than 100% and the amount of energy required to run the pump is greater than the actual energy transferred to the water. The efficiency of the pump can be calculated from the water power (WP) and brake power (BP):

$$E\% = (WP/BP) \times 100 \tag{3}$$

The efficiency of a pump is determined by conducting tests. It varies with pump size, type and design. Generally, larger pumps have higher efficiencies. Materials used for pump construction also influence its efficiency. For example, smoother impeller finishes will increase the efficiency of the pump.

Net Positive Suction Head

The required net positive suction head (NPSH_r) is the amount of energy required to prevent the formation of vapor-filled cavities of fluid within the eye of impeller. The formation and subsequent collapse of these vapor-filled cavities is called cavitation and is destructive to the impeller.

The NPSH_r to prevent cavitation is a function of pump design and is usually determined experimentally for each pump. The head within the eye of the impeller, also called net positive suction head

available (NPSH_a), should exceed the NPSH_r to avoid cavitation.

Specific Speed

Specific speed is an index number correlating pump flow, head and speed at the optimum efficiency point. It classifies pump impellers with respect to their geometric similarity. Two impellers are geometrically similar when the ratios of corresponding dimensions are the same for both impellers.

This index is important when selecting impellers for different conditions of head, capacity and speed (Figure 1). Usually, high head impellers have low specific speeds and low head impellers have high specific speeds.

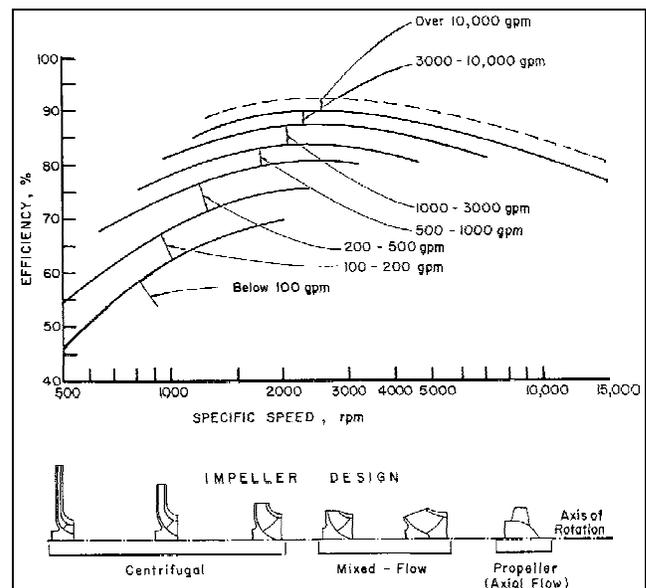


Figure 1. Theoretical pump efficiencies as functions of specific speed, impeller design, and pump capacity.

There is often an advantage in using pumps with high specific speeds. For a given set of conditions, operating speed is higher. As a result the selected pump can generally be smaller and less expensive. However, there is also a trade-off since pumps operating at higher speeds will wear out faster.

DETERMINATION OF OPERATING CONDITIONS

Before a pump is selected it is necessary to determine the head (H) and discharge (Q) required by the irrigation system. The system head versus discharge relationship should be evaluated for the entire range of operating conditions. When the

system head and/or discharge vary significantly, special attention must be given to selecting a pump (or set of pumps) that can satisfy all conditions. Since most pumps are not very efficient over wide ranges in operating heads, the most prevalent conditions should be determined and a pump that operates efficiently over this set of conditions, and can operate under all other possible conditions, should be selected.

System Capacity

The flow rate required by the irrigation system depends on the size and type of the irrigation system, crop water requirement, time of operation, and efficiency of the system.

Frequently, the discharge will be constant for a given irrigation system. However, it may vary, especially for large systems with several zones. A typical example of a variable discharge system is one where the same pump is used for several irrigation zones consisting of solid set sprinklers and when the zones are not the same in size. If possible, the system should be designed to minimize this type of differences.

Total Dynamic Head Required By The System

For a given irrigation system a pump must provide the required flow rate at the required head (or pressure). The total dynamic head (TDH) curve of the system (Figure 2) illustrates that more head is required to increase the total flow through the system.

