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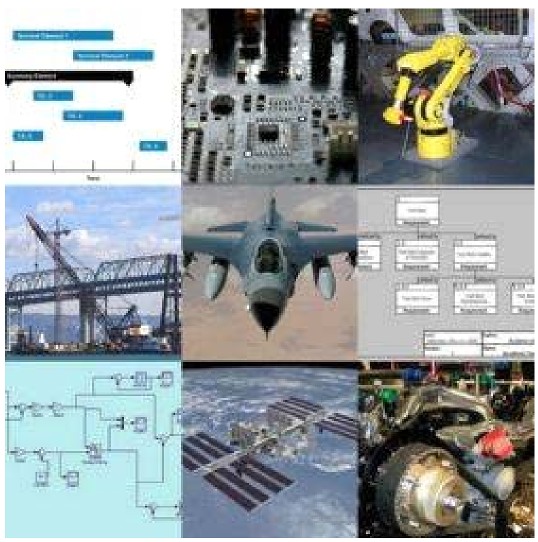

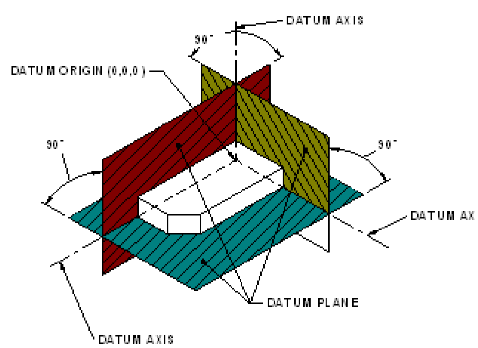


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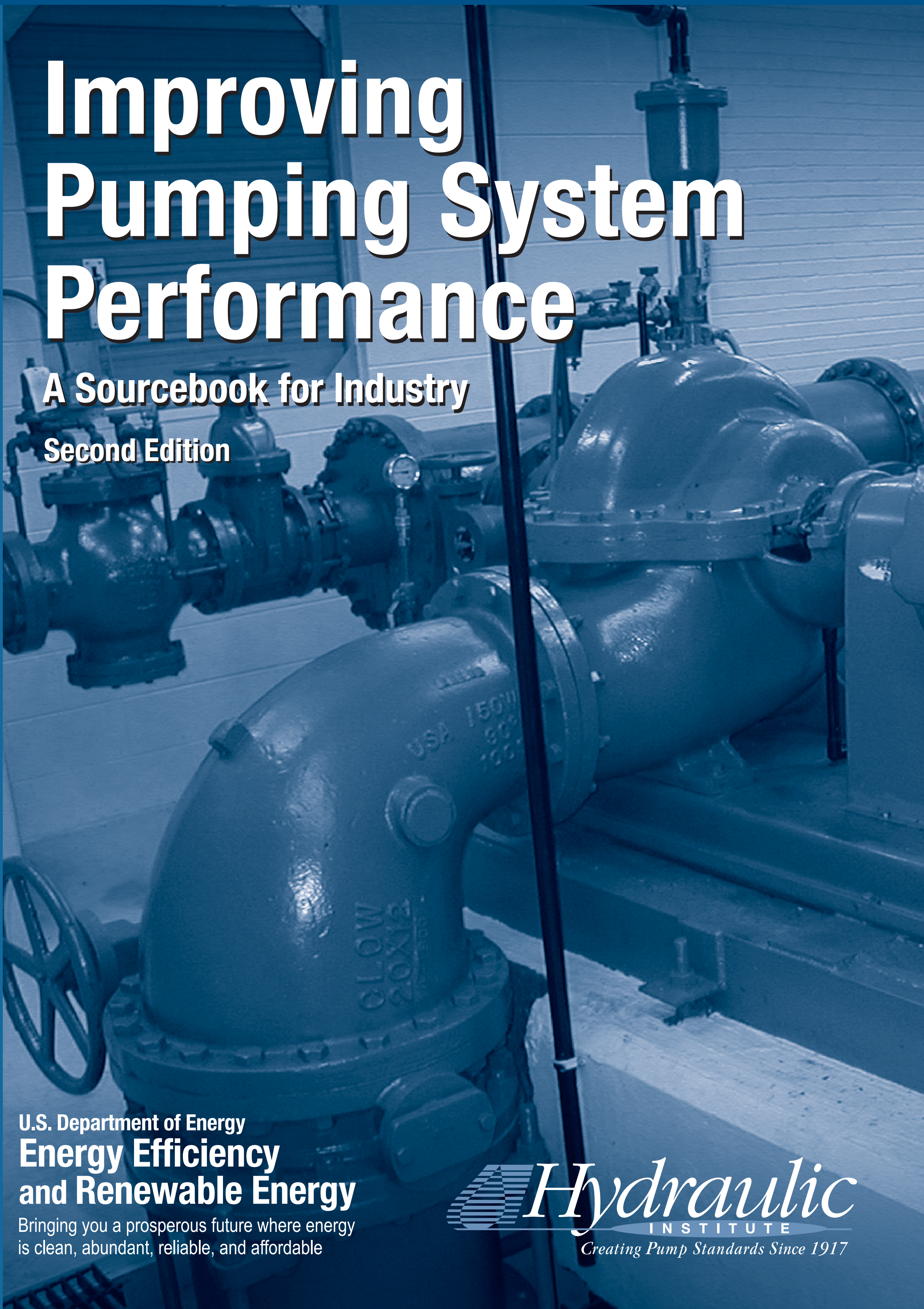

