# Pump System Improvements

**Course Description**

The Pump System Improvements Course provides four hours of professional development. Designed as a remote learning program, this course offers a comprehensive overview of pumping systems and explores strategies to optimize performance and efficiency.

**Objectives**

This course aims to equip students with a solid understanding of pumping systems, their components, and practical techniques for improving efficiency and overall performance.

**Grading**

To successfully complete the course, students must score at least 70% on the online quiz. The quiz can be retaken multiple times until a passing score is achieved. A copy of the quiz questions is included in the final pages of this document.

# Fundamentals of Pumping Systems

**Overview**

Pumps play a crucial role across various industries, serving functions such as cooling, lubrication, fluid transfer, and hydraulic system operation. They are integral to manufacturing plants, commercial buildings, and municipal infrastructure. In industrial settings, pumps account for approximately 27% of electricity consumption. In commercial applications, they are primarily used in heating, ventilation, and air conditioning (HVAC) systems to circulate water for temperature regulation. Municipalities depend on pumps for water and wastewater management, treatment processes, and land drainage. Due to their diverse applications, pump sizes range from small fractional-horsepower units to large-scale pumps with thousands of horsepower.

Beyond their varying sizes, pumps are categorized based on how they impart energy to a fluid. Positive displacement pumps function by directly displacing fluid, whereas centrifugal pumps (also known as rotodynamic pumps) accelerate the fluid and convert kinetic energy into pressure. These broad classifications include multiple subtypes. Positive displacement pumps encompass piston, screw, sliding vane, and rotary lobe designs, while centrifugal pumps include axial (propeller), mixed-flow, and radial types. The selection of an appropriate pump depends on several factors, and in many cases, multiple pump types can fulfill the same operational requirements.

Pump reliability is a critical concern. In cooling systems, pump failures can lead to overheating and severe equipment damage. In lubrication systems, inadequate pumping performance can result in catastrophic failures. In petrochemical and power generation facilities, unplanned pump downtime can lead to significant productivity losses.

Since pumps are vital for daily operations, engineers often design systems with oversized pumps to ensure they meet peak demands. While this approach prioritizes reliability, it can lead to unnecessary energy consumption, increased operational costs, and frequent maintenance. Oversized pumps generate excessive flow energy, which accelerates component wear, causes valve damage, creates pipe stress, and contributes to excessive noise levels. Properly sizing pumps can enhance system efficiency, reduce maintenance needs, and lower overall operating expenses.

## Components of a Pumping System

A typical pumping system consists of five key components: pumps, prime movers, piping, valves, and end-use equipment such as heat exchangers, tanks, and hydraulic machinery. These components work together to ensure the efficient movement of fluids within a system.

### Pumps

Pumps come in various types, sizes, and materials, but they generally fall into two main categories: positive displacement pumps and centrifugal pumps. These classifications are based on how the pumps transfer energy to the fluid.

- Positive displacement pumps operate by compressing fluid within a chamber, forcing a fixed volume of liquid through each piston stroke or shaft rotation.
- Centrifugal pumps use a rotating impeller to accelerate the fluid, converting kinetic energy into pressure as the fluid slows down in the pump's diffuser section.

While both types can be used for many applications, centrifugal pumps are more commonly chosen due to their simplicity, reliability, and minimal maintenance requirements. They generally experience less wear and require fewer component replacements compared to positive displacement pumps. Although mechanical seals or packing materials may need periodic replacement, these maintenance tasks typically result in minimal downtime. Additionally, centrifugal pumps can function under a wide range of operating conditions with a lower risk of major damage caused by improper valve operation.

Centrifugal pumps exhibit a variable relationship between flow rate and pressure. As system pressure increases, the pump produces less flow, and vice versa. This relationship is illustrated through a performance curve, which plots flow rate against head (pressure). Properly understanding and utilizing this curve is crucial for selecting the right pump size and designing an efficient system. More details on this topic can be found in Section 2 under Centrifugal Pumps.

In contrast, positive displacement pumps operate at a fixed displacement volume, meaning their flow rate is directly tied to their operating speed. The pressure they generate depends on the system's resistance to flow. These pumps offer several advantages, making them suitable for specific applications, such as:

- Handling highly viscous fluids
- Providing high-pressure, low-flow performance

- Operating in self-priming conditions
- Ensuring fluids are not subjected to high shear forces
- Delivering precise flow control or metering
- Maximizing efficiency in specific applications

However, positive displacement pumps require additional safety measures, such as relief valves, to prevent over-pressurization. If downstream valves are fully closed (a condition known as deadheading), system pressure can increase to dangerous levels, potentially leading to pipe or fitting failure, motor stalling, or relief valve activation. Although relief valves help protect the system, relying solely on them introduces operational risks. Additionally, in systems handling hazardous fluids, relief valves may release fluid into the environment, posing further safety concerns. More details on the proper use of positive displacement pumps can be found in Section 2 under Positive Displacement Pump Applications.

**Prime Movers in Pumping Systems**

Most pumps rely on electric motors as their primary source of power. While some systems use direct current (DC) motors, the low cost and high reliability of alternating current (AC) motors make them the preferred choice for most industrial applications. Over the years, advancements in motor technology, partly driven by efforts from the U.S. Department of Energy (DOE), have led to significant improvements in AC motor efficiency.

A key milestone in energy efficiency was the Energy Policy Act (EPAct) of 1992, which established minimum efficiency standards for commonly used industrial motors. These regulations became enforceable in October 1997, giving industries access to a wider selection of energy-efficient motors.

Additionally, the National Electrical Manufacturers Association (NEMA) introduced the NEMA Premium™ efficiency motors program, which is supported by the Hydraulic Institute. This program sets efficiency standards that exceed those established by EPAct, helping industries achieve even greater energy savings. In applications where motors operate continuously, selecting high-efficiency motors can lead to substantial reductions in operational costs. However, improving efficiency often requires a holistic approach, including correct pump sizing and regular maintenance to minimize unnecessary energy use.

## Motor Controllers

An essential component of a pump motor is the motor controller. This device acts as the interface between low-power control circuits and high-power circuits, allowing the motor to start and stop as needed. In DC motors, motor controllers also include a switching sequence that gradually increases motor current during startup, preventing excessive electrical stress.

## Alternative Prime Movers

In specialized applications, pumps may be powered by alternative energy sources instead of electric motors. For example, in large machinery, some emergency lubricating oil pumps are powered by compressed air systems or are mechanically driven directly from the machine's main shaft. This design ensures continued lubrication in the event of a power failure, allowing the equipment to safely coast to a stop.

Similarly, in fire protection systems, many fire pumps are driven by diesel engines instead of electric motors. This setup ensures that pumps remain operational even during power outages, which is critical for emergency situations.

## Piping

Piping serves as the conduit for transporting fluid from the pump to its intended destination. Key factors in piping design include its size, material composition, and cost. These elements are interconnected, making pipe selection an iterative process. As the diameter of a pipe increases, its resistance to fluid flow at a given rate decrease. However, larger pipes tend to be heavier, occupy more space, and are more expensive than smaller ones.

In high-pressure systems, such as hydraulic applications, pipes with smaller diameters can have thinner walls, making them easier to install and maneuver. However, narrow pipes can restrict flow, which may become a significant issue in systems with fluctuating flow rates. Additionally, smaller pipes cause fluids to move at higher velocities, leading to increased erosion, accelerated wear, and greater frictional resistance. This frictional resistance, or friction head, directly impacts the energy required for pumping.

## Valves

Valves play a crucial role in regulating flow within a pumping system. Some operate in a binary manner—either fully open or completely closed—while others allow for controlled throttling of fluid movement. Choosing the appropriate valve for a specific application depends on several factors, including ease of maintenance, reliability, potential for leakage, cost, and the frequency of operation.

Valves serve two primary functions: isolating equipment and controlling flow. Isolation valves are used to shut off sections of a system for maintenance or operational purposes. Flow-regulating valves either limit flow within a specific branch (throttle valves) or provide an alternate route for fluid movement (bypass valves). Throttle valves manage flow by adjusting resistance across the valve, whereas bypass valves enable fluid to move around a component by altering resistance in the bypass line. Additionally, check valves permit fluid to travel in only one direction, preventing backflow and protecting equipment from unintended pressure buildup. They are commonly installed at pump discharge points to stop flow reversal when the pump is not running.

**End-Use Equipment (Heat Exchangers, Tanks, and Hydraulic Machinery)**

Pumping systems are often designed to serve specific functions, such as cooling, filling or draining tanks and reservoirs, or supplying hydraulic power to machinery. Because of this, the characteristics of the end-use equipment play a crucial role in determining the optimal configuration of piping and valves.

Various types of end-use equipment have different requirements for fluid pressure and flow. Heat exchangers, for example, rely primarily on consistent flow rates for efficient thermal transfer, whereas hydraulic machinery depends on maintaining adequate pressure to function properly. To ensure optimal performance, pumps and other system components must be carefully selected and configured to meet the specific demands of the end-use application.

# Pumping System Principles

**Design Considerations**

Fluid systems are typically designed to meet the demands of other interconnected systems. For example, in cooling applications, heat transfer requirements dictate the number and size of heat exchangers, as well as the necessary flow rate. The pump's capabilities are then determined based on the system's layout and equipment specifications. In other cases, such as wastewater management, the pump must be selected based on the volume of water to be moved and the pressure or height required for proper transfer. The flow rate and pressure demands of the system directly influence pump selection and configuration.

Once the operational needs of a pumping system are established, engineers must determine the appropriate pump and motor combination, system layout, and valve specifications. Choosing the right pump type, along with its speed and power characteristics, requires a solid understanding of its performance and operational principles.

One of the key challenges in system design is balancing efficiency with cost-effectiveness. Significant variations in flow and pressure can make it difficult to match pump and motor specifications precisely to system requirements. To account for peak demand scenarios, designers may select oversized equipment, which can lead to excessive material, installation, and energy costs. However, utilizing larger piping diameters can sometimes help reduce overall pumping energy consumption, optimizing system efficiency in the long run.

**Fluid Energy in Pumping Systems**

In practical pump applications, fluid energy is commonly measured in terms of head, which represents the height of a fluid column that contains an equivalent amount of potential energy. This measurement, typically expressed in feet or meters, is useful because it accounts for both density and pressure, making it easier to evaluate centrifugal pump performance across different fluids. For instance, a centrifugal pump will generate varying discharge pressures for fluids with different densities at the same flow rate, but the corresponding head remains consistent.

A fluid system's total head consists of three main components: static pressure (gauge pressure), height (potential energy), and velocity head (kinetic energy).

- Static Pressure refers to the pressure within the system and is measured using standard pressure gauges. While the height of the fluid column influences static pressure, it is considered a separate factor in fluid energy calculations. For example, if a vented tank is positioned 50 feet above a pump, the pump must generate at least 50 feet of static pressure to move water into the tank. For tap water, this would require a pressure of approximately 21.7 psi.
- Velocity Head, also known as dynamic head, represents the kinetic energy of the fluid. In most systems, velocity head is relatively small compared to static head. For example, in cooling systems where flow velocities generally do not exceed 15 feet per second, the corresponding velocity head would be around 3.5 feet of head, which translates to approximately 1.5 psi gauge for water.

Understanding velocity head is crucial when placing pressure gauges, designing a system, and interpreting pressure readings—especially in systems with varying pipe diameters. For example, a pressure gauge installed just after a pipe reduction will display a lower reading compared to one positioned before the reduction, even if the two points are only inches apart.

**Fluid Properties in Pumping Systems**

Pump performance and selection depend heavily on the fluid properties within a system. Key characteristics such as viscosity, density, particulate content, and vapor pressure all influence a pump's efficiency and longevity.

**1. Viscosity and Energy Consumption**

Viscosity measures a fluid's resistance to shear—how easily it flows. A highly viscous liquid requires more energy to move because its resistance generates heat. For example, cold lubricating oil (below 60°F) may be too viscous for centrifugal pumps to handle effectively. If a pump/motor combination is sized for oil at 80°F, it may be undersized at 60°F, resulting in inefficient operation.

**2. Particulates and Pump Durability**

The presence and properties of particulates in a fluid also impact pump selection.

- Some pumps are sensitive to debris and can suffer performance degradation if seals or components erode.
- Multistage centrifugal pumps are especially vulnerable, as erosion between stages can reduce efficiency.
- Other pumps are designed for high-particulate fluids, such as those used in coal slurry transportation. Centrifugal pumps are often used in these cases due to their ability to handle such conditions.

**3. Vapor Pressure and Cavitation Risks**

A crucial factor in pump design is the difference between a fluid's vapor pressure and system pressure.

- Centrifugal pumps accelerate fluid to high velocities, leading to a drop in static pressure.

- If this pressure drops below the fluid's vapor pressure, the fluid boils, forming vapor bubbles—a process known as cavitation.

**Cavitation Effects:**

- Vapor bubbles collapse violently, creating high-velocity water jets that erode pump surfaces.
- Over time, cavitation can cause severe damage to pumps, valves, and pipes.
- Suction recirculation (turbulent flow near the pump inlet) and discharge recirculation (turbulence at the impeller's outer edge) cause similar damage.

To prevent cavitation and recirculation damage, many pumps have a minimum flow rating, ensuring they operate at optimal conditions. Proper pump selection and system design help mitigate these risks, improving efficiency and extending equipment lifespan.

**System Types**

Pumping systems can generally be classified into two types: closed-loop and open-loop systems.

A closed-loop system continuously circulates fluid within a defined pathway, meaning the starting and ending points are the same. For example, cooling water systems operate in a closed loop, where water is repeatedly cycled through heat exchangers. In these systems, static head is typically not a concern unless vented tanks are placed at different heights. Instead, the primary resistance that pumps must overcome comes from friction losses in pipes and system components.

On the other hand, an open-loop system moves fluid from one location to another, meaning the system has distinct input and output points. For instance, mine dewatering systems transport water from the bottom of a mine to the surface. Unlike closed-loop systems, open-loop designs often require pumps to generate enough pressure to overcome static head, which results from elevation changes and tank pressurization. In such cases, static head is the primary factor affecting pump performance.

By understanding whether a system is closed-loop or open-loop, engineers can determine the most efficient pump size and configuration, ensuring optimal performance while minimizing energy consumption and operational costs.

## Principles of Flow Control

Effective flow control is crucial for maintaining system performance. Proper flow ensures that equipment stays adequately cooled and that tanks fill or drain efficiently. To meet system requirements, pumps must provide sufficient pressure and flow. However, this often leads to oversized pumps and motors, which can place unnecessary strain on flow control devices by increasing energy dissipation.

There are four primary methods for regulating flow within a system: throttle valves, bypass valves, pump speed control, and multiple pump configurations. The best approach depends on factors such as system size, fluid properties, pump power curve, system load, and sensitivity to flow fluctuations.

### Throttle Valves

Throttle valves restrict fluid flow, causing a pressure drop across the valve. They are generally more efficient than bypass valves because, when partially closed, they maintain upstream pressure, which can aid fluid movement in parallel branches of a system.

### Bypass Valves

Bypass lines allow fluid to flow around certain system components. However, this method is less efficient because energy is wasted pumping the bypassed fluid. In systems where static head (the pressure required to move fluid to a higher elevation) is the primary load, bypass valves can sometimes be more effective than throttle valves or adjustable speed drives (ASDs).

### Pump Speed Control

Adjusting pump speed, either mechanically or electrically, allows the pump to match system demands for flow and pressure. Adjustable speed drives (ASDs), multiple-speed pumps, and multiple pump setups are usually the most efficient options, especially in systems where friction head is the dominant factor. These methods ensure that the pump only adds as much energy to the fluid as needed.

### ASDs vs. Multiple-Speed Motors

Both ASDs and multiple-speed motors help optimize system efficiency by adjusting pump speed to meet demand. During low-demand periods, pumps operate at reduced speeds, saving energy. The key difference between ASDs and multiple-speed motors lies in speed control:

- ASDs modify the speed of a standard motor through mechanical or electrical adjustments, making them ideal for systems with continuously changing flow requirements.
- Multiple-speed motors contain separate windings for each speed, making them more suitable for systems where flow fluctuates between fixed levels. However, they are more expensive than single-speed motors and slightly less efficient.

**Multiple Pump Configurations**

Using multiple pumps in parallel is another method of flow control. There are two main configurations:

1. Large Pump/Small Pump (Pony Pump) Setup
    a. The pony pump (a smaller pump) handles normal operating conditions.
    b. A larger pump activates only during peak demand periods.
    c. This setup is more efficient than using a single large pump for all conditions, as it prevents the large pump from running below its optimal capacity.
2. Identical Pumps in Parallel
    a. Multiple pumps of the same size operate together, adjusting to demand by turning pumps on or off.
    b. Identically sized pumps ensure uniform efficiency; if pumps were different sizes, larger pumps could dominate, making smaller ones inefficient.
    c. Parallel pumps work well in systems with high static head and offer redundancy—if one pump fails or requires maintenance, the system can continue running with the others.
    d. To maintain efficiency, identical pumps should run for equal hours and undergo servicing at the same time.

