Tech Brief

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Reading Centrifugal Pump Curves

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Summary

Reading and understanding centrifugal pump curves is key to proper pump selection, and to their reliable and efficient operation. This *Tech Brief* examines how pump curves can provide data about a pump's ability to produce flow against certain head, shows how to read a typical centrifugal pump curve, and provides information about pump efficiency and brake horsepower.

Pumps are the workhorses of any drinking water distribution or wastewater collection system. They operate 24 hours a day, 365 days a year getting water to homes and business, and removing wastewater from them. A correctly sized pump will work efficiently for many years, saving a system money and energy. An incorrectly sized pump can fail if it's too small or result in unnecessary expense if it's too big. Pump curves provide a way to see the correct size a pump should be for specific conditions.

Pump Terminology

Before discussing specific details, it helps to understand typical terms associated with pump curves:

Impeller—the moving element in a pump that drives the liquid.

Volute—the spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Head—a measure of the pressure or force exerted by water expressed in feet. Centrifugal pump curves show pressure as head, which is the equivalent height of water with specific gravity = 1.

Static Head—the vertical height difference from the surface of a water source to the centerline of the impeller. The vertical height difference from the centerline of the impeller to the discharge point is called discharge static head, while the vertical height difference from the surface of the water source to the discharge point is known as total static head.

Total Head / Total Dynamic Head—the total height difference (total static head) plus friction losses and demand pressure from nozzles etc. (total discharge head) = total dynamic head.

Capacity/Flow—the rate of liquid flow that can be carried, typically measured in gallons per minute (gpm).

Net Positive Suction Head—how much suction lift a pump can achieve by creating a partial vacuum. Atmospheric pressure then pushes liquid into pump. A method of calculating if the pump will work or not.

Cavitation—cavities or voids in liquid. Bubbles take up space leading to a drop in pump capacity. Collapsing bubbles can damage the impeller and volute, making cavitation a problem for both the pump and the mechanical seal.

Specific Gravity—the weight of liquid in comparison to water at approximately 20° C (SG = 1).

Specific Speed—a measure of the function of pump flow, head, and efficiency.

Vapor Pressure—the force exerted by the gas released by a liquid in a closed space. If the vapor pressure of a liquid is greater than the surrounding air pressure, the liquid will boil.

Viscosity—a measure of a liquid's resistance to flow (i.e., how thick it is). The viscosity determines the type of pump used, how fast it can run, and with gear pumps, the internal clearances required.

Friction Loss—the amount of pressure / head required to force liquid through pipes and fittings.

Pump Efficiency—the ratio of energy delivered by the pump to the energy supplied to the pump shaft. Some pump curves will show you the percent of efficiency at the best efficiency point. The number varies with impeller design and numbers from 60 percent to 80 percent are normal.

Best Efficiency Point—the point of highest efficiency of the pump.

Pump Performance Curve

A centrifugal pump performance curve is a tool that shows how a pump will perform in terms of head and flow. Pumps can generate high volume flow rates when pumping against low-pressure head or low volume flow rates when pumping against high-pressure head. The possible combinations of total pressure and volume flow rate for a specific pump can be plotted to create a pump curve. The curve defines the range of possible operating conditions for the pump. Pump curves plot data on a graph with x and y axes. The x axis (vertical) shows total head while the y axis (horizontal) shows flow capacity, typically gpm.

For example, to pump against a total head of 120 feet and using an impeller trim of 8.5 inches, you could pump at a rate of about 42 gpm (gallons per minute) with a NPSH (net positive suction head) required of three feet and at a efficiency of about 73.3 percent (see Figure 1). Using the above data, the brake horsepower (HP) would be three HP. To account for future expansion and pump at a higher rate, such as 55 gpm, the total head would stay the same. On the pump curve, the intersection of 120 feet of total head and 55 gpm shows the need for a new impeller trim of nine inches, a brake horsepower of about four HP, and a NPSH of 3.75 feet. The efficiency would be about 73.5 percent.