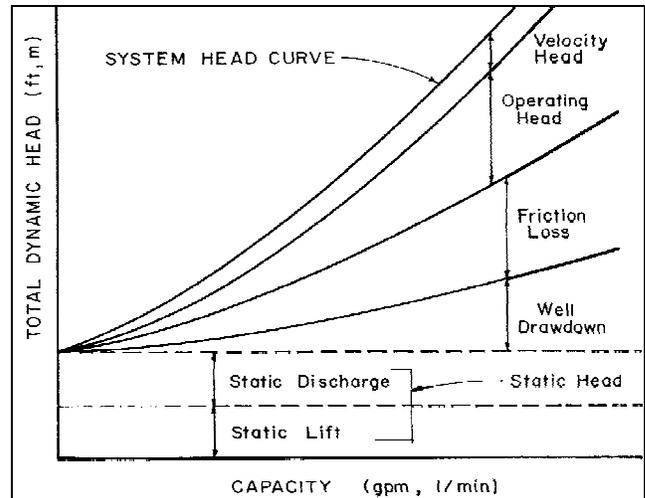


Figure 2. Total system curve and its components.

The pressure required for operating a given sprinkler or emitter represents only a portion of the total dynamic system head. Additional pressure must be produced by the pump to lift water from the well or other water source, to overcome friction losses in the pipe and other components of the system, and to provide velocity for the water to flow through the pipe. As a result, the total dynamic head for the system is the sum of static head (distance the water must be lifted), well drawdown, operating pressure (pressure required at the sprinkler or emitter), friction head (energy losses) and velocity head (energy required for water to flow). Figure 2 illustrates these components of the system TDH. It can be expressed as:

$$H_t = H_s + H_d + H_p + H_f + H_v \quad (4)$$

where:

- H_t = total dynamic head of the system (TDH)
- H_s = static head (static lift + static discharge)
- H_d = drawdown
- H_p = operating head (required pressure)
- H_f = friction loss head
- H_v = velocity head

Static Head

Static head is the vertical distance from the water level at the source to the highest point where the water must be delivered. It is the sum of static lift and static discharge. Static head is independent of the system discharge (gpm) and is constant for all values of discharge. However, it is possible that the

static head may vary with time due to the changes in the system.

Static Lift

The static lift is the vertical distance between the center line of the pump and the elevation of the water source when the pump is not operating. If the water elevation of the source is below the pump elevation, the static lift is positive. If the pump is located at the elevation below the water surface elevation, the static lift is negative.

Static Discharge

The static discharge head is a measure of the elevation difference between the center line of the pump or top of the discharge pipe and the final point of use. When pumps discharge directly into canals a short distance from the pump at the same elevation, the static discharge head is zero. If, however, a pump supplies water to some distant point at another elevation, then it is necessary to compute the static discharge head. To obtain this value, subtract the elevation of the pump or discharge pipe from the elevation of the final point of delivery.

Well Drawdown

As a well is pumped the water level in the well declines. This phenomena is commonly called the well drawdown. The amount of the drawdown is a function of the pumping rate, the aquifer properties, well size, method of construction (well screen, etc.) and the time the pump is operated. The best way to determine the well drawdown is to test pump a well at various rates and observe the drawdown. Testing of wells is described in detail in IFAS Extension Circular 803 "Water Wells for Florida Irrigation Systems".

When the water is to be pumped from the well it is important to know the drawdown to account for the additional lift. For a surface water source such as lake or river this water level may drop during a dry season. Any changes in static lift must be accounted for in the static head portion of the total system head.

Operating Head

Some irrigation systems require pressure to operate. The range of this pressure varies among systems. High pressure systems, such as traveling guns and high pressure center pivots or sprinkler

systems, may require large operating pressures (up to 100 psi). Micro irrigation systems can operate at much lower pressures (8-30 psi). For gravity irrigation systems (furrow, flood or open ditch subirrigation) the operating pressure can be close to zero.

For most irrigation systems, the operating pressure is constant. However, some systems may have a variable operating pressure. A good example of such a system is a center pivot system with an end gun for corner irrigation. Operating the gun requires additional pressure head for a relatively short time.

Friction Loss

When water flows through a pipe there is a loss of head due to friction. This loss can be calculated using hydraulic formulas or can be evaluated using friction loss tables, nomographs, or curves provided by pipe manufacturers. The pump must add energy to the water to overcome the friction losses. As the discharge of the system increases the velocity also increases. The friction loss increases as the square of the flow velocity. Due to the high cost of energy, it is often recommended that a user select a larger pipe size to decrease the velocity for the same discharge. This is usually economically feasible if the water velocity is more than 5 ft/sec.