By selecting the right flow control method, systems can maximize efficiency, reduce energy waste, and extend equipment lifespan.

**System Operating Costs**

A system's fluid power consumption is determined by head and flow, following this equation:

Fluid Power = $H \times Q \times (s.g.)$

Where:

- H = Head (feet)
- Q = Flow rate (gallons per minute [gpm])
- s.g. = Specific gravity of the fluid

A conversion factor of 3,960 is used to express fluid power in terms of horsepower.

The actual motor power required to achieve these head and flow conditions is higher due to inefficiencies in the pump and motor. A pump's efficiency is calculated by dividing fluid power by the pump shaft power—also known as brake horsepower (bhp) for directly coupled pump/motor systems.

**Pump Efficiency and Operating Costs**

Pump efficiency varies widely, typically ranging from 35% to over 90%, depending on design factors. The Best Efficiency Point (BEP) refers to the operating condition where a centrifugal pump performs most efficiently. Running a pump at or near its BEP reduces energy costs, minimizes equipment strain, and lowers maintenance requirements.

Systems that run for long hours each year often experience higher operating and maintenance costs than the initial purchase price of equipment. Inefficiencies in oversized, high-run-time systems can significantly increase annual costs. However, these inefficiencies are often overlooked in favor of system reliability. For insights into oversized pumps, see Section 2: Indications of Oversized Pumps.

**The Hidden Costs of Oversized Pumps**

The impact of oversized pumps goes beyond excessive energy consumption. Extra fluid power must be dissipated by:

- Valves
- Pressure-regulating devices
- System piping

This accelerates system wear and increases maintenance costs. Valve seat wear, caused by excessive throttling and cavitation, leads to frequent overhauls. Additionally, high flow rates create noise and vibration, which strain pipe welds and supports and can even erode pipe walls in severe cases.

Ironically, oversizing equipment to improve reliability often has the opposite effect. Increased wear and inefficient operation reduce the overall lifespan and performance of the system, ultimately making it less reliable.

# Opportunity for Enhancing Performance

**Overview**

Efficient operation and maintenance of a pumping system depend on addressing both individual equipment needs and the overall system. Operators often become so absorbed in the immediate requirements of the equipment that they overlook how various system parameters may be impacting its performance.

A systems approach evaluates both the supply and demand aspects of the system and their interactions, shifting the focus from individual components to the overall system performance. This approach generally includes the following interconnected steps:

- Assess current conditions and operating parameters
- Identify current process production needs and project future requirements
- Collect and analyze operational data to develop load duty cycles
- Evaluate alternative system designs and potential improvements
- Select the most technically and economically viable options, considering all subsystems
- Implement the chosen solution
- Examine energy consumption in relation to performance
- Monitor and optimize the system continuously
- Operate and maintain the system to ensure peak performance

**Performance Tips**

This section outlines 11 valuable tips that address both individual components and overall system performance. Each tip highlights a specific opportunity to enhance the efficiency of an industrial pumping system. The tips include:

1. Evaluating Pumping System Requirements
2. Common Pumping System Issues
3. Identifying Oversized Pumps
4. Optimizing Piping Configurations for Better Efficiency

5. Essential Pump Maintenance Practices
6. Understanding Centrifugal Pumps
7. Applications for Positive Displacement Pumps
8. Efficient Multiple Pump Configurations
9. Utilizing Pony Pumps
10. Trimming Impellers for Improved Performance
11. Managing Pumps with Adjustable Speed Drives

**1. Evaluating Pumping System Requirements**

There are three key stages in a system's lifecycle where opportunities for enhancing pumping system performance arise:

- During the initial system design and pump selection
- While troubleshooting to resolve system issues
- When adjusting for system capacity changes

**Analyzing System Needs**

A crucial aspect of boosting system performance and reliability is thoroughly understanding system requirements, including peak demand, average demand, and demand variability throughout the day and year. Designing and operating systems with relatively stable demands is much simpler than accommodating significant fluctuations.

Problems often emerge when pumps are oversized, typically because systems are designed for peak demand, even though normal operating loads are much lower. This results in excessive flow energy being forced into the system, leading to higher operating costs and unnecessary wear on components such as valves, piping, and supports.

Operators frequently overlook the consequences of running systems at higher-than-required flow and pressure levels. For example, cooling systems might be set up to handle maximum heat load but are not adjusted during periods of lower demand.

By recognizing demand variability and more closely matching flow and pressure requirements to actual system needs, both operating costs and system reliability can be significantly improved.

**Initial Pump Selection**

The pump selection process begins with understanding the system's operating conditions, such as fluid properties, pressures, temperatures, and layout. These factors determine the type of pump needed to meet specific service requirements. Generally, there are two primary types of pumps: positive displacement and centrifugal. While axial-flow pumps are sometimes categorized separately, they operate on the same principles as centrifugal pumps.

Positive displacement pumps pressurize fluid by compressing it within a collapsing volume, such as through a piston in a cylinder. In contrast, centrifugal and axial pumps convert kinetic energy into potential energy to increase fluid pressure. Typically, positive displacement and centrifugal pumps are suited to different applications.

Positive displacement pumps are ideal for low-flow, high-head applications, especially when handling high-viscosity fluids. On the other hand, centrifugal pumps are commonly used in high-flow, low-head applications where fluid viscosity is not a major concern.

However, there are many exceptions to these general guidelines. For a deeper understanding of the factors that determine when to use positive displacement versus centrifugal pumps, refer to Section 1 and the accompanying fact sheets on Centrifugal Pumps and Positive Displacement Pump Applications.

Pump selection is usually based on finding the best fit for the system rather than being designed specifically for one application. A pump is chosen from a wide selection of types and models, depending on its ability to meet the system's anticipated demands. Pumps have two interdependent outputs: flow rate and head. The variability of these outputs, along with other factors like efficiency, suction inlet conditions, operating lifespan, and maintenance needs, can make pump selection challenging.

Centrifugal pumps are the most used type due to their affordability, low maintenance, and long service life. However, selecting the right centrifugal pump is complex, which can lead to oversizing. To address uncertainties in system design, fouling effects, or future capacity increases, designers often select larger pumps than necessary. Additionally, the fear of inadequate system performance may drive this tendency.

Oversizing a pump, unfortunately, increases both operating and maintenance costs, while creating additional problems such as excessive flow noise, inefficient pump performance, and pipe vibrations. The energy cost of running an oversized pump alone is significant. For more details on this issue, refer to the tip titled Indications of Oversized Pumps.

## Troubleshooting a System Problem

Certain pumping system issues are significant enough to warrant a thorough system assessment. Common problems that may justify this include inefficient operation, cavitation, poor flow control, and excessive maintenance.

### Inefficient Operation

Inefficiency in a system can arise from a variety of causes, such as incorrect pump selection, poor system design, excessive wear-ring clearances, and inefficient flow control practices. Indicators of an inefficient system include high energy costs, excessive noise from pipes and valves, and high maintenance demands.

Every centrifugal pump has a best efficiency point (BEP) where it achieves optimal operating efficiency and minimal radial bearing load (except for pumps with concentric case designs). Operating at the BEP allows for the most cost-effective performance, balancing energy efficiency and maintenance requirements. However, because system demands often fluctuate, it is challenging to run a pump continuously at its BEP. Nonetheless, selecting a pump with a BEP close to the system’s normal operating range can result in substantial energy savings.

### Cavitation

Centrifugal pumps are vulnerable to cavitation, a damaging phenomenon that negatively affects performance. Cavitation occurs when the static pressure within the pump falls below the fluid's vapor pressure, causing the liquid to vaporize and form tiny bubbles. As the surrounding pressure increases, these bubbles collapse violently, releasing high-velocity water jets that can damage the impeller and erode the pump casing and piping surfaces. This leads to accelerated wear of bearings and seals, diminishing system performance.

While cavitation is typically seen at high flow rates when a pump is operating near the far-right end of its performance curve, it can also occur at low flow rates due to the formation of damaging vortices in the pump. Cavitation is often indicated by crackling or popping noises, similar to marbles moving through pipes. If left uncorrected, cavitation can lead to costly repairs. For more information, refer to the tip titled Common Pumping System Problems.

### Internal Recirculation

Internal recirculation is another issue that degrades pump performance, similar to cavitation. It typically occurs at low flow rates when fluid exiting the impeller creates damaging vortices. To prevent this, pump manufacturers specify minimum flow rates for their pumps. Operators must ensure that these minimum flow rates are met and avoid excessive restrictions on pump output.

**Poor Flow Control**

Ineffective flow control can result from a variety of factors, such as improper pump selection or poor system design. The performance curves of certain pumps highlight the importance of considering the variability in operating conditions. If the performance curve is relatively flat or "droops" at low flow rates, the designer must carefully evaluate the full range of operating requirements before selecting a pump.

Typically, head curves decrease from the zero-flow condition, meaning that as backpressure decreases, flow increases. The specific shape and slope of the curve are influenced by the impeller vane design and pump speed.

The slope of the pump curve indicates how the pump's output responds to changes in backpressure. A flat pump curve shows that even a small decrease in backpressure can Cause a significant increase in flow. This sensitivity can lead to system instability, particularly in systems where throttle or bypass valve positions fluctuate. For example, in the pump curve shown in Figure 3, a 10-foot increase in backpressure at 160 feet of head and 250 gallons per minute (gpm) results in a 100-gpm drop in pump flow.

Some pumps have performance curves that drop at low flow rates. This occurs mainly with pumps that have low specific speeds. As illustrated in Figure 4 (a generic example), the performance curves of such pumps rise at low flow rates. Since system curves also rise, the intersection of the system and pump curves may occur at multiple points, leading to instability. In these situations, a pump may "hunt," constantly adjusting its output while trying to find a stable operating point. While manufacturers usually specify a minimum flow requirement to prevent a pump from operating in this unstable range, pump wear over time can cause the operating point to shift into this region. Operators should be mindful that surging pump operation may indicate a deteriorating pump combined with a drooping head curve. On the plus side, pumps with drooping curves are generally more efficient.

**Excessive Maintenance**

All pumping systems require maintenance; however, systems with unusually high maintenance demands often result from improper design or operation. Issues such as cavitation, frequent start/stop cycles of the pump motor, and valve seat leakage can reduce the time between necessary repairs.

The maintenance requirements of a system can be measured by the mean time between failure (MTBF) for its components. While systems operate in diverse service environments, making it challenging to define MTBF for every component, seal and bearing manufacturers usually provide estimated MTBFs for specific products. If the actual time to failure is significantly shorter than the manufacturer's suggested interval, it's important to investigate the root cause of the failure.

**Bearing Replacement**

Centrifugal pumps typically use two main types of bearings: thrust and radial. Operating conditions greatly affect the load each bearing endures and the rate at which it wears. To evaluate whether bearings are performing adequately, it's helpful to look at the history of similar pumps in comparable environments. If bearings need frequent replacements, it could indicate that the system's operating conditions or the bearing design needs reassessment.

Factors that accelerate bearing wear include high loads, poor lubrication, elevated operating temperatures, and vibration. Implementing preventive maintenance measures, such as vibration analysis, temperature monitoring, and oil analysis, can help optimize bearing replacement schedules. For more details, check the tip in this section titled Common Pumping System Problems.

**Packing/Mechanical Seal Replacement**

Packing and mechanical seals are used to prevent leaks around the pump shaft where it enters the casing. Packing is less costly and used when leaks are not critical. Mechanical seals, now common in most pumps, are more effective at preventing leaks but come at a higher cost and require more frequent maintenance.

Packing requires frequent adjustments to maintain adequate lubrication and cooling while preventing leakage. The lifespan of packing depends on factors such as service conditions, material quality, and installation care.

Mechanical seal performance is influenced by several factors, making troubleshooting challenging. Since there are many types of mechanical seals for different applications, the expected lifespan of a seal can vary significantly. Common causes of seal issues include contamination of the seal faces, overheating due to inadequate lubrication, and improper installation. For more information, refer to the Common Pumping System Problems tip in this section.

**Wear-Ring Clearances**

Wear rings are used in centrifugal pumps to create gaps between impellers and pump casings or other impellers. As pumps operate, erosion from abrasive particles or fluid leakage can increase these gaps, leading to greater fluid leakage within the pump. This leakage reduces pump efficiency, as more fluid moves from the high-pressure side to the low-pressure side of the impeller.

Wear ring gaps should be set according to the manufacturer's specifications during installation. Some pump designs require axial positioning of the impeller to maintain proper clearance. Engineers should consult the product manual for the correct wear ring gap settings. During major pump overhauls or if performance declines, the wear ring gaps should be reset properly.

**Electrical System Wear**

The stress on a motor and its supporting electrical components is minimized when the motor starts under the lowest mechanical load. For a radial centrifugal pump, the brake horsepower (bhp) curve typically increases consistently on the performance curve, indicating that motor current rises as the flow rate increases.

This rising bhp line implies that the pump's mechanical load is lowest at zero flow, such as when all valves downstream of the pump are closed. Consequently, starting a centrifugal pump while it is deadheaded (i.e., when the downstream valves are closed) and then opening the valves shortly after the pump reaches speed can help reduce electrical stresses on the motor and the controller.

In contrast, an axial pump behaves differently. For axial pumps, the relationship between flow and power is reversed. Power decreases as the flow increases. Therefore, when soft-starting axial pumps, it's essential to ensure that the downstream valves are open until the pump reaches full speed.

In some systems, the effect of pump starts on the fluid system might be a larger concern than their impact on the electrical system. For example, rapidly accelerating large volumes of fluid can lead to damaging water hammer effects. However, from an electrical system perspective, proper start-up practices and using special soft-start switchgear to minimize electrical surges and high starting currents can extend the operating life of the system and improve its overall reliability.

**System Capacity Increases**

When upgrading or modifying a system, it's crucial to assess the available pumping capacity. Unless the existing pump is significantly overdesigned, adding a branch or increasing the flow in an existing component will typically require installing a larger or additional pump. In most cases, the same type of pump as the original can be used, but the size of the new pump(s) will depend on service needs.

A large pump capable of handling the highest system demand can be equipped with an adjustable speed drive (ASD) to optimize efficiency over various system conditions (depending on the system curve). ASDs are particularly beneficial for systems with significant frictional resistance. However, they must be carefully evaluated for systems with high static head. In such systems, reducing the pump speed may cause the pump to operate near shut-off head conditions, leading to poor performance or, in severe cases, damage. For more details, refer to the tip in this section titled Controlling Pumps with Adjustable Speed Drives.

Another way to expand pumping system capacity is by utilizing multiple pump arrangements. This allows several pumps to serve the system, with the number of pumps activated depending on the current flow requirements. The main advantage of this approach is that it keeps each pump operating closer to its best efficiency point (BEP), as opposed to requiring a single large pump to handle a broad range of conditions.

Multiple pump arrangements work well for systems with high static heads and low friction losses. Unlike reducing pump speed, this method avoids the risk of operating a pump near shut-off head, provided the pumps are properly matched, enabling each pump to function more efficiently. For additional information, see the tip titled Multiple Pump Arrangements.

Another option for system expansion is the use of two differently sized pumps: a smaller "pony pump" to handle normal loads and a larger one for worst-case scenarios. The advantage of a pony pump is that it can be sized for efficient operation during typical conditions, leading to lower operating and maintenance costs. For more details, see the tip titled Pony Pumps.

**2. Common Issues in Pumping Systems**

Poor design and improper system operation can lead to various problems in both pumps and pumping systems. Pumps, being rotating equipment, are particularly vulnerable to wear, erosion, cavitation, and leakage. When pumps are not selected or operated properly, it can result in increased maintenance requirements.

**System Problems**

Many components in a pumping system are static, meaning they allow fluid or heat transfer but do not move, unlike dynamic components with moving parts that wear out. Common issues in static components include leakage, fouling, valve failure, and cracks in pipe supports. Hydraulic systems are an exception, having their own set of operating challenges.

**Leakage**

Leakage typically occurs at mechanical joints. After a hydrostatic test (pressurizing the system beyond normal operating levels to check for leaks), solid pipe and welded joints rarely develop leaks unless there's corrosion or erosion. Mechanical joints, which rely on fastener tension to ensure tightness, can loosen over time, or the gasket material may degrade.

Repairing leaking joints may be as simple as tightening fasteners or as complex as disassembling and replacing gaskets or O-rings. Common causes of mechanical joint leakage include sagging pipes (due to inadequate support), thermal strain, and fluid or structure-borne vibrations. If improper pump selection or operation induces high vibration, a pump issue can quickly escalate into a broader system problem.

**Valve Problems**

Valves, like pumps, are prone to wear and leakage and require regular maintenance. They are often installed using bolted flange connections, which can suffer from the same leakage issues as mechanical joints. Valve packing controls leakage around a valve stem, but improper installation or degradation can lead to leaks.

