Energy and Life Cycle Cost Savings in Pumping Systems

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ABSTRACT

In this paper the authors examine opportunities for energy savings at water treatment facilities in North America and how energy savings can be achieved. The authors discuss specific approaches, such as using variable speed drives and high efficiency motors as primary sources to realize increased payback of original equipment cost. In addition, this paper explores life cycle costing as a method to justify investment in equipment upgrades, moving beyond just simple payback periods. The authors use existing treatment facilities for reference throughout the paper.

I. Overview

Industrial 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[1], 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 additional life cycle cost savings through reduced maintenance costs, improved system reliability, enhanced process control, extended 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.

At every stage of the water treatment facility there is an opportunity to reduce energy consumption, improve pumping performance, and reduce mechanical wear. It is the intent of this paper to outline critical pumping applications within the water treatment facility and suggest how to apply more energy efficient equipment and operating strategies to reduce overall operating and maintenance costs. Another objective is to provide ideas on how to improve overall pumping efficiency and life cycle costing with currently available technology.

II. Water Treatment Cycle

There are many thousands of water treatment facilities throughout the United States, however, the majority would be classified as "rural municipal" water. These rural stations typically have 10,000 customers or less and provide municipal water outside of the urban centers. Most systems are owned and operated by local governments (e.g. towns, villages, counties or regional authorities), though some systems are privately owned. In order to start the process of clean drinking water, raw source water must be used. This is typically a lake, river or reservoir. The intake to the treatment facility will typically use this raw water source as the start of process. This raw water is then processed through several stages of filtration or chemical treatment to meet Federal, state, and local regulations on clean drinking water.

The raw water intake pumps are sized to meet the overall demand or maximum capacity for the facility. The facility size is measured in millions of gallons per day (MGD) and is based on peak system use throughout the year. For a typical facility that has 9,500 users, this may be approximately 1.3 MGD with peak capacity of 4 MGD. In this example, the raw water intake pumps must be sized to accommodate this inflow which is approximately 1,000 gallons per minute (GPM). This is typically accomplished with the use of vertical turbine pumps, which are designed to be submerged into a "wet-well" and draw raw water into the plant. These turbine pumps are typically at or below water intake levels; therefore, minimal static head is required. Turbine pumps for this application generally have high flow, low head characteristics. In the example plant above, three 15 horsepower turbine pumps would be used for maximum flow, providing just enough pressure to move the raw water from the wet-well to the first stage of filtration.

The first stage of filtration may vary depending upon the raw water's clarity. Some form of filter media must be used to remove particulates or coagulants from the raw water. There are other chemical processes that are used for initially treating the raw water and throughout the different stages of production. The focus will be on the movement of the water through the plant. Figure 1 shows different filter stages where back flushing or cleaning is necessary.