For a system having very long pipelines or undersized pipe for a given flow rate, the friction loss can be very significant.

Friction losses must be considered on both the intake and discharge sides of the pump. It is especially necessary to compute or evaluate the friction loss on the suction-side of centrifugal pumps to assure enough net positive suction head available (discussed below) to prevent pump cavitation.

Pump cavitation is caused by the reduction in pressure behind the impellers to the point that the water vaporizes. It can be very damaging to the pump. The process of cavitation is described in IFAS Circular 832 "Pumps for Florida Irrigation and Drainage Systems".

In every irrigation system there are some additional friction losses due to various fittings and other components of the system such as flow meters and intake strainers. These are often called minor losses. Minor losses of fittings can be estimated using

tables that relate each type of fitting to the certain equivalent length of the same diameter pipe.

Velocity Head

Velocity head is the amount of energy required to provide kinetic energy to the water. For systems with a high total head this component is very small compared with other components of the total system head. Velocity head is calculated using the following equation:

$$H_v = V^2/2g \quad (5)$$

where:

$$\begin{aligned} H_v &= \text{velocity head ft (m)} \\ V &= \text{water velocity in the system ft/sec (m/sec)} \\ g &= \text{acceleration of gravity } 32.2 \text{ ft/sec}^2 \text{ (9.81 m/sec}^2\text{)}. \end{aligned}$$

In most installations velocity head is less than one foot (.3m). An increase of water velocity in the system will not usually result in large increases in velocity head. However, velocities that are too high will increase friction losses as discussed above and also may result in water hammer which should be avoided. Water hammer is a sudden shock wave propagated through the system. To avoid it, the velocity is generally maintained below 5 ft/s.

System Head Variations

The total system head can vary with time due to variations in well drawdown, friction, operating conditions, and static water level changes throughout the seasons. The friction losses will increase with system age due to corrosion or deposits in the pipe and other components. The static lift component of the total dynamic head may vary due to fluctuating water levels throughout the season, or from year to year.

In some systems there is a periodic change in the operating head of the system. It may not be possible to select a pump that is efficient under a wide range of system heads. In some cases an additional (booster) pump, in series with a main pump, may provide the additional head when necessary (see the section on pumps in series). This arrangement is frequently used in center pivot systems, where a small booster pump provides the additional operating head required for end gun operation at the corners of the field.

CHARACTERISTIC CURVES FOR CENTRIFUGAL PUMPS

A set of four curves known as the pump's characteristic curves is used to describe the operating properties of a centrifugal pump. These four curves relate head, efficiency, power, and net positive suction head required to pump capacity (Figure 3). Pump manufacturers normally publish a set of characteristic curves for each pump model they make. Data for these curves are developed by testing several pumps

of a specific model. The operating properties of a pump depend on the geometry and dimensions of the pump's impeller and casing.

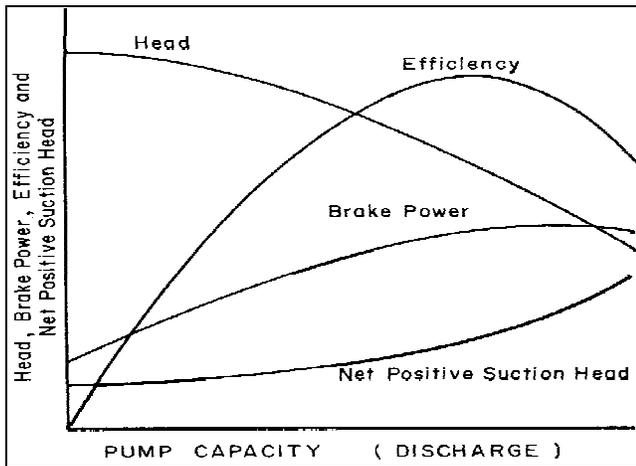


Figure 3. Characteristic curves for a single-stage centrifugal pump.

