Knowledge Equals Power Savings when it comes to Pumping Systems

David Werner, Michaels Energy

ABSTRACT

Pumping systems are not intuitive and can represent a significant portion of the overall energy use for industrial customers. It is common to find pumping systems that have gone through several generations of pump replacements, where the pump is replaced with one of the same size or larger without considering what size is actually required. The facility may have gone through multiple expansions, contractions, or process changes and many of the pumping systems are no longer operating as designed or installed and are ripe for optimization.

The current "go to" solution is to install variable frequency drives (VFDs). However, production interruptions for VFD installation are very costly to industrial customers and the added complexity and potential failure point can be a barrier to implementation. Pumping systems can be optimized without installing VFDs by studying the operating parameters and adjusting the pumping systems to better match the existing loads on the system. After constant volume optimization, VFDs can still be added for more savings and better control, if desired.

This paper discusses pumping optimization of operational pumping systems. Pump diagrams of various system modifications are used to show the savings potential with and without variable speed controls. The secret to optimizing existing pumping systems is knowledge. Without the correct knowledge, simply installing a VFD on a system may produce only part of the available savings that can be achieved with a detailed pumping system study.

Introduction

As an energy efficiency engineer, I have had the opportunity to audit hundreds of small, medium, and large industrial facilities. During these analyses, it became apparent that centrifugal pumping systems have some of the largest energy savings potential available. Most of the time, the easiest way to reduce the power consumption of these systems is to install variable frequency drives (VFDs) and reduce pump speed. Installing VFDs can be good projects with a very reasonable payback.

However, VFDs are not always desired for several reasons discussed later in this paper. If VFDs are not desired, there are several other methods to reduce the energy consumption of most pumping systems. These methods may not completely optimize the system, but can produce projects that the customers want to implement if VFDs are not a viable option. The secret to optimizing systems within facility parameters is to understand the pumping system and how all the parameters are dependent on each other.

To illustrate where energy savings potential comes from, current engineering and construction practices are explained. Understanding the savings potential requires some discussion of how pumps operate. Pump curves are used to illustrate the physics of pumps and how they interact with different control strategies.

The goal of this paper is to demonstrate how detailed pumping studies could be employed by utilities to find projects with quick simple paybacks that may or may not involve the installation of variable speed drives. The knowledge required to properly analyze pumping systems is not rare, but system optimization takes time which is valuable in low staffing situations commonly found in major industries.

Most industries with large pumping systems know that energy savings potential exists in their systems. Providing customers with detailed analysis and several options in addition to a VFD can drive program participation and project implementation. Detailed pumping studies have the potential to produce cost effective projects for both the customer and the utility program regardless of the customer's ~~feelings~~ opinions on VFDs.

System Design

Engineering in classrooms and laboratories is an exact science, where calculating something like pressure drop through a piping system can take hours. Practical engineering is based on science, but many tools and approximations have been developed to make the design process less time consuming and more cost effective. In order to select a pump, the desired flow rate and the pressure losses throughout the system at the design flow rate must be known. Without these parameters, a pump cannot be specified.

In practical engineering, the required or estimated flow rates are summed for all of the different components in the system. Pipes are then sized based on the established flow rates and rules of thumb. Pressure losses are calculated based on the flow rates and the size of the pipe. Losses are calculated with empirical data for pipes, fittings, valves and components. Once those two parameters are known, a safety factor is added to ensure that the delivered pump will meet the needs of the system.

When specifying a pump, the engineer must select a pump and impeller size. It is not uncommon for a pump with a slightly larger impeller to be purchased as an additional safety precaution. This is done to ensure the system works and that system design and construction costs are reasonable. However, it leads to oversized pumps for these systems. Even with VFDs being common today, many systems have been designed and installed in the past and are operating with oversized constant flow pumps.

Consider an ethanol plant that may have been designed to produce 50 million gallons per year. The owner wants to double production, so the designer may install pumps that are double the size of the current pumps. It will work, but it will also double the energy waste if the current system is oversized.

This is not to say the design process is flawed, but rather shows where inefficiencies may be introduced and why they are very common. Additionally, systems may be installed significantly different than as designed. More valves and fittings may have been required to install the system; the reason for safety factors previously mentioned. The system may have also been designed for plant expansion that was never built. Oversizing leads to a system operating at higher than required pressures, or the system can be "corrected" with existing balancing valves.

