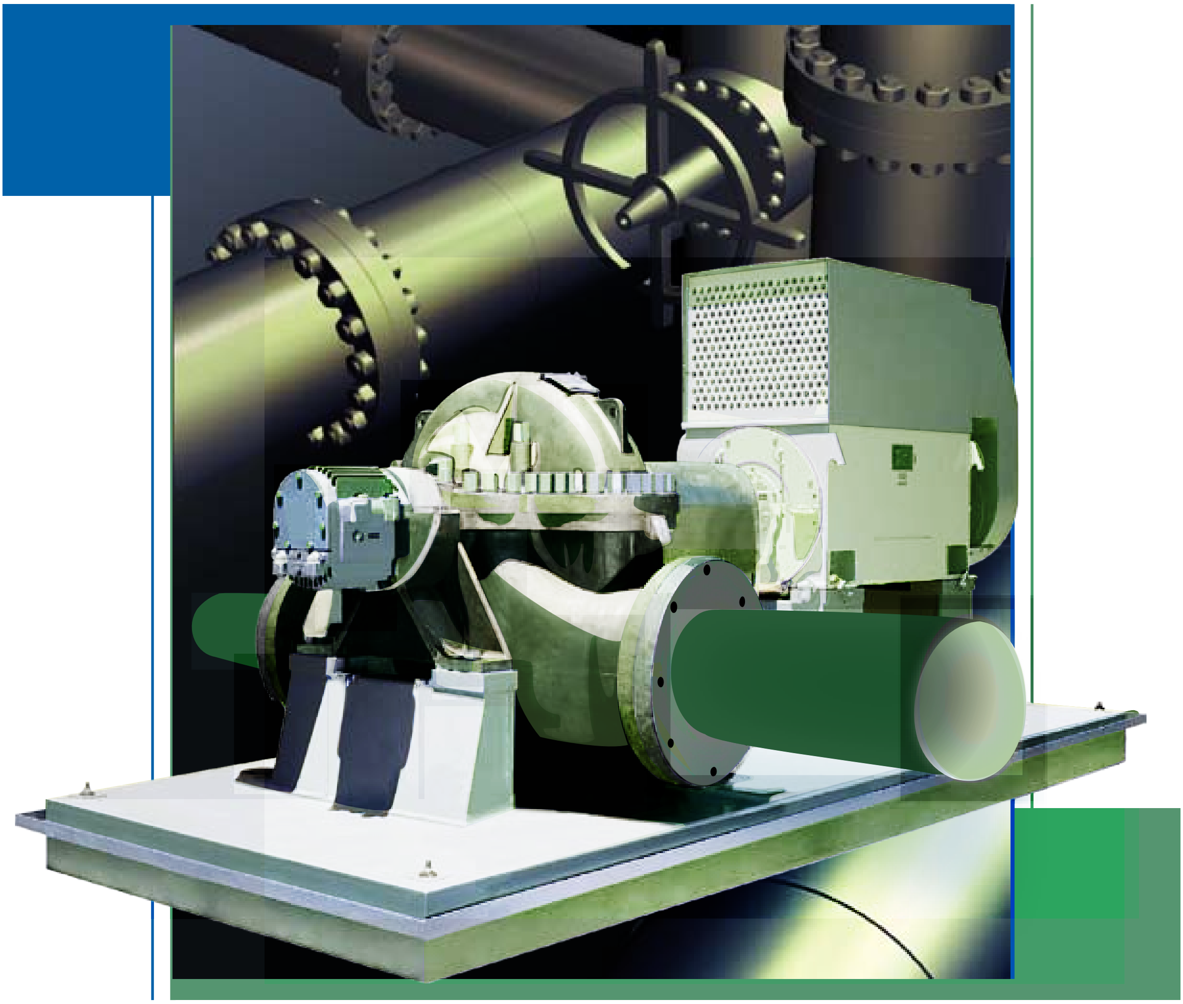
Optimizing Pumping Systems

Executive Summary



A Guide for Improved Energy Efficiency, Reliability & Profitability

Pump Systems Matter™ and Hydraulic Institute

Executive Summary

Introduction

Pumping systems are used throughout the world to transport water and other fluids and in the operation of most industrial processes. Commercial and residential buildings also rely on pumps for heating and cooling, fire protection, and other functions. Pumping systems account for nearly 25% of the energy consumed by electric motors, and for 20% to 60% of the total electrical energy usage in many industrial, water, and wastewater treatment facilities. (Reference 1) Fortunately, economically feasible opportunities exist to make industrial pumping systems more efficient (see Figure 1), allowing for reduced energy costs, lower operating and maintenance expenses, and enhanced profitability. Figure 1 shows the potential saving in gigawatt hours (GW-h) per year for optimization opportunities in key energy intensive industries

The initial purchase and installation cost of a new pumping system is typically a small part of the total cost to operate a system over its life, which can be more than 15 to 20 years, depending on the application. It's the routine operating costs of energy, maintenance, and other recurring expenses that are the primary components of the total lifetime costs. Therefore, optimum efficiency in designing and operating pumping systems is in the best interests of all facilities. However, the importance of pumping