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Screening pumping systems for energy savings opportunities

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# SCREENING PUMPING SYSTEMS FOR ENERGY SAVINGS OPPORTUNITIES

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## ABSTRACT

In most industrial settings, energy consumed by pumping systems is responsible for a major part of the overall electricity bill. In some cases, the energy is used quite efficiently; in others, it is not. Facility operators may be very familiar with pumping system equipment controllability, reliability, and availability, but only marginally aware of system efficiency.

The cost of energy consumed by pumps usually dominates the pump life cycle cost. But many end users, already stretched to support day-to-day facility operations, lack the time and resources to perform a methodical engineering study of, in some cases, hundreds of pumps within their facilities to understand the energy costs and the potential opportunity for reduction.

Under the auspices of the Department of Energy's (DOE) Best Practices Program, prescreening guidance documents and a computer program called PSAT (Pumping System Assessment Tool) have been developed to help end users, consultants, and equipment distributors recognize, both qualitatively and quantitatively, pumping system efficiency improvement opportunities.

This paper describes the general methodologies employed and shows case study examples of the prescreening and software application.

## BACKGROUND

Industrial electrical motors account for two-thirds of the US industrial electricity. Pumping systems account for an estimated 25% of this electrical motor consumption. A recent study funded by the US Department of Energy estimates potential energy savings of approximately 20%, representing over 20,000 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. For example, an average paper mill can save up to $200,000/year through pumping systems optimization alone, based on the DOE study. Additionally, it has been shown that energy efficiency improvements to industrial systems usually provide improved reliability, improved productivity, and reduced environmental costs.

Many end-users are consumed by the day-to-day activities required to support facility operations, and lack the time and resources to perform a methodical engineering study of what can be hundreds of pumps at their facility. The following discussions will provide a background on pumping systems efficiency and introduce some tools available to help end-users quickly recognize opportunities to profit from their pumping systems.

### System Optimization

Generally speaking, the best strategy for pumping systems optimization is to begin at the end of the line and work backwards through the pump, motor, and back to the transformer. The elements and the order of review contemplated is:

1) Ultimate goal or purpose
2) Piping system
3) Pump
4) Gear or coupling
5) Motor
6) Adjustable speed drive (if applicable)
7) Motor starter
8) Transformer

There are several reasons for this reverse sequence. In many cases, the greatest efficiency improvement opportunities are found in situations where the fluid system is simply doing a lot more work (e.g., delivering a higher flow rate or head) than is truly needed to support the ultimate goal of the system. Another important reason is that energy savings identified at the end of the energy transfer path are multiplied at the power line (the billing point) because of the inefficiencies of the upstream elements.

Some of these elements, such as the motor starter and shaft-to-shaft coupling, are important from a reliability standpoint, but are inconsequential from an energy efficiency perspective.

For those elements that are more important, how would one go about analyzing the individual components? There are methods for estimating efficiencies for the individual components, such as the motor), in the field (Ref. 2). But as noted previously, the BestPractices program encourages taking a systems approach. The general thesis of this approach is that it is more important to gain a measure of the overall system efficiency or effectiveness rather than dwell on individual components (Ref. 3). In common terms, the idea is to see the forest, not just the trees.

Pump efficiency is defined as the pump's fluid power divided by the input shaft power. The efficiency of any pump 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. Pumps with special characteristics, such as canned motor pumps, self-priming pumps, pumps for solids handling, and low flow/high head duty pumps will have low efficiency ratings.

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. These efficiency measures are illustrated in the following figures (Ref. 4).

In the simple pumping system shown in Fig. 1, fluid is drawn from a tank and pumped through a piping system which includes one flow control valve, to an elevated tank. A recirculation line with another control valve is also included. The pump is driven by an electric motor fed from a motor control center (MCC) which is, in turn, fed by a station transformer. How would one measure efficiency in such a system? Consider a series of boxes drawn at different levels around the system. At each level, the power input and useful output are measured, and the ratio defines the efficiency of the process inside the box.

