Understanding Pump Fundamentals for an Energy Efficient World

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This first in a series is based on the opening chapter of *Optimizing Pumping Systems, A Guide to Improved Energy Efficiency, Reliability, and Profitability*, written by pump systems experts. This new guidebook continues the mission of Pump Systems Matter (PSM) and the Hydraulic Institute (HI) to advance knowledge on pumping systems.

The U.S. Department of Energy has determined that 25 percent of industrial motor systems energy consumption is currently consumed by pumping systems. Interest in energy efficiency is not a fad; industrial production economics, global energy supply limitations and environmental conservation realities will likely be an enduring theme for decades, if not indefinitely.

As energy costs continue to increase, pump manufacturers understand that making equipment more efficient will contribute to saving energy. While traditional methods of specifying and purchasing piping, valves, fittings, pumps and drivers often result in lowest first cost, these methods often produce systems with unnecessary, expensive energy consumption and higher maintenance costs. A business entity that incorporates the energy, reliability and economic benefits of optimized pumping systems can enhance profits, gain production efficiency improvement opportunities and initiate necessary capital upgrades for long-term business survival.

Pump Fundamentals

The pumps used in pumping systems fall into two general categories: rotodynamic (centrifugal, mixed flow and axial flow) and positive displacement. Because the majority of pumps and energy usage in industrial and commercial applications are in the rotodynamic pump category, the forthcoming guide from HI and PSM deals exclusively with rotodynamic pumps.

How a Rotodynamic Pump Works

A rotodynamic pump converts kinetic energy to potential or pressure energy. The pumping unit's energy conversion components have three major parts: the driver that turns the rotating element, the impeller and shaft (the rotating element) and the stationary diffusing element.

Typically connected to the pump's rotating element by a coupling, the driver causes the shaft and connected impeller to spin. With the pump casing primed, the liquid enters the rotating impeller eye, located along the axis of the impeller. The liquid is accelerated into the impeller's vaned passageways, where the continuous transfer of momentum and energy conversion occurs. As liquid flows through the impeller passageways, velocity increases.

When the fluid leaves the impeller, liquid velocity is greatest at the tip of the vanes. The rapidly moving liquid leaves the pump impeller, and the fluid enters the diffusing element of the pump. An increase in cross-sectional area of the flow passage occurs and the fluid slows down. The deceleration of the fluid in the diffusing section converts the kinetic energy of the liquid to potential or pressure energy. The diffusing section of the pump can be either a diffuser or a volute depending on the pump's configuration.

The shape, size, speed and design of the impeller and diffusing section establish the pump's head and flow characteristics. The pump impeller and diffusing section designs are based on the intended application, the user's specifications for the pump and the pump manufacturer's experience. Once a pump is selected, the casing design envelope cannot readily be changed, but the user can often change the pump impeller diameter and/or adjust the speed to better meet pumping requirements. For certain pumps, the manufacturer may have an alternate impeller, designed for a higher or lower capacity.

Pump Selection Considerations

Selecting a rotodynamic pump requires careful analysis of the system head versus flow requirements; the pump performance characteristics; the pumping application; the footprint available for the pump and driver; applicable specifications, codes, regulations and reliability; maintainability and energy cost considerations. The specifying engineer may need to work closely with the pump manufacturer or distributor to select the optimal pump and its size, speed and power requirements, type of drive, mechanical seal and ancillary equipment.

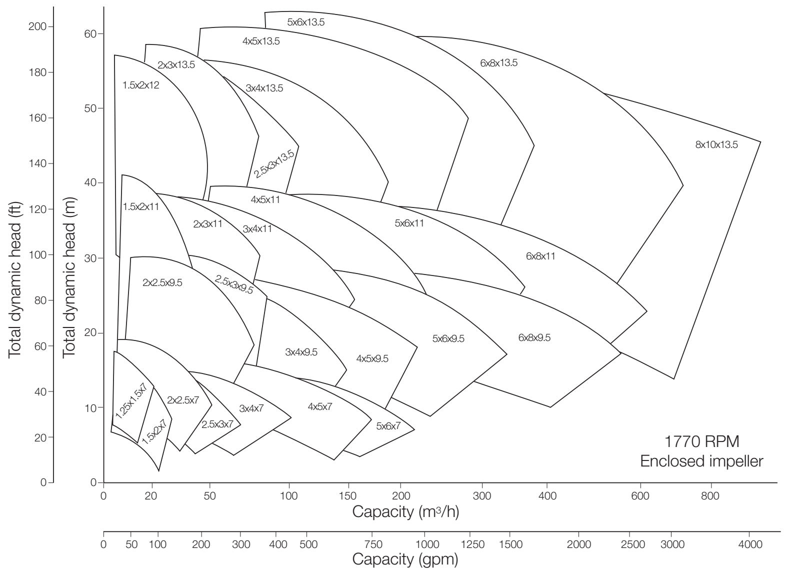

Figure 1. Example selection chart

Understanding the Pump Performance Curve

All pump selections must include matching the operating characteristics of the pump with the system requirements over the expected range of flows.