# Improving Pumping System Performance

## A Sourcebook for Industry

**Second Edition**

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

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Creating Pump Standards Since 1917

# Acknowledgements

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# Quick Start Guide

This sourcebook is designed to provide pumping system users with a reference that outlines opportunities for improving system performance. It is not meant to be a comprehensive technical text on pumping systems; rather, it provides practical guidelines and information to make users aware of potential performance improvements. Guidance on how to find more information and assistance is also included.

Throughout this sourcebook, performance and efficiency improvements are described in terms of a "systems approach." For cost-effective operation and maintenance of pumping systems, attention must be paid not just to individual pieces of equipment but to the system as a whole. A systems approach to optimizing a pumping system analyzes both the supply and demand sides of the system and how they interact, shifting the focus from individual components to total system performance.

Often, operators are so focused on the immediate demands of equipment that they overlook the broader question: How do the system's parameters affect this equipment? For example, frequently replacing pump seals and bearings can keep a maintenance crew so busy that they overlook the system operating conditions that are causing most (or all) of the problems.

A systems approach involves the following types of interrelated actions:

- Establish current conditions and operating parameters
- Determine present and estimate future process production needs
- Gather and analyze operating data and develop load duty cycles
- Assess alternative system designs and improvements
- Determine the most technically and economically sound options, taking into consideration all of the subsystems
- Implement the best option
- Assess energy consumption with respect to performance
- Continue to monitor and optimize the system
- Continue to operate and maintain the system for peak performance.

To use a systems approach effectively, a pumping system designer needs to understand system fundamentals, know where opportunities for improvements are commonly found, and have a list of key resources that can help to identify and implement successful projects. Therefore, this sourcebook is divided into four main sections, as outlined below.

### ◆ Section 1. Pumping System Basics

If you are not familiar with the basics of pumping systems, the first section provides a brief discussion of terms, relationships, and important system design considerations. It describes key factors involved in pump selection and system design; it also provides an overview of different types of pumps and their general applications. Key terms and parameters used in selecting pumps, designing systems, and controlling fluid flow are discussed. If you are already familiar with pumping systems, you might want to skip this section and go straight to the next one.

### ◆ Section 2. Performance Improvement Opportunity Roadmap

This section describes the key components of a pumping system and opportunities to improve the system's performance. Also provided is a figurative system diagram identifying pumping system components and performance improvement opportunities. A set of fact sheets describing these opportunities in greater detail follows the diagram; they discuss the following:

1. Assessing Pumping System Needs
2. Common Pumping System Problems
3. Indications of Oversized Pumps
4. Piping Configurations to Improve Pumping System Efficiency
5. Basic Pump Maintenance
6. Centrifugal Pumps
7. Positive Displacement Pump Applications
8. Multiple Pump Arrangements
9. Pony Pumps
10. Impeller Trimming
11. Controlling Pumps with Adjustable Speed Drives

### ◆ Section 3. The Economics of Improving Pumping Systems

Section 3 describes key considerations in determining the life-cycle costs of pumping systems. Understanding life-cycle costs is essential to identifying and prioritizing improvement projects and presenting these projects in terms that will gain management support. Therefore, this section discusses life-cycle cost components, ways to measure these costs, and key success factors in prioritizing and proposing improvement projects.

### ◆ Section 4. Where To Find Help

Section 4 describes useful sources of assistance that can help you learn more about pumping systems and ways to improve their performance and efficiency. Included in this section are descriptions of resources within the U.S. Department of Energy (DOE) Industrial Technologies Program (ITP) and the Hydraulic Institute and a directory of associations and other organizations involved in the pump marketplace. This section also provides lists of helpful resources, such as tools, software, videos, and workshops.

### ◆ Appendices

This sourcebook on improving pumping systems includes four appendices. Appendix A is a glossary of terms used throughout the pumping system industry (and printed in bold type in parts of this sourcebook). Appendix B describes the Pumping System Assessment Tool (PSAT), which can help you identify and prioritize energy improvement projects for pumping systems. Appendix C contains a series of pumping system tip sheets. Developed by DOE, these tip sheets are brief summaries of opportunities for improving the efficiency and performance of pumping systems. Appendix D includes a form for submitting suggested improvements to this sourcebook.

