

Taking Another Look at Pumping Systems: Opportunities Go Well Beyond Just Energy Savings

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ABSTRACT

Pump Systems Matter™ (PSM) is an educational initiative created by a group of pump manufacturers from within the membership of the Hydraulic Institute (HI), an association of pump producers, to assist pump users gain a more competitive business advantage through strategic, broad-based energy management and pump system performance optimization, addressing both installed systems and new design aspects of pumping systems. PSM is developing a variety of methods to integrate pumping system performance optimization and efficient energy management practices into normal business operations – a long-term goal of the initiative.

This paper will discuss the PSM initiative and some of the educational resources, tools and collaborative opportunities it is developing. One new tool recently made available is the *Pump System Improvement Modeling Tool™* (PSIM) educational software package and pump systems modeling package. PSIM will be examined in some detail, including an example of its use to demonstrate cost savings and ways to save energy.

INTRODUCTION

Nationwide, industrial facilities managers, municipality authorities, building owners and operators and many others are struggling to cope with soaring electricity and natural gas prices. Improving the energy efficiency of these facilities should be a “no-brainer” for facilities managers seeking to survive in this era of increasing energy costs. While many facilities managers are either unaware or unconvinced regarding the opportunities for cost savings through energy efficiency, other facilities managers who may wish to pursue energy efficiency projects are often unable to get these projects funded due to existing policies requiring extremely short payback periods. Basing decisions, however, on total cost of ownership and established life-cycle cost methodologies provides compelling arguments to shift business decision-making away from initial cost considerations.

Pumping systems account for about 25% of all industrial electricity consumption, and for over 50% of the electricity in certain pumping-intensive industries, including municipal water and wastewater. Based on a U.S. Department of Energy study, economically-viable energy optimization of pumping systems can reduce a typical facility’s pumping system energy costs by over 20%. Pursuing these opportunities can have a significant impact on facility operating costs. Just as importantly, these pumping system optimization projects typically have corollary benefits, such as reduced life cycle costs through reducing maintenance costs, improved system reliability, improved process control and product quality, and other areas. Clearly, facilities personnel, both at the operational level and the decision-making level, need to fully understand both the energy and economic potential of pumping systems optimization.

While reducing energy usage in installed pumping systems is important, of equal importance is to improve the design process so that systems are designed to be energy efficient from the start. This too will require training and greater awareness of available tools. In addition, it will require a cultural change in the typical owner/operator and engineering, procurement and construction (EPC) relationship.

The purchase and operation of pumping systems is a significant expense for most facilities. However, it is common practice for pumping system design and procurement to be based primarily upon the initial purchase cost of the equipment. Often such decisions, particularly with new systems, are under the control of the engineering contractor – who has few incentives in the world of fixed price contracts to embrace energy efficient pump system design and reduce energy.

Through the leadership of the Hydraulic Institute (HI), along with some guidance from the U.S. Department of Energy and other organizations, leading North American pump manufacturers have created Pump Systems Matter™ to inform pumping system users and economically viable opportunities for life cycle cost savings. PSM is considered to be

the first industry-led market transformation initiative in the U.S.

IDENTIFYING THE OPPORTUNITIES

Pumps are widely used in industry to transfer fluids for processing applications, to supply water and process wastewater, to provide fluid circulation in cooling systems and to provide the motive force in hydraulic systems. In fact, virtually all manufacturing plants, commercial buildings, and municipalities rely on pumping systems for their daily operation. After motors, pumps are the second most widely used machine in the world.

In the United States industrial sector, electric motor systems consume over 679 billion kWh of electricity per year, with pumping systems accounting for about 25 percent of that total (1). In the commercial sector, pumps are primarily used in heating, ventilation, and air conditioning (HVAC) systems to provide water for heat transfer. Municipalities use pumps for water and wastewater transfer and treatment and for land drainage. Because they serve such diverse needs, pump sizes range from fractions of a horsepower to several thousand horsepower (1).

Pumping system energy efficiency improvement opportunities fall into two distinct categories: existing and new systems. A successful pumping systems market transformation initiative will need to encompass both new and existing systems, even though the markets for servicing new and existing pumping systems are very different (3).