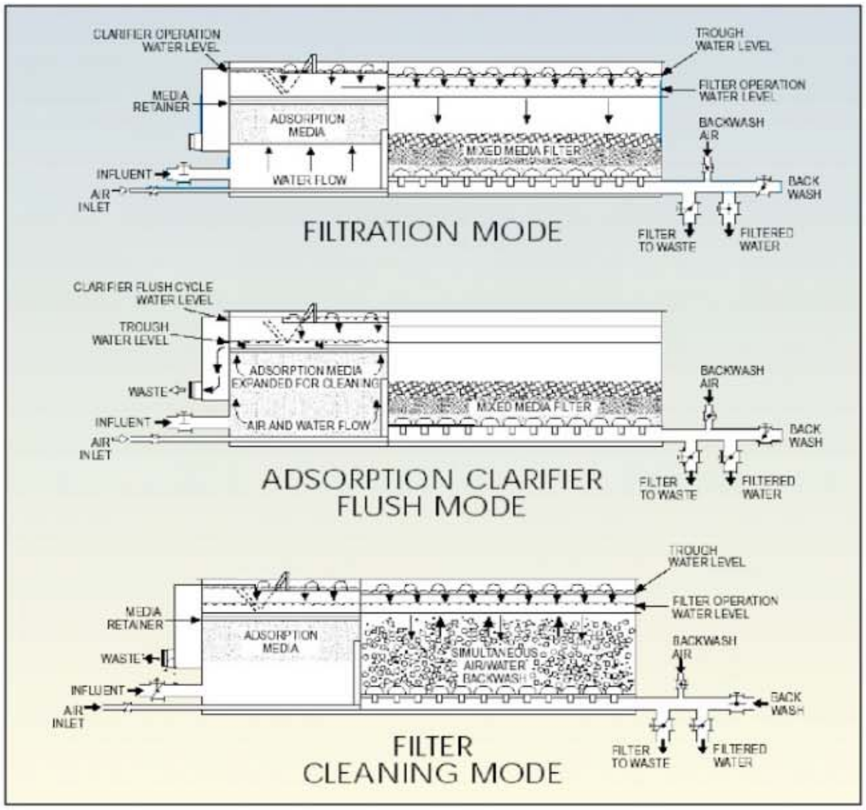

Figure 1. Filter stages. (source: www.wellswater.org)

After the filtration process, the water goes into a "clear-well" where chemicals are added to properly treat the water. The clear well generally utilizes end-suction centrifugal pumps which transfer the water from the filter tanks into the clear well. Again, depending upon demand, these transfer pumps will operate at different rates. Typically these pumps are selected for lower heads and higher flows. In the plant example, the maximum horsepower of these pumps would be 20 horsepower (hp).

The transfer pumps fill the next stage, which is known as the clear well. The clear well is used to stage the filtered and treated water before distribution. This well provides different chemicals and additives. A wet well typically uses submerged turbine pumps (Figure 2) to provide the necessary flow and pressure to reach storage reservoirs and to feed the distribution system. The plant example above uses one 60 hp and two 100 hp pumps that operate as needed, depending upon demand. The distribution system pressure leaving the plant is approximately 85 pounds per square inch (psi). Each pump is brought online in sequence via a remote SCADA (Supervisory Control and Data Acquisition) system. During this process the water may be injected with further chemicals and is monitored before entering the distribution system.

Figure 2. Vertical turbine pumps in clear well.

The distribution system will generally contain a storage reservoir at the highest elevation point in the system for gravity feed, and an extensive network of large diameter piping. The main lines are then reduced down to smaller zone lines which feed street level lines. At further reaches of the network, multi-pump booster stations may be required to provide additional pressure boost to outlying customers.

In this example the distribution network stretches in a nine mile radius from the treatment plant using 12" and 10" main lines. It has a 3 million gallon storage tank at an elevation of approximately 80 feet to the fill point.

There are many more facets to a water treatment facility than above. However, the largest pumps are typically used to bring raw water into the plant and distribute the clean water through the distribution system.

III. 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 (including energy costs), maintain, and dispose of all components of the system. Used as a comparison tool between possible design and 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 water facility 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[2].

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 smaller pump and motor, thereby reducing both initial purchase costs and life cycle costs. In many typical pumping systems though, approximately 75% of the total life cycle cost stems from energy and maintenance costs. (This can 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. See Figure 3.

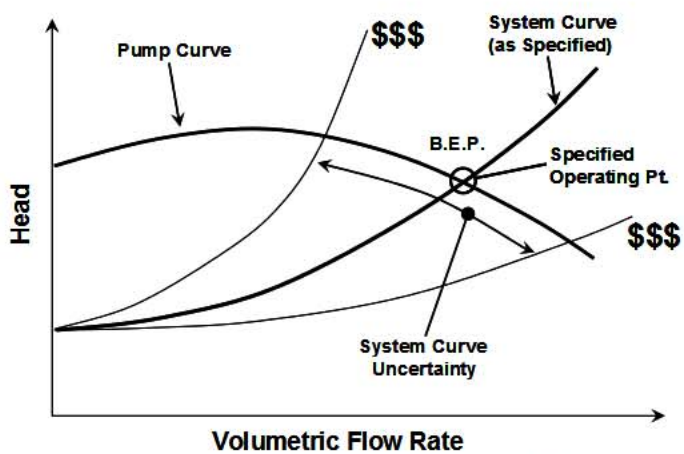

Figure 3. Pump system curve uncertainty[3].

