Prescreening Pumping Systems

for

Potential Energy Savings

Developed for the Department of Energy
Office of Industrial Technologies Best Practices

by: Don Casada

Address questions or comments to Don Casada at:
e-mail: A85@ornl.gov or
doncasada@icx.net
phone: (865) 576-4271

Initial prescreening of motor systems for potential energy savings
- Generic considerations -

This article provides a general approach and some guidelines for identifying and prioritizing candidates for energy reduction opportunities in motor-driven systems. It does not address non-motor system energy usage. It focuses primarily on fluid pumping systems, although the first selection criterion is general in nature.

The intended use is as a prescreening tool, particularly for motor users who are not familiar with the energy-related aspects of pumping systems. It cannot identify solutions or even pinpoint pumping systems where guaranteed savings are feasible. It *can* be used to develop a list of likely candidates. Pumps and systems identified with this prescreening tool will require further engineering review to determine the actual potential for savings and to identify alternative methods of achieving those savings.

BEFORE SCREENING

For any motor driven device (or any energy user, for that matter), the first question asked should be:

CAN IT BE TURNED OFF?

This should not only be the first question that is asked, but it should be asked frequently, and at each level of review. This is an action with a guaranteed savings percentage – 100%. Although simplistic, it is an amazingly common action, particularly in systems with multiple, parallel pieces of equipment.

I. PRIMARY SCREENING

A. Filter by COMPONENT SIZE and OPERATING TIME

Classify the systems by motor size and estimated annual service hours, and calculate the product of the motor rated power and the annual operating hours (see Table 1 for an example).

Select a portion of the systems for more careful examination based primarily, but not exclusively, on the product of the motor size and service hours. Other factors that should be considered include the system complexity and interrelated systems. Relatively simple systems can be more quickly assessed and corrected if necessary, resulting in a reduced payback period. Where there are interrelated systems (such as a chilled water system with the attendant chiller compressor, chilled water pumps, tower water pumps and cooling tower fans) they should be addressed concurrently, and not simply segregated by size, since changes made to one system may have an impact on related systems.

Table 1. Example Prioritization Summary

System	Device Name/ID	Rated HP	Annual operating hours	1000's HP-hrs
Chilled water	Pump CW101	10	8760	88
Aeration	Fan S227	50	8760	438
Compressed air	Compressor AC31	450	6000	2700
Boiler feed	Pump FW16	100	8000	800
Waste treatment	Transfer pump P11	75	4000	300

Note: the 1000's HP-hrs is the product of the rated hp and annual operating hours; it is not a true estimate of energy consumption, since at this survey level, the actual motor load is not known.

The primary screening filter is a very simple approach. There is no definite criterion for what fraction of the systems at a particular facility require further review. Keep in mind that the level of effort should be proportional to the size of the potential reward. As an extreme example: it might literally take several years to recover the cost of having an engineer or technician spending just a day searching for pump performance curves, analyzing measuring system conditions, and investigating more efficient alternatives on a 5-hp pumping system. Of course, if there are only 5-hp systems in your facility and many are similar, the effort might be worthwhile. The table in Attachment 1 shows some example savings for a variety of loads, costs, and efficiency improvements. It is useful to spend a minute reviewing Attachment 1 to get a feel for the kinds of savings afforded by energy efficiency improvements.

B. Screening by LOAD TYPE

The type of load driven by motors is an important factor in prioritization. Current generation motors are very efficient devices, particularly when operated above 40% of their rated load. The motor-driven devices and the systems where the devices are used are normally the prime opportunities for energy savings. Generally speaking, fluid handling components and systems, such as pumps and fans and the systems they serve, are the most likely candidates for efficiency improvement.

Pump systems screening
- Specific considerations -

After identifying pumping systems for further consideration in the generic screening activity described above, there are two general approaches to take. One approach involves looking for symptoms. The other involves acquiring and analyzing data. These two approaches are complementary, and both should be used when possible. Even when one is committed to the more rigorous data acquisition and analysis method, the value of simply being around the operating equipment and the people that operate it cannot be overstated. Some specific features associated with these approaches are described below.

II. SECONDARY SCREENING — SYMPTOMS

Generally speaking, looking for symptoms involves *walking down* the system, talking with operators to find out how the system is operated (and how operation varies with time), and generally using the human senses (sight, sound, touch, smell) to observe indications of waste energy.

The following are common symptoms that at least suggest the potential for energy savings. In many cases, these symptoms may also indicate a likelihood of reliability improvement opportunities.