The number of retrofit opportunities far exceeds the number of new systems each year. Therefore, the bulk of potential savings lies within these existing systems. Opportunities in existing systems often involve changes to the control system or the pump, or both. Significant changes to the piping system and other equipment in existing systems are typically not economically viable. The average energy savings potential through economically viable pumping system optimization projects is approximately 20%, although certain installations might realize significantly greater savings, ranging from 25% - 50%. If all facilities in the U.S. implemented such measures, the savings would equal over 28,000 GWh/year, based on a midrange estimate (1). This energy savings potential represents significant cost savings potential for industrial facilities and their owner/operators. Significantly, energy efficiency improvements to industrial systems usually provide improved reliability, productivity, and reduced environmental costs.

Opportunities in new system design must not be ignored, though. For a given *new* system, the potential savings in energy and life cycle costs are far greater than in a given *existing* system of similar size and application. One reason for this is the opportunity to optimize the piping system design. Other aspects of the pump system can also be better tailored to the system requirements in the design of new systems. But since new system designs are typically under the control of engineering contractors, promoting a systems optimization approach is often difficult, as the contractors typically do not directly benefit (3). PSM will address this situation.

The efficiency of a given pump is one small factor affecting the efficiency of a pumping system. A systems approach analyzes both the supply and demand sides of a pumping system and how the performance characteristics of the pump and the system interact. The focus of the analysis thus shifts from individual components to total system performance, the equivalent of looking at the forest, not just the trees. The potential energy and cost savings through a systems approach to optimization typically far outweighs the sum of the savings through component optimization. In fact, approximately 75% of the total life cycle cost of a typical pumping system is accounted for in energy and maintenance costs. (This will vary significantly by application.) To maximize pump system efficiency and reliability, the pump should be operated as close to its “Best Efficiency Point” (B.E.P) as possible.

A systems approach to new pumping system design is equally important, and often overlooked. A recent survey of seven pump manufacturers revealed a significant lack of understanding on the part of pump specifiers and purchasers regarding the proper application of pumps (4). These pump manufacturers were asked “What percentage of the pumps your company sells are incorrectly specified by the contractor or owner/operator?” Of the five manufacturers that responded with a percentage, three indicated a value of 60% or greater, and one indicated that 30-40% were incorrectly specified. A follow-up question asked “Of the pumps that are incorrectly specified, what percentages are a result of inaccurate operating point specifications (i.e., rate of flow, required pressure, and net positive suction head)?” The answers varied between “most” to 90%. Even though this was a small survey, the responses indicate a severe lack of understanding of the proper application of pumps and properly matching their characteristics to the system.

Misapplication of pumps has a direct effect on pumping system operating costs. A pump forced to operate away from its Best Efficiency Point (B.E.P.) increases energy and maintenance costs, and shortens the life expectancy of that pump. Figure 1 shows this graphically.

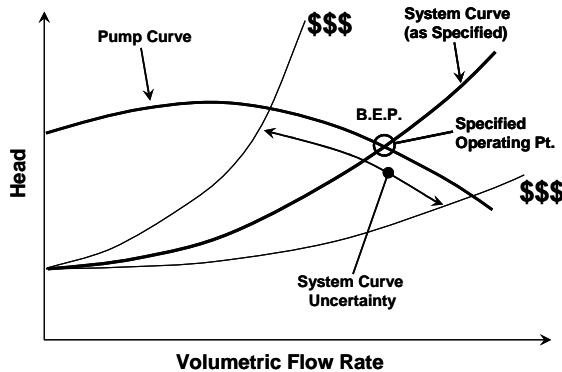


Figure 1. Pump System Curve Uncertainty

CONSIDERING LIFE CYCLE COSTS

Understanding all the components that make up the total cost of a pumping system provides an opportunity to significantly reduce energy, operational, and maintenance costs. Life-cycle cost (LCC) analysis, a management tool, takes into consideration the costs to purchase, install, operate, maintain, and dispose of all components of the system. Used as a comparison tool between possible design or overhaul alternatives, the LCC analysis offers a way to predict the most cost-effective solution. LCC does not guarantee a particular result but allows the plant personnel to make a reasonable comparison between alternate solutions within the limits of the available data.

Pumping systems often have a life span of 15 to 20 years. Some cost elements will be incurred at the outset, with others incurred at different times throughout the lives of the different solutions being evaluated. Therefore, a *present* or *discounted* value of the LCC must be calculated to accurately assess the different solutions.