Introduction to Pump and System Curves

The previous section emphasized why most industrial pumping systems can be improved and highlighted the potential for the large number of energy efficiency projects that may be achievable in industries with heavy pumping energy consumption. To illustrate where these opportunities exist, a basic understanding of the interaction between the system and pump curves is required. Pressure and flow are not independent for both pumps and systems. Both pump and system curves operate at one pressure for a given flow rate. However, they are very different and where they intersect dictates the flow and pressure output of the pump.

System curves are set based on three factors, the vertical pressure required to lift the fluid, major, and minor losses. Major and minor losses are pressure losses generated from the flow moving through the pipe and fittings, and are dependent on the flow rate squared. This results in a parabolic (bowl shaped) curve on the pressure versus head loss graphs. The slope of the parabola is dependent on the pressure loss through the system which again depends on the flow rate.

The system operates where the system curve intersects the pump curve. The pump curve is fixed for a given pump model and impeller size. A pump cannot achieve any pressure at any given flow rate by itself without modifying the physical parameters of impeller diameter, pump speed, or modification of the system curve. The system curve is typically adjusted by adding balancing valves and it can change continuously as control valves modulate for loads served.

Figure 1 shows a published pump curve, from the Bell and Gossett pump selection software, for a pump with system design parameters of 1,000 gallons per minute (GPM) and 200 feet of head pressure drop.

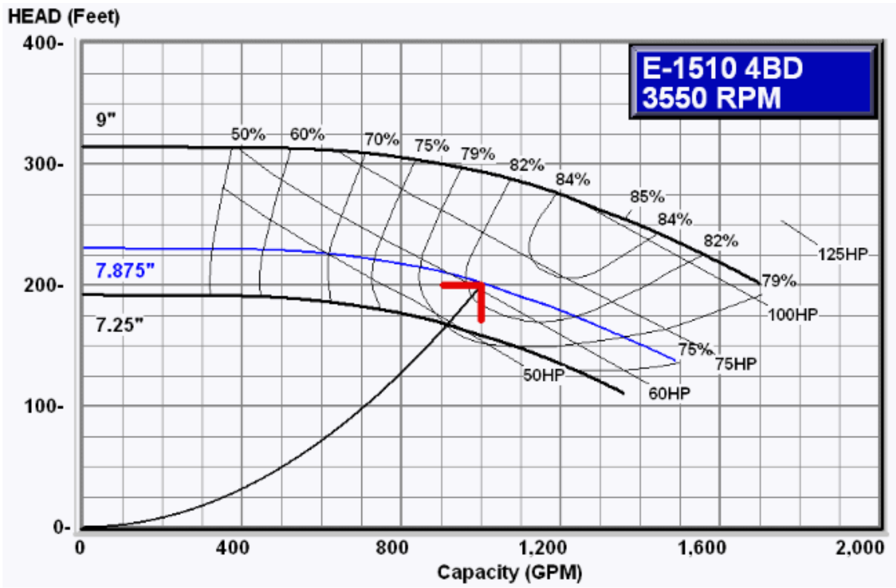

Figure 1: An example of a pump and system curve interaction. *Source*: ESP Selection Software

This chart displays a lot of information in one package. The line that starts in the bottom left corner and trends upwards is the system curve that is set by the piping design, including its valves and fittings, plus component losses. The pump curves are labeled with the impeller diameter and the efficiency and horsepower lines are also shown. For the operating point selected, a 7.875 inch diameter impeller is recommended and would operate with a pumping efficiency of 82.4% and a brake horsepower of 61.7-HP.

This specified pump can produce flow and pressure parameters anywhere along its curve, the blue line. Without modifying the speed, impeller diameter, or system curve, this pump could not provide 400 GPM and 100 ft of head, for example. Likewise, it cannot produce 1,000 GPM at 300 ft of head.

Once the system is installed, the pump may turn on and produce 1,200 GPM at 180 ft of head. That would mean that the as-built system curve has a shallower slope and would be operating at 65.9 HP with a pumping efficiency of 82.8%. The additional flow is not needed, so the system curve is adjusted by closing a balancing valve and increasing the slope. This brings the system back to the design point and also decreases the energy consumption of the pump by 4.2-HP.

Control Methods

There are three main methods commonly used within industrial facilities to control flow rates: throttling valves used to introduce a pressure drop in the system in order to change the flow, recirculation lines used to build pressure within the system and provide pump deadhead protection, and variable speed control that modulates the speed of the pump based on control parameters. The piping layout usually drives the control method used, but the different piping arrangements are not addressed in this paper.