A. Look for:

1. Systems with throttled flow control, particularly with significantly throttled valves[1],
2. Systems which employ normally open bypass lines for flow control or pump minimum flow protection (unless the minimum flow protection bypass flow is known to be small - e.g., less than 5% of the normal flow rate),
3. Systems with multiple parallel pumps for which the number of operating pumps is seldom changed,
4. A system that operates in a batch or cyclical start/stop mode where the pump cycles frequently (i.e., many starts and stops), and
5. The presence of significant cavitation noise either at the pump or in the system (such as at a throttled valve). Cavitation, at low levels, sounds like gravel is being pumped through the system. At high levels, it is more like a raspy roar and is very unpleasant to be around without hearing protection.

B. Other features to note:

Consider the nature of the system. If it is obvious that the *required* flow rate *should* change significantly over time (for example, chilled water pump flow requirements should vary significantly between winter and summer), a single pump would not likely be suited to the wide range of flow rate. Unless the pump uses a variable speed drive (see discussion on variable speed drives at the end of this article), further consideration of the pump application should be given.

Another factor to consider is whether the requirements for the system have evolved and changed over time. In many older systems, particularly in industrial process facilities, systems may serve significantly different functions or see dramatically different loads than what they were originally designed to meet. Such systems are certainly candidates for further review.

III. SECONDARY SCREENING — ACQUIRING, ANALYZING DATA

The acquisition and analysis of data is a more disciplined, and hopefully more accurate and quantifiable approach. Within this approach, there are opportunities for multiple levels of activity. Ideally, the energy input into the system and the useful work done by the system would be measured and an overall efficiency or measure of effectiveness developed. To that end, a Pumping System Assessment Tool (software), currently under development by the Motor Challenge Program, will greatly simplify the identification of savings opportunities in pumping systems. However, there are some relatively simple measurements and analysis actions that can be done with pencil and paper (a calculator is helpful).

[1] Particularly note systems where globe-style control valves are used and are significantly smaller than the adjacent piping. Even if the valve is full open, the frictional losses can be substantial.

Pump systems screening
- Specific considerations -

It should be noted that at a good fundamental understanding of pumping system parameters like flow rate and head are needed to undertake this effort, including a familiarity with pump and system performance curves. The Motor Challenge Program offers workshops on pumping system optimization that cover the necessary information.

There are two general sources of inefficiency in pumping systems:

1. An imbalance between the system requirements and actual conditions (or between needs and supply), and
2. Operation of the pump at an inefficient point.

These two categories are individually discussed below. It is important to note that they can co-exist (i.e., there is an imbalance between needs and supply *and* the pump is operating at an inefficient condition). However, one can also exist without the other (e.g., a pump operates at its best efficiency point, but provides twice as much flow as the system needs).

A. Looking for an Imbalance in Requirements and Actual Conditions

To do a useful assessment of the pumping system, there are two fundamental parameters that must be known - the flow rate and head. In addition, it is important to distinguish between the *required* system flow rate and head and what *actually exists*. It is often the case that more flow and/or more head are being developed than are truly needed. Excess in either area directly translates into excess energy consumption.

Obviously, if you are to discern whether there is a difference in what is required and what actually exists, you must:

1. Understand the purpose and ultimate goal of the system, and
2. Be able to take necessary measurements to determine what actually exists.

By gathering this information and using the imbalance procedure identified in Table 2, an indication of energy savings opportunities will begin to emerge.

Table 2 shows examples of imbalance between system requirements and actual pump conditions. For this example table, if there is an imbalance between requirements and measured conditions exceeding 20%, the system is marked for further review.[2] Note that there are two entries for chilled water, which reflect different system conditions (e.g., summer vs. winter). For the higher flow rate requirement condition (1400 gpm), the system requirements and actual operating conditions are reasonably balanced, but at the low flow rate (800 gpm), there is considerable imbalance. This illustrates the importance of clearly distinguishing different modes of system operation which can, of course, vary by the time of day, week, or month as well as year.

Table 2. Example Imbalance table

System	Required system (GPM)	Required system head (FT)	Measured pump (GPM)	Measured pump head (FT)	Imbalance (%)	Further review?
Chilled water	800	45	800	70	56	Yes
Chilled water	1400	55	1400	60	9	No
Tower water	1200	40	2000	50	108	Yes
Demin water	2000	110	2200	115	15	No

$$\text{Imbalance (\%)} = \left[\left(\frac{\text{Measured flow rate x Measured head}}{\text{Required flow rate x Required head}}\right) - 1\right] \text{x } 100$$

[2] The value of 20% as a mismatch threshold is arbitrary. The important thing is to record the level of imbalance, and use this as *one* of the factors in prioritizing the systems needing further investigation.