In some systems, slight leakage around valve stems is acceptable. However, in systems handling toxic fluids, even small leaks need immediate attention. In high-temperature systems like steam systems, valve packing may leak at lower temperatures and seal once the valve reaches higher temperatures and expands.

Adjustments to valve packing should be done carefully. Over-tightening the valve packing gland can drastically increase the torque needed to operate the valve. If the packing is too tight, the valve's handwheel torque may become too high to turn by hand, creating a potential safety risk.

**Valve Seat Wear**

Valve seats, which form the seal to stop flow, can experience wear from erosive fluids and high-velocity flow. Valve seats are classified as “soft” or “hard,” depending on the material. Soft-seated valves, with a polymer coating, tend to seal tightly but wear faster than hard-seated valves, which usually feature metal-to-metal contact.

Oversizing a pump can lead to high pressure drops across throttle valves and high flow rates through bypass valves, both of which can accelerate valve seat wear and reduce the time between valve overhauls.

**Pipe Supports and Equipment Foundations**

In well-designed systems, pipe hangers and equipment foundations should last for the system’s life. However, high vibration levels can cause fatigue, leading to structural damage such as yielding or cracking. Oversized pumps are often the culprit for inducing these vibrations.

**Centrifugal Pump Issues**

Centrifugal pumps offer many benefits, such as simplicity, reliability, and longevity. To enjoy these advantages, however, certain issues must be prevented, including cavitation, internal recirculation, seal or packing wear, improper material selection, and incorrect shaft loading.

**Cavitation and Internal Recirculation**

Cavitation is a damaging issue that erodes pump impellers, shortens their lifespan, and accelerates bearing and seal wear. It serves as both a problem and a signal of poor system performance.

Cavitation happens when the fluid’s static pressure drops below its vapor pressure at a given temperature. In centrifugal pumps, fluid acceleration at the impeller causes this pressure drop. If the drop is large enough, the fluid vaporizes, forming unstable bubbles that eventually collapse violently. This collapse sends destructive water jets onto the impeller surfaces.

Symptoms of cavitation include crackling or popping noises that resemble marbles passing through the pump. Incorrect pump selection, operation at high temperatures, or low suction pressure can all cause cavitation. While cavitation typically occurs at high flow rates, it can also occur at low flow rates under certain conditions.

Additionally, cavitation can result from pump suction starvation, caused by air pockets or pipe fouling. The major effects of cavitation include reduced pump performance and impeller erosion. Cavitation hinders pump performance by restricting flow and reducing the head.

If cavitation damages impellers enough, they can become unbalanced, which leads to alternating bearing loads and accelerated bearing wear. This makes cavitation a serious threat to system reliability. Furthermore, cavitation-induced vibrations stress pump foundations and piping, increasing maintenance needs.

Internal recirculation, a similar issue to cavitation, can occur when the system operates at low flow rates. This can create damaging flow patterns in the pump's suction or discharge regions.

For systems where cavitation is inevitable, high-tensile-strength materials for impellers are recommended. These materials can withstand higher energy levels from cavitation, though it's crucial to ensure compatibility with the system fluid.

To prevent cavitation, centrifugal pumps must maintain a certain level of pressure at the inlet. This required pressure is known as the net positive suction head (NPSH), as detailed in the accompanying tip titled Centrifugal Pumps.

**Seal and Packing Issues**

The shaft penetration point of a pump casing, known as the stuffing box, creates a potential leak path that must be sealed. This is usually achieved with packing or mechanical seals (see Figure 6). For systems where fluid leakage isn't a significant concern, packing is often used because it is more cost-effective and requires simpler maintenance skills. On the other hand, mechanical seals offer superior sealing but are typically more expensive and require more expertise for repair or replacement. Most modern pumps come with mechanical seals as standard.

**Packing Problems**

There are two main issues with packing: overtightening and improper installation. Packing generally needs to allow for some leakage to remain lubricated and cooled. If the packing rings are overtightened, friction between the packing and the shaft generates excessive heat, which can destroy the packing and even damage the shaft.

As packing wears over time from direct contact with the pump shaft, it increases the leakage rate. To counter this, the packing gland must be periodically tightened to ensure the packing stays compressed against the shaft, keeping leakage within acceptable limits. Improper installation of packing can result in uneven compression of packing rings (with some tightened too much and others too little) or an excessively loose fit between the packing and the shaft. These issues can lead to excessive leakage, causing housekeeping problems such as wet floors and high moisture levels. In cases where the fluid is toxic, this can lead to contamination, while expensive fluids may be lost due to leakage.

If the fluid pressure at the stuffing box is below atmospheric pressure, poor packing installation can allow air to enter the system. Air intake into the suction region can degrade pump performance by 3% or more. Additionally, systems requiring precise fluid chemistry, especially those sensitive to oxygen content, may be contaminated by the air. Excessive air leakage can prevent pumps from staying primed and disrupt self-priming operations during start-up.

**Mechanical Seal Problems**

Mechanical seals are used when superior sealing is required. Their performance is highly dependent on correct installation and maintaining a clean operating environment. The two main failure mechanisms for mechanical seals are degradation of the seal face material and loss of spring or bellows tension, which causes the faces to separate more easily. Seal face degradation typically occurs when debris enters the seal faces and causes damage. To reduce the risk of this, mechanical seals are often serviced with special flushing lines that include filters to trap debris.

Mechanical seals rely on springs or bellows to maintain force between the seal faces. Over time, however, the compressive properties of these components can degrade due to fatigue, fouling, or corrosive environments, which affects the materials of the springs and bellows.

To minimize fatigue loads on mechanical seals, precise alignment is crucial to minimize spring movement with each shaft revolution. In systems with highly corrosive fluids, mechanical seals with external springs are recommended. The seal faces must be perfectly aligned with tolerances of microns (one-millionth of a meter), as slight variations in the contact between the two faces can quickly reduce the seal's effectiveness. Since pumps often rotate at speeds of 1,800 or 3,600 rpm, even small misalignments can destroy seal performance.

**Shaft Deflection**

Shaft deflection is a common issue in long-shafted centrifugal pumps. It occurs due to unequal pressure distribution around the impeller. The side of the impeller closest to the pump discharge experiences higher pressure than the opposite side, creating a radial force on the shaft. Some pumps have multiple volutes to reduce this imbalance.

Shaft deflection is most problematic when a pump operates under low flow conditions. The consequences of severe deflection include increased wear on bearings, leakage at shaft seals, and bending fatigue in the pump shaft. Although pump shafts are generally designed to last for the pump's entire life, extreme deflection can subject the shafts to forces they are not designed to withstand. If this condition is sustained, it can lead to catastrophic pump shaft failure.

Pump shaft failure is costly and often requires the replacement of the entire pump. The risk is particularly high in pumps with long shafts and small diameters between shaft bearings. Operating such pumps at or near their minimum flow for extended periods increases the likelihood of shaft failure.

**Positive Displacement Pump Issues**

Positive displacement pumps share many of the same challenges as centrifugal pumps, but they also present unique problems of their own. One of the primary concerns with positive displacement pumps is the cyclical nature of their pumping action, which can lead to fatigue in components such as bearings and diaphragms.

Another key issue with these pumps is that their flow rate is largely independent of backpressure, which creates a risk of over pressurizing the discharge piping. If the discharge lines downstream of a positive displacement pump are closed while the pump is running, the system can quickly reach dangerous pressure levels. Without a functional pressure relief mechanism, the pump motor could either reach its lockout torque, or the pressure will continue to build until some part of the system fails or ruptures.

To prevent these catastrophic failures, pressure relief valves must be properly installed and maintained. If these valves fail to operate correctly, they can lead to severe damage to the system. It is essential to implement a regular maintenance schedule to check and ensure that pressure relief valves are functioning as intended.

Many positive displacement pumps also experience pulsating flow, which can generate both fluid-borne and structure-borne vibrations. These vibrations can create load conditions that accelerate the wear and tear of piping, valves, and piping supports. Therefore, pumping systems that are not designed to accommodate the vibration loads from positive displacement pumps may face significant operational and maintenance issues.

Lastly, positive displacement pumps are highly vulnerable to wear when pumping abrasive fluids. The abrasives can cause accelerated wear of the pump components, reducing their lifespan and requiring more frequent maintenance.

**3. Signs of an Oversized System**

**Indications of an Oversized Pump**

Conservative engineering practices often lead to specifying, purchasing, and installing pumps that exceed the actual process requirements. Engineers tend to add a margin of safety to account for design uncertainties, system capacity expansions, and potential fouling. As a result, pumps are often "one size up" from what the system truly needs. However, oversizing pumps increases operating costs in terms of energy consumption and maintenance requirements, which are frequently overlooked during the system specification process. Correcting an oversized pump can be a cost-effective improvement to reduce these unnecessary expenses.

**Common Indicators of Oversizing**

There are several common signs that indicate a pump is oversized:

1. Excessive Flow Noise
2. Oversized pumps typically cause excessive noise levels, which operators may ignore as normal system behavior. However, the vibrations from the flow-induced pipe noise can cause significant damage over time, loosening flanged connections and creating fatigue loads on welds in pipes and piping supports.
3. Highly Throttled Flow Control Valves

In systems with oversized pumps, control valves often remain in a throttled position, forcing the pump to operate against high backpressure. This causes the pump to function inefficiently, leading to excessive bearing wear. Throttling also impacts process control loops and can cause control valve backlash and stiction, exacerbating process variability.

4. Heavy Use of Bypass Lines

Excess flow in systems with oversized pumps is often diverted through bypass lines. While these bypass lines help prevent pressure differential buildup, they waste energy. A system that frequently uses open bypass valves is likely inefficient due to oversized pumps or improper balancing.

5. Frequent Replacement of Bearings and Seals

Oversized pumps often generate high backpressure, causing them to operate far from their best efficiency point (BEP). This leads to greater wear on bearings and seals due to the higher radial-bearing and thrust-bearing loads, and increased pressure on mechanical seals and packing glands.

6. Intermittent Pump Operation

Many pumps in systems are used to maintain fluid levels in tanks. If the pump is frequently energized and de-energized, it will result in higher friction losses and shorten the life of the motor controller and pump assembly. An oversized pump can exacerbate this issue by pushing fluid through pipes at higher velocities.

**Corrective Measures**

Several corrective measures can help reduce operating costs and extend maintenance intervals in systems with oversized pumps. Depending on the specific symptoms, one or more of the following actions can be taken:

- Replace the Impeller: If the current impeller is generating excessive flow or head, consider replacing it with a smaller one. Most pumps allow for impeller changes since they use standardized models to reduce manufacturing costs.
- Trim the Impeller: When a smaller impeller isn't available, trimming the impeller diameter can reduce the impeller tip speed. This adjustment shifts the pump’s performance curve downward, improving efficiency without changing the pump motor.
- Install an Adjustable Speed Drive (ASD): An ASD can help control the pump's flow if the flow varies over time, reducing the unnecessary operation of an oversized pump.
- Add a Smaller Pump: In cases where intermittent operation is a problem, adding a smaller pump can help manage the flow better.

By addressing these indicators, systems can achieve more efficient and cost-effective pump operations.

**Use Variable Frequency Drives (VFDs)**

Pumps that face highly variable demand conditions are excellent candidates for adjustable speed drives (ASDs), with the variable frequency drive (VFD) being the most common type. VFDs control the motor speed electronically, which adjusts the pump's output accordingly. The main advantage of VFDs is their ability to better match the energy required by the system with the energy delivered by the pump. As system demand fluctuates, the VFD modifies the pump speed to meet this demand, minimizing energy losses due to throttling or bypassing excess flow. This adjustment results in significant energy and maintenance cost savings, which often justify the initial investment in a VFD.

However, VFDs are not suitable for every application. For instance, systems that operate under high static head conditions or those that remain under low-flow conditions for extended periods may not benefit from a VFD. For more detailed information, refer to the section titled Controlling Pumps with Adjustable Speed Drives.

**Use Smaller Pumps to Augment Larger Pumps**

In systems that maintain fluid levels in tanks or reservoirs, pumps are often sized based on worst-case or peak service conditions. These conditions are usually far higher than the typical demands, leading to oversized pumps. As a result, oversized pumps often run inefficiently, frequently energizing and de-energizing, operating far from their best efficiency point (BEP), and causing high friction losses—all of which increase energy and maintenance costs.

To alleviate the strain on oversized pumps, consider adding a smaller pump to handle regular system demand. This smaller pump can run efficiently under normal operating conditions, while the larger pump can be activated when high load conditions occur. This strategy helps reduce energy consumption and extends the life of the equipment. For more information, see the section titled Pony Pumps.

**4. Optimizing Piping Configurations for Enhanced Pumping System Efficiency**

Optimizing a pumping system's configuration involves several key steps, including selecting the appropriate pipe size, designing a layout that minimizes pressure losses, and choosing low-loss components. When determining pipe size, designers must balance the initial cost of the pipe against the cost of moving fluid through it. While larger pipes reduce friction loss for a given flow rate, they come with higher material and installation costs. Unfortunately, designers often focus solely on the initial cost and overlook the energy costs associated with using smaller piping.

The piping layout should also account for energy losses due to poor flow profiles. Although space constraints often dictate the layout, there are usually opportunities to minimize unnecessary pressure drops by avoiding sharp bends, expansions, and contractions, and by keeping the piping as straight as possible. A useful tip is to align valves and system equipment with the pipe run to reduce losses.

Another way to improve efficiency is by selecting low-loss components during system design. While it's important to consider the initial cost of these components, long-term energy costs should also be factored in. For example, selecting valves with high flow losses may seem cost-effective initially, but over time, they could significantly impact energy consumption.

Many times, valves are chosen based on service requirements such as sealing capabilities and durability, but for systems with light service requirements, valves are often selected for their low upfront cost, resulting in high flow losses. Globe valves, for example, are chosen for their simplicity and low cost but come with relatively high flow loss coefficients. Designers can improve life-cycle costs by considering flow losses in their valve selection.

Additionally, valves are often incorrectly sized. Designers sometimes specify an unnecessarily large pressure drop across the valve at the design point, leading to energy waste. Also, specifying a maximum system flow that exceeds normal operating conditions can result in excessive pressure drops during regular operation.

**Pump Concerns**

Centrifugal pumps function most efficiently when the inlet flow has a uniform profile. Therefore, system designs should ensure that nonuniform flow at the pump inlet is minimized. In centrifugal pumps, fluid enters the pump through the suction piping and moves into the eye of the impeller, where it is caught by the impeller vane and accelerated toward the tip. If the inlet flow is uneven, the impeller's ability to transfer energy to the fluid is compromised, leading to reduced efficiency. Furthermore, uneven flow at the pump suction can cause excessive vibrations, which not only shorten the pump’s lifespan but also weaken pipe welds and mechanical joints.

Common issues that lead to poor pump performance include improper flow profiles, vapor collection, and vortex formation. These issues are often caused by inadequate pipe configurations. Figure 7 illustrates typical piping installation problems and provides the correct arrangements to improve performance.

# Flow Issues Affecting Pump Performance

**Poor Flow Profile**

Improper piping configurations often lead to uneven flow, which disrupts the efficiency of centrifugal pumps. Elbows and valves placed too close to the pump can create flow disturbances, especially when the flow velocity is high and suction pressure is low. When a small-radius elbow or a globe valve causes a sharp redirection of the flow, it results in turbulent flow, significantly reducing pump performance.

**Vapor Collection**

Vapor entrapment can occur when the suction piping leading to the pump does not maintain a constant slope. In such cases, vapor can accumulate at high points, limiting the flow through the pipe and generating pressure pulsations that degrade pump performance. Piping installations that promote vapor collection are shown in Figure 7.

**Vortex Formation**

In tank applications, when the fluid level drops too close to the suction inlet, a vortex can form. This can lead to a loss of suction head, allow air into the pump, or in severe cases, cause the pump to lose its prime. If the pump loses its prime, it must be refilled and vented to restart. Centrifugal pumps are not designed to operate without fluid, and running dry can damage mechanical seals, packing, and impeller wearing rings. Self-priming centrifugal pumps, while capable of recovering their prime, tend to be less efficient than conventional centrifugal pumps and should only be used when necessary.

**Guidelines for Improving Pipe Configurations**

1. Ensure Uniform-Velocity Flow Profile

To achieve a uniform-velocity flow profile upstream of the pump, it is essential to have a straight run of pipe leading directly into the pump inlet. If space constraints force the use of an elbow near the pump, a long-radius elbow should be chosen. In certain situations, installing a flow straightener, such as a baffle plate or a set of turning vanes, can help to correct flow disruption caused by the elbow (see Figure 8). These flow straighteners help smooth out the flow, resulting in a more consistent velocity profile. However, care must be taken to ensure that the pressure drop across the flow straightener does not lead to cavitation.