Most pumping systems will have life cycle costs dominated by energy and maintenance costs. It is therefore important to accurately determine the current cost of energy, the expected annual energy price escalation for the estimated life, and the expected maintenance labor and material costs. Other elements, such as the lifetime costs of downtime, decommissioning, and environmental

protection, can often be estimated based on historical data for the facility.

Any pump optimization project provides an opportunity to update operation and maintenance practices. Vibration analysis can determine if problems are developing in the pump or motor bearings. Vibration and various electrical test methods can evaluate the motor stator and rotor health. Where oil lubrication is used, oil analysis can indicate bearing condition. Routine maintenance, such as valve overhauls, heat exchanger cleaning, and mechanical joint repair, can further improve system efficiencies.

A well-designed distribution system can affect pumping requirements, potentially allowing for the selection of a small pump and motor, thereby reducing both initial purchase costs and life cycle costs.

FORMATION OF PUMP SYSTEMS MATTER™

Inspired by industrial energy efficiency success stories such as the Compressed Air Challenge and Motor Decisions Matter, HI and several champions from within HI member companies formed a Market Transformation Committee and set out to educate themselves on energy efficiency initiatives, including market transformation. This process included attendance at national energy efficiency and market transformation conferences and meetings, and discussions with organizations involved in market transformation, such as the U.S. Department of Energy, Lawrence Berkeley National Laboratory, the American Council for an Energy-Efficient Economy, and the Alliance to Save Energy.

Building consensus within the Hydraulic Institute required numerous steps over a three-year time period, including sessions on energy-efficiency and market transformation efforts related to motors, compressors and other industries at regularly-scheduled HI meetings.

Pump Systems Matter™ is now a 501(c)(3) nonprofit corporation with over 40 sponsors, primarily from within the membership of HI, as of March 2006. PSM is now looking to expand its sponsorship base to include electric utilities, energy efficiency organizations, government organizations, and engineering firms.

The founding sponsors developed the following goal for Pump Systems Matter™: “*Pump Systems Matter™ will assist North American pump users in*

gaining a more competitive business advantage through strategic, broad-based energy management and pump system performance optimization.”

CREATING AWARENESS

The stated mission of the initiative is “*to provide end-users, engineering consultants and pump suppliers with tools and collaborative opportunities to integrate pump systems performance optimization and efficient energy management practices into normal business operations.*”

Pursuant to this mission, and to achieve the stated goal, Pump Systems Matter™ has formed teams to develop specific objectives and build the elements of the initiative. A marketing team is seeking ways to build awareness through a web site, informational materials, trade shows, trade press articles, and other means. A PSM objective is to create a Pump Systems Matter™ “brand” incorporating relevant existing resources of the sponsors while creating new resources that will turn awareness into knowledge, and knowledge into action.

The education team is developing a series of training workshops which will serve to educate as well as build awareness of optimization opportunities in pumping systems. The workshops will range from a two-hour web cast targeting management personnel to a three-day course for engineers and operators. The team is evaluating existing training offerings from PSM sponsor organizations, the U.S. Department of Energy, and other groups involved in energy efficiency training for industry, such as the Northwest Energy Efficiency Alliance. This team will also create appropriate software tools to help accomplish PSM’s goals. An objective of the PSM is to eventually develop a certification program for pump systems engineers.

The first tool, the Pump System Improvement Modeling Tool™ (PSIM), is currently available. This tool was created by Applied Flow Technology, a developer of pipe flow modeling software and a sponsor of Pump Systems Matter™, and is based on the company’s AFT Fathom™ software package. PSIM is available for download at no charge.

PSIM can help pump users and designers understand the complete pump system and thereby better identify areas for efficiency improvements. PSIM uses a drag-and-drop graphical interface to map out and calculate pressure drop and flow in pumping systems. PSIM can create pump and system curves, estimate energy usage and cost over time

using Net Present Value concepts. Users of the software can input pipe, pump, and component data and simulate a wide range of pump system behavior.

PSIM OVERVIEW

It is well known that industries tend to adopt new software tools and methods when business forces make such adoption attractive. Pump system design has long been primarily performed using historical guidelines and design methods have not progressed as quickly as other fields such as Finite Element Analysis (FEA) analysis and Computational Fluid Dynamics (CFD). The majority of pumping systems today are still designed using cookie cutter or historically based sizing methods. Such approaches do not take advantage of the advances in computer modeling tools that have been achieved in recent years.