Head Versus Pump Capacity

Figure 4 shows a typical head, H (ft), versus capacity (discharge), Q (gpm), curve for a single-stage pump. This curve relates head produced by a pump to the volume of water pumped per unit time. Generally, the head produced decreases as the amount of water pumped increases. The shape of the curve varies with pump's specific speed and impeller design. Usually, the highest head is produced at zero discharge and it is called the shut-off head.

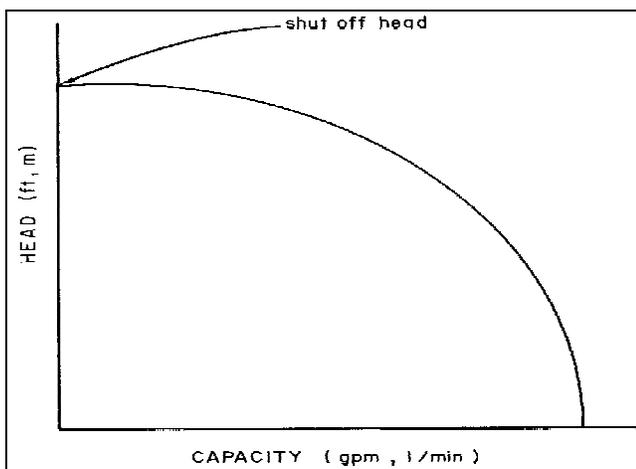


Figure 4. A typical head versus capacity characteristic curve of a centrifugal pump.

Efficiency Versus Pump Capacity

The curve relating efficiency (E) to discharge (Q) is presented in Figure 5. The E - Q relationship can also be drawn as a series of envelope curves upon the H - Q curve (Figure 6). The efficiency of a pump steadily increases to a peak, and then declines as Q increases further. Efficiencies vary between types of pumps, manufacturers and models.

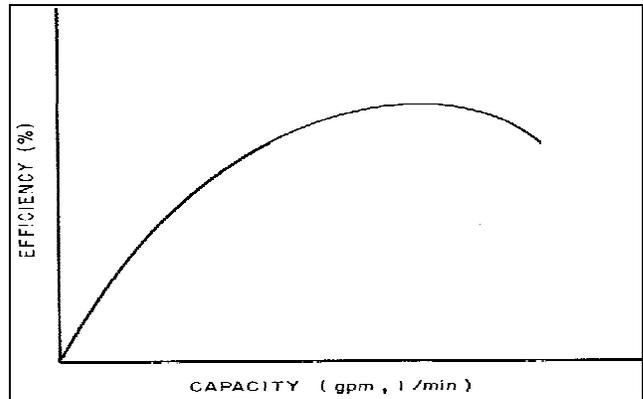


Figure 5. A typical efficiency versus capacity characteristic curve of a centrifugal pump.

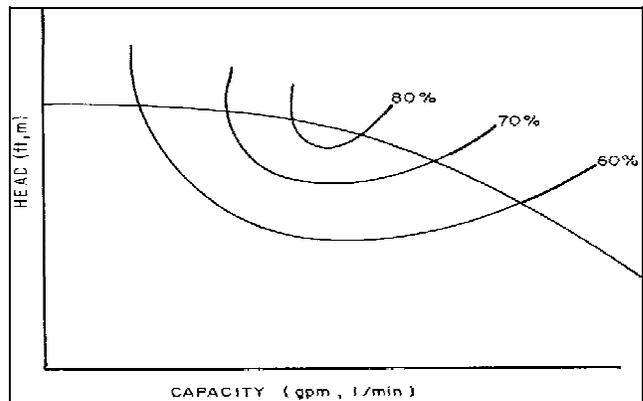


Figure 6. Efficiency expressed as a series of envelope curves upon the head versus discharge characteristic curve of a centrifugal pump.

Efficiency is defined as the output work divided by the input work. The input work is usually expressed as the size of the engine that would be required to drive the pump. It is commonly expressed in English units as the brake horsepower.

Brake Power Versus Pump Capacity

The shape of the brake power versus discharge curve is a function of the head versus discharge and efficiency versus discharge curves. The most common form of the BP-Q curve for centrifugal pumps is presented in Figure 7. In some cases the highest power demand is at the lowest discharge rate and it continues to decline as the discharge increases. It is important to notice that even at zero discharge, when the pump is operating against the shut-off head, an input of energy is needed.

