

Pumping System Efficiency Improvements Flow Straight to the Bottom Line

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INTRODUCTION

Industrial electrical motors account for two-thirds of the US industrial electricity usage. Pumping systems account for an estimated 25% of this electrical motor consumption, while pumping systems in use in US chemical facilities consume over 37,000 GWh/year, based on US Department of Energy (DOE) data. A study funded by DOE estimates potential energy savings within the chemical industry alone of approximately 20%, representing an energy savings of over 7,500 GWh/year, through industrial pumping systems optimization using existing, proven techniques and technologies (Ref. 1). This energy savings potential represents significant cost savings potential for industrial facilities. Additionally, it has been shown that energy efficiency improvements to industrial systems usually provide improved reliability, improved productivity, and reduced environmental costs.

- increased productivity
- reduced costs of environmental compliance
- reduced production costs
- reduced waste disposal costs
- improved product quality
- improved capacity utilization
- improved reliability, and
- improved worker safety

Often, project developers will be better served to avoid the term “energy”, and describe potential projects as “efficiency” or “productivity” improvement projects when presenting to management. Potential projects should be supported by a financial analysis that includes both the energy and non-energy costs and benefits (savings). Analyses can be in terms of net present value, internal rate of return, or life cycle cost, all of which take into account the time value of money.

MAKING A BUSINESS CASE

Energy efficiency is generally not a motivating factor for decision-makers in industry (Ref. 2). Plant and corporate management personnel are typically bound by the profit motive when considering the investment of capital funds. Decision-makers are more attuned to activities that directly translate to the bottom line, such as projects to increase productivity. Fortunately, many, if not most, energy efficiency projects provide non-energy benefits in addition to the energy cost savings, including:

LIFE CYCLE COST CONSIDERATIONS

A greater understanding of all the components that make up the total cost of pumping system ownership will provide an opportunity to significantly reduce energy, operational, and maintenance costs. Life cycle cost (LCC) analysis is a management tool that can help companies realize these opportunities. The analysis takes into consideration the costs to purchase, install, operate, maintain, and dispose of all components of the

system. Determining the LCC of a system involves following a methodology to identify and quantify all of the components of the LCC equation. When used as a comparison tool between possible design or overhaul alternatives, the LCC process identifies the most cost-effective solution within the limits of the available data.

Pumping systems often have a lifespan of 15 to 20 years. Some cost elements will be incurred at the outset and others will be incurred at different times throughout the lives of the different solutions being evaluated. It is therefore necessary to calculate a *present* or *discounted* value of the LCC to accurately assess the different solutions.

For a majority of facilities, the lifetime energy and/or maintenance costs will dominate the life cycle costs. It is therefore important to accurately determine the current cost of energy, the expected annual energy price escalation for the estimated life, along with the expected maintenance labor and material costs. Other elements, such as the lifetime costs of down time, decommissioning, and environmental protection, can often be estimated based on historical data for the facility. Depending upon the process, down time costs can be more significant than the energy or maintenance elements of the equation. Careful consideration should therefore be given to productivity losses due to down time.

The Hydraulic Institute, an association of US pump manufacturers, in cooperation with Europump, a European pump manufacturers association, has produced Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems (Ref. 3). This guide explains in detail life cycle costing for pumping systems and provides substantial technical guidance on new pumping systems design as well as assessing improvements to existing systems. The guide is available through the Hydraulic Institute (www.pumps.org or (973) 267-9700).

DEFINING EFFICIENCY

Pump efficiency is defined as the pump's fluid power divided by the input shaft power, and is influenced by hydraulic effects, mechanical losses and internal leakage. Pump manufacturers have many ways to improve pump efficiencies. For example, the pump surface finish can be made smoother by polishing to reduce hydraulic losses, but the additional first cost must be weighed against the energy savings. A "good" efficiency for a pump will vary depending on the type of pump. A more useful efficiency term is the wire-to-water efficiency, which is the product of the pump and motor efficiency. An even better measure of efficiency for analysis purposes is the system efficiency, which is defined as the combined efficiency of the pump, motor, and distribution system (Ref. 4).

For example, the system shown in Figure 1 has a box drawn around the pump, the motor, and the entire normal distribution piping network, from the source to the discharge tank. The input power is the electrical power supplied to the motor; the useful output power is the net hydraulic power delivered *across* the fluid system.