2. Keep Transitions and Joints Smooth

To avoid flow disruptions, installers should ensure that transition pieces and joints between pipes or fittings are as smooth as possible. Any burrs or misalignments in the pipes can create turbulence and interfere with the flow.

3. Properly Support Suction and Discharge Piping

Suction and discharge piping near the pump should be adequately supported (see Figure 9). Many pump and motor issues arise from pipe reactions that cause misalignment of the pump. When installing a pump, the connecting piping is often not perfectly aligned with the pump, requiring mechanical adjustments. If the piping is pulled too far to make the connection, it can cause the pump and motor to become misaligned, putting excessive strain on the pump casing. Proper support ensures that the pipe reaction is carried by the pipe hangers rather than the pump itself, reducing stress on the system. Additionally, properly supported piping helps to stiffen the system and reduce vibrations.

**5. Essential Pump Maintenance**

Centrifugal pumps are popular due to their low maintenance needs, but they still require periodic upkeep to ensure long-term reliability and efficiency. Common maintenance tasks for centrifugal pumps include:

- Bearing lubrication and replacement
- Mechanical seal replacement
- Packing tightening and replacement
- Wear ring adjustment or replacement
- Impeller replacement
- Pump/motor alignment
- Motor repair or replacement

These tasks help maintain optimal pump performance and prevent costly repairs or downtime. Regular maintenance is essential for extending the pump's lifespan and minimizing operational disruptions.

**Common Failures**

The most expensive consequence of improper pump maintenance is unscheduled downtime. The causes of this downtime vary depending on the specific demands of the application. In systems handling corrosive or hazardous fluids, mechanical seal leaks often require shutdowns for safety reasons, though some systems can tolerate these leaks. In other cases, bearing failures or seizures may pose the greatest threat to continuous operation. As each system has its own set of requirements for pump and motor equipment, maintenance needs will vary significantly.

**Preventive Maintenance and Schedules**

To minimize unscheduled downtime, it is essential to perform basic system maintenance at regular, predetermined intervals. Factors to consider when setting a maintenance schedule include the cost of downtime, the risk and cost of catastrophic failure, the expected mean time between repairs (MTBR) for components like motors, bearings, and seals, as well as the availability of backup equipment. Maintenance schedules can be based on hours of operation or calendar intervals, such as quarterly or semiannually. For instance, operators can follow a sample basic maintenance checklist.

Operators should determine maintenance frequency based on both manufacturer recommendations and their own experience with pumps in similar applications. For systems without unusually harsh operating conditions, a general maintenance schedule like the one below may be suitable:

**Packing and Mechanical Seal Adjustments**

- Weekly checks:
    - Packing: Adjust the gland bolts to maintain the cooling flow leakage rate specified by the pump manufacturer (typically 2 to 60 drops per minute). Avoid over-tightening the bolts to prevent burning the packing, which would require repacking the stuffing box. As the packing wears, add additional packing rings. Eventually, all packing rings will need replacement. When repacking, clean and lubricate the gland bolts.
    - Mechanical seals: Regularly check the seal performance and measure any leakage.

**Bearing Lubrication**

- Semiannual or annual checks:
    - Grease-lubricated bearings: Add grease according to the pump's technical manual, but be careful not to over-grease as it may cause overheating by interfering with the ball or roller motion.
    - Check grease quality and repack if needed.

- Oil-lubricated bearings: Inspect oil levels and quality. If necessary, add or replace the oil, but avoid overfilling the oil reservoir.

**Motor/Pump Alignment**

Shifting of the pump foundation feet or piping can lead to pump/motor misalignment, which can impact performance. To ensure proper alignment, it is essential to check it periodically. Alignment is typically measured using a dial indicator and reading the total indicated runout (TIR), also referred to as full indicator movement (FIM), of the pump/motor coupling. Regular vibration readings can help detect changes in the status of bearings.

For pumps that require highly precise alignments, laser measurement systems are often more accurate than other methods. Alignment specifications can typically be found in the pump's technical manual.

**Repair Items**

Common repair items that may need regular replacement include mechanical seals, bearings, packing, wear rings, motors, and impellers.

**Replacing Mechanical Seals and Bearings**

Although mechanical seals and bearings are part of regular maintenance, they can fail catastrophically. Worn bearings can cause excessive noise or even result in seizure. In some cases, bearing or mechanical seal failure can score the shaft sleeve, requiring removal of the pump shaft and installation of a new sleeve.

Mechanical seals are typically used in applications where a superior seal is required compared to packing. Although more expensive, mechanical seals provide better sealing capabilities with less friction. They depend on a precisely fit contact between dynamic surfaces, and contaminants can degrade the seal quickly. However, when installed correctly, kept clean, and properly flushed, mechanical seals can last for thousands of hours.

**Replacing Packing**

Packing is a malleable, rope-like material used to create a seal between the pump and motor shaft when compressed by the packing gland. Since packing makes direct contact with the rotating shaft, it relies on the system fluid for cooling and lubrication. As the packing wears, it must be compressed by tightening the gland nuts. Over time, packing loses its ability to create an effective seal and must be replaced.

Packing typically comes in rolls, and it must be cut into sections that are then wrapped around the pump shaft. Accurately cutting packing rings is essential for proper sealing, but it can be challenging. To simplify this process, many mechanics use a piece of pipe or bar stock that is machined to the exact diameter of the pump shaft. This mockup shaft allows the mechanic to cut the rings directly to fit, eliminating the need for measuring and then cutting the packing. Since packing is often stretchy, using the measure-and-cut method can result in a poor fit, which is why the mockup shaft method is preferred for ensuring a precise and proper seal.

**Replace Wear Rings**

Wear rings are attached to the impeller or casing (or both) to act as a wear surface between impeller stages or between the impeller and pump casing. These rings are designed to maintain a specific gap between the high- and low-pressure sides of the impeller. If the gap widens too much, fluid can flow back into the suction side of the pump, causing a loss in efficiency. Some wear rings have an axial gap to compensate for wear, while some pump designs feature adjustable wear plates. A noticeable decrease in pump performance is a key sign that wear rings need to be replaced. Replacing wear rings requires disassembling the pump.

**Replace Motors**

Even well-maintained motors eventually wear out as winding insulation degrades over time. The insulation deteriorates more quickly when the motor’s winding temperatures exceed rated values for prolonged periods. For motors below 50 horsepower, the most common approach is to replace the motor, whereas, for larger motors, rewinding is often more economical. However, repeated rewinds can reduce motor efficiency. It is essential to ensure the repair facility has a proper quality assurance program to avoid losing motor efficiency through poor rewinds.

High-efficiency motors should be considered when replacing motors. These motors are 3% to 8% more efficient than standard ones, offering significant cost savings in high-use applications. The Energy Policy Act (EPAct) of 1992 set minimum efficiency standards for general-purpose motors between 1 to 200 horsepower. Additionally, NEMA Premium™ motors offer even higher efficiencies. DOE’s MotorMaster+ software can assist in selecting energy-efficient motors, comparing options, and estimating energy and lifecycle costs.

**Replace Impellers**

Impellers typically last the lifetime of the pump, but severe cavitation or erosion can damage them, leading to reduced pump performance and efficiency. Replacing an impeller is similar to replacing wear rings, requiring disassembly of the pump.

**Predictive Maintenance**

Many pump maintenance tasks are reactive, addressing issues like bearing noises, excessive packing or seal leakage, and poor performance due to wear ring degradation. However, advancements in instrumentation and signal analysis software have improved predictive maintenance strategies.

**Vibration Analysis**
Vibration analysis tools help identify issues before they become major failures. These tools "listen" to the vibrations of machinery and detect problems such as bearing failure, motor winding issues, or dynamic imbalances. Using accelerometers, vibration equipment measures machinery vibrations and compares the results with baseline data to pinpoint problems early. This allows operators to schedule repairs before catastrophic failure occurs, reducing downtime.

**Oil Monitoring and Analysis**
For pumps with oil-lubricated bearings, oil monitoring and analysis help determine the condition of the bearings and seals. Oil analysis can identify overheating, leaks, and the approaching end of bearing life. It also helps optimize oil change schedules and can reduce unnecessary oil replacements, offering cost savings, especially when using expensive oils like synthetic types.

**Thermography (IR Scanning)**
Infrared scanning detects hot spots in machinery, offering early detection of issues such as overheating bearings or deteriorating winding insulation. This technology helps prevent unexpected shutdowns by identifying problems before they escalate.

## 6. Overview of Centrifugal Pumps

Centrifugal pumps, also referred to as rotodynamic pumps, operate with a variable flow rate even when maintaining a constant rotational speed. This differs from positive displacement pumps, which move a fixed volume of fluid with each stroke or revolution. These pumps utilize an impeller—a rotating wheel-like component—to impart energy to the fluid. As the high-velocity fluid exits the impeller tip, it enters a diffuser, a chamber that directs the flow into the discharge piping. Within the diffuser, the fluid slows down, converting its kinetic energy into increased pressure.

The performance of a centrifugal pump is typically represented by a graph that illustrates the relationship between the pressure generated (measured as head) and various flow rates. The graph, known as a pump performance curve, provides key insights into the pump's operation.

The volume of fluid a centrifugal pump moves is influenced by the pump's differential pressure. As this pressure increases, the flow rate decreases, and the specific rate of decline depends on the pump's design. Understanding this interaction is crucial when selecting, designing, and operating a centrifugal pump system.

A typical pump performance curve also includes efficiency and brake horsepower (bhp), both of which are plotted against flow rate. Pump efficiency is determined by comparing the pump's fluid power to the power delivered to the pump shaft. In direct-coupled pump/motor systems, this power corresponds to the motor's brake horsepower.

**Best Efficiency Point (BEP)**

A key aspect of the head/flow curve is the Best Efficiency Point (BEP), which represents the optimal operating condition for a pump in terms of energy efficiency and maintenance costs. When a pump runs at its BEP, it achieves maximum efficiency while minimizing wear on components. Further insights into BEP can be found in the tip titled Multiple Pump Arrangements.

Operating a pump significantly away from its BEP can lead to increased wear on mechanical seals, bearings, and other internal components. In real-world applications, maintaining a pump precisely at its BEP is challenging due to fluctuating system demands. However, keeping pump operations within a reasonable range of its BEP can help lower overall system operating costs.

**Pump Performance Curves**

Pump manufacturers provide a coverage chart to illustrate the performance characteristics of various pump models, often referred to as a family of pump curves. This chart, shown in Figure 11 on page 33, aids in selecting the most suitable pump size for a specific application. The numbers associated with each pump in Figure 11 indicate the inlet size, outlet size, and impeller size. Because different impeller sizes can be used within the same pump model, there is often considerable overlap between pump sizes.

**Pump Curves for Different Impeller Sizes**

Once a pump has been selected to generally meet system requirements, its specific performance curve must be analyzed. Many pumps can accommodate multiple impeller sizes, each with its own distinct performance characteristics.

Figure 12 illustrates performance curves for various impeller sizes, along with iso-efficiency lines, which represent efficiency levels across different flow conditions. Selecting the right impeller size and motor involves an iterative process, using these curves to assess efficiency and performance over the pump's expected operating range. For more details, refer to the tip titled Impeller Trimming.

**Net Positive Suction Head (NPSH)**

To prevent cavitation, centrifugal pumps require a certain amount of pressure at the inlet, known as net positive suction head (NPSH). There are two key types:

1. NPSH Available (NPSHA): The pressure at the pump's inlet, determined by the system and flow rate.
2. NPSH Required (NPSHR): The minimum pressure needed by the pump to operate without cavitation, which varies with flow rate and is typically included in pump performance curves.

If the NPSHA is sufficiently higher than the NPSHR, cavitation should not occur. Cavitation reduces pump efficiency and can cause serious damage over time.

The Hydraulic Institute defines NPSHR based on a 3% reduction in pump total head (or the first-stage head of a multistage pump) due to cavitation. This standard is now referred to as NPSH3, following ANSI/HI 1.6-2000–Centrifugal Tests.

Most pumps operate effectively with a small margin above NPSH3 when running near the Best Efficiency Point (BEP). However, significantly higher margins may be needed to prevent cavitation when operating away from the BEP.

To ensure reliable performance, system designers commonly follow a 25% rule, meaning that NPSHA should be at least 25% higher than NPSHR at all expected flow rates. If an oversized pump operates far beyond its design point, the gap between NPSHA and NPSHR can shrink dangerously, increasing the risk of cavitation.

**Selecting the Right Pump Speed**

Pump speed is a critical factor in system design, influencing efficiency and performance. The optimal speed is often determined by examining the performance of similar pumps in comparable applications. However, when direct comparisons are unavailable, specific speed serves as a valuable dimensionless parameter for estimating pump speed.

Specific speed can be classified into two key types:

1. Impeller Specific Speed (Ns): Used to assess pump performance across different impeller sizes and speeds.
2. Pump Suction Specific Speed: Evaluates suction characteristics for optimal design.

In mechanical terms, specific speed (Ns) represents the impeller speed required to produce 1 gallon per minute (gpm) at 1 foot of head. It is calculated using the following equation:

Where:

$$N_s = \frac{n\sqrt{Q}}{H^{3/4}}$$

- Ns = Specific speed
- n = Pump rotational speed (rpm)
- Q = Flow rate (gpm)
- H = Total head per stage (ft)

For standard impellers, specific speeds typically range from 500 to 10,000. Pumps with specific speed values between 2,000 and 3,000 tend to achieve the highest efficiency. Selecting a pump within this range can significantly enhance energy efficiency and system performance.

# Selecting the Right Pump for Your System

**Key Data for Pump Selection**

To properly size and select a pump, designers must consider system flow requirements and the system resistance curve. The system curve is determined using factors such as:

- System configuration
- Total pipe length
- Pipe size
- Number of elbows, tees, fittings, and valves

By incorporating these details along with fluid properties and the available suction head, designers can estimate head loss and Net Positive Suction Head Available (NPSHA) at the pump's inlet.

**Evaluating Pump Options**

Once system requirements are established, designers review pump manufacturers' data to find suitable options. This process involves comparing several factors, including:

- Best Efficiency Point (BEP)
- Pump speed
- Net Positive Suction Head Required (NPSHR)
- Pump type

Each pump has multiple performance curves based on impeller size. In some cases, impeller trimming can further fine-tune performance (see Impeller Trimming section).

Example: 4x1.5-6 Pump Selection

Consider a 4x1.5-6 pump with a design point just below the 6-inch impeller curve. Based on its performance data:

- Efficiency = 74%
- Motor requirement = 5 HP
- BEP = Slightly right of the design point
- NPSHR = 6 ft
- Required NPSHA = At least 7.5 ft (25% higher than NPSHR)

If these conditions are met, the 4x1.5-6 pump is a good match for the system.

**Using Pump Manufacturer's Software**

Due to the complexity of pump selection, many manufacturers offer electronic selection tools. These tools allow designers to input system parameters such as:

- Head
- Flow rate
- Pipe size
- NPSHA
- Fluid properties

The software then generates a list of suitable pumps, refining options based on additional constraints like pump speed. While engineering expertise is still necessary for evaluating head/flow sensitivity and multiple pump configurations, manufacturer software simplifies the selection process and improves accuracy.

## 7. Applications of Positive Displacement Pumps

The term "positive displacement" describes how these pumps generate pressure and transfer fluid. They work by reducing the volume within a chamber, forcing the fluid out. One common type is the piston pump, which moves a fixed amount of fluid with each stroke. Another example is the screw pump, a rotary displacement pump that utilizes two intermeshing screws to move a set volume of fluid with every rotation.

**Applications**

While positive displacement pumps may require more maintenance than other pump types, they excel in specific applications where their unique characteristics are advantageous. These applications include:

High-Pressure/Low-Flow Applications: Positive displacement pumps are typically more efficient in generating high pressures in low-flow situations. While centrifugal pumps can also be designed for high-pressure applications—often by using multiple stages—these specialized pumps tend to be more expensive.

High-Viscosity Fluid Handling: Positive displacement pumps are more efficient than centrifugal pumps when it comes to pumping viscous fluids. Since these pumps directly pressurize the fluid, they experience less energy loss due to the high shear stresses common in thick or sticky substances.

Accurately Controlled Flow Applications: Positive displacement pumps are ideal for applications that require precise flow control. Each stroke or revolution moves a fixed volume of fluid, allowing for accurate metered flow. By regulating the number of pump cycles, these pumps ensure consistent and controlled fluid delivery.

Additionally, positive displacement pumps offer several unique advantages that make them appealing in various systems. For example, they are typically self-priming and can handle gases in the suction line, which allows them to be positioned above the fluid level. This feature can simplify system design, unlike centrifugal pumps that often need additional equipment to remove gases and prime the impeller. While some centrifugal pumps are designed to be self-priming, they are often more expensive, less reliable, and less efficient, and still require gas removal.