# Section 1: Pumping System Basics

## Overview

Pumps are used widely in industry to provide cooling and lubrication services, to transfer fluids for processing, and to provide the motive force in hydraulic systems. In fact, most manufacturing plants, commercial buildings, and municipalities rely on pumping systems for their daily operation. In the manufacturing sector, pumps represent 27% of the electricity used by industrial systems. In the commercial sector, pumps are used primarily in heating, ventilation, and air-conditioning (HVAC) systems to provide water for heat transfer. Municipalities use pumps for water and wastewater transfer and treatment and for land drainage. Since they serve such diverse needs, pumps range in size from fractions of a horsepower to several thousand horsepower.

In addition to an extensive range of sizes, pumps also come in several different types. They are classified by the way they add energy to a fluid: **positive displacement pumps**[1] squeeze the fluid directly; **centrifugal pumps** (also called "roto-dynamic pumps") speed up the fluid and convert this kinetic energy to pressure. Within these classifications are many different subcategories. Positive displacement pumps include piston, screw, sliding vane, and rotary lobe types; centrifugal pumps include **axial** (propeller), mixed-flow, and **radial** types. Many factors go into determining which type of pump is suitable for an application. Often, several different types meet the same service requirements.

Pump reliability is important—often critically so. In cooling systems, pump failure can result in equipment overheating and catastrophic damage. In lubrication systems, inadequate pump performance can destroy equipment. In many petrochemical and power plants, pump downtime can cause a substantial loss in productivity.

Pumps are essential to the daily operation of many facilities. This tends to promote the practice of sizing pumps conservatively to ensure that the needs of the system will be met under all conditions. Intent on ensuring that the pumps are large enough to meet system needs, engineers often overlook the cost of oversizing pumps and err on the side of safety by adding more pump capacity. Unfortunately, this practice results in higher-than-necessary system operating and maintenance costs. In addition, oversized pumps typically require more frequent maintenance than properly sized pumps. Excess flow energy increases the wear and tear on system components, resulting in valve damage, piping stress, and excess system operation noise.

## Pumping System Components

Typical pumping systems contain five basic components: pumps, prime movers, piping, valves, and end-use equipment (e.g., heat exchangers, tanks, and hydraulic equipment). A typical pumping system and its components are illustrated in Figure 1 on page 4.

### ◆ Pumps

Although pumps are available in a wide range of types, sizes, and materials, they can be broadly classified into the two categories described earlier—positive displacement and centrifugal. These categories relate to the manner in which the pumps add energy to the working fluid. Positive displacement pumps pressurize fluid with a collapsing volume action, essentially squeezing an amount of fluid equal to the displacement volume of the system with each piston stroke or shaft rotation. Centrifugal pumps work by adding kinetic energy to a fluid using a spinning **impeller**. As the fluid slows in the diffuser section of the pump, the **kinetic energy** of the fluid is converted into pressure.

[1] Terms in bold type are defined in the glossary in Appendix A.