systems in the daily operation of facilities promotes the practice of oversizing pumps to ensure that the needs of the system will be met under all conditions. This practice, unfortunately, often leads to inefficient operation, resulting in unnecessarily high energy and maintenance costs.

Pumping System Fundamentals

Pumping systems are typically designed to support the needs of other systems, such as process fluids transfer, heat transfer, and the distribution of

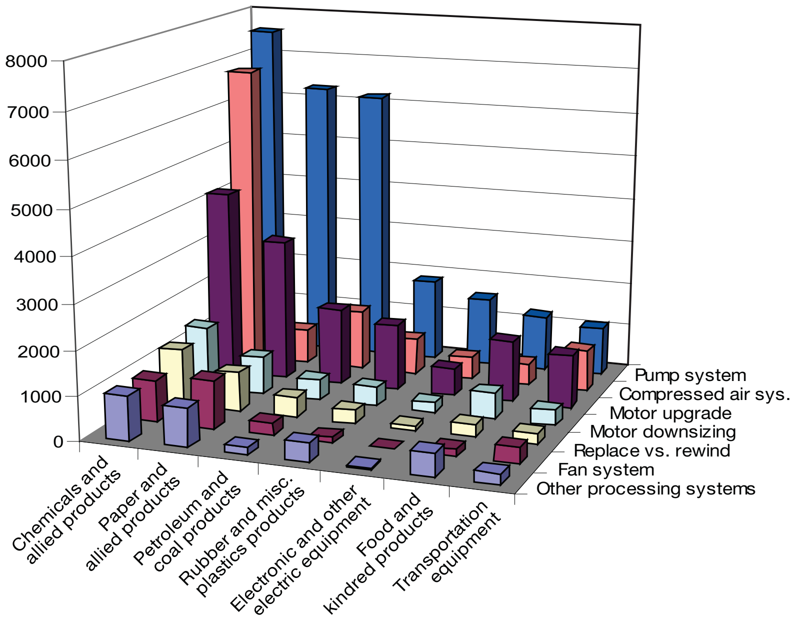


Figure 1: Overview of industrial motor systems optimization opportunities (Reference 1)

water and wastewater. Systems are generally classified as closed or open. Closed systems recirculate fluid around set paths, while open systems have specified inputs and outputs, transferring fluids from one point to another. For closed systems, the frictional losses of system piping and equipment are the dominant loads. Open systems often have significant static head requirements due to elevation and tank pressurization needs.

Pumping systems are typically composed of pumps, prime movers, piping, valves, and the end-use equipment. Other common systems components include filters, strainers, and heat exchangers. Any evaluation of a pumping system should consider the interaction between these components, and not just the pump itself. This is referred to as the *systems approach* to pumping system evaluation. The pump(s) and the system must be designed and treated as one entity, not only to ensure correct operation, but also to reap the benefits of energy-efficient pumping.