Certain positive displacement pumps, such as diaphragm and peristaltic pumps, eliminate the need for seals, meaning they do not leak. In systems dealing with corrosive or hazardous fluids, this absence of seals can lead to significant savings by reducing maintenance costs.

**Special Considerations**

Positive displacement pumps are typically equipped with pressure relief valves, and many models have these valves integrated internally. This protection is crucial because these pumps push fluid into the discharge line regardless of the backpressure. As a result, if the flow path becomes completely blocked downstream, fluid pressure can increase until the motor torque overloads or the piping or other equipment fails. While relief valves are designed to prevent such damage, they must undergo regular testing and maintenance. A malfunctioning relief valve can lead to costly damage to the system.

Positive displacement pumps often produce pulsating flow, which can lead to vibration issues in some systems. These pulsations can be problematic, particularly if the pulse rate aligns with the natural frequency of any piping or structural components. Flow-induced vibrations can result in cyclic loading on piping welds and supports, potentially loosening mechanical joints. To mitigate this, accumulators can be used to absorb some of the vibrational energy and reduce the impact.

Another factor to consider is the need for spare parts storage. Many positive displacement pumps contain a significant number of moving parts, which may require facilities to maintain a large inventory of replacement components. For instance, the internal valves of reciprocating pumps, where mating surfaces are prone to wear, may need periodic replacement. While these parts can be sourced from manufacturers or suppliers, plants often keep common replacement parts in stock to minimize downtime. As a result, using pumps with numerous moving parts can increase maintenance workloads and the costs associated with holding inventory.

**8. Configurations of Multiple Pumps**

An alternative to using a single pump for a system's needs is the use of multiple smaller pumps working together in parallel operation.

In systems with fluctuating demand, relying on a single pump may prevent it from operating near its best efficiency point (BEP). Operating away from the BEP can lead to higher operating and maintenance costs. By using multiple pumps, especially in systems with high static head requirements, pumps can be energized or de-energized to match demand fluctuations, allowing each pump to run more efficiently. This setup improves overall system performance, though the efficiency gain depends on factors such as the pump curves, the system curve, and the nature of the demand change.

The benefits of multiple pump setups include flexibility, redundancy, and efficient handling of varying flow requirements in systems with significant static head. For systems with high friction, alternative solutions like adjustable speed motors may offer greater efficiency for managing variable demand.

Typically, parallel pump systems use identical pumps, ensuring balanced load-sharing when all pumps are in operation. Adding a pump increases flow and shifts the system's operating point to the right along the system curve. However, if pumps of different sizes are used, careful consideration is needed to avoid situations where the largest pump dominates, causing other pumps to operate below their minimum flow ratings. In such cases, the performance curves of the pumps should be thoroughly analyzed to ensure no pump falls below its minimum flow requirement.

**Best Efficiency Point (BEP)**

The Best Efficiency Point (BEP) is a key design characteristic that optimizes both performance and service life of a pump.

Every centrifugal pump has a BEP, which is the point at which the pump operates most efficiently and experiences the lowest radial bearing loads. The BEP is determined by factors such as the pump's inlet configuration, impeller design, casing design, and speed. At this point, the hydraulic efficiency is at its peak, and the fluid enters the impeller vanes, casing diffuser (discharge nozzle), or vaned diffuser in a smooth, shock-free manner. Flow through the impeller and diffuser vanes (if applicable) is uniform, well-controlled, and free of separation.

The pump operates within a preferred operating region (POR), where the flow remains stable, and the service life of the pump is not negatively impacted by hydraulic loads, vibration, or flow separation. The allowable operating region (AOR) defines the exact limits of minimum and maximum flow for the pump.

Centrifugal pumps typically use roller or ball bearings. Since the lifespan of these bearings is inversely proportional to the cube of the load, selecting a pump with a BEP that aligns closely with the system's normal operating range can significantly reduce the frequency of bearing replacements, thus extending pump life.

**Advantages of Multiple Pump Arrangements**

Using multiple smaller pumps in combination offers several key benefits over relying on a single large pump. These advantages include increased operational flexibility, redundancy, lower maintenance requirements, and improved efficiency.

Operating Flexibility: As illustrated in Figure 14 (note: this is a conceptual example, not actual pump curves), multiple pumps in parallel expand the flow range that can be delivered to the system. This setup allows for energizing and de-energizing pumps, helping to maintain the operating point closer to each pump’s Best Efficiency Point (BEP), especially in systems with flat performance curves. However, operators must ensure that the minimum flow requirement for each pump is met when operating pumps in parallel.

Redundancy: A multi-pump arrangement provides redundancy in case of pump failure. If one pump needs repair, others can continue to operate, ensuring the system remains functional and minimizing downtime. This reduces the risk of system shutdowns caused by individual pump failures.

Maintenance: With multiple pumps, each unit can run closer to its BEP (for systems with flat curves), reducing bearing wear and allowing smoother pump operation. This configuration also minimizes the need for energy-wasting flow control mechanisms like bypass lines and throttle valves. In contrast, a single large pump operating under low-flow conditions forces excess flow to be either throttled or bypassed, which causes wear on throttle valves and results in energy losses. Using multiple pumps with variable speed drives can be an energy-efficient solution, especially when managing variable flow demands.

Efficiency:

One potential benefit of using multiple pumps is the higher overall efficiency they offer. Each pump can operate closer to its Best Efficiency Point (BEP) for systems with flat performance curves. By energizing or de-energizing pumps as demand fluctuates, each pump stays within a smaller, more efficient range of its performance curve, ideally around the BEP. A single pump, on the other hand, would need to operate over a broader range, often moving further away from its BEP.

High-speed pumps are generally more efficient than low-speed pumps at a given head and flow. However, pumps with specific speed values greater than 3,000 tend to be less efficient at higher speeds, though this is uncommon in most pump types. Smaller pumps require less motor power, and using multiple high-speed pumps can offer an efficiency advantage over using one large, low-speed pump. That said, the increased maintenance needs of high-speed pumps must be considered when weighing the efficiency benefits.

**Other Options**

Other design options that can accommodate widely varying operating conditions include pony pumps, multiple-speed pumps, and variable frequency drives (VFDs). For more details on pony pumps, refer to the tip titled "Pony Pumps." Information on VFDs can be found in the section titled "Controlling Pumps with Adjustable Speed Drives."

Multiple-speed pumps can be used similarly to manage system demands. By adjusting the speed, the entire performance curve shifts, moving up or down to match the system’s needs, as illustrated in Figure 15 (note: this figure is a conceptual example and not an actual pump curve).

Although multiple-speed pumps are typically less efficient than single-speed pumps at a specific operating point, their ability to perform over a wide range of conditions is a key advantage. Additionally, multiple-speed pumps are compact and space-saving, as they eliminate the need for additional piping and valves required when using parallel pumps.

**9. Pony Pumps**

Pumping systems often experience a wide variation in flow needs. Many applications have a significant difference between the flow required during normal operation and the flow required during peak load conditions. For instance, cooling systems and rainwater collection applications typically need a relatively low flow rate. However, during heavy storms or sudden increases in production demand, the required pumping capacity can surge.

If pumps are sized to handle peak flow or worst-case scenarios, they may operate at much less efficient levels for extended periods during normal conditions. Oversized pumps in these situations can waste energy and require more frequent maintenance due to their operation far from their Best Efficiency Points (BEP).

For example, in sewage treatment plants, the normal operating demands on pumps may be relatively low. However, during storms, the volume of fluid that must be drained from holding ponds or tanks increases significantly. Pumps designed to maintain holding pond levels need the capacity to handle these storm conditions.

To avoid the friction losses and maintenance issues associated with the continuous operation or frequent starting of oversized pumps, a facility can install smaller pumps—known as "pony pumps." These pony pumps are used to handle normal operational conditions, while the larger pumps are employed only during extreme load conditions. This approach can offer considerable cost savings and enhance overall system efficiency.

**When to Consider Pony Pumps**

Indicators that a smaller pump may be needed for normal operating conditions include:

- Intermittent Pump Operation: When the system's flow conditions vary significantly.
- Excessive Flow Noise, Cavitation, and Piping Vibrations: These issues often diminish during periods of high demand. If they persist, it may indicate that the primary pump is oversized and should be downsized instead.

**Costs of Intermittent Pump Operation**

Intermittent pump operation arises from an unbalanced flow system. For instance, a pump with a high flow rate may drain a tank to the point where the low-level switch de-energizes or shuts off the pump. When the fluid level rises and triggers the high-level switch, the pump is re-energized to drain the tank again (as shown in Figure 16 on page 42).

Repeatedly starting and stopping the pump causes wear on motor controllers and dynamic surfaces in the pump/motor assembly, potentially leading to unreliable pump operation. This issue is especially problematic with large pumps due to their high starting currents. Each start-stop cycle also risks sparking, which can damage high-voltage contacts. Furthermore, discontinuous loading of transformers and switchgear can shorten their lifespan.

For such applications, pumps and motor assemblies specifically designed to handle frequent starts and stops should be selected, although these tend to be more expensive.

Additionally, many pumps suffer from poor performance during start-ups and shut-downs. Mechanical seals, for example, depend on a lubricating film created by system fluid, which takes a couple of revolutions to form. Repeated start-ups can accelerate seal wear. Similarly, bearings subjected to cyclical loading have a shorter operational lifespan compared to those in constant-use applications.

**Costs of High Flow Velocity**

Using an oversized pump can increase friction losses due to higher flow velocities. As the flow rate increases, so does the velocity, which causes higher friction losses. The relationship between flow velocity and friction loss is given by the Darcy-Weisbach equation:

$$h_f = \frac{fLV^2}{2gD}$$

Where:

- hf = head loss
- f = pipe friction coefficient
- V = fluid velocity
- g = gravitational constant
- D = inner diameter of the pipe
- L = length of pipe

The equation shows that head loss is proportional to the square of the fluid velocity. Consequently, if the flow rate doubles, the friction loss quadruples. This means pumping fluid at a higher-than-necessary flow rate can significantly increase operational costs, requiring more energy to move the same volume of fluid.

**Recovering the Costs of Installing a Smaller Pump**

Installing a smaller pump in parallel to an existing one can offer substantial energy savings. Alternative energy-saving strategies include:

- Reducing the Impeller Size: This modification can optimize the pump for smaller flow rates, saving energy during low-demand periods.
- Replacing the Pump/Motor Assembly: A smaller pump/motor assembly may provide an efficient solution for lower flow needs without compromising overall system capacity during peak demand.
- Adjustable Speed Drives (ASDs): Installing an ASD on the pump motor allows for variable speeds, reducing energy consumption during low-flow periods. However, ASDs are better suited for varying demand rather than consistently low demand.

While these energy-saving strategies can be effective, there are some drawbacks:

- VFD Efficiency Losses: Variable frequency drives (VFDs) introduce efficiency losses, especially if the motor runs for extended periods below its full load capacity. The cost of these losses can add up over time.
- Harmonics in Motor Windings: VFDs can cause harmonic distortions, raising the motor winding temperature. Over time, this accelerates the breakdown of motor insulation, potentially leading to premature motor failure.

A real-world example of the effectiveness of pony pumps comes from a project undertaken by the city of Milford, Connecticut. The addition of a pony pump to the city's Welches Point Sewage Lift station resulted in significant energy savings and reduced maintenance costs. This case study is available on the DOE’s Industrial Technologies Program BestPractices Web site.

**10. Impeller Trimming**

Impeller trimming is the process of machining the diameter of an impeller to reduce the energy transferred to the system fluid. This process is particularly useful for correcting pumps that have been oversized for their application due to overly conservative design practices or changes in system loads.

While trimming an impeller is a slightly less effective solution than replacing it with a smaller impeller from the manufacturer, it can still provide substantial benefits. In many cases, opting for the next smaller impeller size could reduce the pump's capacity too much for the intended load. Additionally, smaller impellers may not always be available for certain pump sizes, making impeller trimming the only viable option without replacing the entire pump and motor assembly.

## When To Consider Impeller Trimming

End users should consider trimming an impeller when the following conditions occur:

- Excess Flow Availability: When many system bypass valves are open, indicating excess flow is available to the system equipment.
- Excessive Throttling: When excessive throttling is needed to control flow through the system or process.
- Noise and Vibration: High levels of noise or vibration, which indicate excessive flow.
- Operating Far From Design Point: When the pump is operating far from its intended design point.

## Why Impeller Trimming Works

Impeller trimming works by reducing the tip speed, which directly lowers the energy imparted to the system fluid. This results in lower flow and pressure generated by the pump. The affinity laws describe a centrifugal pump's performance in relation to impeller size and pump output, showing a theoretical relationship between the impeller diameter and pump performance at constant speed.

The equations are:

$$Q_2 = Q_1 \left(\frac{D_2}{D_1}\right)^3$$

$$H_2 = H_1 \left(\frac{D_2}{D_1}\right)^2$$

$$bhp_2 = bhp_1 \left(\frac{D_2}{D_1}\right)^5$$

Where:

- Q = Flow
- H = Head
- bhp = Brake horsepower of the pump motor
- D = Diameter of the impeller

For example, a 2% reduction in impeller diameter results in approximately:

- 2% reduction in flow
- 4% reduction in head
- 8% reduction in power

While these relationships are approximations due to system curve and performance nonlinearities, they hold true for small changes and can guide the trimming process effectively.

**Benefits of Impeller Trimming**

A primary benefit of reducing the impeller size is the resulting decrease in operating and maintenance costs. The main advantages include:

- Energy Savings: Reducing impeller size results in lower fluid energy waste in the bypass lines, throttle valves, and dissipated as noise and vibrations throughout the system. Energy savings are roughly proportional to the cube of the diameter reduction, as shown in the fluid power equation:Where the motor power required to generate this fluid power is higher due to inefficiencies in both the motor and pump.

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

- Reduced Wear: Impeller trimming reduces wear on system piping, valves, and piping supports. Flow-induced vibrations can fatigue pipe welds and mechanical joints, leading to cracks and loosened joints, which cause leaks and downtime for repairs.
- Less Fluid Energy: Excessive fluid energy is undesirable from a design perspective. Pipe supports are designed to withstand static loads, internal pressure, and temperature changes. The vibrations caused by excessive fluid energy put an undue load on the system, potentially leading to leaks and additional maintenance.

For a practical example, refer to the case study titled Optimized Pump Systems Save Coal Preparation Plant Money and Energy. It is available on the DOE's Industrial Technologies Program Best Practices website.

**Limitations**

While impeller trimming offers several benefits, it comes with some limitations:

- Efficiency Changes: Trimming the impeller changes its operating efficiency, and the nonlinearities of the affinity laws related to impeller machining complicate performance predictions. As a result, impeller diameters are rarely reduced below 70% of their original size.
- Increased NPSHR: In some pumps, trimming the impeller increases the required net positive suction head (NPSHR), which is necessary to avoid cavitation. To reduce the risk of cavitation, the effect of impeller trimming on NPSHR should be evaluated using the manufacturer's data across the full range of operating conditions. For more information, see the tip on Centrifugal Pumps.

**Controlling Pumps with Adjustable Speed Drives**

Centrifugal pumps often operate under a wide range of conditions, such as changes in ambient temperature, occupancy, or production demands. To accommodate these variable loads, flow can be controlled using one of the following methods:

1. Bypass Lines
    a. Bypass lines provide accurate flow control while avoiding the risk of “deadheading” the pump, where flow is completely blocked by closed downstream valves. However, bypassing flow is usually the least energy-efficient option for controlling flow.
2. Throttle Valves
    a. Throttle valves control flow by increasing upstream backpressure, reducing pump flow, and directly dissipating fluid energy. While throttle valves are effective, they make the pumping system less efficient. In low-static-head systems, variable-speed operation is more efficient, allowing the pump to run near its best efficiency point (BEP) for a given head or flow.
3. Pump Speed Adjustments
    a. Pump speed adjustments are the most efficient way to control pump flow. Reducing the pump speed reduces energy imparted to the fluid and minimizes the energy required to throttle or bypass. There are two main methods for adjusting pump speed:

i. Multiple-Speed Pump Motors: These motors have different windings for each speed setting, but they are more expensive, less efficient, and lack subtle speed-changing capabilities.
ii. Adjustable Speed Drives (ASDs): ASDs allow for continuous speed adjustments without the need to jump between discrete speeds. They can use mechanical systems like hydraulic clutches, fluid couplings, and adjustable belts or pulleys. Electrical ASDs, such as eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs), adjust the motor's rotational speed by changing the electrical frequency supplied to the motor. VFDs are the most popular type of ASD.

Considerations for Using ASDs: While ASDs are highly efficient, they may not be suitable for all systems. In applications with high static head, reducing the pump speed could induce vibrations and performance issues, similar to when a pump operates against its shutoff head. For systems with a high static head component, operators should proceed with caution and consult ASD manufacturers to assess compatibility with the system. Additionally, system analysis can help identify opportunities for reducing operating costs, such as energy losses caused by bypass lines or throttle valves.