B. Looking for an improperly sized pump

An improperly sized pump often accompanies an imbalance between required and actual system conditions, although the two can also exist independently. To make a determination of whether a pump is properly sized or not, it is necessary to measure or estimate the existing operating condition and compare it to the pump design condition. There is one flow rate where the pump is most efficient, called the best efficiency point (BEP). The further the actual pump flow rate is away from the BEP, the greater the efficiency loss. Unlike motors, for which the efficiency varies little across a wide range of operation (there is typically less than a 2% variation in motor efficiency across the range of 40-100% of rated load), the pump efficiency is strongly affected by flow rate.

For systems with measurable pump flow rate, compare the measured flow rate with the pump BEP flow rate. The BEP flow rate can be determined from the pump performance curves. If the pump performance curve is not available and the BEP flow rate is unknown, but there is a nameplate flow rate on the pump, use that flow rate as a reference. Pumps that are operating more than 30% away from the BEP (or nameplate) flow rate should be included in the group for further analysis.

If the pump flow rate is not measurable, but pressure is, use the pump performance curve[3] to estimate flow rate. Alternatively, if a batch process is involved, deduce flow rates by observing level changes in a tank or reservoir over time. After estimating the flow rate, make the comparison discussed in item 1 above.

If a pump performance curve is not available, but the pump nameplate flow and head values are, a cruder indication can be developed if only the pump head can be measured. If the measured head is more than 20% away from the nameplate value, further analysis is warranted. It is important to note that there is much more uncertainty in comparing head values than flow rates, so this should be a last resort.

IV. SPECIAL CONSIDERATION — VARIABLE SPEED DRIVES

Variable speed drives applied to pumps can be very helpful in reducing energy consumption. In systems where the flow rate varies with time, and the head for the system is mostly frictional, a variable speed drive is an excellent solution. However, the simple existence of a variable speed drive does not guarantee optimization. Some situations in variable speed driven systems that suggest further review would be worthwhile include:

1. A variable speed drive used in a system for which most of the system head is static (i.e., due to an elevation or ambient pressure change),
2. A system which has been retrofitted with a variable speed drive but which still has high pressure drop control valves (e.g., globe valves) installed, or
3. Older variable speed drives such as eddy current devices or wound rotor motors routinely operated at significantly reduced speeds (that is, low as a fraction of the rated speed).

FORMS

Tabular and checklist style forms are included in Attachment 2 that may be useful in performing primary prescreening and pumping system secondary prescreening activities consistent with the guidelines described in this paper.

[3] If a pump performance curve is not available, ask the pump vendor for one, or consider having a field performance curve developed, particularly if the pump is a large energy user. The availability of performance curves is a critical part of any effort to optimize pumping systems.

Attachment 1
Example savings, cost and simple investment return periods

				Operational change only			Design and operational changes			
Power required, kwe	Typical motor hp	Annual operating hours	Annual cost ($) at 5 cents/kwhr	Annual savings for 10% improvement	One day of engineering labor	10% simple payback period, years	Annual savings for 40% improvement	5 days of engineering, craft labor	Simulated equipment cost	40% simple payback period, years
3	5	2000	$300	$30	$700	23.33	$120	$3,500	$600	34.17
3	5	4000	$600	$60	$700	11.67	$240	$3,500	$600	17.08
3	5	6000	$900	$90	$700	7.78	$360	$3,500	$600	11.39
3	5	8000	$1,200	$120	$700	5.83	$480	$3,500	$600	8.54
7	10	2000	$700	$70	$700	10.00	$280	$3,500	$1,000	16.07
7	10	4000	$1,400	$140	$700	5.00	$560	$3,500	$1,000	8.04
7	10	6000	$2,100	$210	$700	3.33	$840	$3,500	$1,000	5.36
7	10	8000	$2,800	$280	$700	2.50	$1,120	$3,500	$1,000	4.02
10	15	2000	$1,000	$100	$700	7.00	$400	$3,500	$1,400	12.25
10	15	4000	$2,000	$200	$700	3.50	$800	$3,500	$1,400	6.13
10	15	6000	$3,000	$300	$700	2.33	$1,200	$3,500	$1,400	4.08
10	15	8000	$4,000	$400	$700	1.75	$1,600	$3,500	$1,400	3.06
70	100	2000	$7,000	$700	$700	1.00	$2,800	$3,500	$8,000	4.11
70	100	4000	$14,000	$1,400	$700	0.50	$5,600	$3,500	$8,000	2.05
70	100	6000	$21,000	$2,100	$700	0.33	$8,400	$3,500	$8,000	1.37
70	100	8000	$28,000	$2,800	$700	0.25	$11,200	$3,500	$8,000	1.03
200	300	1000	$10,000	$1,000	$700	0.70	$4,000	$3,500	$18,000	5.38
200	300	2000	$20,000	$2,000	$700	0.35	$8,000	$3,500	$18,000	2.69
200	300	4000	$40,000	$4,000	$700	0.18	$16,000	$3,500	$18,000	1.34
200	300	6000	$60,000	$6,000	$700	0.12	$24,000	$3,500	$18,000	0.90
200	300	8000	$80,000	$8,000	$700	0.09	$32,000	$3,500	$18,000	0.67