The Hydraulic Institute recognizes about 40 different types of pumps, broadly classified into two categories, which relate to the manner in which the pumps add energy to the working fluid. These two categories are positive displacement and rotodynamic (centrifugal). Rotodynamic pumps are much more common and have a variable flow/pressure relationship, which is described by a performance curve that plots the rate of flow at various pressures.

Positive displacement pumps have a fixed displacement volume. Their rates of flow are directly proportional to their speed. The two main groups of positive displacement pumps are rotary and reciprocating. The type of pump selected for a given application will depend on many factors, including rate of flow, total system head, system pressure, net positive suction head, type of fluid, fluid temperature, fluid viscosity, fluid vapor pressure, specific gravity, and the installation environment.

The other major components of typical pumping systems will have a large effect on the system efficiencies. The selection of efficient and properly sized electric motors is vital, along with the use of variable speed drives, when appropriate. Proper piping inlet and outlet configurations are also important for efficient system operation. Additionally, the appropriate selection and operation of valves is critical, especially any throttling or bypass valves.

Along with pump speed control and multiple pump arrangements, bypass valves and throttling valves are the primary methods for controlling rates of flow in pumping systems. The most appropriate type of speed control depends on the system size and layout, fluid properties, and sometimes other factors. Bypass arrangements allow fluid to flow around a system component, but at the expense of system efficiency because the power used to bypass any fluid is wasted. Throttling valves restrict fluid flow at the expense of pressure drops across the valves.

Proper system design and modification require understanding the operating range of the pumps being considered. A pump curve is a graphical representation describing the operation of a rotodynamic pump for a range of flows. Likewise, system curves graphically represent the operation of a given piping system. When a pump is installed in a system, the effect can be illustrated as shown in Figure 2 where the x-axis is the rate of flow and the y-axis is the head (pressure). The intersection of the pump curve and system curve is the duty point.

This figure shows that increasing the system pressure will reduce the rate of flow. If the pressure reaches a certain point, the rate of flow may

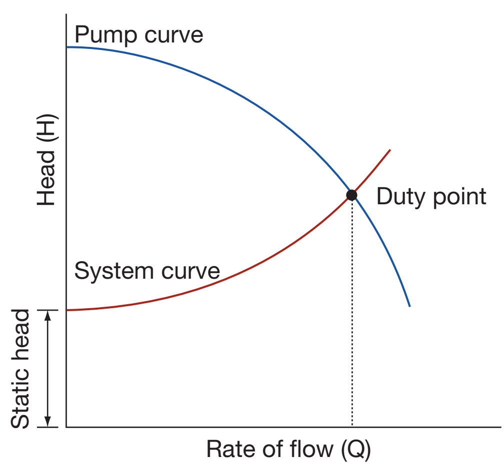


Figure 2: Example rotodynamic pump and system curves (Reference 2)

approach zero, a condition to be avoided. To allow for unforeseen pressure increases, pumping system designers often select an oversized pump. The consequence of this oversizing is that the system will operate with excessive flow or will need to be throttled, thereby increasing energy use, increasing maintenance requirements, and decreasing the life of the pump.

Specific energy is a useful measure to consider when evaluating combinations of pump type, model, and system. Specific energy is the power consumed per unit volume of fluid pumped. Specific energy is determined by measuring the flow delivered into the system over a period of time and calculating the power consumed during the same period of time. This measure takes into account all of the factors that will influence the efficiency of an installation, not just pump efficiency. It also takes account of where the pump is operating on its curve when delivering flow into that particular system. Thus, a pump with a lower efficiency may consume less power than a higher efficiency pump, simply because of how its characteristics fit with the system in question. Another benefit of using specific energy as a measure is that it then becomes possible to apply some approximate comparisons between similar pumping installations.

Steps to Improving Efficiency

Existing Systems

The process of identifying, understanding, and effectively eliminating unnecessary losses, while reducing energy consumption, improving reliability, and minimizing the cost of ownership over the economic life of the pumping systems is commonly referred to as *systems optimization*. The key to improving the efficiency of existing pumping systems, systems optimization begins by looking for the existence of some of the symptoms of an inefficient system. Table 1 contains a checklist of typical symptoms.