A control system that uses throttling valves is introducing a pressure drop to the system, which allows the pressure at the pump to increase reducing the flow through the system. In this case, as the valves are closed the slope of the system curve is increased and, just like with balancing valves, the horsepower is decreased slightly. As the load increases, the valves open up, decreasing the slope of the system curve and increasing the horsepower required. With this control system, the pump curve remains the same but the system curve is changing the operating point. Going back to the previous example, the only way to achieve a reduced flow rate of 600 GPM is by using a valve to introduce enough pressure drop that the pressure exiting the pump would be about 220 ft of head. This would be like operating a vehicle by holding the accelerator down and adjusting the speed of the vehicle with the brakes. It should also be noted that although throttling a system will generally reduce the energy consumption of the system, it also affects the efficiency of the pump. In the example shown above, if the system was throttled to 600 GPM, the pumping efficiency would be in the 69% range.

A recirculation control system is similar, but is always recirculating a portion of the fluid back into the suction side of the pump, common in large systems with no return line at the end of the system or when the system supplies multiple locations that are not physically close to each other. The unnecessary pumping makes this method one of the least efficient methods of control. .

Finally, a variable speed system adjusts the pump speed with the load. In this case, the system is generally set to maintains a set pressure differential across the piping system and the pump curve changes. Figure **2** is a variable speed system graph for the same pump as shown before. As the pump slows down, the pump curve shifts down and to the left. This reduces the flow generated by the pump and lowers the horsepower based on the affinity laws. For systems with low static head pressure, the efficiency of the pump changes very little at normal speeds, but can be affected at really low speeds. For systems with large static head, the efficiency of the pump does change as the speed is reduced; this needs to be accounted for when predicting energy usage. In general, variable speed controls are the most efficient option, but have limitations and issues that will be discussed in the next section.

All of these examples are for systems with minimal static head pressure or circulation loops. Systems with large static head pressure, which shifts the system curve directly up, may not be a good option for variable speed controls. Large static head losses reduce the minimum speed at which the system can be operated while still providing required flow. Graphically, a small reduction in speed in a system with large static losses can reduce flow rates substantially.

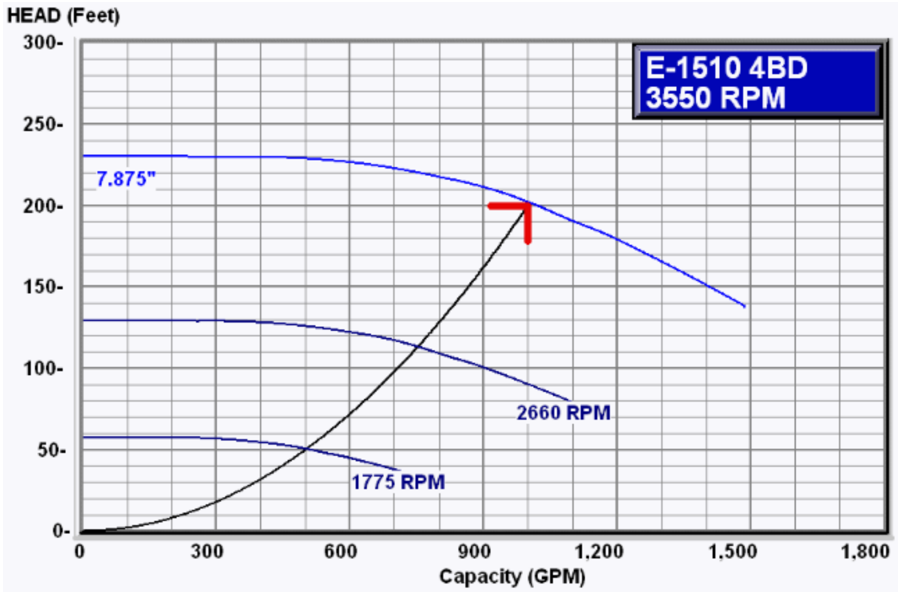

Figure 2: Example of a variable speed system and pump curves. *Source:* ESP Selection Software

Variable Frequency Drive Issues

Variable frequency drives have come a long way in both reliability and cost. However, complaints made about VFDs include that they add an additional failure point to the system, installation in motor control centers (MCC) is expensive and difficult, VFDs can create harmonic issues with the electrical system, and previous experiences with VFDs were not successful. There are ways to approach each of these issues.