Types of Curves

There are three basic types of pump curves supplied by the pump manufacturer: the selection chart (also known as the *range chart* or the *family of curves*), the published curve and the certified curve.

Selection Chart

A selection chart shows the performance map for a similar pump family. Figure 1 shows a selection chart for a line of general-purpose end suction pumps. The head and flow scales on the hydraulic coverage range chart are often formatted on semi-log or log-log scales to display a wider range of flow and head values on a single chart.

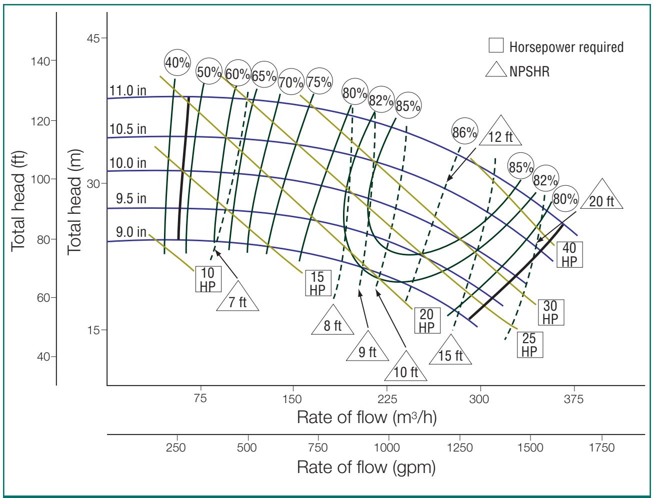

Figure 2. Example pump curve. A manufacturer's typical published curve for a given pump size and speed showing the available range of impeller diameters.

The selection chart shows the various pump sizes available for a given manufacturer's pump type and speed. The required head and flow rates are plotted on the curve, and the manufacturer evaluates the pumps with a best efficiency point near the specified operating points.

Published Curves

Once a shortlist of acceptable pumps is developed, the manufacturer's published curves can be referenced to help determine the best pump for the application. Figure 2 is an example of a published curve for a 5x6x11 pump running at 1,770-rpm. Useful operating information can be derived from the manufacturer's pump curve for this application, including the following:

- The impeller diameter falls between 10- and 10.5-in
- The pump is 85 percent efficient at the design point
- The power (at the operating point) is approximately 30-hp
- The net positive suction head required is approximately 10-ft

Contacting the pump manufacturer or sales office to review the suitability of a given pump model for the specified service conditions is recommended when specifying a pump.

Certified Curve

After a pump has been ordered and released for construction, the manufacturer builds it, and if testing is required, a certified performance curve is supplied. For reliable, consistent test results, it is recommended that the certified curve be based on the testing requirements contained in ANSI/HI 1.6 or 2.6. Unlike the published curve, which is a general curve for a given pump model type and size, the certified curve reflects the test results for the particular pump supplied under the purchase order.

Pump Suction Intake Considerations

Pump Location in the System

The pump's location in the system has a major effect on the net positive suction head available (NPSHA). A change in the pump or suction source elevation directly corresponds to an increase or a decrease in the NPSHA. In a new system, placing the pump at the lowest possible point or elevating the suction source can often be accomplished with minimal cost impact. After the system is built, changing NPSHA—except for changing level set points—is often cost-prohibitive.

Pump Suction Piping

The head loss component of the NPSHA is based on the friction losses in the pump suction piping. These losses can be significant and increase with the square of the increased ratio of flow rate. Pump performance can be limited by the NPSHA. Reducing the piping friction losses may be possible by increasing the diameter of the suction piping, reducing the number of elbows or fittings, or selecting valves with lower losses, i.e., by replacing a globe valve with a gate valve.

Liquid Properties

The temperature-dependent properties of the process liquid can significantly affect NPSHA, head, rate of flow and power requirements. Water at 68-deg F has a vapor pressure head of 0.78-ft, but has a vapor pressure head of 33.9-ft at 203-deg F. The increased water temperature represents a 33-ft reduction in NPSHA if no other changes are made. Changes in liquid temperature affect the liquid viscosity. For Newtonian liquids, raising the temperature tends to reduce viscosity, and lowering the temperature tends to increase viscosity.

Supply Tank and Atmospheric Pressure

The pressure acting on the liquid surface of a supply tank directly affects the NPSHA. It may be possible to increase the NPSHA by increasing the suction tank pressure, but this option should not be selected without verifying the supply tank pressure limitations and related process factors.