Table 1: Symptoms of an inefficient pumping system (Reference 3)

Existence of flow control valves that are highly throttled
Existence of bypass line (recirculation) flow regulation
Batch-type processes in which one or more pumps operate continuously
Frequent on/off cycling of a pump in a continuous process
Presence of cavitation noise either at the pump or elsewhere in the system
A parallel pump system with the same number of pumps always operating
A pump system that has undergone a change in function, without modification
A pump system with no means of measuring flow, pressure, or power

Pumping systems possessing one or more of the symptoms in Table 1 should be considered for further investigation, with priority given to large, high-maintenance systems that are mission critical to the process or facility operation. Next, the pump systems selected for assessment should be thoroughly evaluated to determine the system requirements. In some situations, it may be determined that the system is operating with excessively high pressure or rates of flow. Occasionally, this analysis will find one or more pumping systems that can actually be turned off without any compromise to the process. An awareness of system demand variability will help to better match flow and pressure requirements more closely to system need.

The next step in the system optimization process involves data collection. Data may be acquired with installed process transmitters or portable instruments to determine discharge flow rate, discharge pressure, or power consumption. The instruments used should be both accurate and repeatable. The data acquisition equipment should be matched to the application, and the length of data collection should provide statistically valid averages. Systems with varying or seasonal loads may require long-term data logging equipment.

The collected data can then be used to compare the *measured* rates of flow and head to the *required* rates of flow and head. This may reveal an imbalance between measured and required conditions, which is evidence of an inefficient system. Comparing the existing operating conditions to the design conditions can also reveal an improperly sized pump.

If the original pump performance curve is available, it will be useful to construct a curve for the operating points of the existing system. Comparing the two can provide a general understanding of the current pump condition. Even a comparison of a single test point to the original curve can determine whether or not the first step is to overhaul a worn pump or to investigate the system further. Every rotodynamic pump has a best efficiency point (BEP). A pump operating outside of an acceptable operating range (within a reasonable range of BEP) will be inefficient and have higher energy use and shorter mean time between failure (MTBF).

Other components of the existing system must also be assessed. Incorrectly sized valves can result in excessive pressure drops, and the different types of valves each have different loss coefficients. When throttling valves or bypass lines are used to control flow, an analysis should be conducted to determine the most efficient means of flow control. These variable flow systems may benefit from pump speed control, such as variable speed drives.

The system piping configuration should be evaluated for optimization opportunities. A proper configuration will include a straight run of pipe leading into the pump inlet to ensure a uniform velocity of fluid entering the pump. Turning vanes or some other means of "straightening" the flow may be used when this is not possible. Also, the suction piping should be of sufficient size to minimize friction losses.

New Systems

The design and selection of new systems provides the opportunity for facilities to purchase systems optimized for minimum life cycle costs, including energy, maintenance, and other costs. Significant life cycle opportunities exist through optimal pipe sizing (larger pipes can deliver fluid at lower pressures), variable speed pump control, and pump and valve selection.

The selection of pump type and size, the impeller size, and pump operating speed all impact the pump operating point and determine the pump best efficiency point. Getting the BEP matched to the actual system operating point is an important part of designing an efficient system. The piping size, material, and associated fittings and other components influence the system resistance and hence the system curve and operating point. These materials should be selected through the consideration of life cycle costs, especially since they are the most difficult parts of the pumping system to change in the future.

It is also important to note that all pumping systems change over time, affecting their operating points. As the systems age, corrosion, abrasion, or solids buildup are likely to occur in the piping, altering the effective piping diameters. Cyclic mechanical and thermal loadings may cause piping fatigue damage over time. Valves, gaskets, and other components are subject to wear and corrosion as well. Worn or damaged wearing rings, impellers, and other parts in the pump itself will impact system performance. This also has a degrading impact on the process control loop associated with the pumping system. Additionally, operational changes over the life of the system will influence system efficiency, as industrial processes are often evolving or responding to changing demands. Thus, the pump operating parameters can change as well as the duty cycles.