One way to approach and remedy the additional failure point issue is to leave the original control valves within the system, so if the VFDs fail, the system can revert back to the original control with minimal down time.

Installation of VFDs in MCC rooms is substantially more expensive, including more equipment and wiring. Most large facilities that would require MCC installation have long operating hours, so even a relatively small energy reduction can result in significant kWh and cost savings. MCC installations, even with the additional costs, can often yield paybacks below two years.

Harmonic issues with the electric system can be addressed by adding harmonic filters to the system. Some newer VFDs have filters integrated, and most engineers will specify harmonic filters with the installation.

The final complaint is the most difficult to overcome. Bad past experience with anything is always hard to defeat. In such a situation, it is often best to focus on other optimization strategies.

Non-Variable Speed Optimization Strategies

The design and construction discussion earlier in this report is important to show why and how almost all industrial pumping systems are oversized. Compounding the design issues, once the system is built, the actual pressure and flow rate needed can be different the design values and industrial pumping systems get modified quite regularly. For instance, the sample used throughout this paper is a system with the design parameters of 1,000 GPM at 200 ft of head. But the highest demand that the pump operates at may be 700 GPM at 50 PSI, or roughly 115 ft of head. In the example system, the throttling valve would operate partially closed and the pressure the pump had to produce would be approximately 225 feet of head, or 95.7 PSI. At this pressure and flow rate, the pump efficiency is roughly 73% and the pump has a requirement of roughly 54 horsepower, which is less than the design horsepower but more than it could be.

Revisiting the pump selection software by inputting a pressure and flow requirement of 750 GPM and 130 feet of head (for some cushion) results in the selection of a different pump. See Figure 3 for the new pump curve.

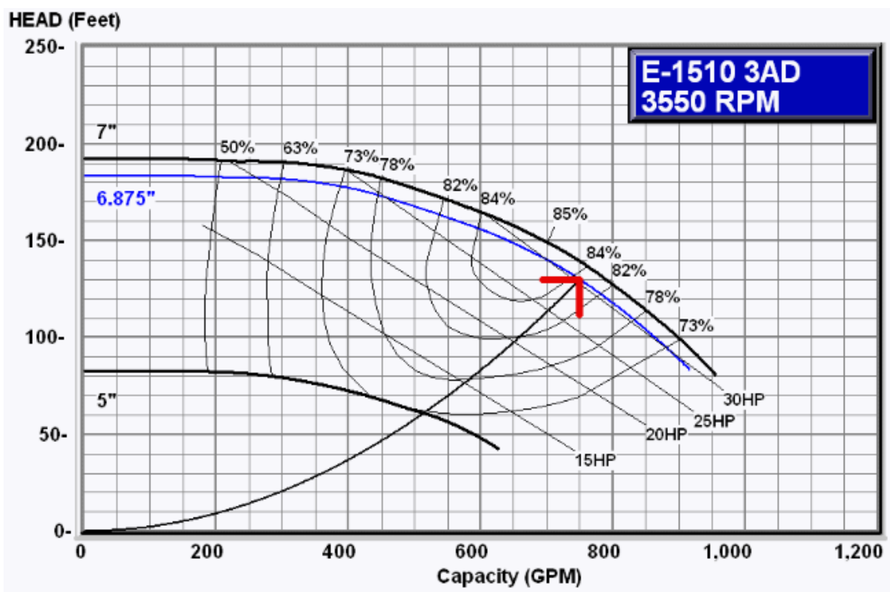

Figure 3: The right sized pump curve. *Source:* ESP Selection Software

As can be seen, the new correctly sized pump is a smaller pump that would operate with a pumping efficiency of approximately 85% when throttled back to the actual flow rate of 700 GPM. This system would operate with a break horsepower requirement of roughly 30 horsepower, resulting in a reduction of 14 horsepower. For a facility that operates 24/7 with an annual week long down period, this would result in an annual savings of roughly 90,000 kWh, or at $0.05/kWh and $120/kW per year, $5,700 annually. This project would have an estimated installation cost of roughly $10,000 for a simple payback of less than 2 years with no changes made to the electrical or control systems.