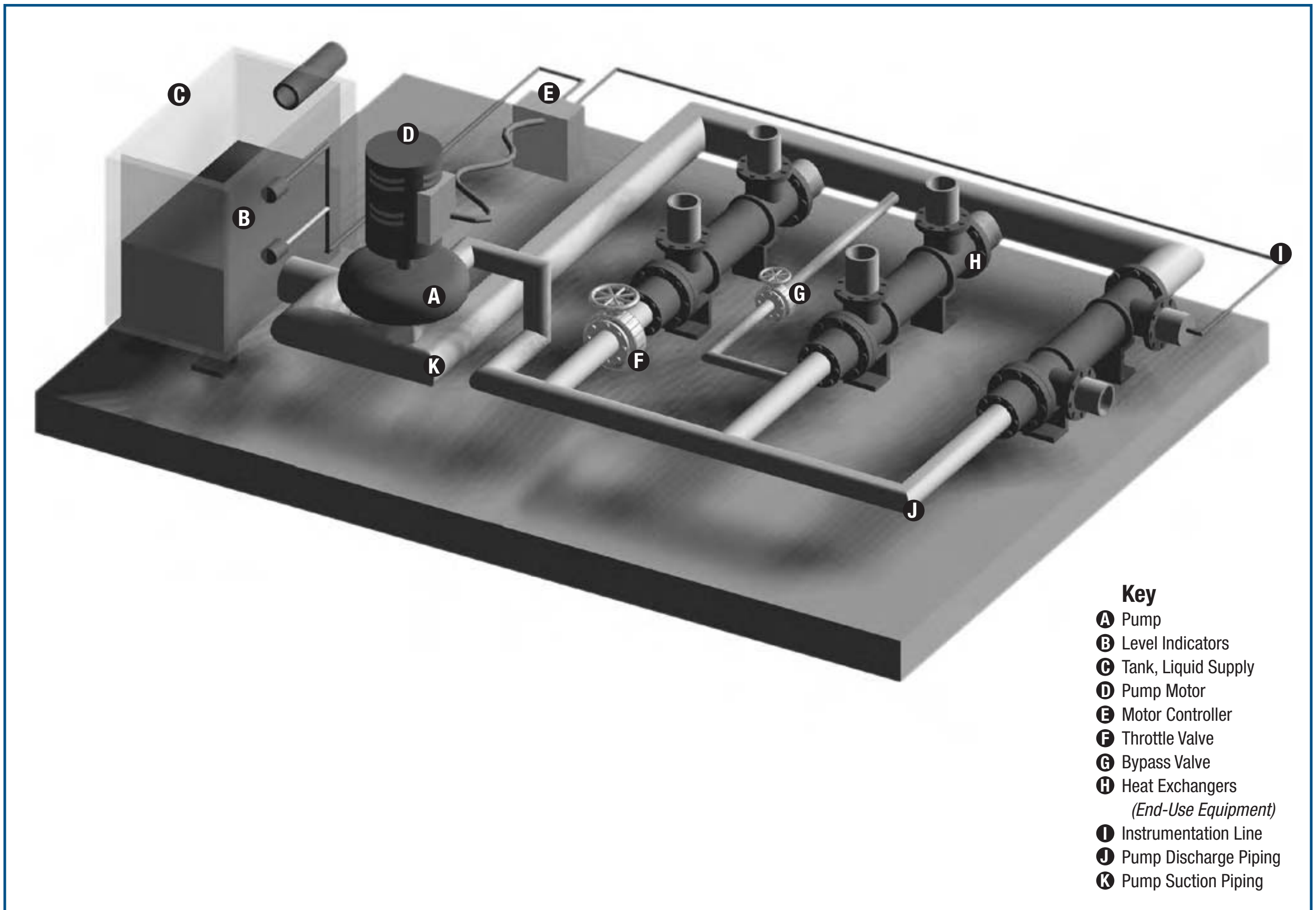



**Figure 1. Typical Pumping System Components**

Although many applications can be served by both positive displacement and centrifugal pumps, centrifugal pumps are more common because they are simple and safe to operate, require minimal maintenance, and have characteristically long operating lives. Centrifugal pumps typically suffer less wear and require fewer part replacements than positive displacement pumps. Although the **packing** or **mechanical seals** must be replaced periodically, these tasks usually require only a minor amount of downtime. Centrifugal pumps can also operate under a broad range of conditions. The risk of catastrophic damage due to improper valve positioning is low, if precautions are taken.

Centrifugal pumps have a variable flow/pressure relationship. A centrifugal pump acting against a high system pressure generates less flow than it does when acting against a low system pressure.

A centrifugal pump's flow/pressure relationship is described by a **performance curve** that plots the flow rate as a function of head (pressure). Understanding this relationship is essential to properly sizing a pump and designing a system that performs efficiently. For more information, see the fact sheet in Section 2 titled *Centrifugal Pumps.*

In contrast, positive displacement pumps have a fixed displacement volume. Consequently, the flow rates they generate are directly proportional to their speed. The pressures they generate are determined by the system's resistance to this flow. Positive displacement pumps have operating advantages that make them more practical for certain applications. These pumps are typically more appropriate for situations in which the following apply:

- The working fluid is highly viscous
- The system requires high-pressure, low-flow pump performance
- The pump must be self-priming
- The working fluid must not experience high shear forces
- The flow must be metered or precisely controlled
- Pump efficiency is highly valued.

A disadvantage is that positive displacement pumps typically require more system safeguards, such as relief valves. A positive displacement pump can potentially overpressurize system piping and components. For example, if all the valves downstream of a pump are closed—a condition known as **deadheading**—system pressure will build until a relief valve lifts, a pipe or fitting ruptures, or the pump **motor** stalls. Although relief valves are installed to protect against such damage, relying on these devices adds an element of risk. In addition, relief valves often relieve pressure by venting system fluid, which may be a problem for systems with harmful or dangerous system fluids. For more information on this type of pump, see the fact sheet in Section 2 titled *Positive Displacement Pump Applications.*

### ◆ Prime Movers

Most pumps are driven by electric motors. Although some pumps are driven by direct current (dc) motors, the low cost and high reliability of alternating current (ac) motors make them the most common type of pump prime mover. In recent years, partly as a result of DOE's efforts, the efficiencies of many types of ac motors have improved. A section of the Energy Policy Act (EPAct) of 1992 that set minimum efficiency standards for most common types of industrial motors went into effect in October 1997. EPAct has provided industrial end users with greater selection and availability of energy-efficient motors.

In addition, the National Electrical Manufacturers Association (NEMA) has established the NEMA Premium™ energy efficiency motors program, which is endorsed by the Hydraulic Institute; the program defines premium efficiency motors with higher efficiency levels than those established by EPAct. In high-run-time applications, improved motor efficiencies can significantly reduce operating costs. However, it is often more effective to take a systems approach that uses proper component sizing and effective maintenance practices to avoid unnecessary energy consumption.

A subcomponent of a pump motor is the motor controller. The motor controller is the switchgear that receives signals from low-power circuits, such as an on-off switch, and connects or disconnects the high-power circuits to the primary power supply from the motor. In dc motors, the motor controller also contains a sequence of switches that gradually builds up the motor current during start-ups.