Economics: Life Cycle Costing

The pursuit of optimum systems efficiency is typically not a sufficient justification for a pumping system improvement or replacement project. Fortunately, systems optimization projects can often be justified based on having lower total cost of ownership. The odds of receiving approval for optimization projects are greatly enhanced when the potential projects can be proven to improve plant profitability and reduce operating costs. Because industrial and municipal pumping systems often have life spans of 15 years or longer, it is valid to consider the total cost of ownership for each project, factoring in the lifetime costs of energy, maintenance, and other elements. A life cycle cost (LCC) analysis is one proven way to determine and compare the total costs for projects.

The basic elements of life cycle cost include:

- Initial purchase
- Installation and commissioning

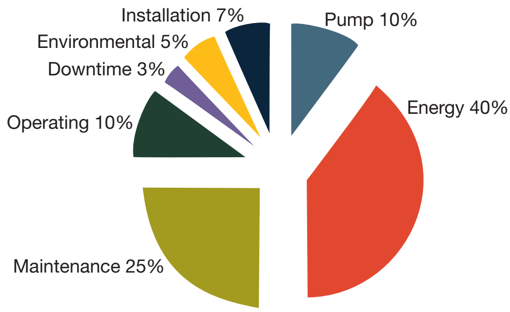


Figure 3: Example life cycle costs for a pumping system (Reference 2)

- Electrical or other energy costs
- Operation costs (labor costs of normal system supervision)
- Maintenance and repair costs
- Downtime costs
- Environmental costs
- Decommissioning/disposal costs

LCC analysis requires evaluation of alternative systems. It is quite common for the lifetime energy and maintenance costs to dominate life cycle costs. Thus, it is important to know the current cost of energy and to estimate the annual price escalation for energy and maintenance costs. Other LCC elements can often be estimated based on historical data for the facility.

The various costs incurred in the operation of a pumping system will occur at varying times throughout the life of the system. Therefore, the analysis should use *present* or *discounted* values for these cost elements to accurately assess the different solutions. Minimizing life cycle costs often requires trade-offs between cost elements, such as paying a higher initial or installation cost to reduce maintenance, energy, and downtime costs.

Winning Project Approval

An analysis showing the financial benefits of a pumping system optimization project may not always be sufficient to ensure approval of a given project. To help ensure success, the project developer should:

- Seek support from a key member of management before pursuing any projects
- Obtain input from key department personnel to identify current corporate priorities
- Begin with simple projects to increase chances of success

- Create a written summary or proposal that clearly identifies the options with the greatest net benefits

Some of the benefits of pumping system optimization cannot be readily quantified through a cost-benefit or LCC analysis, but are nonetheless important to consider and qualify. These benefits may include:

- Increased productivity
- Reduced production costs
- Improved product quality
- Improved capacity utilization
- Improved reliability
- Improved worker safety

These benefits should be documented in any presentation or proposal to management.

When management is reluctant to approve a project based on perceived risks or lack of familiarity with similar projects, it may be helpful to reference documented case studies of successful projects implemented at other facilities. The Industrial Technologies Program within the US Department of Energy (www.eere.energy.gov/industry) and the Pump Systems Matter initiative (www.pumpsystemsmatter.org) both have case studies on various systems efficiency projects at a variety of industrial and municipal facilities.

The Future - Pump Systems *Do* Matter

Industrial companies face stiff competition for global market share. This puts downward pressure on price, while labor, capital, and raw material costs are all escalating at the same time. Faced with margin pressure from multiple fronts, companies must find new avenues to reduce operating costs. In many cases, sustainable net earnings increases can only be achieved through higher manufacturing efficiencies, requiring reengineering of existing or new processes to achieve quantum leaps in performance. Making pumping systems more intelligent and integrating them into production and asset management systems is becoming of paramount importance for the future.

Historically, the fundamental building blocks of process automation have been process sensors and control valves, with little consideration given to the role of pumps. Still, one of the easiest and often overlooked ways to make a dramatic impact on process performance is through increased pumping efficiency.