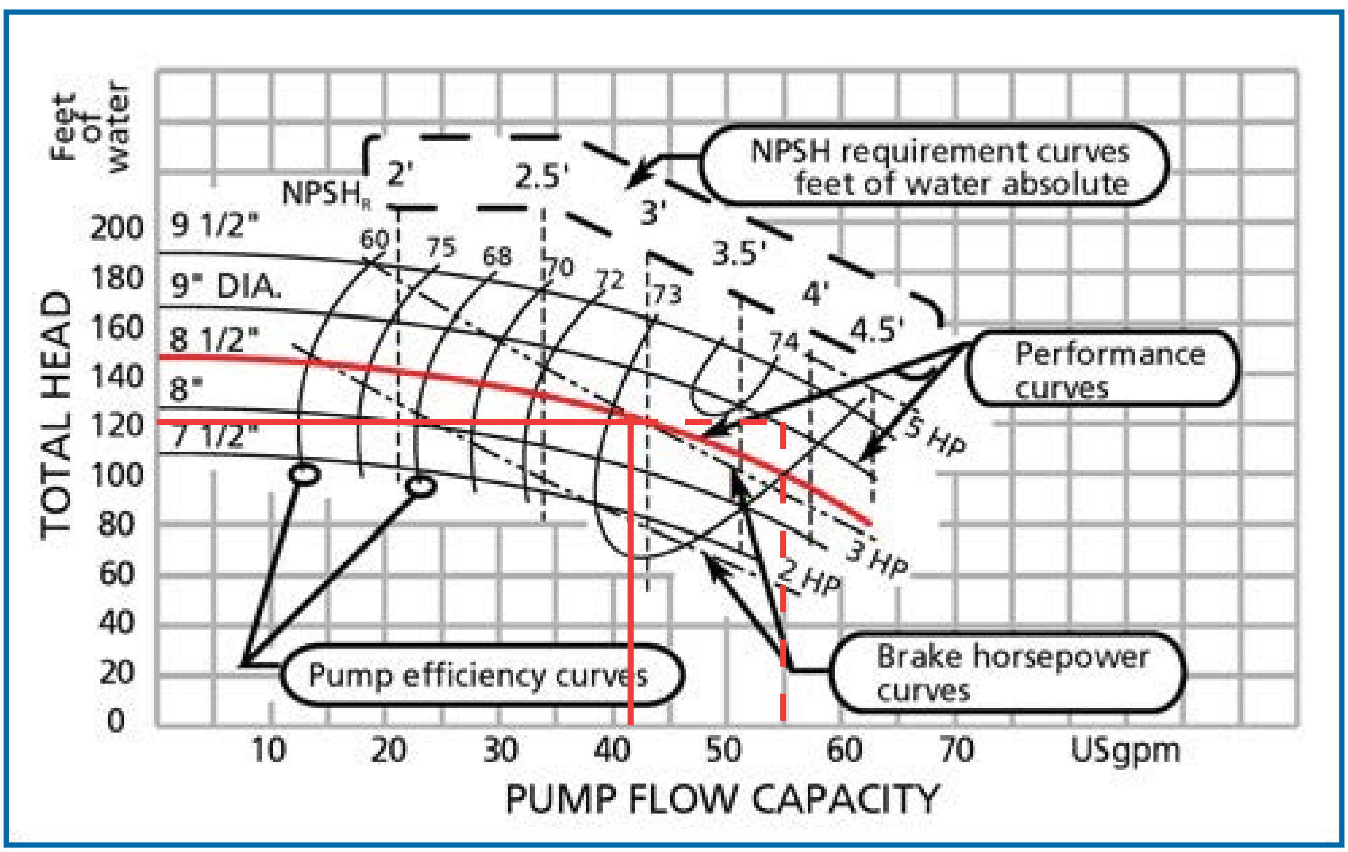
Head and Capacity Relationship

Every pump will be capable of developing a specific pressure (PSI or BAR measurement translated into feet or meters head) at a specific flow (normally represented in gallons per minute or liters per minute). The pump will pump any liquid to a given height or head depending upon the diameter and speed of the impeller. The amount of pressure you get depends upon the weight (specific gravity) of the liquid. Head (feet) is a convenient term because when combined with capacity (gallons or pounds per minute) you come up with the conversion for horsepower (foot pounds per minute).

Efficiency

Pump efficiency is the ratio of the liquid horsepower delivered by the pump and the brake horsepow-

Figure 1: Typical Pump Performance Curve



Source: City College of New York, Department of Civil Engineering er delivered to the pump shaft. When selecting a pump, a key concern is optimizing pumping efficiency. It is good practice to examine several performance charts at different speeds to see if one model satisfies the requirements more efficiently than another. Whenever possible the lowest pump speed should be selected, as this will save wear and tear on the rotating parts.