In special applications, such as emergency lubricating oil pumps for large machinery, some pumps are driven by an air system or directly from the shaft of the machine. In the event of a power failure, these pumps can still supply oil to the bearings long enough for the machine to coast to a stop. For this same reason, many fire service pumps are driven by diesel engines to allow them to operate during a power outage.

### ◆ Piping

Piping is used to contain the fluid and carry it from the pump to the point of use. The critical aspects of piping are its dimensions, material type, and cost. Since all three aspects are interrelated, pipe sizing is an iterative process. The flow resistance at a specified flow rate of a pipe decreases as the pipe diameter gets larger; however, larger pipes are heavier, take up more floor space, and cost more than smaller pipe. Similarly, in systems that operate at high pressures (for example, hydraulic systems), small-diameter pipes can have thinner walls than large-diameter pipes and are easier to route and install.

Small-diameter pipes restrict flow, however, and this can be especially problematic in systems with surging flow characteristics. Smaller pipes also operate at higher liquid velocity, increasing erosion effects, wear, and friction head. Increased friction head affects the energy required for pumping.

### ◆ Valves

The flow in a pumping system may be controlled by **valves**. Some valves have distinct positions, either shut or open, while others can be used to throttle flow. There are many different types of valves; selecting the correct valve for an application depends on a number of factors, such as ease of maintenance, reliability, leakage tendencies, cost, and the frequency with which the valve will be open and shut.

Valves can be used to isolate equipment or regulate flow. Isolation valves are designed to seal off a part of a system for operating purposes or maintenance. Flow-regulating valves either restrict flow through a system branch (throttle valve) or allow flow around it (bypass valve). A throttle valve controls flow by increasing or decreasing the flow resistance across it. In contrast, a bypass valve allows flow to go around a system component by increasing or decreasing the flow resistance in a bypass line. A check valve allows fluid to move in only one direction, thus protecting equipment from being pressurized from the wrong direction and helping to keep fluids flowing in the right direction. Check valves are used at the discharge of many pumps to prevent flow reversal when the pump is stopped.

### ◆ End-Use Equipment (Heat Exchangers, Tanks, and Hydraulic Equipment)

The essential purpose of a pumping system may be to provide cooling, to supply or drain a tank or reservoir, or to provide hydraulic power to a machine. Therefore, the nature of the end-use equipment is a key design consideration in determining how the piping and valves should be configured. There are many different types of end-use equipment; the fluid pressurization needs and pressure drops across this equipment vary widely. For heat exchangers, flow is the critical performance characteristic; for hydraulic machinery, pressure is the key system need. Pumps and pumping system components must be sized and configured according to the needs of the end-use processes.

## Pumping System Principles

### ◆ Design Practices

Fluid system designs are usually developed to support the needs of other systems. For example, in cooling system applications, the heat transfer requirements determine how many heat exchangers are needed, how large each heat exchanger should be, and how much flow is required. Pump capabilities are then calculated based on the system layout and equipment characteristics. In other applications, such as municipal wastewater removal, pump capabilities are determined by the amount of water that must be moved and the height and pressure to which it must be pumped. The pumps are sized and configured according to the flow rate and pressure requirements of the system or service.

After the service needs of a pumping system are identified, the pump/motor combination, layout, and valve requirements must be engineered. Selecting the appropriate type of pump and its speed and power characteristics requires an understanding of its operating principles.

The most challenging aspect of the design process is cost-effectively matching the pump and motor characteristics to the needs of the system. This process is often complicated by wide variations in flow and pressure requirements. Ensuring that system needs are met during worst-case conditions can cause designers to specify equipment that is oversized for normal operation. In addition, specifying larger than necessary pumps increases material, installation, and operating costs. Designing a system with larger piping diameters might reduce pumping energy costs, however. See the fact sheet titled *Piping Configurations To Improve Pumping System Efficiency* in Section 2 and the tip sheet in Appendix C titled *Reduce Pumping Costs Through Optimum Pipe Sizing.*

## ◆ Fluid Energy

For practical pump applications, the energy of a fluid is commonly measured in terms of **head**. Head is usually expressed in feet or meters, which refers to the height of a column of system fluid that has an equivalent amount of potential energy. This term is convenient because it incorporates density and pressure, which allows centrifugal pumps to be evaluated over a range of system fluids. For example, at a given flow rate, a centrifugal pump will generate two different discharge pressures for two different-density fluids, but the corresponding head for these two conditions is the same.

The total head of a fluid system consists of three terms or measurements: static pressure (gauge pressure), height (or potential energy), and **velocity head** (or kinetic energy).

Static pressure, as the name indicates, is the pressure of the fluid in the system. It is the quantity measured by conventional pressure gauges. The height of the fluid level has a substantial impact on the static pressure in a system, but it is itself a distinct measurement of fluid energy. For example, a pressure gauge on a vented tank reads atmospheric pressure. If this tank is located 50 feet (ft) above the pump, however, the pump would have to generate at least 50 ft of static pressure (for tap water, the gauge would have to read 21.7 pounds per square inch [psi]) to push water into the tank.