Quality pump system analysis tools exist which can help reduce first costs and life-cycle cost costs (2). Unfortunately, such tools are not used as frequently as they could be for many reasons. One reason has been the relatively low cost of energy and the lack of awareness of how much energy pumps actually consume.

To help build awareness of how such tools can benefit the design process, PSIM was created as a freely available educational tool. PSIM allows engineers to model pumping system hydraulics on small but non-trivial systems and evaluate the pump energy usage and cost. Further, it allows engineers to modify the system on a computer to evaluate the potential cost savings. PSIM is intended to expose engineers to the benefits of using pumping system modeling tools and to support *Pump Systems Matter* training courses on pumping system improvement and optimization. The tool features a graphical interface which allows engineers to build pump system models using drag-and-drop operations.

PSIM allows modeling of a broad range of pumping system behavior critical to ensuring proper pumping system operation including:

- NPSH adequacy
- Pump efficiency and Best Efficiency Point (BEP) identification
- Modified pump performance due to impeller trimming
- Variable frequency drives (VFDs) modeling
- Positive displacement pumps
- Flow and pressure control valves
- Pump vs. system curve generation

The PSIM tool can be downloaded at www.pumpsystemsmatter.org at no cost.

PSIM EXAMPLE

Original System

The following discussion relates an example of a small pump system that exhibits the common problem of a pump not matched to its system. Several possible system improvements are hydraulically evaluated, and the energy and economic impact on each improvement is discussed.

Figure 2 shows the pump performance data, while Figure 3 shows the PSIM model layout. There are no control valves or pump controls to limit flow; the system rate of flow is determined by the system resistance. The system pumps cooling water to two heat exchangers, and discharges into a vessel at higher pressure and higher elevation (values not shown).

The cost of energy can be entered into PSIM, as well as system life time and interest and inflation rates. The energy costs are thus presented in Net Present Value (NPV) terms. Energy is assumed to cost \$0.10 per kWh, the system life is five years, interest rate is 15% and inflation rate is 3%.

The requirements are to supply 125 gallons per minute (gpm) to each heat exchanger. PSIM models the existing system using well-accepted principles from fluid mechanics, including Bernoulli's equation. The PSIM Output window is shown in Figure 4. Figure 5 shows the pump vs. system curve.

Of note from Figures 4 and 5 is that the pump is operating at 367 gpm, while the pump Best Efficiency Point (BEP) is 243 gpm. The operating point is thus at 151% of the BEP. Aside from increased power required due to low efficiency, operating a pump significantly above or below its BEP leads to low reliability and hence increased downtime and maintenance. Figure 4 shows the efficiency to be 64% and the energy cost to be \$63,000 over five years.

Improved System Evaluation

Using the same PSIM model, various improvement options can be evaluated. The various options that will be given in this example are:

1. Throttle the manual heat exchanger valves to increase system resistance.
2. Trim the impeller
3. Install a variable frequency drive (VFD)

4. Install a new pump better matched to the system

Commercial modeling tools exist which can evaluate all of the capital and recurring costs for such a comparison (2). As PSIM is educational in focus, it will just look at the energy component of cost.

Each option was evaluated with PSIM, and Table 1 shows the results. The first improvement option, to throttle the manual valves, yields a surprising energy reduction of almost \$20,000. This can be performed quickly and requires no capital cost. A side benefit of this option is that the pump now operates near its BEP, which will also reduce maintenance costs on the pump. However, the increase in pressure drop across the valve from 21 to 73 pounds per square inch (psi) may require increased maintenance on the valves.

The second option to trim the impeller reduces the cost an additional \$13,000, but also keeps the pump operating at well over its BEP (at 144%), which will mean that maintenance costs on this pump will remain high. Impeller trimming is a relatively low cost option. A higher cost option is to install a VFD, but for this application does not accomplish much more than trimming the impeller – and at much higher capital cost (not shown). The largest potential in energy saving is to just replace the pump with one that better matches the system. This can reduce the energy cost by almost \$50,000 and also reduce maintenance costs by operating the new pump at its BEP. Note that this option reduces the required motor size for the pump from 25 to just 7 horsepower. The payback time for this could be easily calculated, and would likely be much less than a year.