Explanation and discussion

The example values used above are to help provide a general idea only. Clearly, there are several variables involved in determining costs, savings, and payback periods. The simple payback period is calculated as follows:

$$\text{Simple payback period} = \frac{\text{labor + equipment costs}}{\text{annual savings}} = \frac{\text{labor + equipment costs}}{\text{kwe} \bullet \text{annual operating hours} \bullet \text{electricity cost (cents/kwhr)} \bullet \text{(percentage savings/100)}}$$

The general concept of the table is to illustrate the relative costs of labor and materials and the combined impact on the payback period. The important points to be drawn from the table are:

1. It is very difficult to cost justify expending significant effort on investigating operational changes in small equipment, even when it runs most of the time. For example, in the case of a 200 kwe load (300 hp motor) which only runs 1000 hours per year (less than three hours a day), the cost of a day of engineering review spent to develop a 10% savings would only take about 4 months to recover. It would take more than 8 times as long to recover the cost of the engineer-for-a-day if a similar percentage improvement were made for the 3 kwe load (5 hp motor) *that runs more than 90% of the time.*
2. It is even more difficult to cost justify design and equipment changes in small motor systems. While there certainly may be some changes that can be made with less expense than the values assumed in the table, the values shown are not atypical.

In summary, efforts should obviously be structured to start with the largest equipment first. There is not only a greater likelihood of finding cost effective opportunities, but the energy savings will be more clearly detectable in the overall cost of doing business. From a practical standpoint, this can be very important in justifying similar efforts on other equipment and facilities.

Attachment 2

Prescreening Forms

Pump system energy opportunity screening
Symptoms-based approach

Facility: ______________________________

System: ______________________________

By: ____________________ Date: ____________

Field observations, discussions with operators

Look for:	YES	NO
Significantly throttled valves in primary flow path(s)		
Normally open pump bypass line used for flow control or pump minimum flow protection		
Multiple parallel pumps where the number of operating pumps is seldom changed		
Batch or cyclical start/stop system with frequent pump cycling		
Significant cavitation noise at the pump or in the system		

Looking at the forest, not the trees

Consider:	YES	NO
Should the system flow or head requirements change over time (time can include from hours to months)? (If the answer is yes, but either a variable speed drive or multiple parallel pumps are available and used, check no).		
Have the system requirements changed over the course of time (normally years), but the system design has remained fixed?		

Complete the following only for systems with variable speed drives

Consider:	YES	NO
Is the system dominated by static head, with only a single pump normally in operation?		
Does the system still have high pressure drop valves installed (typically, where a drive has been retrofitted to the pump)?		
Is the speed control device an older drive, such as an eddy current device or a wound rotor motor normally operated at reduced speed?		

NOTES:

Energy use primary screening

Facility: ______________________________

System	Device Name/ID	Rated HP	Annual operating hours	1000's HP-hrs	Fluid system?	Review further?	Notes

By: ______________________________ **Date:** ______________________________

Note: An Excel spreadsheet of this form with embedded imbalance calculations is available here: Primary_prescreening calc.xls

Pump system screening imbalance sheet

Facility: ______________________________

System	Required system gpm	Required system head (ft)	Measured pump gpm	Measured pump head (ft)	Imbalance* (percent)	Review further?	Notes

By: ______________________________ **Date:** ______________________________

* Imbalance % = {[(Measured gpm x Measured ft)/(Required gpm x Required ft)] – 1} x 100
Note: An Excel spreadsheet of this form with embedded imbalance calculations is available here: Imbalance_calc.xls