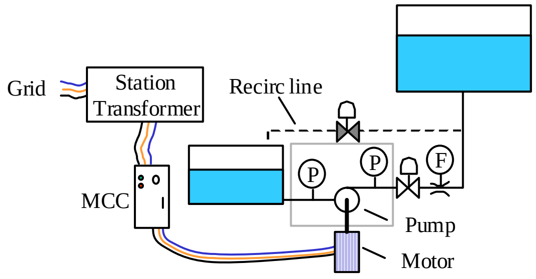


Figure 1. The pump efficiency

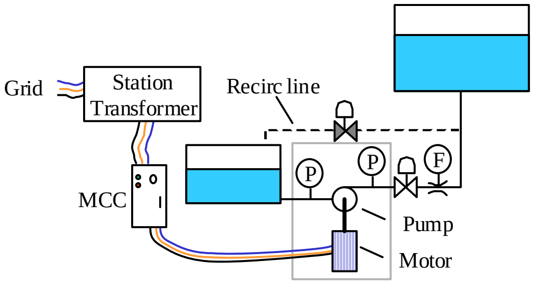


Figure 2. Combined motor and pump efficiency

In Fig. 1, a box is drawn around the pump. The input power is the shaft mechanical power; the output power is the hydraulic power delivered to the system. The ratio is the *pump* efficiency.

In Fig. 2, a box is drawn around both the pump and the motor. The input power is the electrical power supplied to the motor; the useful output power is the hydraulic power delivered to the system. The ratio is the combined motor and pump, or *wire-to-water* efficiency.

In Fig. 3, a box is drawn around the pump, the motor, and the entire normal distribution piping network, from the source to the discharge tank. The input power is, again, 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. 3 is:

$$\eta_{sys} = \frac{P_f}{P_e} = \frac{QH_s\gamma}{P_e}$$

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
$\eta_{sys}$ = overall system efficiency
$\gamma$ = fluid specific weight

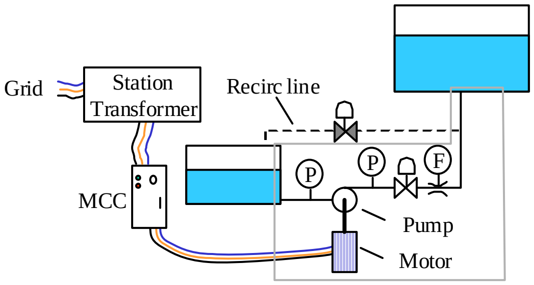


Figure 3. System efficiency

The flow rate in the above equation 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).

## Analysis Tools

### *Prescreening Guideline*

The US Department of Energy 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**.

### *Pumping System Assessment Tool*

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 pumping systems (Ref. 4). PSAT is available at no cost through the DOE BestPractices program web site (**www.oit.doe.gov/bestpractices/software_tools.shtml/**) The prescreening guide noted above is included in the PSAT installation. PSAT applies to centrifugal pumps directly coupled to 3-phase induction motors. The minimum size motor is 5 hp; there is no maximum.

PSAT estimates the existing motor and pump efficiency using field measurements and nameplate type motor and pump information. 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.

#### Display layout

The primary or front panel of the software is shown in Fig. 4. The “inputs” are all located in the three boxes that cover the left one-third of the panel.

The *Pump, motor, system information* in the upper left corner is general design information:

- Pump style, nameplate speed, and number of stages
- Fluid viscosity, specific gravity
- Motor class, nameplate hp, rpm, and voltage.

The *Operating parameters* for the system are at the middle left:

- Operating fraction (fraction of time the pump is operated at the specified conditions)
- Cost of electricity (cents/kwh).

The *Measured or required conditions*, at the middle to lower left are:

- Measured (or required) flow rate and head
- Measured motor power or current (depending on the selected load estimation method)
- Measured bus voltage.

The *Calculated Results* are displayed in the upper right portion. In the next sections, the sources of motor and pump data, and how they are used in PSAT to achieve these results will be discussed.

Finally, *Log, summary file controls* are just below the *Calculated Results*. The log controls enable the user to store and retrieve data for subsequent display and comparison. Data can be stored by plant, process, or any other structure the user elects. Tab-delimited text summary files that save the essential inputs and results can be created or existing summary files appended. The summary files can be opened and manipulated in other applications. For example, a summary file with the analysis results for all of a particular facility’s pumps can be created, allowing further analysis in a spreadsheet program.

#### Motor performance characteristics used by PSAT

The BestPractices Program distributes the MotorMaster+ (MM+) software, a motor selection, comparison, and management tool (Ref. 5). Part of the underlying supporting structure for the MM+ package is an extensive database of motors. The database, constructed using motor manufacturer-supplied data, includes a fairly comprehensive list of parameters such as motor rated power, efficiency, power factor, speed, full load current, enclosure style, NEMA design type, rated voltage, and price.