Another option for this system would be to install a smaller impeller in the current pump housing. For the current example, the impeller could be trimmed by approximately 0.5 inches. Trimming the impeller has a similar result to slowing down the pump, with affinity laws stating that the power requirement reduces by the diameter ratio cubed. This is for a theoretically ideal pump, with no change in the pumping efficiency. Because the pumping efficiency does decrease as the impeller is trimmed, it is best to use the pump curve to estimate savings. Using the same operating parameters as used in the correctly sized pump example above of 700 GPM and 115 feet of head, along with the existing pump curve shown in Figure 1, the impeller can be trimmed to a diameter of 7.25 inches. The system would still need to be throttled back to 700 GPM, but would only need to be throttled back to 180 feet of head or 78 PSI. The pump would be operating with a pumping efficiency of 73% and a horsepower requirement of 44-HP. Using the previous operating hours and cost structure, this would lead to a savings of roughly 7.5 kW and 64,000 kWh, or $4,000 annually. The cost to trim impellers ranges significantly, mostly due to the labor involved. Also, the timeframe for trimming may not coincide with a scheduled shutdown, so a new impeller may need to be ordered from the manufacturer rather than trimming the existing impeller. Using the average cost of past projects, the cost would be roughly $6,500 for a simple payback of less than 2 years.

Installing correctly sized pumps based on the actual operating parameters can produce significant energy savings without the difficulty of adding a VFD to the electrical and control system. If desired, after each system is optimized for a constant speed operation, VFDs can be added to produce additional savings during periods of low demand.

The Scope of Pumping Studies

The scope of a pumping study should be discussed with the end user very early in the process of optimizing the pumping system. The first issue that needs to be addressed is how many pumps can be worked on during the next scheduled shutdown. For instance, it is not recommended to complete a detailed study of 30 pumps. Most facilities will require the process to be shut down in order to facilitate working on the pumping systems. If the plant is only shut down 5 days a year, the study should only look at the amount of pumps that can be modified during the shutdown. This would need to be decided by the end user. Also, if the project will not be implemented for say, two years, it is best to wait until the process parameters are set at that point of time. Setting the scope at the beginning of the project also allows the customer to focus on pumps that may be causing other issues in the facility.

In addition to installing VFDs on the pump motors, a detailed study should also consider optimizing the system with constant volume systems along with other changes to the control such as reducing recirculation flow rates and modifying valving arrangements. Although VFDs can be the option with the quickest payback, installing a correctly sized pump and/or trimming the pump impeller can achieve much of the savings without installation of more electrical equipment. This study strategy will provide the customer various options to reduce the energy consumption of the system, without converting the entire system to variable speed.

In detailed pumping studies the cost of the measures is also very important. In some industrial facilities, energy saving measures involving VFDs can be more costly than a commercial installation. MCC rooms can be at capacity and may need to be expanded to handle the additional size of the VFD over the standard contactors, new wires may need to be pulled, new MCC buckets may be required, and the conduit may need to be modified. Any of these issues can lead to the constant speed options being more cost effective due to the lower costs. The costs associated with all of the options require detailed cost estimates involving all parties and contractors that may be used.

Pumping studies generally lead to projects that pay back in less than 2 years, making them a possible addition to DSM program portfolios. Utilities may be able to claim impacts, while providing a service to their customer. Facility staff may have the knowledge to complete a pumping study in–house, but they are also tasked with operating the plant and optimizing system performance, and may not have time to perform their own study. A detailed pumping study provided by a third party would eliminate this issue. In addition, if part or all of the study cost could be reimbursed through a utility program, facilities may conduct them more often and it would likely generate higher implementation rates.

Conclusion

In conclusion, there are several strategies available for optimizing pumping systems with and without the use of VFDs. A lot of opportunity exists for energy savings through pumping system optimization, but only if the system is analyzed with energy efficiency in mind. Studying and understanding the equipment, its use, interactions, and the goals of the system are paramount to creating the correct optimization strategy. However, creating that strategy often requires a detailed study, including analyzing a select number of pumps. A detailed study will be most effective, as current and proposed pump curves need to be analyzed in order to determine accurate pumping needs and energy savings. By adding a pumping study program to a utility's energy efficiency portfolio, the utility may provide a much needed and specialized service to its large industrial customers to help them optimize their facility, save money, and reduce their energy footprint.

References

"ESP-Online Pump Selection Application." *ESP-Online Pump Selection Application*. Xylem Inc., n.d. Web. 21 Feb. 2015.