The pump performance curve also gives information on pump efficiency. The efficiency curves intersect with the head-capacity curve and are labeled with percentages. The pump's efficiency varies throughout its operating range. Each pump will have its own maximum efficiency point. The best efficiency point (BEP) is the point of highest efficiency of the pump. All points to the right or left of the BEP have a lower efficiency.

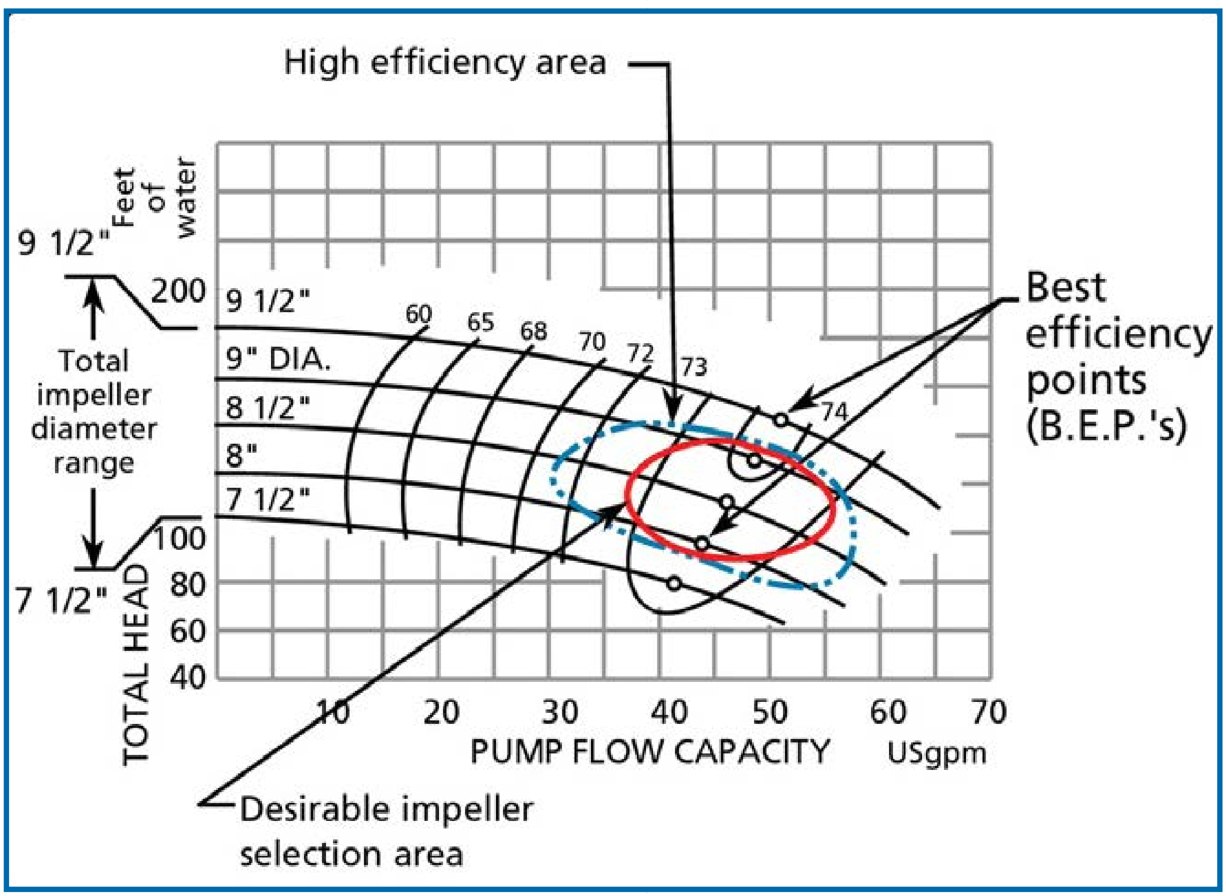
The impeller is subject to axial and radial forces, which get greater the further away the operating point is from the BEP. These forces manifest themselves as vibration depending on the speed and construction of the pump. The point where the forces and vibration levels are minimal is at the BEP. Pumps should be sized as close as possible to its best efficiency point or flow rate. This not only makes the pump more efficient but also improves the reliability of the pump. Note that total efficiency is never realized because of mechanical and hydraulic losses incurred in the pump.