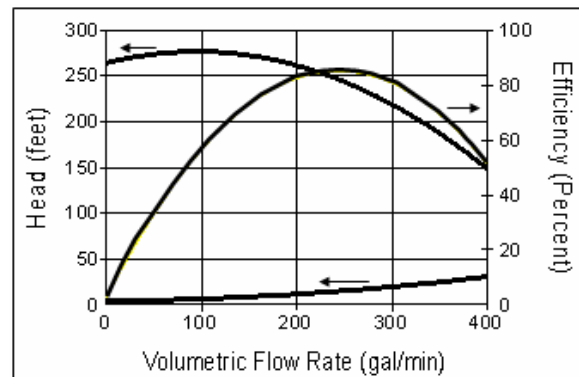


Figure 2. Pump performance data for example.

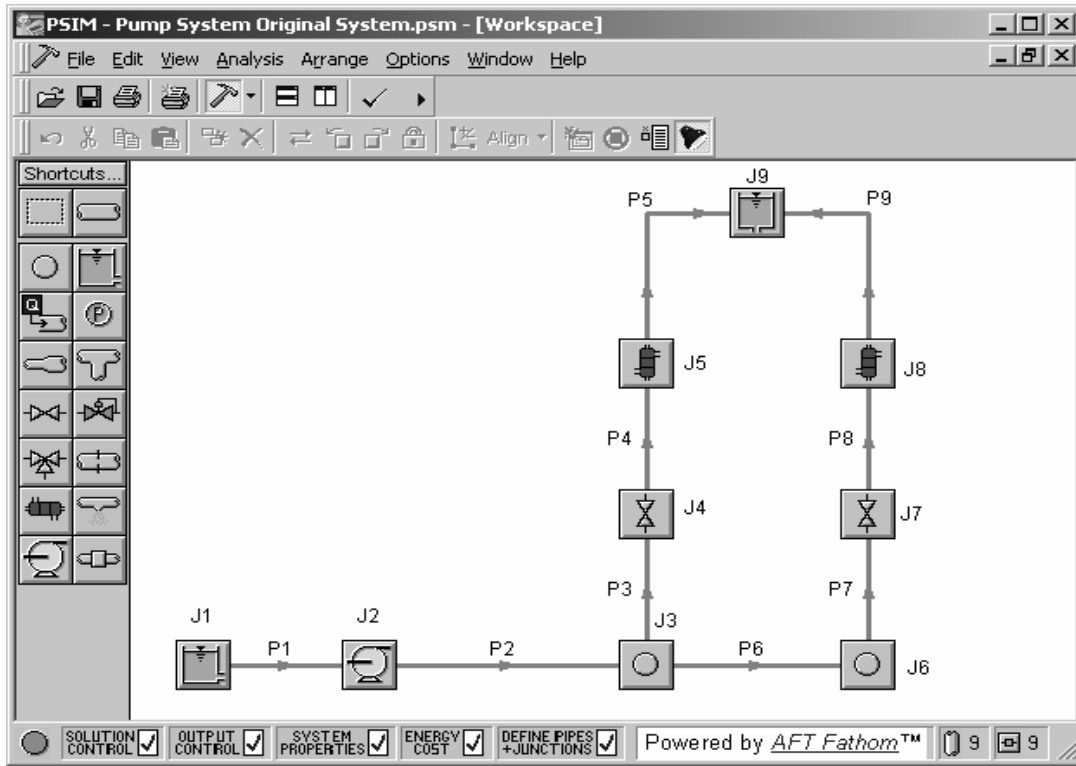


Figure 3. Example PSIM model.

The output window displays hydraulic predictions and energy cost data. It includes a summary table for junctions, a detailed table for pipes, and a table for all junctions.

Jct	Name	Vol. Flow (gal/min)	dH (feet)	Overall Efficiency (Percent)	Overall Power (hp)	Energy Cost (U.S. Dollars)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)	NPSHR (feet)
2	Pump	367.4	174.3	63.85	25.36	63,261	243.0	151.2	60.13	26.86

Pipe	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	dP Stag. Total (psid)	dP Static Total (psid)	dH (feet)	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)
1	9.260	26.29	25.65	0.6328	0.6328	1.460	26.29	25.65	26.86	26.23
2	9.260	101.20	99.62	1.5818	1.5818	3.649	101.20	99.62	101.78	100.20
3	7.997	99.77	97.76	2.0053	2.0053	4.627	99.77	97.76	100.20	98.19

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Jct Net (gal/min)	Mass Flow Rate Jct Net (lbm/sec)	Loss Factor (K)
1	Supply Tank	24.70	26.86	24.70	26.86	-367.4	-51.09	0.00
2	Pump	25.65	101.20	26.23	101.78	0.0	0.00	0.00
3	Tee/Wye	99.72	99.72	100.20	100.20	0.0	0.00	0.00

Figure 4. PSIM Output window for original system displays hydraulic predictions and energy cost.