Velocity head (also known as "dynamic head") is a measure of a fluid's kinetic energy. In most systems, the velocity head is small in comparison to the static head. For example, the flow velocity in cooling systems does not typically exceed 15 ft per second, which is roughly equivalent to 3.5 ft of head (if the system fluid is water, this velocity head translates to about 1.5 psi gauge [psig]). The velocity head of a fluid must be considered when siting pressure gauges, when designing a system, and when evaluating a reading from a pressure gauge, especially when the system has varying pipe sizes. A pressure gauge downstream of a pipe reduction will read lower than one upstream of the reduction, although the distance may only be a few inches.

## ◆ Fluid Properties

In addition to being determined by the type of system being serviced, pump requirements are influenced greatly by fluid characteristics such as **viscosity**, density, particulate content, and **vapor pressure**. Viscosity is a property that measures the shear resistance of a fluid. A highly viscous liquid consumes more energy during flow because its shear resistance creates heat. Some fluids, such as cold lubricating oil (at less than 60°F), are sufficiently viscous that centrifugal pumps cannot move them effectively. As a result, the range of fluid viscosities over the operating temperatures of a system is a key system design factor. A pump/motor combination that is appropriately sized for oil at a temperature of 80°F may be undersized for operation at 60°F.

The quantities and properties of particulates in a system fluid also affect pump design and selection. Some pumps cannot tolerate much debris. And the performance of some multistage centrifugal pumps degrades significantly if seals between stages become eroded. Other pumps are designed for use with high-particulate-content fluids. Because of the way they operate, centrifugal pumps are often used to move fluids with high particulate content, such as coal slurries.

The difference between the vapor pressure of a fluid and the system pressure is another fundamental factor in pump design and selection. Accelerating a fluid to high velocities—a characteristic of centrifugal pumps—creates a drop in static pressure. This drop can lower the fluid pressure to the fluid's vapor pressure or below. At this point, the fluid "boils," changing from a liquid to a vapor. Known as **cavitation,** this effect can severely impact a pump's performance. As the fluid changes phase during cavitation, tiny bubbles form. Since vapor takes up considerably more volume than fluid, these bubbles decrease flow through the pump.

The damaging aspect of cavitation occurs when these vapor bubbles return to liquid phase in a violent collapse. During this collapse, high-velocity water jets impinge onto surrounding surfaces. The force of this impingement often exceeds the mechanical strength of the impacted surface, which leads to material loss. Over time, cavitation can create severe erosion problems in pumps, valves, and pipes.

Other problems that cause similar damage are suction and discharge **recirculation.** Suction recirculation is the formation of damaging flow patterns that result in cavitation-like damage in the suction region of an impeller. Similarly, discharge recirculation is the formation of damaging flow patterns in the outer region of an impeller. These recirculation effects usually result from operating a pump at a flow rate that is too low. To avoid this type of damage, many pumps are listed with a minimum flow rating.

## ◆ System Types

Like pumps, pumping system characteristics and needs range widely, but they can be classified in general as either closed-loop or open-loop systems. A closed-loop system recirculates fluid around a path with common beginning and end points. An open-loop system has an input and an output, as fluid is transferred from one point to another. Pumps that serve closed-loop systems, such as a cooling water system, typically do not have to contend with static head loads unless there are vented tanks at different elevations. In closed-loop systems, the frictional losses of system piping and equipment are the predominant pump load.

In contrast, open-loop systems often require pumps to overcome static head requirements as a result of elevation and tank pressurization needs. A mine dewatering system is one example; it uses pumps to move water from the bottom of a mine up to the surface. In this case, static head is often the dominant pump load.

## ◆ Principles of Flow Control

Flow control is essential to system performance. Sufficient flow ensures that equipment is properly cooled and that tanks are drained or filled quickly. Sufficient pressure and flow must be guaranteed to satisfy system requirements; this creates a tendency to oversize pumps and the motors that run them. Because systems are designed with flow control devices to regulate temperature and protect equipment from overpressurization, oversizing system pumps can burden these flow control devices with high energy dissipation loads.

There are four primary methods for controlling flow through a system or its branches: throttle valves, bypass valves, pump speed control, and multiple pump arrangements. The appropriate flow control method depends on the system size and layout, fluid properties, the shape of the pump power curve, the system load, and the system's sensitivity to flow rate changes.

A throttle valve chokes fluid flow so that less fluid can move through the valve, creating a pressure drop across it. Throttle valves are usually more efficient than bypass valves, because as they are shut, they maintain upstream pressure that can help push fluid through parallel branches of the system.

Bypass lines allow fluid to flow around a system component. A major drawback of bypass valves is their detrimental impact on system efficiency. The power used to pump the bypassed fluid is wasted. In static-head-dominated systems, however, bypass valves could be more efficient than throttle valves or systems with **adjustable speed drives** (ASDs).