Ideally, a pump would run at its best efficiency point all the time, but we seldom hit ideal conditions. As you move away from the BEP the shaft will deflect and the pump will experience some vibration. You should check with the pump manufacture to see how far you can safely deviate from the BEP and still get satisfactory operation (a maximum of 10 percent either side is typical).

Pump efficiency is greatest when the largest possible impeller is installed in a pump casing. Pump efficiency decreases when smaller impellers are installed in a pump because of the increased amount of fluid that slips through the space between the tips of the impeller blades and the pump casing. Pump efficiency also decreases as the rotational speed of the pump is reduced. However, the magnitude of the decrease in pump efficiency depends on the individual pump.

Keep in mind that running the pump outside the recommended operating range could and most likely will damage the pump by shortening bearing and seal life or even damage the shaft. Also sustained excess velocity and turbulence will re-

Figure 2: Desireable Pump Selecton Area



Source: City College of New York, Department of Civil Engineering sult in vortexes, which can create cavitation damage capable of destroying the pump casing, back plate, and impeller in a short period of operation.

As a guide, select a pump with an impeller size no greater than between 1/3 and 2/3 of the impeller range for that casing with an operating point in the high efficiency area (see Figure 2). It is also important not to go too far right or left from the B.E.P.. A guideline is to locate the operating point between 110 and 80 percent of the B.E.P. flow rate with an operating point in the desirable impeller selection area (see Figure 2).

Brake Horsepower

The pump performance curve will give information on the brake horsepower (BHP) required to operate a pump (horsepower required at the pump shaft) at a given point on the performance curve. The brake horsepower curves run across the bottom of the pump performance curve usually sloping upward from left to right. These lines correspond to the performance curves above them (the top performance curve corresponds to the top BHP line and so on). Like the head-capacity curve, there is a brake horsepower curve for each different impeller trim.

Impeller Trims

Impeller trims or impeller diameter is measured in either inches or millimeters.

Pump performance curves generally show performance for various impeller diameters or trims. Manufacturers will put several different trim curves on a pump performance curve to make pump specification easier, although this sometimes makes the pump performance curve more difficult to read. It is good practice to select a pump with an impeller that can be increased in size permitting a future increase in head and capacity.

End of Curve Horsepower

When sizing the motor to drive the pump it is necessary to consider whether the pump will ever be required to operate at a flow higher than the duty point or operating point. The motor will need to be sized accordingly. If the pump may flow out to the end of the curve (if someone opens the restriction valve all the way, for example) it is important that the motor does not become overloaded as a result. Therefore it is normal practice to size the motor not for the duty point/operating point, but for the end of the curve (EOC) horsepower requirements.

Affinity laws

The affinity laws associated with the rotational speed or rpm of a centrifugal pump is that if the speed or impeller diameter of a pump change, we can calculate the resulting performance change using:

1. The flow changes proportionally to speed: double the speed / double the flow.
2. The pressure changes by the square of the difference: double the speed/multiply the pressure by four.
3. The power changes by the cube of the difference: double the speed/multiply the power by eight.

These laws apply to operating points at the same efficiency. Variations in impeller diameter greater than 10 percent are hard to predict due to the change in relationship between the impeller and the casing.

Closing

Pump curves are not only used to pick the correct pump for an application but can also be used to estimate flow rates for an already installed system. By knowing the model, discharge pressure, suction pressure, and impeller size, the flow rate can easily be determined from the curve. When selecting or specifying a pump, it is important not to add safety margins or base selection on inaccurate information.


Tech Brief

Fundamentals of Hydraulics: Flow

Summary

Download all of our Tech Briefs at www.nesc.wvu.edu/techbrief.cfm

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More Information

In addition to the links provided in the references, the National Environmental Services Center had three additional Tech Briefs that may be of interest:

"Pumps"
www.nesc.wvu.edu/pdf/dw/publications/ontap/2009_tb/pumps_DWFSOM56.pdf

"Fundamentals of Hydraulics: Pressure"
www.nesc.wvu.edu/pdf/dw/publications/ontap/2010_tb/hydraulics_pressure_DWFSOM147.pdf

"**Fundamentals of Hydraulics: Flow"**
www.nesc.wvu.edu/pdf/dw/publications/ontap/2010_tb/hydraulics_pressure_DWFSOM150.pdf

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Zoeller Engineering. "How to Read Pump Curves." Accessed at: https://app.qleapahead.com/rtp/LibraryGet.aspx?asset=85798,63

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