This motor database was used to develop algorithms used in PSAT. The motor population was thus categorized by size, speed and efficiency class, and average performance characteristics (current, power factor, and efficiency vs. load) were established. Using these average values, curve fits of the performance characteristics were developed.

The curve fits developed from the average performance characteristics of the MM+ database allow motor efficiency to be estimated based on motor size, speed, and measurement of either motor input power or current. If power is measured, PSAT determines the shaft power and efficiency that is consistent with the specified motor size and speed. If current is measured, the power is estimated from the current vs. load profiles in PSAT. A full set of motor characteristics (shaft power, current, power factor, and electrical power) can be established, regardless of whether current or power is measured.

Although the motor characteristics used in PSAT were derived exclusively from 460-V motors, the user can select from other nominal voltages, such as 230, 2300, or 4160 Volts. The current data is linearly adjusted for nominal voltage.

The user also selects from one of three motor efficiency classes – energy efficient, standard efficiency, and average. The average selection simply calculates motor performance characteristics based on the average of the standard efficiency and energy efficient motor values.

### Pump capability estimation used by PSAT

There are many different pump designs applied to the broad spectrum of pumping applications. As mentioned previously, certain applications, such as sewage or stock pumping, have service reliability considerations that prevent the use of more efficient designs that are used in clean water pumping.

Fortunately, the Hydraulic Institute (HI) has published a standard that provides guidance on achievable efficiencies (Ref. 6). The standard addresses the effects of general pump style, capacity, specific speed, and variability in achievable efficiency from miscellaneous other factors such as surface roughness and internal clearances.

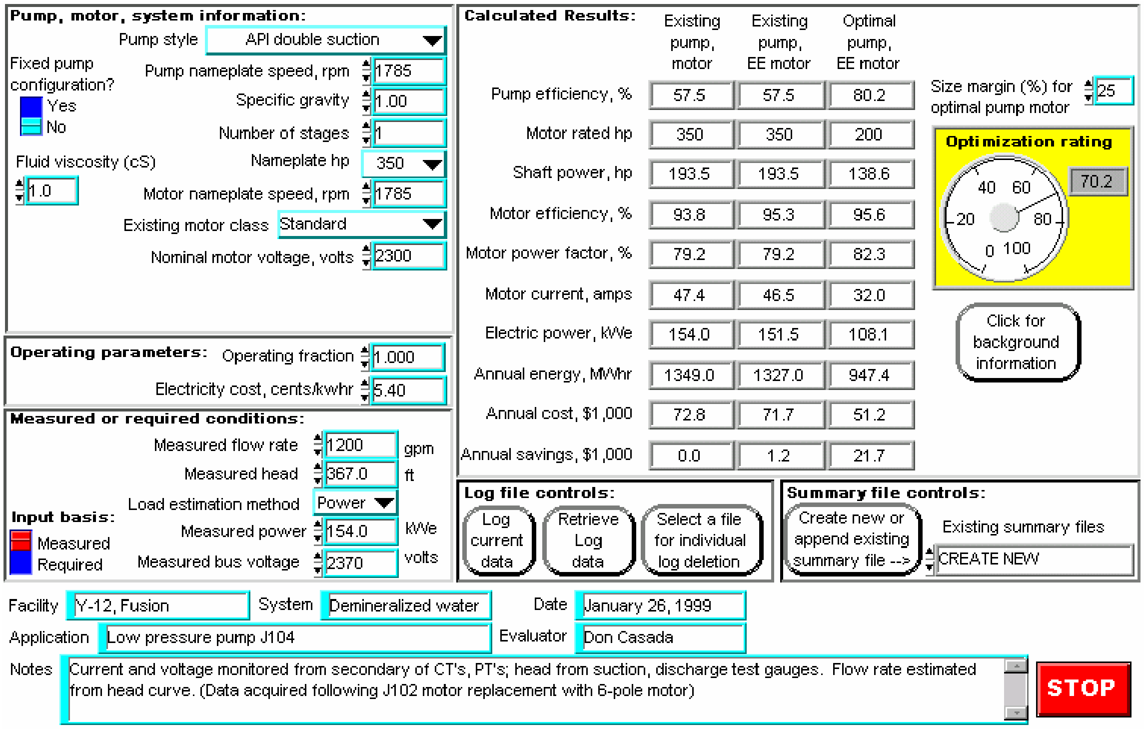
### Putting the pieces together

Based on the input data, PSAT first estimates the existing shaft power from the motor data measurements. It then calculates fluid power from the specified flow rate, head, and specific gravity. At this point, the motor input power, the shaft power, and the fluid power are known, as are the existing motor and pump efficiencies. Given the fraction of time the pump is operated and the electricity cost rate, the annual energy and energy cost is also calculated.

