How to Select an Energy-Efficient Centrifugal Pumping System

Energy Efficiency and Renewable Energy
Federal Energy Management Program

Why Agencies Should Buy Efficient Products

- *Executive Order 13123 and FAR section 23.704 direct agencies to purchase products in the upper 25% of energy efficiency, including all models that qualify for the EPA/DOE* ENERGY STAR® *product labeling program.*
- *Agencies that use these guidelines to buy efficient products can realize substantial operating cost savings and help prevent pollution.*
- *As the world's largest consumer, the federal government can help "pull" the entire U.S. market towards greater energy efficiency, while saving taxpayer dollars.*

For More Information:

- DOE's Federal Energy Management Program (FEMP) Help Desk and World Wide Web site have up-to-date information on energy-efficient federal procurement, including the latest versions of these recommendations.
  Phone: (800) 363-3732
  www.eren.doe.gov/femp/procurement
- DOE's Office of Industrial Technologies' clearinghouse offers *Improving Pumping System Performance: A Sourcebook for Industry.*
  Phone: (800) 862-2086
  www.oit.doe.gov/bestpractices/just_need/motors.shtml
- DOE's Office of Industrial Technologies' clearinghouse also offers the "Pumping System Assessment Tool," a free software program to help pump users identify opportunities for efficiency improvements to existing pumping systems.
  www.ornl.gov/etd-equip/PSAT/PSATdesc.htm
- Hydraulic Institute, a pump manufacturers' trade association, develops and publishes standards and engineering data for pumps. Also available is a video-based self-study workshop, "Energy Reduction in Pumps and Pumping Systems." A life-cycle cost guide is currently under development.
  Phone: (973) 267-9700
  www.pumps.org
- Lawrence Berkeley National Laboratory provided supporting analysis for this recommendation.
  Phone: (202) 646-7950

Operating Cost Comparison: Two Pump Sizes for a 100-hp Application[a]

Performance	Pump oversized by 15% beyond flow requirement (150 hp)	Pump sized to meet flow requirement (100 hp)
Annual Energy Use	623,000 kWh	471,000 kWh
Annual Energy Cost	$37,400	$28,300
Lifetime Energy Cost	$392,000	$296,000
Lifetime Energy Cost Savings	–	**$96,000**

a) Assumes 6,000 operating hours, 95% motor efficiency, 75% pump efficiency, and $0.06/kWh. Lifetime Energy Cost is the sum of the discounted value of annual energy costs based on a pump life of 15 years. Future electricity price trends and a discount rate of 3.4% are based on federal guidelines (effective from April, 2000 to March, 2001).

Pumping System Basics for Federal Facilities

The most common applications for pumps at federal facilities are for fresh water supply, hydronic heating and cooling systems, wastewater treatment, and drainage. For these applications, the most common type of pump is the centrifugal pump.

Proper pump selection should consider both constant and variable flow and head conditions. In systems with little change in demand, pumping system efficiency depends largely on selecting the correct pump size. In systems with variable demand, pump system efficiency depends on effectively matching supply with demand, which can be achieved in several ways, depending on system requirements.

The table above shows a pump application with fairly constant flow and pressure requirements that can be satisfied with a properly sized pump requiring 100 brake horsepower. A common practice is to specify a larger pump, thus providing a safety factor; in this example, the base pump provides 15% greater flow, requiring a 150

Definition

Head is a measure of pressure indicating the height of a column of system fluid that has the same amount of potential energy as the system.

horsepower pump (since a 125-hp pump will not provide the desired increase in flow). The use of a larger pump often requires throttling to meet actual system needs. The energy losses due to this throttling can be substantial; note that the oversized pump requires over 30% more power.

In systems that experience wide variations in demand, system efficiency depends on configuring a pump, or set of pumps, so that efficiency remains high over the range of operating conditions. The following table shows the difference between throttling the system flow and using speed adjustment to control pump output for a typical application.

Operating Cost Comparison: Two Flow Control Options for a 100-hp Application[a]

Performance	Flow control by throttling	Flow control by speed adjustment
Annual Energy Use	380,000 kWh	282,000 kWh
Annual Energy Cost	$22,800	$16,900
Lifetime Energy Cost	$239,000	$177,000
Lifetime Energy Cost Savings	–	**$62,000**

a) Assumes 1,200 operating hours each at 50% and 100% flow, and 3,600 hours at 75% flow; 95% motor and variable frequency drive efficiencies; pump efficiency in the throttled case of 75%, 70%, and 65% at 100%, 75%, and 50% flow, respectively; pump efficiency of 75% for all flow conditions in the VFD case; $0.06/kWh; and a 15-yr. pump life.