- System Efficiency: Often, increasing flow through bypass lines doesn't affect the backpressure on the pump significantly. However, reviewing the entire system can reveal where energy is being lost due to fluid movement through bypass lines and throttle valves.

Figures 19 and 20, though illustrative, depict energy losses from bypass valves and throttling, showing where energy losses typically occur during different flow control methods.

**Pump Operating Efficiency Improvements**

Variable Frequency Drives (VFDs) can significantly improve the operating efficiency of pumps, especially when dealing with changing system conditions. The impact of slowing a pump's speed is shown by the three curves in Figure 18, which highlight the effect on head/flow and brake horsepower (bhp). As the VFD slows the pump, both the head/flow and bhp curves shift downward and to the left. Additionally, the efficiency curve also shifts leftward, demonstrating the essential cost advantage of maintaining high efficiency across variations in system flow demand. This ability to keep operating efficiency optimal, even with fluctuating conditions, helps reduce both energy and maintenance costs. VFDs can also be used with positive displacement pumps, further extending their benefits.

**System Operating Efficiency Improvements**

VFDs offer substantial energy savings by decreasing frictional or bypass flow losses. By adjusting the pump's speed to reduce unnecessary fluid energy, VFDs can reduce the overall system flow or head, leading to significant savings in the cost per gallon of liquid pumped. Additionally, VFDs provide a soft-start capability, minimizing the impact of high in-rush currents that motors typically experience during start-up. Normally, motors draw 5 to 6 times more current during start-up than during normal operation, but VFDs reduce this to about 1.5 times the normal operating current, which lowers wear on the motor and its controller.

**Maintenance Requirements**

VFDs require maintenance and repair as part of the system, but they can also reduce the maintenance requirements for the pump and system components. The key factors contributing to this are reduced load on the pump and lower static and dynamic fluid forces. By slowing the pump, a VFD often shifts the Best Efficiency Point (BEP) to the left, meaning the pump operates with lower bearing loads and reduced shaft deflection, which results in less wear on the pump bearings. Since bearing life is often proportional to the cube of the load, this reduction in bearing load extends the intervals between maintenance tasks.

VFDs also reduce the stress on pipes and piping supports. In systems with excessive flow, excess fluid energy is dissipated as noise and vibration, which can loosen joints and cause cracks in pipes and welds. By lowering the fluid energy, VFDs help reduce these vibrations, thereby lessening the wear on the entire system.

For further details on how to identify signs of oversized pumps and ways to address them, refer to the section on Indications of Oversized Pumps.

# The Economics of Improving Pumping Systems

**Overview**

Pumping systems are vital to many industrial operations, particularly in power and petrochemical plants, where they directly support production processes. In these settings, pumps often run continuously, making them some of the most frequently used equipment at the facility. The energy consumed by pumping systems is a significant contributor to annual operating costs. In fact, about 27% of all the energy used by motor-driven equipment in manufacturing plants is consumed by pumps. This makes pumping systems a prime target for energy reduction initiatives.

However, while some pumping systems are energy-efficient, others are not. Operators are generally well-versed in the controllability, reliability, and availability of their pumping systems, but they may not be fully aware of efficiency issues within the system. Increasing awareness of these efficiency concerns is crucial because pumps that operate near their best efficiency point (BEP) tend to perform more reliably and have fewer operational disruptions.

**Steps to Improve Pumping System Efficiency**

There are several opportunities to enhance the reliability, performance, and efficiency of pumping systems. To implement these improvements effectively, consider the following three steps:

1. Conduct a Systems Assessment A comprehensive assessment of the pumping system helps identify areas where energy is being wasted or inefficiencies exist. This evaluation should examine the entire system, from the pumps themselves to the associated piping, valves, and controls. It’s important to assess both the individual components and the system as a whole to uncover potential improvements.
2. Analyze Life-Cycle Costs Before Making a Decision When evaluating potential upgrades or changes to a pumping system, it's critical to consider life-cycle costs rather than just initial investment costs. This includes energy costs, maintenance expenses, and the expected lifespan of the equipment. By factoring in long-term costs, operators can make more informed decisions that provide better value over time, potentially leading to significant savings and enhanced performance.
3. Sell Your Projects to Management Once opportunities for improvement are identified, it is important to effectively communicate the benefits to management. Presenting the potential cost savings, efficiency gains, and reliability improvements in a clear and compelling manner is essential for securing approval and support for system upgrades.

By following these steps—assessing the system, considering life-cycle costs, and gaining management buy-in—companies can realize substantial improvements in their pumping system efficiency, resulting in reduced operating costs, extended equipment lifespan, and a more reliable operation.

**Conduct a Systems Assessment**

A systems assessment involves reviewing the operation of a pumping system using various tools and approaches to identify areas for improvement. By taking a systems approach, it becomes easier to analyze the efficiency of the entire system, which helps in identifying optimization opportunities.

**A Systems Approach**

A systems approach is a comprehensive method for assessing the performance of a pumping system. Instead of focusing on the performance of individual components, engineers and operators evaluate both the supply and demand sides of the system and how these elements interact. This holistic approach ensures that the performance of the system as a whole is optimized.

Focusing on individual components may cause analysts to overlook potential cost savings, even when individual components, like a pump, are operating efficiently. For example, a pump might be running at its best efficiency point but could be producing more flow than the system actually requires. In this case, evaluating the system as a whole could lead to an optimization that reduces unnecessary energy consumption.

A systems approach not only identifies inefficiencies but also helps optimize the performance of the entire system before selecting components and control strategies that match the specific process load.

**Pumping System Assessment Tool (PSAT)**

To help identify improvement opportunities in pumping systems, the U.S. Department of Energy (DOE) has developed a Pumping System Assessment Tool (PSAT). DOE studies have shown that system optimization accounts for almost two-thirds of the potential energy savings in motor systems. PSAT is a computer-based tool that helps users recognize, both qualitatively and quantitatively, areas where pumping system efficiency can be improved.

PSAT uses a combination of fundamental electrical, mechanical, and fluid power relationships, industry-standard performance characteristics, and field measurements of fluid and electrical parameters. It estimates the efficiency of existing motor-pump systems based on field measurements and nameplate information.

Once the system's efficiency is assessed, PSAT compares the results to an optimal configuration. It calculates the potential power savings and, based on user-specified utility rates and operating times, provides estimates for potential cost and energy savings.

**Key Considerations for Using PSAT**

- Accuracy of Input Data: Field measurements, such as pressure readings, must be taken accurately to ensure reliable results. Understanding system or process demands is crucial to make the most effective use of PSAT.
- Comparison of Current vs. Optimized Performance: PSAT compares the current system's efficiency to what could be achieved if the motor and pump were optimally selected for the specified flow and head requirements.

Using PSAT and taking a systems approach can help facilities identify significant savings opportunities, optimize pump and motor performance, and reduce operating costs over time.

**Performance Characteristics of Pumps**

Different pump designs are applied to a wide range of pumping needs. For certain applications like sewage or stock pumping, reliability concerns may prevent the use of the more efficient designs commonly used in clean water pumping. For instance, high-efficiency impellers with narrow channels may clog when used to pump sewage.

The Hydraulic Institute (HI) has released a standard offering guidance on achievable pump efficiencies. This standard addresses the effects of pump style, capacity, specific speed, and factors such as surface roughness and internal clearances that can impact efficiency. It provides a step-by-step process for determining efficiency, starting with a graph to find efficiency at the optimal specific speed for the selected pump style and flow rate.

PSAT software applies curve fits from HI's graphical data to estimate achievable efficiency. It automatically completes the necessary steps to estimate pump performance.

**PSAT Software Process**

PSAT operates through the following steps:

1. Estimate Shaft Power: Derived from motor data.
2. Calculate Fluid Power: Using flow rate, head, and specific gravity data.

3. Determine Efficiencies: By comparing motor input power, shaft power, and fluid power, PSAT determines the existing motor and pump efficiencies.

PSAT also calculates potential annual energy usage and energy costs based on operational time and electricity rates.

**Field Measurements for Fluid and Electrical Parameters**

Motor input power typically isn't monitored by permanent instruments, though larger motors may have current measurements available. Portable test equipment can be used to measure motor input power and/or current at low-voltage (e.g., 480-V) busses.

Fluid properties such as viscosity and specific gravity can either be assumed constant or determined via direct measurement or by relating them to temperature. These properties are necessary for calculating fluid power and determining pump efficiency.

Pressure measurements at the suction and discharge connections are crucial for calculating pump head. Static head is determined from system drawings, level gauges, or pressure gauges.

Flow rate instruments are used less frequently than pressure gauges in pump applications. When permanent flow meters are not available, temporary devices can be used to measure flow. Alternatively, flow rate can be estimated using differential pressure and pump performance curves, though this approach is less accurate. If using performance curves, it is important to measure actual pump speed and adjust based on pump affinity laws if it deviates from the speed used in the curves.

**Conclusion**

Accurate field measurements, combined with established industry standards like those from the Hydraulic Institute, are essential for optimizing pump system efficiency. Using tools like PSAT alongside this data can help improve pump performance, identify energy savings opportunities, and ultimately reduce operational costs.

**Pumping System Energy Costs**

To accurately evaluate pumping system projects, it is essential to quantify operating costs, which generally consist of both fixed and variable components. Energy costs are typically the largest of these. Tools such as PSAT can help estimate energy costs and identify potential reductions. However, other methods are also available for estimating energy usage and its associated costs. Below are some alternative approaches.

**Load Factor**

The economic efficiency of a pump is primarily determined by how long it operates and the percentage of its full capacity during operation. To assess energy use effectively, it's necessary to convert "snapshot" data into an average indication of energy use over time. The **load factor** refers to the average percentage of full-load power the pump operates at during a specific period.

**Load Factor Formula**:

Accurately determining the load factor can be challenging without extensive records or knowledge of the pump's operation. When such information isn't available, reasonable

$$\text{Load factor} = \frac{\sum(\text{Actual load} \times \text{number of operating hours at this load})}{(\text{Rated full load} \times \text{number of operating hours in the period})}$$

estimates may be necessary. If the pump runs at full load throughout the period, the load factor is simply the percentage of time it operates.

**Calculating Electricity Costs**

Electricity costs can be calculated using several methods, including the following:

- Utilizing motor nameplate data
- Measuring motor current directly
- Using performance curve data

The reliability of these methods depends on how accurately they represent average system operating conditions. In systems with varying operating conditions, a single data point may not reflect the true energy consumption.

**Nameplate Data**

One straightforward method to estimate energy costs is by using motor nameplate data. Often, the pump/motor setup is oversized, meaning the motor operates below its full-load capacity.

Estimating the load factor can then allow for the calculation of the pump's annual operating costs.

Required data includes:

- Annual hours of operation (hours/year)
- Unit cost of electricity ($/kWh)

The unit electricity cost is an average value, encompassing both consumption and demand charges.

**Direct Measurement Method**

A more precise way to determine electricity consumption involves taking direct electrical measurements. Depending on available instrumentation and access to measurement points, this method requires using a wattmeter to read power (kW) or measuring amps and volts to calculate kW using the motor's nameplate power factor.

Wattmeter's require both voltage and current inputs simultaneously, which may not always be readily accessible in many motor installations.

To calculate electricity consumption, the measured kW value is multiplied by the operating hours and electricity costs, as shown in the "Direct Measurement" calculation example. This method assumes a constant load for the motor, meaning it doesn't vary over time.

If a wattmeter is unavailable or impractical, amps and volts can be measured separately. However, if the motor load is less than 65% of its rated capacity, this approach may not yield useful results.

To measure current, a clamp-on ammeter is used, which reads the current on each of the three power cables running to a three-phase motor. In some sites, the motor controller is convenient for taking these readings, while at other sites, the motor's connection box is more accessible. Line voltage is typically measured at the motor controller, and it should be done simultaneously with the current measurement. In some facilities, the line voltage may drop when power usage increases. A calculation example for this method is provided in the "Direct Measurement" box, assuming a constant load.

However, measuring motor current directly is not always practical. Taking live current measurements can pose safety risks, especially in environments where power connections are exposed to moisture or contaminants.

**Using Pump Curves**

Another method for determining a pump's power consumption is by recording pressure readings during its operation and using the pump’s performance curve to calculate the corresponding brake horsepower. Pump performance curves use total head to determine pump output, so this method requires pressure instrumentation on both the suction and discharge sides of the pump, along with corrections for the velocity head.

Once the pressure readings are available, the engineer can calculate the total head developed by the pump, which corresponds to horsepower. To calculate annual energy costs, see the "Using a Pump Performance Curve to Determine Annual Electricity Costs" box.

However, this method has limitations. Many applications do not have a gauge on the suction side of the pump. If suction pressure cannot be reasonably assumed, such as from the height of a fluid level in a vented tank feeding directly into the pump, the total head cannot be determined.

Another potential limitation is the accuracy of pressure gauges, as many are not calibrated regularly and may lack the precision needed for accurate power consumption calculations. This is especially true for pumps with relatively flat performance curves, where small differences in head can significantly affect flow and brake horsepower (bhp).

If the system gauge lacks sufficient precision, a test gauge can be installed. Many systems include secondary ports in the pipe fittings for calibration equipment, which can accommodate a more accurate test gauge.

Using pump curves to estimate power consumption should be considered a last resort, as actual power consumption can vary by as much as 20% higher or 10% lower than the estimate. Wearing components such as wear rings and impellers can lead to inaccuracies.

Performance curves are typically based on factory testing or standardized tests, so they may not account for normal manufacturing variations, which can lead to power consumption estimates that are 5% higher or lower than actual consumption.

To use the pump curve, the engineer must convert the total pressure into head, which requires two key factors: fluid density and an estimate of the velocity head. Fluid density is typically measured by checking the fluid temperature and referencing a properties table for that fluid.

The velocity head is more challenging to determine, as it requires knowing the pump flow rate. Since the flow rate is based on the pump head, assumptions may need to be made. In cooling systems, a typical design guideline assumes a maximum flow velocity of 10 feet per second, corresponding to a velocity head of 1.55 feet. While this estimation may introduce some error, it is likely minor compared to other uncertainties in annual energy consumption estimates.

**Understanding Energy and Demand Charges on Your Electricity Bill**

The simplified calculations previously presented use basic approximations of electricity rates, expressed in dollars per kilowatt-hour ($/kWh). However, electric utilities employ more intricate pricing structures when billing industrial clients. These structures typically include both energy charges ($/kWh) and demand charges ($/kW), with varying rates based on consumption levels and seasonal factors. Demand charges are determined by the highest level of power demand within a specific month or season, potentially leading to significant cost impacts for certain users. When evaluating the financial benefits of energy efficiency measures, it is essential to consider the marginal cost of electricity, which includes energy and demand charges, seasonal rate variations, and tiered consumption rates.

**The Importance of Maintenance**

Ensuring the continued benefits of system improvements beyond the payback period requires proper operation and maintenance procedures. Without these, system performance can deteriorate over time.

A proactive approach to system management helps maintain cost savings and efficiency. A key component of this approach is increasing awareness among operators regarding operational costs and the consequences of poor maintenance or inefficient operation.

Preventive maintenance (PM) plays a crucial role in enhancing system reliability, minimizing unplanned downtime, and preventing costly failures. Generally, PM is more cost-effective than reactive repairs. A well-structured PM schedule can detect and address issues before they escalate into major problems.

**Evaluating Life-Cycle Costs Before Making Decisions**

Much like preventive maintenance reduces repair costs, a well-designed system can help avoid excessive operating expenses. By considering life-cycle costs during initial system design or when planning upgrades, businesses can enhance system efficiency and reliability while lowering overall costs.

Life-cycle costs encompass various elements, including equipment purchase, energy usage, maintenance, and eventual decommissioning. Because costs can vary significantly—even among pumps of the same size—industry professionals are encouraged to incorporate life-cycle cost analysis into decision-making processes. Organizations such as the Hydraulic Institute have developed resources to promote a better understanding of these costs.

A highly efficient pumping system goes beyond merely installing an energy-efficient motor. Achieving optimal cost savings requires a holistic approach to system efficiency. However, many users prioritize upfront costs and opt for the lowest bid, overlooking long-term operational efficiencies. To maximize economic benefits, equipment selection should be based on life-cycle cost analysis, and systems should be maintained for peak performance.

**Justifying Energy Efficiency Investments**

Corporate and plant managers often focus on investments that directly improve profitability, such as projects that enhance productivity. Fortunately, energy efficiency initiatives offer benefits beyond just reducing energy costs, including:

- Increased productivity
- Lower maintenance expenses
- Reduced environmental compliance costs
- Lower production expenditures
- Minimized waste disposal costs
- Enhanced product quality
- Better capacity utilization
- Improved reliability
- Enhanced worker safety

An efficiency project is more likely to receive funding if it considers all potential cost savings and operational benefits over its expected lifespan. A thorough understanding of total ownership and operational costs helps decision-makers identify opportunities to significantly cut energy, maintenance, and operational expenses.