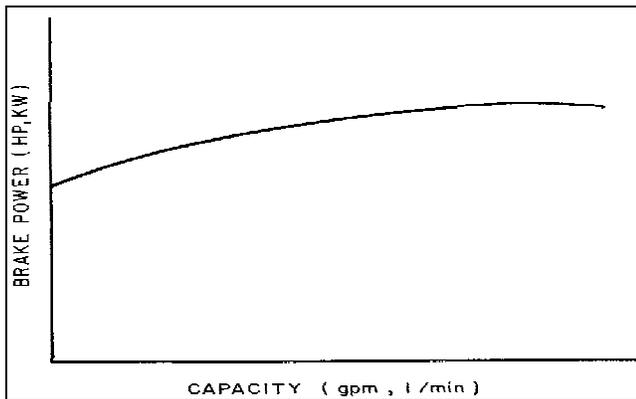


Figure 7. A typical brake power versus capacity characteristic curve of a centrifugal pump.

It is recommended that the power requirement (brake power) be calculated using equation (1) since the vertical scale for most BP-Q curves can not be read very accurately.

Net Positive Suction Head Required Versus Pump Capacity

One of the curves typically published by manufacturers is the net positive suction head required, $NPSH_r$, versus capacity, Q . For a typical centrifugal pump the $NPSH_r$ steadily increases as Q increases. To assure that the required energy is available, an analysis must be made to determine the net positive suction head available $NPSH_a$ which is a function of the pumping system design. Net positive suction head available in the system can be calculated using following formula:

$$NPSH_a = BP - SH - FL - VP \tag{6}$$

where:

- BP = barometric pressure
- SH = suction head or lift
- FL = friction losses in the intake pipe
- VP = water vapor pressure at a given temperature

(all terms should be expressed in feet of water).

After these calculations are performed the $NPSH_r$ versus Q curve can be used. The $NPSH_a$ must be greater than $NPSH_r$ at a given Q to avoid pump cavitation. A typical curve representing $NPSH_r$ versus capacity Q is shown in Figure 8.

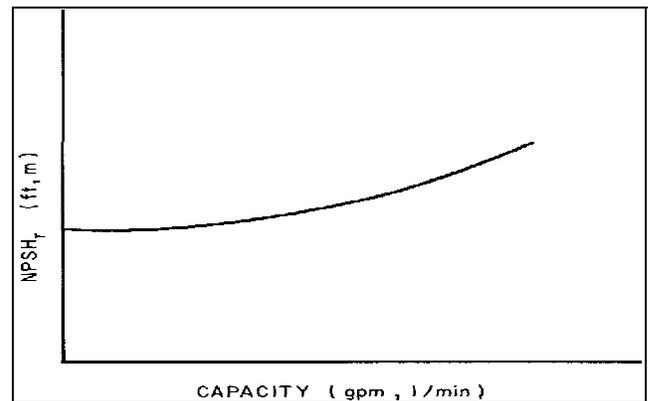


Figure 8. A typical characteristic curve representing net positive suction head required ($NPSH_r$) versus capacity for a centrifugal pump.

PUMP OPERATING POINT

A centrifugal pump can operate at a combination of head and discharge points given by its H-Q curve. The particular combination of head and discharge at which a pump is operating is called the pump's operating point. Once this point is determined brake power, efficiency, and net positive suction head required for the pump can be obtained from the set of pump curves.

The operating point is determined by the head and discharge requirement of the irrigation system. A system curve, which describes the head and discharge requirements of the irrigation system, and a head-discharge characteristic curve of the pump are used to determine the pump operating point (Figure 9). The operating point is where the head-discharge

requirements of the system are equal to the head-discharge produced by the pump.

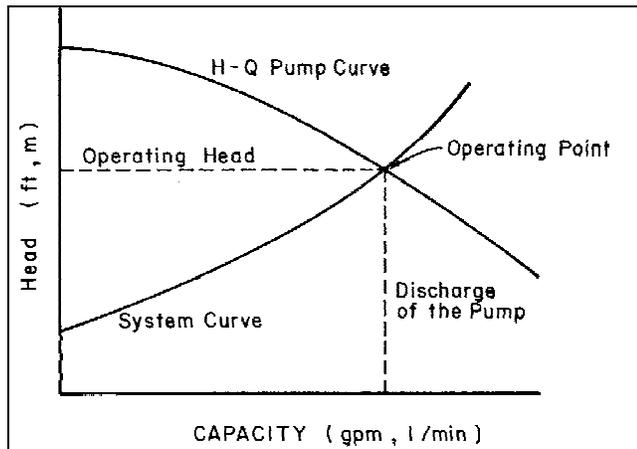


Figure 9. Determination of the operating point for a given centrifugal pump and water system.