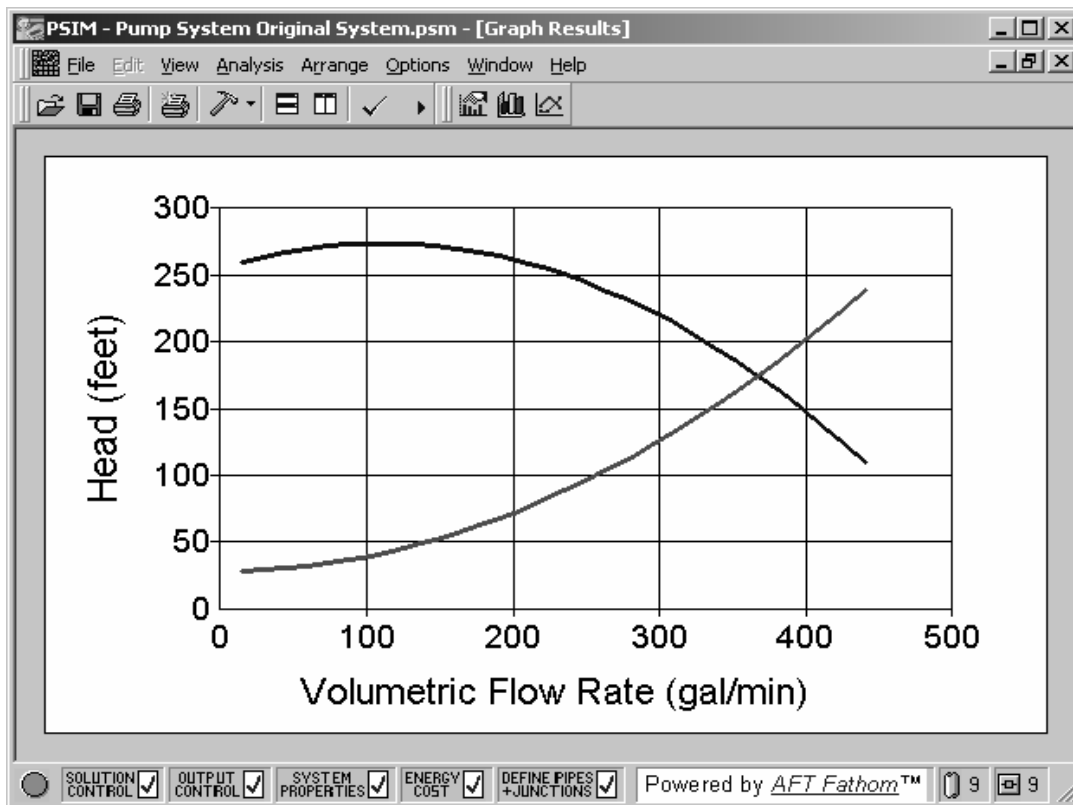


Figure 5. PSIM pump vs. system curve for original system.

Table 1. Improvement options for example system.

Case	Energy Cost (\$ for 5 yrs)	Pump Flowrate (gpm)	Pump Efficiency (%)	Pump Power (hp)	BEP Proximity (%)	Valve Pressure Drop (psi)
Original System	63,261	367	64	25	151	21
Throttle Valves	45,518	255	85	18.3	105	73
Trim Impeller	22,147	252	70	8.9	144	10
VFD	21,749	250	70	8.7	144	10
New Pump	17,507	250	86	6.7	102	10

SUMMARY

Pump Systems Matter™ is an industry-led effort created by the Hydraulic Institute and forty of its member companies. PSM is seeking to transform the market for pumping systems to a focus on energy efficiency and life cycle costs. A wide range of new awareness materials, educational resources, and tools is being developed.

Using PSIM (and hydraulic modeling tools in general) to quickly evaluate system improvement options has several benefits. The increased adoption of such tools in industry will lead to improved pumping systems and significant cost and energy reduction. Hydraulic modeling tools can benefit both existing system improvement projects as well as new system designs.

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