Pump Affinity Rules

The pump affinity rules describe how changing the impeller diameter (up to 5 percent change only) and rotational speed affect pump performance. The pump curve is derived from a series of test points connected together forming a smooth line. The discrete flow and head test values can be thought of as belonging to a coordinate point. When using the pump affinity rules, it is important to adjust both the head and flow values for the same coordinate point.

Changes in Rotational Speed

When the rotational speed of a pump is changed, the rate of flow (capacity), head and power for a point on the pump curve vary according to the pump affinity rules.

Flow	$Q_2 = Q_1 \times [N_2/ N_1]$
Head	$H_2 = H_1 \times [N_2/ N_1]^2$
Power	$P_2 = P_1 \times [N_2/ N_1]^3$

Where:

Q = rate of flow
H = head
P = power
N = speed
subscript 1 indicates existing value
subscript 2 indicates changed value

Figure 3 shows a pump performance curve at the manufacturer's test speed of 1,770-rpm and a speed of 1,500-rpm. As the speed is reduced, the pump curve moves down and shifts to the left. The pump affinity rules do not recommend what should be done to the pump efficiency at the new speed. However, pump efficiency usually follows with the affinity rule adjustment of flow. The values of efficiency do not typically change much with modest speed changes.

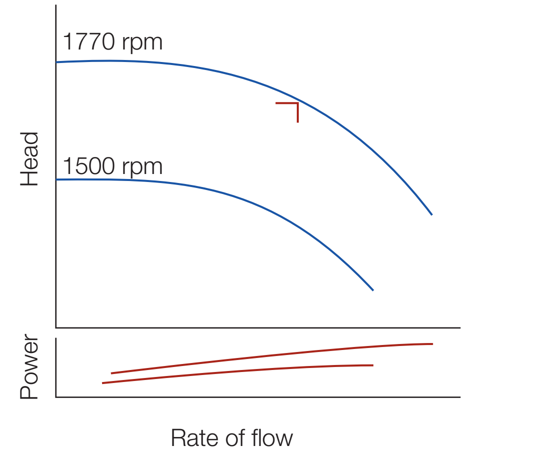

Figure 3. Pump performance curve at test speeds of 1,770- and 1,500-rpm

The pump affinity rules provide an accurate representation of pump performance change over a range of speeds.

Changes in Impeller Diameter

When the diameter of a pump impeller is trimmed (up to 5 percent change only), the rate of flow, head and power for a point on the pump curve vary approximately with the pump affinity rules.

Flow $Q_2 = Q_1 \times [D_2/D_1]$
Head $H_2 = H_1 \times [D_2/D_1]^2$
Power $P_2 = P_1 \times [D_2/D_1]^3$

Where:
Q = rate of flow
H = head
P = power
D = impeller diameter
subscript 1 indicates existing value
subscript 2 indicates changed value

Pump Operation

A pump must be operated using established procedures to minimize repairs and unexpected downtime. A checklist should be developed to verify that all safety precautions, ancillary equipment and valve settings, manufacturer recommendations, instrumentation hook-ups, etc. are in order before starting a pump.

When shutting down the pump it is important to follow an established shutdown sequence for safety and to prevent hydraulic transient flow-related problems, water hammer, reverse rotation of the pump, unexpected tripping of other equipment in the system and other problems.

"Understanding Pump Fundamentals for an Energy Efficient World" is based on the opening chapter of *Optimizing Pumping Systems, A Guide to Improved Energy Efficiency, Reliability, and Profitability* written by HI and PSM experts. Subsequent articles from this guidebook will include: Pump and System Interaction; Calculating Cost of Ownership; Improving Performance of Existing Pumping Systems; Building Better Pumping Systems: Optimizing New Designs; Pumping System Economics: Opportunities to Improve Life Cycle Performance and Optimizing Pumping Systems Case Studies.

P & S

References
Centrifugal Pump Tests, ANSI/HI 1.6 and *Vertical Pump Tests*, ANSI/HI 2.6 are available at www.Pumps.org

Hydraulic Institute, Inc., 9 Sylvan Way, Parsippany, NJ 07054, 973-267-9700, www.pumps.org.

Pump Systems Matter, 9 Sylvan Way, Parsippany, NJ 07054, 973-267-9700, www.pumpsystemsmatter.org.

Pump Systems Matter (PSM) and the Hydraulic Institute (HI) will soon publish a new guidebook on *Optimizing Pumping Systems* to improve understanding of the complex task of matching pump performance characteristics to the system requirements. It will also contain explanations to justify such systems improvement projects to senior management who make key capital and budget decisions. It presents practical information for those who have not had broad exposure to pumping systems and those who wish to improve their systems. The material assumes the reader has basic familiarity with engineering principles and practices. It presents the collective knowledge of many industry experts, which is intended to empower the reader to optimize systems efficiently, reliably and economically.

The guidebook is one of an evolving range of services offered by *Pump Systems Matter® (PSM)*. See www.PumpSystemsMatter.org for more information.