A system curve is produced by calculating the total dynamic head H_t (see equation 4) required by the irrigation system to deliver certain a volume of water per unit time. By determining the system head curve for a range of discharges above and below the design discharge, sufficient information will be available to evaluate pump performance for all expected operating conditions.

It is important to realize that the system curve does not always remain constant over time. Any change in the system curve results in a shift of the pump operating point. The total range of possible conditions of head versus discharge for a given system must be evaluated before an efficient pump (or pumps) can be selected for this particular system. Two examples of possible changes with time are presented in Figures 10 and 11. In Figure 10 the change in the total system head is due to increased friction losses, while in Figure 11 the change is due to a change in static head.

The pump selection should consider these changes. If the range of discharge is not very large it is possible to select a pump that can operate under all tense conditions with reasonable efficiency.

PUMP SELECTION

Pump selection is the process of choosing the most suitable pump for a particular irrigation system. The performance requirements of the water system must be specified and the pump type must be selected. Alternate pumps that meet the

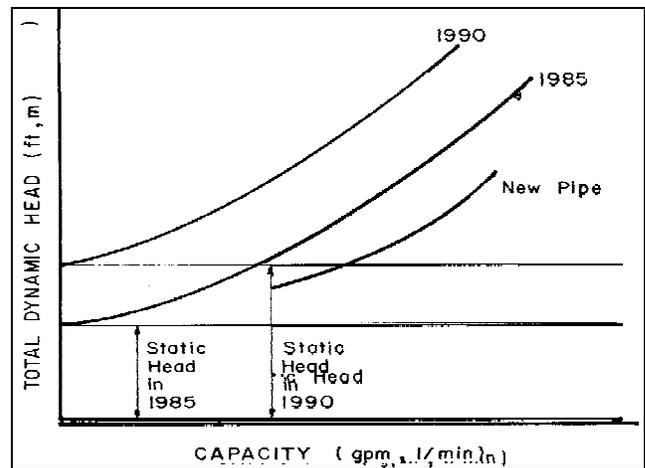


Figure 10. A change in the total dynamic system head due to the increase in friction losses in the old pipe.

requirements of the system also should be specified. Normally, the most suitable pump is chosen from these pumps considering economic factors.

Pump Types

Various types of centrifugal pumps are most commonly used in irrigation and drainage systems. Centrifugal pumps can be classified by type of impeller:

- Radial-flow pumps
- Axial-flow pumps
- Mixed-flow pumps

In addition, a centrifugal pump can be classified in one of four major groups depending on its design and application:

- Volute pumps
- Diffuser pumps
- Turbine pumps
- Propeller pumps

Volute pumps are used where water is obtained from depths generally less than 20 ft (7m). The exact value of possible lift is determined by the net positive suction head required by the pump and intake-side conditions. Whenever possible, it is recommended to use a horizontal volute pump, since it is less expensive and easy to install. However, deep wells and some surface water sources will require a submersible pump to provide their NPSH_r needs. If the suction-side lift is more than 20 ft at any time during pumping, a

horizontal volute centrifugal pump may have cavitation problems. A turbine pump should be used in this system.

Pumps using axial-flow types of impellers are designed for conditions where the capacity is high and the head requirements are low. These impellers are used in propeller pumps. Most axial-flow pumps operate on installations where suction lift is not required. They are installed in such a way that the impeller is submerged in the water. In Florida, they are most frequently found in the south, where the water is pumped from canals. Characteristic curves of these pumps vary from the characteristic curves for centrifugal pumps discussed in this publication. They will not be discussed here. Interested readers should refer to James (1988) for more information on this subject.

Mixed-flow impellers with diffusers are often used in deep-well turbine and submersible turbine pumps. These pumps are used for pumping water from depths larger than 20 ft.

More details on various pump types, classifications, operation, and applications of various pumps are provided in IFAS Extension Circular 832 "Pumps for Florida Irrigation and Drainage Systems".