Pump speed control includes both mechanical and electrical methods of matching the speed of the pump to the flow/pressure demands of the system. ASDs, multiple-speed pumps, and multiple pump configurations are usually the most efficient flow control options, especially in systems that are dominated by friction head, because the amount of fluid energy added by the pumps is determined directly from the system demand. Pump speed control is especially appropriate for systems in which friction head predominates.

Both ASDs and multiple-speed motors provide efficient system operation by driving pumps at different speeds according to system needs. During a period of low system demand, the pump is operated at low speeds. The primary functional difference between ASDs and multiple-speed motors is the degree of speed control available. ASDs typically modify the speed of a single-speed motor through mechanical or electrical methods, while multiple-speed motors contain a different set of windings for each speed. ASDs are practical for applications in which flow demands change continuously. For more information, see the fact sheet in Section 2 titled *Controlling Pumps with Adjustable Speed Drives*.

Multiple-speed motors are practical for systems in which the flow demands change between distinct, discrete levels that feature lengthy periods of operation. One of the drawbacks to multiple-speed motors is the added cost of equipment. Since each speed has its own set of motor windings, multiple-speed motors are more expensive than single-speed motors. Also, multiple-speed motors are slightly less efficient than single-speed ones.

Multiple pump arrangements typically consist of pumps placed in parallel in one of two basic configurations: a large pump/small pump configuration, or a series of identical pumps placed in parallel. In the large pump/small pump case, the small pump, often called the "**pony pump**," operates during normal conditions. The large pump is used during periods of high demand. Because the pony pump is sized for normal system operation, this configuration operates more efficiently than a system would that relies on the large pump to handle loads far below its optimum capacity. For more information on this type of pump, see the Section 2 fact sheet titled *Pony Pumps*.

With a series of identical pumps placed in parallel, the number of operating pumps can be changed according to system demands. Because the pumps are the same size they can operate together, serving the same discharge header. If the pumps were different sizes, the larger pumps would tend to dominate the smaller pumps and could cause them to be inefficient. If the proper pumps are selected, each pump can operate closer to its highest efficiency point. An added flow control benefit of parallel pumps is that a system curve remains the same whether one or several pumps are operating; what changes is the operating point along this system curve.

Multiple pumps in parallel are well suited for systems with high static head. Another advantage is system redundancy; one pump can fail or be taken off line for maintenance while the other pumps support system operation. When identical parallel pumps are used, the pump curves should remain matched; therefore, operating hours should be the same for each pump, and reconditioning should be done at the same time for all of them. For more information on this configuration, see the fact sheet in Section 2 titled *Multiple Pump Arrangements*.

## ◆ System Operating Costs

The amount of fluid power that a system consumes is a product of head and flow, according to this equation:

$$\text{Fluid power} = \frac{HQ}{3{,}960}\ (\text{s.g.})$$

where

- H = head (ft)
- Q = flow rate (gallons per minute [gpm])
- s.g. = **specific gravity** of the fluid
- 3,960 is a units conversion to state fluid power in terms of horsepower.

The motor power required to generate these head and flow conditions is somewhat higher, because of motor and pump inefficiencies. The efficiency of a pump is measured by dividing the fluid power by the pump shaft power; for directly coupled pump/motor combinations, this is the **brake horsepower** (bhp) of the motor.

Pumps have varying efficiency levels. The operating point of centrifugal pumps at which their efficiency is highest is known as the **best efficiency point** (BEP). Efficiencies range widely, from 35% to more than 90%, and they are a function of many design characteristics. Operating a pump at or near its BEP not only minimizes energy costs, it also decreases loads on the pump and maintenance requirements.

Systems with significant annual operating hours incur high operating and maintenance costs relative to initial equipment purchase costs. Inefficiencies in high-run-time, oversized systems can add significantly to annual operating costs; however, costly inefficiencies are often overlooked when ensuring system reliability. For more information on oversized pumps, see the fact sheet in Section 2 titled *Indications of Oversized Pumps*. The Pumping System Assessment Tool (see Appendix B) provides assistance in identifying and prioritizing projects to reduce the amount of energy used by pumping systems.

The cost of oversizing pumps extends beyond energy bills. Excess fluid power must be dissipated by a valve, a pressure-regulating device, or the system piping itself, which increases system wear and maintenance costs. Valve seat wear, which results from throttling excess flow and from cavitation, creates a significant maintenance problem and can shorten the interval between valve overhauls. Similarly, the noise and vibration caused by excessive flow creates stress on pipe welds and piping supports; in severe cases, this can erode pipe walls.

Note that, when designers try to improve a pumping system's reliability by oversizing equipment, usually the unanticipated result is less system reliability. This is caused by both the additional wear on the equipment and low-efficiency operation.

# Section 2: Performance Improvement Opportunity Roadmap

## Overview

Cost-effective operation and maintenance of a pumping system require attention to the needs of both individual equipment and the entire system. Often, operators are so focused on the immediate demands of the equipment that they forget to step back and notice how certain system parameters are affecting this equipment.