The *system* efficiency, as defined by the power transfer in and out of the box in Fig. 1 is:

$$\eta_{\text{sys}} = \frac{P_f}{P_e} = \frac{QH_s\gamma}{P_e} \quad \text{Equation (1)}$$

where:

- H_s = static head (includes elevation & pressure head)
- P_e = motor input power
- P_f = fluid power
- P_s = shaft power
- Q = volumetric flow rate delivered to the tank
- η_{sys} = overall system efficiency
- γ = fluid specific weight

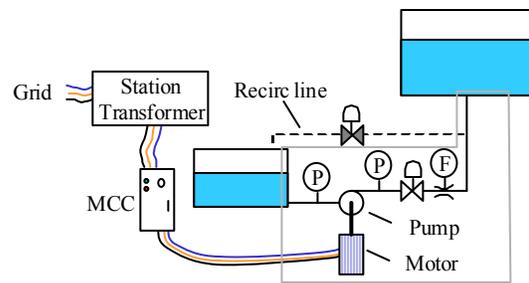


Figure 1. System efficiency

The flow rate in Equation 1 is the net flow between tanks (ignoring recirculation flow). The head is the elevation difference between the tanks, or static head (implicitly ignoring friction losses). This is a true *system* efficiency – it overlooks the details and sees only the big picture.

This approach can be quite useful. However, it does not work for all situations. For example, Equation 1 will produce a system efficiency of zero for a closed-cycle circulating system (with no static head).

SYSTEMS ANALYSIS

When a system is considered for optimization, a "systems approach" is highly recommended. A systems approach analyzes both the supply and demand sides of a pumping system and how they interact, shifting the focus of the analysis from individual components to total system performance, i.e., looking at the forest, not just the trees. The potential energy and cost savings through a systems approach to optimization typically

far outweigh the sum of the savings through component optimization.

Generally, it is neither feasible nor prudent to analyze each pumping system in a facility. However, the DOE BestPractices program has developed a guideline for prescreening pumping systems for potential energy savings. The guideline provides a methodology that can help to identify and prioritize candidate systems for optimization. This prescreening guideline includes sample data collection forms, and can be downloaded at www.ornl.gov/etd-equip/Prescreen/Prescreening.pdf.

Once the prescreening process has identified pumping systems with potential cost savings opportunities, the Pumping System Assessment Tool (PSAT) can be used to further screen systems and quantify the potential savings. The PSAT software was developed for DOE as a tool to assist end users (and others) in assessing the overall effectiveness of centrifugal pumping systems (Ref. 4). PSAT is available at no cost through the DOE BestPractices program web site (www.oit.doe.gov/bestpractices/). The prescreening guide noted above is included in the PSAT installation.

Assessing opportunities for improvement, whether using PSAT or some other methodology, will require relatively accurate measures of flow rate, pressures, and electrical power. These quantitative measurements must be considered in the context of qualitative data obtained through interviews and discussions with the pumping system operators, visual inspections, and review of operator logs (if available). A more thorough discussion of measurement guidelines can be found in a series of articles from the DOE BestPractices' Energy Matters newsletter (available from the BestPractices web site).

PSAT estimates the existing motor and pump efficiency using field measurements and nameplate type motor and pump information. PSAT makes use of a Hydraulic Institute (HI) standard that provides guidance on achievable pump efficiencies for numerous pump types (Ref. 5). It also estimates achievable efficiencies if the motor and pump were optimally selected to meet the specified flow and head requirements. The "existing" and "optimal" results are compared, and potential power savings are determined. Finally, potential cost and energy savings are estimated based on user-specified power cost rates and operating times.

PSAT results are useful in identifying the approximate energy and cost savings that could be achieved if the existing pump system was optimized. PSAT does *not* identify how the savings can be achieved; in other words, it is not a solution provider, but rather an opportunity identifier.

PSAT does not require the user to be a fluid system or pump application expert, and even users with little

pumping system experience can get useful results from the program. However, in the hands of a user with a good working familiarity of pumping systems, PSAT can be used to perform "what-if" evaluations that can actually assist in system design.

A PSAT workshop developed for DOE is offered at various times, by both DOE and its Allied Partners. The BestPractices web site regularly lists upcoming workshops.

TURN OPPORTUNITIES INTO SAVINGS

The results of a systems approach to analysis will vary from system to system and from facility to facility. Some of the more common indications of an opportunity and common modifications are described below.

Sizing -- A system with highly throttled control valves or extensive use of bypass lines can be an indication of an oversized pump. Oversizing is a common problem, and may be the result of conservative design, design for anticipated system capacity increases, or a decrease in the output demand. Possible improvements are to trim the existing pump impeller, install a smaller impeller, remove stages of the pump (if a multi-stage pump), replace with a smaller pump, or reduce the pump speed.