Manufacturers' catalogs are consulted to identify pumps of the proper type that are capable of supplying the discharge and head requirements of the water system. Characteristic curves for these pumps are examined to determine which of these pumps are suitable for the irrigation system. Proper selection of a pump requires knowledge, understanding, and use of pump's characteristic curves.

For example, in the case of the variation in system discharge, a pump with flat Q-H characteristic curve (where the head doesn't change significantly with a change in discharge) should be selected (Figure 12). This pump can deliver 800 gpm at approximately 107 ft of pressure at 70% efficiency. If the flow rate increases to 1000 gpm the head will drop only about 15 ft (6.5 psi) and efficiency will remain the same. If the system can operate with a 15 ft lower head, the same pump can be used for both flow rates.

It is not always possible to select one pump for all anticipated operating conditions. If the discharge varies significantly an additional pump in parallel with a main pump may be used in time of larger flow

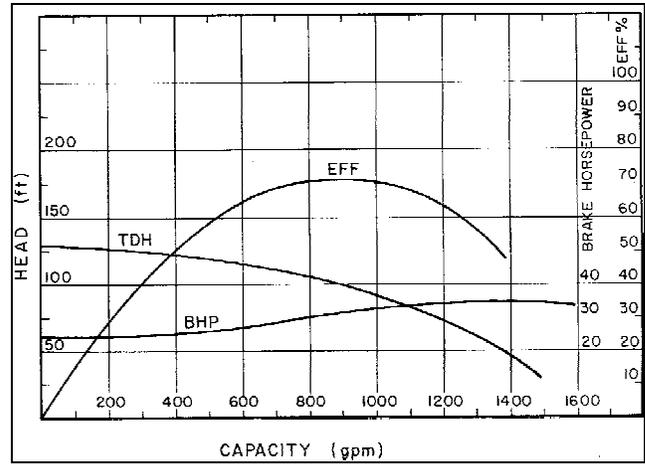


Figure 12. A typical set of characteristic curves for a deep well submersible turbine pump with a relatively flat H-Q characteristic curve.

demands (see section on parallel pumps).

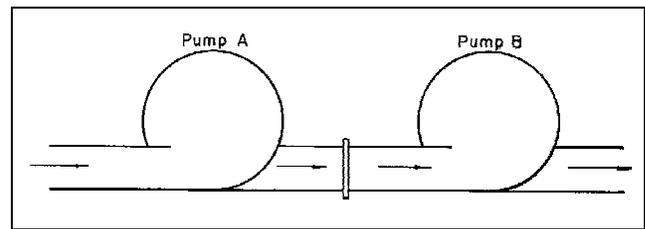


Figure 13. Two pumps connected in a series.

Pumps Operating In Series

To connect two pumps in series means that the discharge from the first pump is piped into the inlet side of the second pump (Figure 13). In this type of arrangement all the flow successively passes from one pump to the next with each pump adding more energy to the water. This is a typical arrangement in multi-stage turbine or submersible pump where the same discharge passes through all stages and each builds additional head. Often, series configurations are used when head requirements of the system exceed that which can be supplied by individual pumps. They are also used in systems with variable head requirements. A small centrifugal pump used as a booster pump for corner irrigation on a center pivot system or, for that matter, any booster pump, in any water system, which works in addition to the main water pump. Figure 14 shows head-discharge curves for two pumps operating in series.

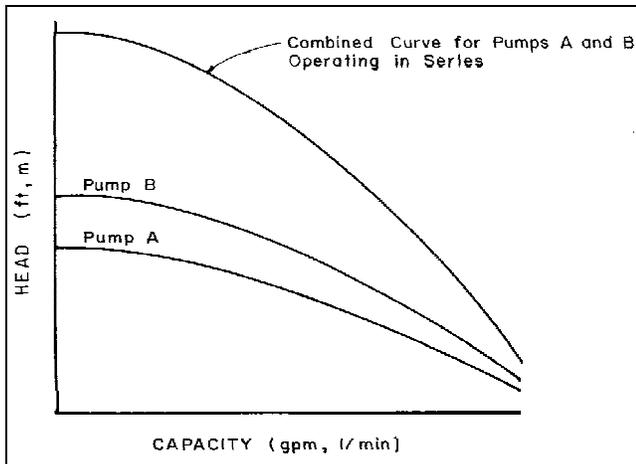


Figure 14. Head versus discharge characteristic curves for two pumps operating in series.