Pump Sizing

Selecting a centrifugal pump can be challenging because these pumps generate different amounts of flow at different pressures. Each centrifugal pump has a "best efficiency point" (BEP). Ideally, under normal operating conditions, the required flow rate will coincide with the pump's BEP.

Definition

Best efficiency point is the operating point at which a pump most efficiently converts shaft power to flow.

The complexity associated with selecting a pump often results in a pump that is improperly sized for its application. Selecting a pump that is either too large or too small can reduce system performance. Undersizing a pump may result in inadequate flow, failing to meet system requirements. An oversized pump, while providing sufficient flow, can produce other negative consequences:

- higher purchase costs for the pump and motor assembly;
- higher energy costs, because oversized pumps operate less efficiently; and
- higher maintenance requirements, because as pumps operate further from their BEP they experience greater stress; ironically, many oversized pumps are purchased with the intent of increasing system reliability.

Unfortunately, conservative practices often prioritize initial performance over system life cycle costs. As a result, larger-than-necessary pumps are specified, resulting in systems that do not operate optimally. Increased awareness of the costs of specifying oversized pumps should discourage this tendency.

Variable Loads

In systems with highly variable loads, pumps that are sized to handle the largest loads may be oversized for normal operating loads. In these cases, the use of multiple pumps, multi-speed motors, or variable speed drives often improves system performance over the range of operating conditions

To handle wide variations in flow, multiple pumps are often used in a parallel configuration. This arrangement allows pumps to be energized and de-energized to meet system needs. One way to arrange pumps in parallel is to use two or more pumps of the same type. Alternatively, pumps with different flow rates can be installed in parallel and configured such that the small pump – often referred to as the "pony pump" – operates during normal conditions while the larger pump operates during periods of high demand.

Speed Control

Speed control is an option that can keep pumps operating efficiently over a broad range of flows. In centrifugal pumps, speed is linearly related to flow but has a cube relationship with power. For example, slowing a pump from 1800 to 1200 rpm results in a 33% decreased flow and a 70% decrease in power. This also places less stress on the system.

There are two types of speed control in pumps: multi-speed motors and variable speed drives. Multi-speed motors have discrete speeds (e.g., high, medium, and low). Variable speed drives provide speed control over a continuous range. The most common type is the variable frequency drive (VFD), which adjusts the frequency of the electric power supplied to the motor. VFDs are widely used due to their their ability to adjust pump speed automatically to meet system requirements. For systems in which the static head represents a large portion of the total head, however, a VFD may be unable to meet system needs.

Motor Selection

In selecting a pump, there are two components to consider: the pump and the motor. In some applications, the pump and the motor are sold as a package. Often, however, the buyer can select one of several motors to be installed with a pump. Motors that are not large enough may have to operate above their rated load, forcing them to run at elevated temperatures, which shortens their operating lives. Motors that are much larger than required not only cost more, but suffer efficiency loss when the operating load falls beneath about one-half of the motor's rated load. For further discussion of electric motors, see the separate FEMP Recommendation, "How to Buy an Energy Efficient Electric Motor."

Motors used in connection with VFDs should have properly insulated windings to handle the harmonics and other power quality issues associated with VFDs. "Inverter-duty" or "definite purpose" motors will provide this protection.

Impeller Selection

Centrifugal pumps use a rotating wheel, called an impeller, to generate pressure. The impeller increases the kinetic energy of the fluid by accelerating it from the impeller center out to the tip. The impeller tip speed largely determines the pressure generated by a pump. Typically, a given pump size can accept a range of impeller sizes.

A common reason that engineers specify a larger-than-necessary pump is to anticipate increases in system capacity. One way to account for future capacity expansion without sacrificing system efficiency is to select a pump that has room to accept larger impellers as the need for system capacity increases. Since an increase in impeller size also requires additional motor power, selecting a motor that is large enough to handle the largest impeller that can fit in the pump can eliminate the need for motor replacement. Care should be taken to balance motor sizing with current operating needs so that the motor operates efficiently, at more than half its rated full load.

In-service pumps that are oversized and generating too much pressure may be good candidates for impeller replacement or "trimming" – reducing impeller diameter by machining (in order to reduce the energy added to the system fluid).