Two actions are considered for comparison:

1. Apply an energy efficient motor in lieu of the existing one. The middle results column shows the potential savings associated with just motor replacement.
2. Employ an optimal pump for the application, with the pump driven by an energy efficient motor.

Of course if the existing motor is energy efficient, no improvement in motor efficiency would be seen.
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.



**Pump, motor, system information:**

Pump style: API double suction
Fixed pump configuration? Yes / No
Pump nameplate speed, rpm: 1785
Specific gravity: 1.00
Number of stages: 1
Fluid viscosity (cS): 1.0
Nameplate hp: 350
Motor nameplate speed, rpm: 1785
Existing motor class: Standard
Nominal motor voltage, volts: 2300

**Operating parameters:**

Operating fraction: 1.000
Electricity cost, cents/kwhr: 5.40

**Measured or required conditions:**

Measured flow rate: 1200 gpm
Measured head: 367.0 ft
Load estimation method: Power
Input basis: Measured / Required
Measured power: 154.0 kWe
Measured bus voltage: 2370 volts

**Calculated Results:**

| | Existing pump, motor | Existing pump, EE motor | Optimal pump, EE motor |
|---|---|---|---|
| Pump efficiency, % | 57.5 | 57.5 | 80.2 |
| Motor rated hp | 350 | 350 | 200 |
| Shaft power, hp | 193.5 | 193.5 | 138.6 |
| Motor efficiency, % | 93.8 | 95.3 | 95.6 |
| Motor power factor, % | 79.2 | 79.2 | 82.3 |
| Motor current, amps | 47.4 | 46.5 | 32.0 |
| Electric power, kWe | 154.0 | 151.5 | 108.1 |
| Annual energy, MWhr | 1349.0 | 1327.0 | 947.4 |
| Annual cost, $1,000 | 72.8 | 71.7 | 51.2 |
| Annual savings, $1,000 | 0.0 | 1.2 | 21.7 |

Size margin (%) for optimal pump motor: 25

**Log file controls:**

**Summary file controls:**

Existing summary files: CREATE NEW

Facility: Y-12, Fusion
System: Demineralized water
Date: January 26, 1999
Application: Low pressure pump J104
Evaluator: Don Casada
Notes: Current and voltage monitored from secondary of CT's, PT's; head from suction, discharge test gauges. Flow rate estimated from head curve. (Data acquired following J102 motor replacement with 6-pole motor)

Figure 4. PSAT primary panel

## EXAMPLE USING PSAT

DOE representatives and personnel from the US Steel Edgar Thompson Works in Pittsburgh, Pennsylvania, USA recently used the pumping systems prescreening checklist and the PSAT software to identify opportunities at the US Steel facility. The process began with discussions between DOE and US Steel personnel. The prescreening checklist was employed to identify several pumping systems that were likely candidates for energy reduction. Several symptoms (cavitation noise and damage, continuously open bypass flow valves, and constant pump operation under varying load) from the checklist that are generally indicative of energy (and reliability) suggested the pumps used for the basic oxygen furnace hood spray were good candidates for further analysis using PSAT. Also, through the earlier discussions, it was known that these pumping systems were high maintenance systems.
Next, field measurements were taken to gather input necessary for the PSAT software tool. Data on flow rate, head, speed, power, and process duration time were recorded. Calculations performed by PSAT estimate that pumping energy costs could be reduced by up to 87%. Using PSAT and the experience of the DOE and US Steel personnel, a project was developed that including replacing a pump with a smaller pump, isolating the normally open bypass line, and installing a soft starter for the motor. A simple payback of less than one year has been calculated, with projected annual energy savings exceeding $40,000.

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4. Casada, Don, “Screening Pumping Systems for Energy Savings Opportunities”, Proceedings from 1999 Industrial Energy Technology Conference, May 1999, pp. 261-270.
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