**Understanding Life-Cycle Cost (LCC) Analysis**

Life-cycle cost analysis is a valuable management tool that helps businesses identify cost-saving opportunities. This methodology evaluates the total expenses associated with acquiring, installing, operating, maintaining, and decommissioning system components. The Hydraulic Institute outlines the LCC equation as follows:

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d$$

Where:

- $C_{ic}$ = Initial cost (purchase price of pump, system, auxiliary components)
- $C_{in}$ = Installation and commissioning costs
- $C_e$ = Energy expenses
- $C_o$ = Operating costs (e.g., labor for routine monitoring)
- $C_m$ = Maintenance costs (e.g., parts, labor hours)
- $C_s$ = Downtime costs (lost production)
- $C_{env}$ = Environmental costs
- $C_d$ = Decommissioning expenses

These calculations should also factor in expenses such as loans, depreciation, and taxes.

Since energy consumption is a major contributor to pump life-cycle costs, businesses need accurate data on current energy costs and projected increases over the system's lifespan. Similarly, future labor and material expenses for maintenance must be estimated. Downtime, decommissioning, and environmental protection costs can often be projected using historical facility data.

Depending on the industry, downtime expenses may outweigh energy or maintenance costs, making productivity losses a crucial consideration. Pumping systems typically last 15 to 20 years, meaning costs occur at different intervals. To accurately compare investment options, it is essential to calculate the present value of total life-cycle costs. This requires consideration of:

- Discount rate
- Interest rate
- Expected lifespan of equipment
- Anticipated cost increases for each factor over time

Using life-cycle cost analysis to compare alternative solutions helps identify the most cost-effective choice based on available data. However, accurate assessments depend on reliable input information—poor data can lead to flawed conclusions. LCC analysis does not guarantee specific outcomes, but it provides a structured approach for evaluating multiple options.

When comparing system designs, decision-makers must ensure evaluations are based on consistent units of measurement. For example, if two solutions have different output capacities, costs should be normalized per unit of production (e.g., $/ton). Additionally, costs associated with maintenance outsourcing or spare part inventories should be consistently applied across all assessed systems.

For further guidance on life-cycle cost analysis in pumping systems, consult the Hydraulic Institute's publication Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems. This resource provides detailed technical insights into system design, efficiency improvements, and manual LCC calculations, along with software tools to facilitate analysis. More information can be found on the Hydraulic Institute's website at www.pumps.org.

**Gaining Management Support for Your Projects**

Industrial facility managers often need to persuade upper management that investing in pumping system efficiency is a smart financial decision. However, conveying this message effectively can be more challenging than engineering itself. Executives typically respond more positively to financial impacts rather than technical discussions about efficiency points. By presenting the benefits in financial terms, facility managers can align pumping system performance with corporate objectives. Collaborating with finance professionals can help craft a compelling proposal that resonates with decision-makers responsible for approving capital investments in pumping system upgrades.

**Understanding Corporate Objectives**

Corporate leaders are accountable to executives, boards of directors, and owners (or shareholders, in the case of publicly traded companies). Their primary goal is to enhance the company's equity value, which is achieved by ensuring that revenue exceeds operational and ownership costs. Equipment used in industrial facilities, including pumping systems, is considered an asset that must contribute to financial returns.

A key financial metric for decision-makers is the return on assets (ROA), calculated by dividing the annual earnings generated by these assets by their total value. Financial officers prioritize investments that offer the highest and quickest returns, favoring projects with the most significant financial impact.

This mindset can place certain demands on facility managers, such as maintaining reliable operations, minimizing risk by using familiar technologies, and cutting costs through reduced maintenance. As a result, some executives may view pumping system efficiency improvements as non-essential expenditures.

However, there is a strong case to be made for these upgrades. The following points illustrate how optimizing industrial pumping systems can contribute to corporate goals, lower costs, and improve energy efficiency. These insights can help facility managers build a persuasive argument for investing in pumping system improvements.

**Evaluating Long-Term Costs and Benefits**

Many companies focus solely on the initial cost of purchasing and installing equipment. However, plant managers and designers can make better decisions by assessing the long-term costs associated with different solutions. Conducting a life cycle cost (LCC) analysis before investing in major equipment or system upgrades helps identify the most cost-effective option.

As businesses compete in national and global markets, finding ways to cut costs and increase profitability becomes essential. Industrial operations provide significant opportunities for cost savings, particularly through energy-efficient equipment that reduces energy consumption and minimizes downtime.

**The Role of Modern Design and Retrofitting**

For new pumping system investments, advancements in piping system design technology now incorporate numerical optimization techniques. These methods allow engineers to consider the entire pipe system as a variable during the design phase. A well-planned system can outlast other designs and should be factored into an LCC analysis.

LCC analysis is also a valuable tool for comparing potential upgrades to existing pumping systems. Over time, inefficiencies emerge due to factors such as shifting system demands, natural wear, and outdated controls. Addressing these inefficiencies through retrofits can enhance performance and reduce costs.

Additionally, the number of installed pumping systems significantly surpasses the number of new pumps manufactured each year—by approximately 20 to 1. This means that upgrading existing systems presents a far greater opportunity for cost savings and efficiency improvements than simply replacing equipment.

By presenting these insights in financial terms, facility managers can demonstrate how pumping system efficiency projects align with corporate goals, making it easier to secure management buy-in for these investments.

**Evaluating the Financial Impact of Pumping System Efficiency**

Projects aimed at improving pumping system efficiency can become a higher priority for corporate decision-makers when proposals align with business objectives. Since corporations face a range of financial and operational challenges, positioning pumping system upgrades as cost-effective solutions creates more opportunities for approval. This course explores multiple areas where improvements can be made.

Once the best options are identified, the next step is to communicate these proposals in financial terms that resonate with management.

**Calculating the Total Financial Impact**

To effectively demonstrate the value of a pumping system efficiency initiative, it is essential to quantify its total financial impact. A reliable method for this is conducting a life cycle cost (LCC) analysis, as previously discussed. This assessment reveals whether the project will result in a net gain or loss and provides a basis for comparing the financial benefits of the investment against alternative options or the cost of inaction.

**Presenting the Financial Case for Pumping System Upgrades**

As with any major business investment, several financial metrics can be used to evaluate the feasibility of a pumping system improvement. Some are more complex than others, so the choice of method depends on both the presenter's expertise and the audience's level of financial understanding.

A commonly used financial metric is the payback period, which measures the time required for a project's benefits to offset its initial cost. If an investment generates consistent annual savings, the payback period is calculated by dividing the initial investment by the annual savings.

Although this method is widely used due to its simplicity, it does have limitations:

- It provides only an estimate, not a precise economic analysis.
- It does not account for the timing of financial benefits.

- It overlooks financial outcomes beyond the payback period.
- It may not always highlight the best option among multiple projects.
- It ignores the time value of money and tax implications.

For a more comprehensive financial assessment, companies may use advanced methods that factor in discount rates, tax considerations, and capital costs.

One such method is the net present value (NPV) calculation, which determines the present value of expected benefits minus the present value of costs:

Net Present Value = Present Worth of Benefits – Present Worth of Costs

Another widely used approach is the internal rate of return (IRR), which identifies the discount rate that equates future net benefits to the initial investment. This rate can be compared to the corporation's borrowing rate or investment return expectations.

Many companies establish a minimum required rate of return—often called a hurdle rate—for project approval. If a project's IRR meets or exceeds this threshold and its NPV is positive, it is considered financially viable.

By using these financial evaluation methods, facility managers can strengthen their case for pumping system efficiency investments, demonstrating their alignment with corporate objectives and long-term cost savings.

**Aligning Pumping System Efficiency with Corporate Goals**

While cost savings alone should be a strong motivator for implementing pumping system upgrades, some corporate decision-makers may require additional justification. Strengthening the business case involves connecting the positive life-cycle cost benefits to specific corporate objectives. Here are a few ways to frame energy cost reductions in a way that aligns with corporate priorities:

- A Sustainable Capital Source: Lower energy expenses, the direct result of enhanced pumping system efficiency, can be viewed as a new and ongoing source of capital for the company. The investment that drives this efficiency will generate annual savings throughout the upgraded system's lifespan. Regardless of how the project is financed—through loans, retained earnings, or third-party funding—these consistent savings will serve as a continuous financial resource.

- Increased Shareholder Value: Publicly traded companies often seek strategies that enhance shareholder value. Pumping system efficiency offers a tangible way to achieve this. Shareholder value is determined by two key factors: annual earnings and the price-to-earnings (P/E) ratio—calculated by dividing stock price by annual earnings per share. To capitalize on this metric, an efficiency proposal should outline the projected increase in annual earnings from energy cost reductions. By multiplying this earnings growth by the P/E ratio, the resulting figure represents the potential boost in shareholder value driven by improved pumping system performance.
- Enhanced Reliability and Asset Utilization: Optimizing a pumping system not only improves energy efficiency but also enhances overall operational performance. A well-maintained and efficient system increases reliability, reducing the risk of downtime and ensuring more effective use of facility assets. From a corporate standpoint, this translates into a higher return on investment (ROI) for plant assets and infrastructure.

**Encouraging Action**

A compelling proposal for a pumping system improvement project should be structured to resonate with corporate leadership. To build a persuasive case, facility managers should:

- Identify opportunities to enhance pumping system efficiency.
- Evaluate life-cycle costs associated with different improvement options.
- Determine the most cost-effective solutions based on net benefits.
- Collaborate with financial teams to align proposals with corporate priorities, such as shareholder value growth or improved capacity utilization.
- Develop a proposal that directly connects the project's advantages to pressing corporate needs.

A successful energy efficiency initiative starts with a solid foundation. Ideally, companies should implement incentive programs that encourage employees to propose cost-saving projects. However, in many cases, these initiatives are driven by dedicated individuals passionate about improving facility performance. To navigate potential challenges and improve the likelihood of project approval, careful preparation before presenting the proposal is essential.

**Secure Management Support Early**

The most successful energy efficiency projects begin with strong backing from management. Without their commitment to investing time and resources, promising cost-saving initiatives may remain overlooked. While some projects may seem like obvious opportunities, they often require management recognition to gain traction. Support should also include setting clear financial expectations, defining an acceptable cost-benefit ratio, and identifying potential funding sources. For larger projects, conducting **life-cycle cost (LCC) analyses** can help align financial goals with energy efficiency improvements.

**Engage Key Personnel Before Proposal Submission**

Consulting with maintenance, operations, and other relevant departments before pitching a project can uncover potential challenges early. By addressing concerns and incorporating practical solutions, facility managers can improve project viability. Case studies from similar facilities can also help demonstrate successful implementation, fostering confidence in new technologies and increasing internal support.

**Start Small to Build Credibility**

Beginning with simple, low-risk projects that demonstrate measurable savings can establish credibility and reduce concerns about project feasibility. Management may hesitate to approve high-cost initiatives if there's uncertainty about the projected savings. By successfully executing smaller projects, facility managers can build a track record of success, making it easier to gain approval for larger energy-saving initiatives in the future.

**Seek External Validation**

Third-party input can strengthen the credibility of a proposed project by filling in missing details or verifying projected cost savings. Consultants, industry peers, and utility providers can offer valuable insights. Many electric utility programs also provide technical assistance or financial incentives to enhance project cost-effectiveness. Additionally, tools like DOE BestPractices software—such as MotorMaster+ and PSAT—can help validate projected savings.

**Effectively Present the Project**

Energy efficiency proposals can be introduced as stand-alone initiatives or as part of a broader energy management strategy. The best approach is to create a concise project profile, typically a one- or two-page document that includes:

- A brief project description
- Key implementation steps
- Estimated costs and projected savings

- Supporting data, such as equipment specifications and financial analysis

Projects requiring minimal investment can be categorized as operational measures, while those involving energy supply changes (e.g., cogeneration or utility rate adjustments) should be labeled energy supply measures. Including detailed calculations and financial breakdowns can further strengthen the case for approval.

### Final Thoughts

Gaining approval for energy efficiency projects requires careful planning, collaboration, and strategic presentation. By increasing awareness among facility personnel and demonstrating the financial and operational benefits of improved pumping system efficiency, organizations can enhance their competitiveness in energy-intensive industries.

## Best Practices Tips

#### Conducting an In-Plant Pumping System Survey

Even a single pump can be a significant energy consumer. For example, a continuously operating centrifugal pump powered by a fully loaded 100-horsepower motor can use approximately 726,000 kWh per year. At an average electricity rate of 5¢ per kWh, this translates to an annual cost of over $36,000. Implementing even a 10% reduction in operating costs can result in savings of $3,600 annually.

#### Assessing Your Pumping Systems

To improve efficiency, pumps that exceed a certain size and operate for extended hours should undergo a comprehensive survey. This assessment helps establish a baseline for current energy consumption and costs, pinpoint inefficient pumps, and identify potential efficiency improvements. The U.S. Department of Energy (DOE) Pump System Energy Opportunity Screening worksheet can help determine which systems warrant further analysis.

A survey team should collect pump and motor nameplate data, document operating schedules, and develop load profiles. Additionally, obtaining head/capacity curves from manufacturers can help define the designed and actual operating conditions. Key details to document include:

- Flow rate and pressure requirements
- Pump type and speed

- Number of stages
- Fluid’s specific gravity
- Suction and discharge pressures

The team should also look for operational inefficiencies, such as:

- Pumps requiring frequent maintenance
- Oversized pumps operating under throttled conditions
- Cavitating or excessively worn pumps
- Incorrectly applied pumps
- Systems with large pressure or flow variations
- Systems with bypass flow
- Throttled control valves used to regulate flow
- Noisy pumps or valves
- Blocked pipelines or pumps
- Impeller or casing wear that increases clearance between components

# Enhancing Pumping System Performance

**Industry Background**

In the U.S., industrial manufacturing facilities use more than 2.4 million pumps, consuming over 142 billion kWh annually. With electricity costs averaging 5¢ per kWh, the total expense of fluid transport exceeds $7.1 billion per year.

**Common Signs of Inefficiency**

Additional indicators of inefficient pumping systems include:

- Excessive wear on bearings and wear rings
- Improper packing adjustments causing shaft binding
- Multiple-pump systems where excess capacity is bypassed or pressure is too high
- Modifications to the original system design, such as pipe diameter changes, distribution cross-connections, or additional main lines
- High-pressure operation to accommodate a single low-flow, high-pressure end use—this may be corrected by adding a booster or dedicated pump

**Strategies to Improve Pumping Efficiency**

Optimizing pumping systems can lead to substantial energy and cost savings. Consider these efficiency measures:

- Turn off pumps that are not needed. When plant water usage changes, re-optimize the system by using pressure switches to control the number of pumps in service.
- Restore internal clearances to improve efficiency.
- Upgrade to high-efficiency motors. Replacing standard pump motors with NEMA Premium™ motors can improve performance.
- Address oversized pumps:
  - Install correctly sized pumps to match system needs.
  - Adjust impeller size or shape to align with system requirements. Consult a vendor to determine the minimum impeller diameter suitable for your pump casing.
- Use adjustable speed drives or multiple-pump arrangements instead of throttling or bypassing excess flow to accommodate variable flow rate demands.

By implementing these improvements, facilities can reduce energy consumption, lower costs, and enhance overall pumping system performance.

**Conducting an In-Plant Pumping System Evaluation**

Pumps play a crucial role in industrial processes, often consuming significant energy. For example, a centrifugal pump operating continuously with a 100-horsepower motor can use up to 726,000 kWh annually. With electricity costs averaging $0.05 per kWh, this translates to an expense exceeding $36,000 per year. Even a modest 10% efficiency improvement could result in savings of $3,600 annually.

**Evaluating Your Pumping System**

Assessing the performance of pumps with substantial operating hours and capacity is essential for optimizing energy use. This evaluation helps establish a baseline for current energy consumption, identify inefficiencies, determine potential improvements, and estimate cost savings. The U.S. Department of Energy (DOE) offers a Pump System Energy Opportunity Screening worksheet to aid in selecting systems for assessment.