Installation and Usage Tips

The proper design and installation of a pump can have significant impact on its long-term performance. A piping system that is improperly designed or poorly installed can promote the formation of air pockets or vortices that may impede flow. Piping that runs into the suction inlet should be very straight since disrupted flow can impair pump efficiency and performance. In addition, the piping should be well-aligned with the pump connections. A common tendency during installation is to force connections to fit rather than carefully readjusting the location of the pump or the piping. Force-fitting a misaligned connection can distort the pump housing, creating a harmful load condition on the pump shaft and bearings.

Pump Replacement

The need for pump replacement can be the result of deterioration or a change in system capacity. If properly sized and maintained, centrifugal pumps can operate for many years with little maintenance; however, in harsh environments or because of poor operating practices, pumps may require frequent attention. Indications of the need for replacement include poor performance, excessive vibration, or leakage due to seal failure. If a pump requires unusually high maintenance, the issue of proper sizing for the application should be considered.

Case Study: Pump Optimization for Sewage Pumping Station

The town of Trumbull, CT was looking for a way to increase the operating performance of one of its ten sewage pumping stations. The station consisted of two identical sewage handling pumps (each with a 40-hp direct drive motor) vertically mounted below ground, handling 340,000 gallons of raw sewage per day. The system used one pump to handle the entire flow under normal operation, and used the second pump only in extreme conditions (heavy rainfall). To meet normal loads, each pump rarely operated more than five minutes at a time. The control system required two continuously running compressors. A constant pump speed of 1320 rpm was obtained using a wound rotor and variable resistance circuit motor control system. The pumping system experienced frequent breakdowns, occasional flooding, and sewage spills.

The "Systems" Solution

After a thorough systems analysis, engineers installed an additional 10-horsepower pump with direct on-line motor starters and a passive level control system with float switches, replacing the old active control system. The new pump handles the same volume as the original 40-hp pumps during normal periods, but runs for longer periods of time. The lower outflow rate reduces friction and shock losses in the piping system, which lowers the required head pressure (and thus the energy consumption).

In addition, the existing pump speed control was eliminated and the motors were wired for direct on-line start. Without the speed control, the motors powering the existing pumps run at 1750 rpm instead of 1320 rpm, so their impellers were trimmed to a smaller diameter. The existing pumps are still used for the infrequent peak flows that the new smaller pump cannot handle. Energy consumption was further reduced through the elimination of the two compressors for the active control system and the two circulating pumps for the old motor control system. The installed cost of all the added measures was $11,000.

Results

In addition to the 17,650 annual kWh of electricity savings from modifying the pump unit, significant energy savings also resulted from changes made to other energy use sources in the station (Figure 1). Annual energy consumption of the active level control (7,300 kWh/year) and the cooling water pumps (1,750 kWh/year) was entirely eliminated. In all, over 26,000 kWh is being saved annually, a reduction of almost 38%, resulting in $2,200 in annual energy savings.

Figure 1: Pump System Energy Use and Savings

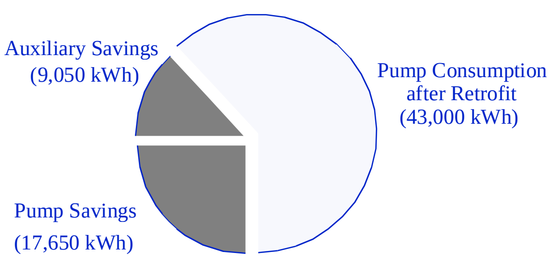
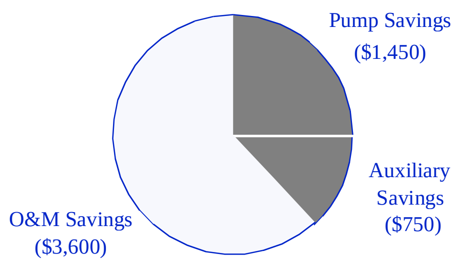


Figure 2: Retrofit Cost Savings ($5,800 ann.)



This project also produced maintenance savings of $3,600. Maintenance staff no longer need to replace two mechanical seals each year. Other benefits of the project savings include extended equipment life due to reduced starting and stopping of the equipment, increased system capacity, and decreased noise. Most of the same measures can be utilized at the town's other pumping stations, as well.

The total annual savings from the project, due to lower energy costs as well as reduced maintenance and supplies, is $5,800 (Figure 2), which is roughly half of the total retrofit cost of $11,000.

Lessons Learned

Several key conclusions from Trumbull's experience are relevant for virtually any pumping systems project:

- **Proper pump selection and careful attention to equipment operating schedules can yield substantial energy savings;**
- **In systems with static head, stepping of pump sizes for variable flow rate applications can decrease energy consumption; and**
- **A "systems" approach can identify energy and cost savings opportunities beyond the pumps themselves.**