Replacing the pump with one that is better suited for the system requirements can provide efficiency and performance improvements. Opportunities for this change include events where the pump must be removed for overhaul or repair. In fact, the cause of a pump replacement may be largely attributable to initially poor pump selection. An oversized pump that operates far off its best efficiency point (BEP) tends to suffer accelerated wear. Consequently, if the pump must be replaced due to premature wear, assessing whether the pump was correctly sized in the first place is advisable. A petroleum refinery has recently documented savings of \$700,000/year through a combination of measures on several large, oversized pumping systems (Ref. 6).

In systems where flow *requirements* vary, but the flow rate is either not controlled, or is controlled by valve throttling or bypass flow control, speed control devices can provide attractive energy savings. The pressure drop created by the throttle valve causes an energy loss and, if the restriction is severe enough, can create significant flow noise and valve seat wear. Since bypass lines divert flow, the pumping energy spent to generate the bypassed flow is essentially wasted.

Speed reduction can be achieved by changing sheave diameters (in belt drive applications), installing a slower speed motor, or installing an adjustable speed drive. In general, such modifications may be feasible if the pump output is consistently higher than the system needs.

Adjustable Speed Drives -- Adjustable speed drives (particularly the variable frequency drive type) have become very popular as a method of pumping system control in recent years. Typically, adjustable speed drives are appropriate for circulating systems with little or no static head. In systems with static head exceeding 50% of the total head, the use of variable frequency drives should be carefully analyzed because the pump operating point moves to lower efficiencies (Ref. 7). In systems with significant static head, the approach used in selecting the pump can have a tremendous influence on the range of efficient operation (Ref. 8).

Multiple Pumps -- The use of multiple parallel pumps can be a very effective method of flow control in a static head-dominated system. The parallel pumps need not be identical; for example, a small pump (commonly referred to as a pony pump) in combination with a large pump can provide an efficient load following option for certain variable demands. Operating the pony pump during normal conditions and the large pump during high flow conditions allows each pump to operate more efficiently. Parallel pumps, of course, also provide redundancy, and are frequently employed for that purpose alone.

Maintenance Practices -- Any pump optimization project provides an opportunity to update operation and maintenance practices. Vibration analysis can often determine if problems are developing in the pump or motor bearings. Vibration and/or various electrical test methods can be used to evaluate the stator and rotor health. Where oil lubrication is used, oil analysis can provide another indication of bearing condition. Maintenance tasks such as valve overhauls, heat exchanger cleaning, mechanical joint repair can further improve system efficiencies. The distribution system should be inspected for scaling or contaminant build-up that can increase system pressure requirements. The piping layout should be installed to avoid sharp edges, excessive branches, and sudden changes in direction, particularly avoiding a bend immediately on the pump suction. Piping diameter should change gradually. Larger pipe diameters require a lower flow velocity.

Many of these topics are discussed in the DOE BestPractices sourcebook titled Improving Pumping System Performance: A Sourcebook for Industry, available from the DOE OIT Clearinghouse (1-800-862-2086) or the BestPractices web site (www.oit.doe.gov/bestpractices/) (Ref. 9).

LOW COST/NO COST RESOURCES

In addition to the prescreening checklist, pumping systems sourcebook, and PSAT software mentioned in this paper, the DOE BestPractices program offers a range of unbiased energy efficiency-related technical materials, software tools, and training geared to

industrial end users. Further information can be found at www.oit.doe.gov/bestpractices/.

The Hydraulic Institute is also a valuable resource. Information on their standards, handbooks, and other materials is available on their web site, www.pumps.org. A video-based education program "Energy Reduction in Pumps and Pumping Systems" is also available. An educational program on pumping system fundamentals is in development.

Other sites known to the authors that focus on pumping systems and include sections related to system efficiency or reliability, along with being useful and unbiased are:

- The co-author's site of <http://user.icx.net/~doncasada/>
- Pumps and Systems Magazine's site: www.pump-zone.com
- Pump World Magazine's site: www.pumpworld.com
- The Rotating Machinery Workshop: www.goldson.free-online.co.uk/
- An independent site: www.pumpline.com

For pump selection assistance and catalog information, many of the pump manufacturers now offer on-line catalogs and tools, along with a range of other useful information related to pumping systems.

CONCLUSION

The pumping systems installed in most US industrial facilities offer many opportunities for efficiency optimization. These opportunities are best identified using a systems approach, which typically will identify savings that far outweigh the savings through component replacement alone.

For projects to gain management approval, consider non-energy benefits, such as productivity improvements and increased reliability, in a financial analysis. Life cycle cost analysis is one effective method of estimating potential project costs and savings, and a guide book developed by the Hydraulic Institute can assist in this analysis.

DOE offers unbiased materials and tools to help identify pumping systems with opportunities for optimization. A prescreening checklist and software program are available at no cost through the DOE BestPractices program.

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