In 1996, a Finnish Technical Research Center report, *Expert Systems for Diagnosis and Performance of Centrifugal Pumps*, revealed that the average pumping efficiency, across the 20 plants and 1690 pumps studied, was less than 40%, with 10% of pumps operating below 10%. Pump oversizing and throttled valves were identified as the two major contributors to this sizeable efficiency loss. Besides hindering overall plant efficiency, poor pump performance can result in lower product quality, lost production time, collateral damage to process equipment, and inordinate maintenance costs. (Reference 4)

Pump manufacturers have made substantial improvements in mechanical efficiency over the years. Unfortunately, once a pump is installed, its efficiency is determined predominately by process conditions. The major factors affecting performance include efficiency of the pump and system components, overall system design, efficient pump control, efficiency of drives, and appropriate maintenance cycles. To achieve the efficiencies available from mechanical design, pump manufacturers must work closely with end-users to consider all of these factors when specifying pumps. In the future, pump selection and sizing should be considered in the context of the overall system, not just the efficiency of the individual components.

Automation and Service Demands

The information revolution that began in the automation industry around 1975, with the advent of microprocessor-based control systems, is now heavily impacting the pump industry. Consequently, the emergence of intelligent pumps and on-line condition monitoring will thrust pump manufacturers into this unfamiliar world that is increasingly driven by software rather than hardware. At the same time, automation companies have limited knowledge of the fluid-handling industry. The resulting technology convergence will drive cross-industry collaboration, which will inevitably require corresponding changes in the way both pump and automation manufacturers approach industrial markets.

Industry consolidation and outsourcing are major trends driven by the need to reduce cost and achieve economies of scale. Accordingly, customers are increasingly seeking new services from their suppliers. Some manufacturers have embedded the service into the product itself. However, even with these design upgrades, it is difficult to provide everything that is needed in the product or system. Increasingly, suppliers are offering the required mix of products, information, training, plus application and implementation services to fully address the customer's needs.

Outsourcing has opened the door for pump manufacturers to provide new and innovative products and services that support plant optimization. While this is the good news, as is often the case, there are significant barriers to entry in the market.

Hurdles to Implementation

In spite of the financial and operating benefits, industrial managers face many hurdles when implementing new technology. Among the major barriers is the lack of awareness among facility managers, plant engineers, and distributors of new technologies and strategies to improve plant performance. When understood, the perceived risk from changing long-established operating practices often delays decisions and project implementation. Low levels of staffing in maintenance, operations, and engineering departments limits the time available for evaluating and commissioning new technologies. Considering these constraints, there's a common attitude among plant staffs that "if it ain't broke, don't fix it."

Alternately, on the supplier side of the equation, there are conflicting incentives for promoting efficient systems and practices. Many end-users continue to make buying decisions based on first cost rather than spend the incremental capital required to achieve long-term savings.

To capture the many benefits of pump optimization, end-users, manufacturers, and distributors, as well as design engineers, must work together to change the way they do business. This is no easy task, but the payback for all of these stakeholders is too compelling to delay the journey. (Reference 5)

Creating Pump Standards Since 1917

About the Hydraulic Institute

Hydraulic Institute (HI), the largest association of pump producers in North America, serves member companies and pump users worldwide by: developing comprehensive industry standards; expanding knowledge by providing education and training; serving as a forum for the exchange of industry information. In addition to the ANSI/HI pump standards, HI has a variety of technical resources, including pump life cycle costing and variable speed drive guidebooks, the "7 Ways To Save Energy" video-based training program, and more.

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About Pump Systems Matter™

Conceived by the Hydraulic Institute, Pump Systems Matter (PSM) is a market transformation and educational initiative created to help North American pump users gain a more competitive business advantage through strategic, broad-based energy management and pump system performance optimization. A primary objective of the initiative is to change the decision-making process for the purchase of pumping systems from a focus on first cost to a focus on life cycle costs. PSM's mission is to provide end-users, engineering consultants, associations, utilities, energy efficiency programs, and pump manufacturers and suppliers with education, tools, and collaborative opportunities to integrate pump system performance optimization and efficient energy management practices into normal business operations. PSM is seeking the active support and involvement of energy efficiency organizations, utilities, pump users, consulting engineering firms, pump manufacturers and suppliers, government agencies, and other associations.

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