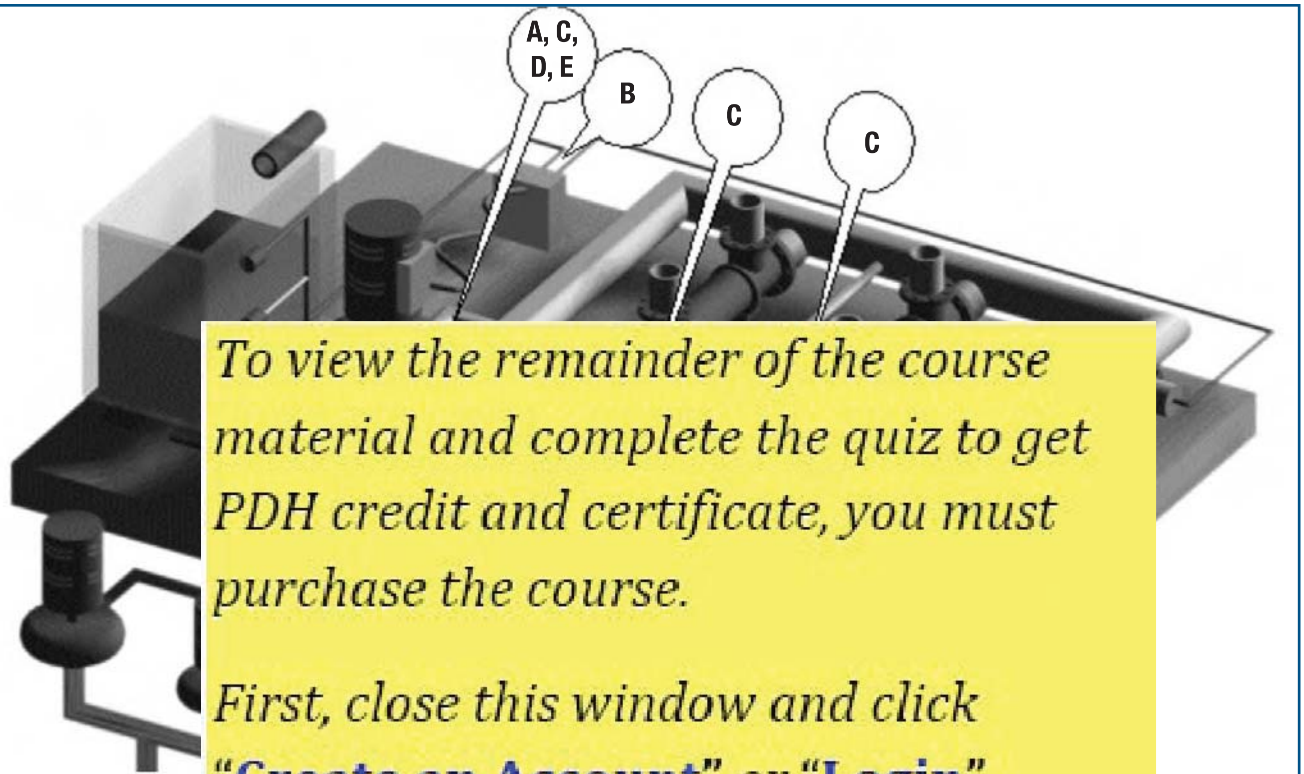
A systems approach analyzes both supply and demand sides of the system and how they interact, shifting the focus from individual components to total system performance. This approach usually involves the following types of interrelated actions:

- Establish current conditions and operating parameters
- Determine present process production needs and estimate future ones
- Gather and analyze operating data and develop load duty cycles
- Assess alternative system designs and improvements
- Determine the most technically and economically sound options, taking into consideration all subsystems
- Implement the best option
- Assess energy consumption with respect to performance
- Continue to monitor and optimize the system
- Continue to operate and maintain the system for peak performance.

## The Fact Sheets

The rest of this section contains 11 fact sheets that address both component and system issues. Each fact sheet describes in detail a specific opportunity to improve the performance of an industrial pumping system. The fact sheets are as follows:

1. **Assessing Pumping System Needs**
2. **Common Pumping System Problems**
3. **Indications of Oversized Pumps**
4. **Piping Configurations to Improve Pumping System Efficiency**
5. **Basic Pump Maintenance**
6. **Centrifugal Pumps**
7. **Positive Displacement Pump Applications**
8. **Multiple Pump Arrangements**
9. **Pony Pumps**
10. **Impeller Trimming**
11. **Controlling Pumps with Adjustable Speed Drives**




**Key**

**A -** Piping Configurat

**B -** Controlling Pump

**C -** Basic Pump Main

**D -** Common Pumpin

**E -** General Pump Fa
Indications of Ov
Applications, Cer

*To view the remainder of the course material and complete the quiz to get PDH credit and certificate, you must purchase the course.*

*First, close this window and click "Create an Account" or "Login" located on the* ***right side of the webpage*** *then select the link at the bottom of the webpage:*

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**Figure 2. Key to the**