A comprehensive survey should collect essential data such as pump and motor nameplate details, operating schedules, and system load profiles. If available, head/capacity curves from pump manufacturers should be reviewed to analyze design specifications and actual performance. Additionally, the team should document system flow rates, pressure requirements, pump type, operating speed, number of stages, and fluid properties. Key indicators of inefficiencies include:

- Frequent maintenance needs
- Oversized pumps operating under throttled conditions
- Cavitation or excessive wear
- Misapplication of pumps
- Large variations in flow rate or pressure
- Systems with excessive bypass flow
- Control valves used for flow regulation instead of proper pump sizing
- Noisy pumps or valves
- Blockages in pipelines or pumps
- Increased clearance due to impeller and casing wear
- Worn bearings and wear rings
- Improper packing adjustments causing shaft binding
- Multi-pump setups where surplus capacity is wasted
- System modifications that alter original flow conditions
- High-pressure systems maintained for a single end-use application

**Strategies for Enhancing Pumping System Efficiency**

To improve efficiency, consider implementing the following measures:

- Deactivate pumps that are not required and adjust system settings to match changing water use demands. Use pressure switches to regulate the number of active pumps.
- Restore internal clearances to enhance performance.
- Upgrade standard-efficiency motors to NEMA Premium™ motors.
- Address oversized pumps by either:
    - Installing appropriately sized replacements
    - Adjusting impeller dimensions to align with system needs (consulting the manufacturer for minimum impeller diameter recommendations)
- Accommodate variable flow demands with adjustable speed drives or multiple pump configurations instead of throttling or bypassing flow.

By carefully analyzing and optimizing pump operations, facilities can achieve substantial energy savings while enhancing overall system performance.

# Key Considerations for Pump Selection

**Understanding Pumping System Needs**

Pumps transport liquids by converting mechanical energy into pressure energy, enabling fluid movement at the required flow rate while overcoming friction losses in piping, valves, and equipment. Selecting the right pump requires an understanding of fluid properties, end-use needs, and environmental factors.

**Fluid Characteristics**

The type of liquid being pumped directly influences pump selection. Key considerations include:

- Chemical composition and pH levels: Corrosive or acidic liquids can degrade pump components, requiring material compatibility considerations.
- Temperature: Pumps handling fluids above 200°F require specialized seals and materials to withstand thermal expansion.
- Solids content and particle size: Pumps used for abrasive slurries must be chosen based on particle hardness, size, and concentration to minimize clogging and premature failure.
- Specific gravity: This factor determines the energy needed for fluid movement and influences pump power calculations.
- Vapor pressure: Understanding a fluid's vapor pressure helps prevent cavitation, which can damage pump components.
- Viscosity: Higher viscosity fluids require additional power and can reduce centrifugal pump efficiency. Designers must account for viscosity at the lowest expected operating temperature.

**System Flow Rate and Head Requirements**

Determining the correct pump capacity (measured in gallons per minute) is essential for system design, including pipe sizing and friction loss calculations. The system may require either a constant or variable flow rate, which can be managed through on/off controls, throttling valves, or variable speed drives.

Total system head consists of:

- Static head: The fluid pressure within the system, measurable via pressure gauges.

- Elevation head: The impact of fluid level height on system pressure.
- Dynamic head: The resistance caused by friction in pipes, valves, and fittings, which increases exponentially with flow rate.

For systems where conditions fluctuate, such as reservoir applications with changing water levels, static and suction lift requirements may vary. In closed-loop systems, such as HVAC circulation pumps, static and elevation heads cancel out.

Centrifugal pumps require adequate inlet pressure to prevent cavitation. A general guideline is to ensure available suction head exceeds pump requirements by at least 25% across expected operating conditions.

### Environmental Factors

External conditions also impact pump selection. Considerations include:

- Ambient temperature and humidity
- Altitude, which affects pressure calculations
- Installation location (indoor vs. outdoor)

### Pump Selection Software

Many pump manufacturers offer digital tools to simplify selection. These programs analyze fluid properties and system demands to recommend suitable models. Additionally, third-party software can help compare long-term operational costs and efficiency.

By carefully evaluating system needs and selecting the right pump, facilities can optimize energy use, reduce costs, and enhance operational reliability.

## Selecting an Energy-Efficient Centrifugal Pump

Centrifugal pumps are ideal for high-flow applications due to their ability to deliver smooth, continuous flow while adjusting rates without causing internal damage. They feature minimal moving parts, reducing wear and simplifying maintenance. Their compact design also facilitates easy disassembly.

### Centrifugal Pump Performance

Centrifugal pumps are categorized into three main types based on impeller design:

- Radial Flow: Best suited for high head, low flow applications.
- Mixed Flow: Balances head and flow requirements.
- Axial Flow: Designed for high flow, low head scenarios.

Flow rate and head are inversely related—flow increases as head decreases. Manufacturers provide performance charts outlining the operating range of each pump model.

Before selecting a pump, review its performance curve, which illustrates:

- Capacity (gallons per minute) versus developed head (feet).
- Efficiency percentage at various operating points.
- Power input requirements (brake horsepower, bhp).
- Suction head needs (net positive suction head, NPSH).

Performance curves also specify pump size, type, speed (RPM), impeller size (inches), and the Best Efficiency Point (BEP). A pump performs most efficiently when operating near its BEP.

**Optimizing Pump Efficiency**

Manufacturers offer multiple impeller sizes, each with unique performance curves. To optimize energy efficiency:

- Select a pump where the system curve intersects within 20% of the BEP.
- Choose a mid-range impeller that can be adjusted for higher or lower flow needs.
- Opt for a pump with high-efficiency contours across expected operating conditions. Even small efficiency improvements translate to significant long-term energy savings.

**Application Example**

A process demands 15,000 gpm at a total head of 150 feet. The centrifugal pump is powered by a 700-hp motor, operates 8,000 hours per year, and handles a fluid with a specific gravity of 1.0.

Two pump options are considered:

- Pump 1: 81% efficiency.
- Pump 2: 78% efficiency.

**Energy Savings Calculation**

Using the formula:

Assuming a motor efficiency of 96%, the annual energy savings are:

At an electricity rate of $0.05 per kWh, this equates to annual savings of $8,393. Over a 15-year lifespan, total savings reach $125,888. Given an upfront cost difference of $5,000, the payback period is approximately 7 months. By selecting a more efficient pump, significant cost savings and operational benefits can be realized over time.

# Testing Pumping System Efficiency

Pumps often operate with efficiencies between 50% and 60%, or even lower. Since inefficiencies are not always obvious, many opportunities to enhance energy savings through repairs, replacements, and system optimizations are frequently overlooked.

**Understanding Pumping System Efficiency**

Pumping system efficiency considers the performance of the pump, motor, and other components. It is calculated using the following equation:

$\eta sys = (Q \times H \times SG) / (5308 \times Pe)$

Where:

- **Q** = Required fluid flow rate (gallons per minute)
- **H** = Required pump head (feet)
- **SG** = Specific gravity
- **Pe** = Electrical power input

This calculation accounts only for the necessary head and flow rates, excluding unnecessary pressure losses or excessive flow caused by bypassing or recirculation.

**Conducting Efficiency Tests**

Testing pumping system efficiency helps facility managers identify underperforming systems, evaluate potential improvements, and estimate possible energy savings. These tests are generally conducted on larger pumps or those that run for extended periods. Industry standards such as ANSI/HI 1.6-2000 for centrifugal pumps and ANSI/HI 2.6-2000 for vertical pumps provide further guidance on these evaluations.

Flow measurements should be taken using reliable instruments installed in the system or specialized tools such as sonic (Doppler-type) or transit-time flow meters, Pitot tubes, and manometers. To ensure accuracy, it is recommended to take measurements on a straight pipe section free from fittings or turbulence.

**Enhancing System Efficiency**

Pump efficiency can decline due to internal leaks, excessive impeller clearance, and worn components. Efficiency can be improved by:

- Restoring internal clearances
- Replacing or refurbishing damaged throat bushings, wear rings, impellers, or pump bowls
- Adjusting process requirements and control strategies
- Reducing losses in deteriorating piping and valves

**Estimating Potential Energy Savings**

Energy savings can be calculated by comparing actual system efficiency (ηa) with optimal efficiency (ηo) using published pump performance curves or software tools such as the DOE's Pumping System Assessment Tool (PSAT). The energy savings equation is:

Savings = kWin x t x (1 - ηa/ηo)

Where:

- Savings = Annual energy savings (kWh)
- kWin = Input electrical energy (kW)
- t = Annual operating hours
- ηa = Actual efficiency (measured from field tests)
- ηo = Optimal efficiency

**Example Calculation**

A 300-horsepower centrifugal pump operates at 55% efficiency, but its manufacturer's specifications indicate it should function at 78% efficiency. The pump consumes 235 kW and runs for 6,000 hours annually. If restored to its original efficiency, the potential energy savings are:

Savings = 235 kW x 6,000 hours/year x [1 - (0.55/0.78)] = 415,769 kWh/year

At an electricity rate of $0.05 per kWh, this results in annual savings of $20,786.

# Maintaining Pumping Systems for Optimal Performance

Proper pump maintenance is essential for keeping industrial pumps running efficiently, identifying issues early for timely repairs, and preventing premature pump failures. Routine maintenance also uncovers efficiency and capacity losses that may occur long before the pump reaches a failure point.

The level of maintenance required varies based on the criticality of the pumping system to the plant's operations. Unplanned downtime can be costly, especially when it impacts key processes. Maintenance can be divided into two main types: preventive and predictive.

**Preventive Maintenance Measures**

Preventive maintenance involves routine tasks such as lubrication, adjustments, and cleaning to maintain the pump system's functionality. Mechanical seals, for instance, should be regularly inspected to ensure there are no leaks, or that leaks are within the acceptable limits. Seals that show excessive leakage often need replacement. Some leakage is necessary for proper lubrication and cooling of the packing seals, but if leakage exceeds the manufacturer's guidelines, adjustments are required. Over-tightening packing glands can lead to unnecessary wear on the shaft and increase energy consumption. Routine motor maintenance, including lubrication and cleaning, is equally crucial for maintaining system efficiency.

**Predictive Maintenance Measures**

Predictive maintenance helps to minimize unexpected breakdowns by identifying potential failures early. Often referred to as “condition assessment” or “condition monitoring,” predictive maintenance has become more accessible thanks to advanced diagnostic tools. Common techniques for pumping systems include:

- Vibration Analysis: By tracking vibration frequency and amplitude over time, this method can detect early signs of bearing failure and reveal issues like impeller erosion

or coupling imbalances. Monitoring vibration trends is more insightful than a one-time snapshot.
- Motor Current Signature Analysis: Also known as dynamic analysis, this technique detects problems such as deteriorating insulation, rotor bar damage, electrical system imbalances, and even flow disturbances caused by malfunctioning control valves. Ongoing monitoring is more useful than isolated measurements.
- Lubrication Oil Analysis: This method, primarily for large oil-lubricated pumps, is an expensive but effective way to identify bearing damage caused by metal particles or overheating. It can also highlight seal failures due to contaminants in the oil and guide the proper intervals for oil changes.

**Background**

Problems like wear ring and rotor erosion can lead to significant losses in pump efficiency, sometimes reducing wire-to-water efficiency by more than 10%.

**References**


- Extend Your Motor's Operating Life, DOE Motor Systems Tip Sheet, 2005.
- Test for Pumping System Efficiency, DOE Pumping Systems Tip Sheet, 2005.


**Periodic Efficiency Testing**

Regular testing of wire-to-water efficiency and keeping track of performance trends can help detect inefficiencies early. Below is a basic maintenance checklist that can be customized for various systems and facilities.

**Basic Maintenance Checklist**

- Packing: Check for leakage and adjust per manufacturer guidelines. Normal leakage is typically between 2 to 60 drops per minute. Add packing rings or replace all packing as needed.
- Mechanical Seals: Inspect for leakage; replace the seal if leakage exceeds the acceptable level.
- Bearings: Assess bearing condition by listening for unusual noises, measuring temperature, or using predictive methods like vibration or oil analysis. Lubricate bearings as recommended and replace if necessary.

- Motor/Pump Alignment: Check alignment to ensure it stays within the pump's service limits.
- Motor Condition: Test motor winding insulation integrity through resistance tests and check the rate at which voltage decays across the insulation. Vibration analysis can also help identify issues with the motor windings early.

By regularly following these maintenance procedures, facilities can ensure pump systems run efficiently, reducing downtime and enhancing system longevity.

# Align Pumps with System Demands

Industrial facilities can significantly reduce energy expenses related to pumping systems by making a few adjustments. These include reducing the flow rate of the system, lowering operating pressure, shortening daily operating hours, and, most importantly, enhancing the system's overall efficiency.

A common cause of inefficiency in pumping systems is a mismatch between the system's current needs and the original design parameters. The initial design may have been overly cautious, or pumps might have been overestimated to accommodate potential future increases in plant capacity. This mismatch leads to an imbalance, causing the system to operate inefficiently, which results in higher operational costs.

## Addressing Imbalanced Pumping Systems

When the discrepancy between the actual system requirements and the measured discharge head and flow rate exceeds 20%, it's crucial to perform a thorough review of the pumping system. You can calculate the imbalance using this formula:

$$\text{Imbalance (\%)} = [(Qmeas \times Hmeas) / (Qreq \times Hreq) - 1] \times 100\%$$

Where:

- Qmeas = measured flow rate (in gallons per minute or gpm)
- Hmeas = measured discharge head (in feet)
- Qreq = required flow rate (in gpm)
- Hreq = required discharge head (in feet)

A pump may be improperly sized for current needs if it is running under throttled conditions, has excessive bypass flow, or if the flow rate fluctuates more than 30% from the pump's best efficiency point (BEP). Pumps showing such inefficiencies should be prioritized for further evaluation, depending on the extent of the imbalance.

Energy-efficient strategies include using multiple pumps, adding smaller auxiliary pumps (pony pumps), trimming pump impellers, or introducing variable-speed drives. In some situations, replacing an electric motor with a lower-speed synchronous motor—such as switching from a 1,800 rpm motor to a 1,200 rpm model—can be a cost-effective solution.

Regular, quick system reviews are essential, especially for systems with multiple pumps. This process can reveal optimization opportunities at little or no cost.

**Case Study**

Here's an example of energy savings from using a correctly sized pump. Imagine a system that needs 1,500 tons of refrigeration during the three summer months but only 425 tons for the remaining nine months. The system operates with two chilled water pumps, each providing 3,500 gpm and requiring 200 brake horsepower (bhp). Both pumps are used in summer, but during the rest of the year, two-thirds of the flow is bypassed.

When one 3,500-gpm pump is replaced with a smaller 1,250-gpm pump (designed to match the original discharge head), the new pump only requires 50 bhp and meets the plant's chilled water needs for most of the year (except during the summer months). The older pump is then used only during summer.

Assuming the motors operate continuously at 93% efficiency, the energy savings from operating the smaller pump can be calculated as:

Savings = (200 hp – 50 hp) / $\eta_m$ × 0.746 kW/hp × (9 months / 12 months) × 8,760 hours/year

= 790,520 kWh/year

With an average energy cost of $0.05 per kWh, this results in annual savings of approximately $39,525.

## Minimize Pumping Expenses by Properly Sizing Pipes

The energy needed to overcome the static head in a pumping system increases proportionally with flow, and there is limited ability to reduce the static component of the system. However, there are several opportunities to lower the power required to overcome the frictional component of the system, which can lead to significant savings in both energy and money.

Frictional power requirements are influenced by several factors, including flow rate, pipe size (diameter), total pipe length, material and surface roughness of the pipe, and the properties of the fluid being pumped. Figure 1 illustrates the annual cost of pumping water (only considering frictional power) over a 1,000-foot pipe length, based on different pipe sizes and flow rates.

**Background**

Every industrial facility relies on a piping network to transport water or other fluids. According to the U.S. Department of Energy (DOE), approximately 16% of a typical facility's electricity costs are attributed to its pumping systems.

**References**


- Xenergy Inc., United States Industrial Motor Systems Market Opportunities Assessment, prepared for DOE, December 1998.
- Piping Handbook, Mohinder K. Nayyar, McGraw-Hill Publications, New York, 1998.
- Engineering Data Book, Hydraulic Institute, Second Edition, New Jersey, 1990.


These calculations assume a 1,000-foot length of clean iron or steel pipes (schedule 40) for pumping water at 70°F, with an electricity rate of $0.05 per kWh and an annual operating time of 8,760 hours. The combined pump and motor efficiency is assumed to be 70%.

**Example**

In this case, a facility requires 10,000 feet of piping to transport 600 gallons per minute (gpm) of water continuously to storage tanks. The annual pumping costs associated with various pipe sizes can be calculated as follows:

- For a 6-inch pipe:

($1,690 per 1,000 feet) × 10,000 feet = $16,900

- For an 8-inch pipe:

($425 per 1,000 feet) × 10,000 feet = $4,250

- For a 10-inch pipe:

($140 per 1,000 feet) × 10,000 feet = $1,400

After calculating the energy costs, it's essential to factor in the installation and maintenance costs for each pipe size. Although larger pipes may have higher initial costs, they could prove to be the most cost-effective solution, as they could significantly reduce both the pump and operating expenses over time.

**General Equation for Estimating Frictional Pumping Costs**

To estimate the frictional portion of pumping costs, use the following formula:

Cost ($) = Friction factor × Pipe length × Energy rate

The friction factor, which depends on pipe roughness, diameter, and Reynolds number, can typically be found in engineering handbooks. For most systems, the friction factor ranges from 0.015 to 0.0225.