Pumps Operating In Parallel

Figure 15 presents a parallel configuration of two pumps. A typical example of this arrangement is a situation where two or more pumps draw water from a single source and all the flows are discharged into a single pipe. Another example is a situation where several small wells are providing the required discharge. Parallel arrangements are also common methods of meeting variable discharge requirements of the system. A head-discharge characteristic curve for two pumps operating in parallel is presented in Figure 16.

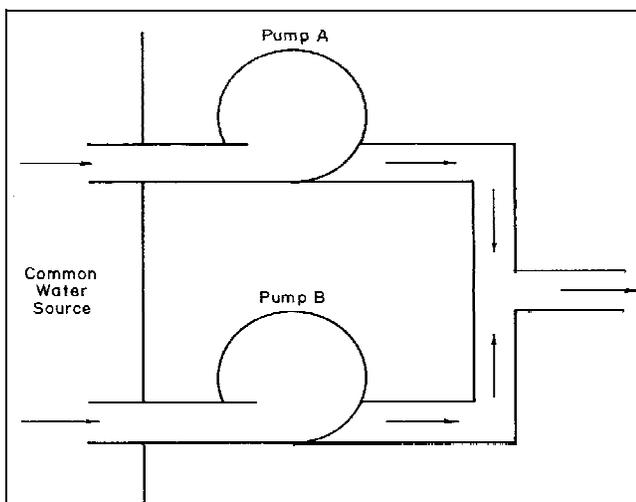


Figure 15. Two pumps connected in parallel.

Efficiency Considerations

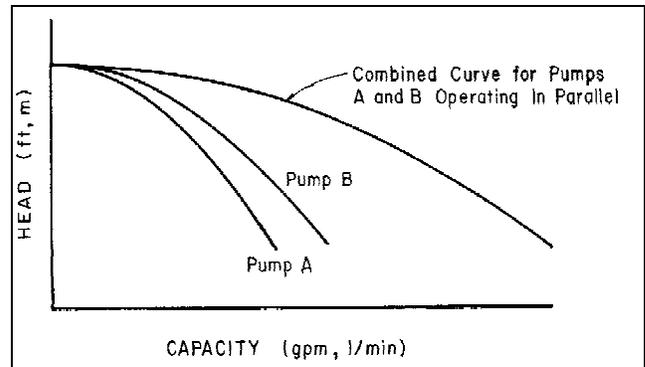


Figure 16. Head versus discharge characteristic curves for two pumps operating in parallel.

During the pump selection process, only pumps having high efficiencies (above 70%) for the design discharge should be considered for a system. It is common practice to select a pump capable of producing higher head and larger flow rate (approximately 10%) than the design parameters. This will assure that as the pump wears, its performance will remain adequate. The impact of low efficiency on power consumption is very significant. Total pump operating costs may justify the purchase of a more expensive pump that can operate with higher efficiency under needed conditions. Economics is often the primary criterion for pump selection. It is important to estimate the cost of pump operation and consider this cost together with the initial cost of the pumping equipment. The economic analysis is beyond the scope of this publication, however, interested readers can find additional information in Jensen (1980), or James (1988).

SUMMARY

Pump performance parameters and their significance for pump selection were discussed. The role and importance of pump characteristic curves in the pump selection process was described. Operating conditions, determined by the water system characteristics, as well as operating point for the pump were discussed in detail. The publication also briefly discussed types of pumps and their applications in irrigation. Finally, the impact of efficiency on the operating cost and pump selection was noted.

REFERENCES

- Haman, D.Z., F.T. Izuno and A.G. Smajstrla. 1989. Pumps for Florida Irrigation and Drainage Systems. Extension Circular 832. IFAS. University of Florida, Gainesville, FL 32611.
- Haman, D.Z., A.G. Smajstrla and G.A. Clark. Water Wells for Florida Irrigation Systems. Extension Circular 803. IFAS. University of Florida, Gainesville, FL 32611.
- James, L.G. 1988. Principles of Farm Irrigation System Design. John Wiley and Sons. New York.
- Jensen, M.E. 1980. Design and Operation of Farm Irrigation Systems. American Society of Agricultural Engineers, St. Joseph, MI 49085.