As pump operation moves away from the Best Efficiency Point (B.E.P.), the energy and maintenance costs will increase and the expected life of the pump will be reduced. A simple calculation can be made to determine Brake Horsepower (BHP):

$$\mathbf{BHP} = \frac{\mathbf{GPM \times TDH}}{\mathbf{3960 \times Pump\ efficiency}}$$

where GPM = gallons per minute at the best efficiency point
TDH = total discharge head (measured in feet)
3960 = conversion factor

From this equation it can be seen that a pump efficiency difference of just a few percentage points (e.g. 74% versus 80%) can have a significant impact on pumping power requirements and energy use. It is critical then to not only install the most efficient pump, but also to match the pump performance accurately to the pump system curve.

IV. Opportunities for upgrade

A majority of the water treatment facilities in the U.S. are already in operation and are well-established. This population of plants provides opportunities for upgrading existing equipment and processes. The first step should be to examine the current pump efficiencies according to system head curves. As indicated previously, the main pumps that bring the raw water into the plant and those that provide overall distribution flow are typically larger horsepower turbine pumps. These pumps are critical to overall pumping performance and consume the largest percentage of energy for the entire facility. When planning to upgrade from existing outdated equipment, the complete efficiency of the pump and motor must be taken into account. This is typically referred to as the "wire to water" efficiency and uses the cumulative efficiency of both the pump and motor. How much does efficiency really matter? A great deal in the realm of payback is derived from energy costs. An example below shows a graph (Figure 4) with the following comparison of pump and motor efficiencies and operating data:

Flow (GPM)	TDH (ft)	Operation hours	cost per kWh
400	80	7920	$0.12

	Pump A	Pump B
Pump Efficiency	84 %	80 %
Motor Efficiency	92 %	86 %
Overall cost of pump/motor *	$5,000	$4,000

*Note: Assumes that installation and maintenance cost are the same.

Figure 4. Life Cycle Cost comparison (overall cost vs. months of operation).

The graph displays the overall operating cost (y-axis) as a function of the months in operation (x-axis) according to the performance data. Therefore, if the pump efficiency is just 4 percentage points higher (84%) compared to (80%), and the motor is 6 percentage points higher in efficiency (92% vs. 86%), the overall energy cost savings after 60 months would be $3,567. This example is based on an electricity rate of 12 cents/kWh (for simplicity, this value includes demand charges as well as consumption). An electricity rate just a few cents/kWh higher would increase this savings dramatically. Below is the breakdown comparison for operating data on pump A versus pump B.

	Pump A	Pump B
Overall Efficiency of Pump & Motor (%)	77.28%	68.80%
Required Brake Horsepower (hp)	9.62 hp	10.1 hp
Energy Usage (kWh)	5146 monthly, 61756 annual	5781 monthly, 69367 annual
Cost of Energy Consumed ($)	$618 monthly, $7411 annual	$694 monthly, $8324 annual
Cost per 1000 Gallons ($)	$0.039	$0.044

This example illustrates how pump and motor efficiency has a noticeable effect on energy consumption over the lifetime of the pump system. Of course, considering just the pump and motor efficiencies while ignoring the rest of the pumping system can result in significant lost opportunities for energy and life cycle savings.

Another opportunity for energy savings that has become increasingly more affordable is the use of Variable Frequency Drives (VFD) or Variable Speed Drives (VSD) for the pump system[4]. A variable speed drive can automatically adjust the speed of the pump motor according to performance conditions. The VFD, the most common type of variable speed drive, uses electronics to vary the frequency and voltage to the motor according to the system requirements, through a pump controller or via a SCADA system. Some of the benefits of using a VFD include:

1) Increased operating control and flexibility.
2) Reduced energy consumption at non-peak times.
3) Complete motor protection and diagnostics.
4) User interface and system integration
5) Soft starting and stopping.
6) Reduced equipment wear.

The use of drives has become more prevalent because of the energy costs associated with pumping systems and the fact that drives are becoming more affordable when compared with conventional fixed speed systems. To find out why a VFD will reduce energy consumption, one must first look into the affinity laws of centrifugal pumping.

For centrifugal pumps (e.g. vertical turbine, end suction) the performance of the system can be determined by using the "Affinity Laws". By utilizing these, one can determine the theoretical load requirements and potential energy savings. Referring to Figure 5, the first curve shows that rate of flow varies linearly with speed. When one decreases pump speed to 50%, the flow decreases to 50%.

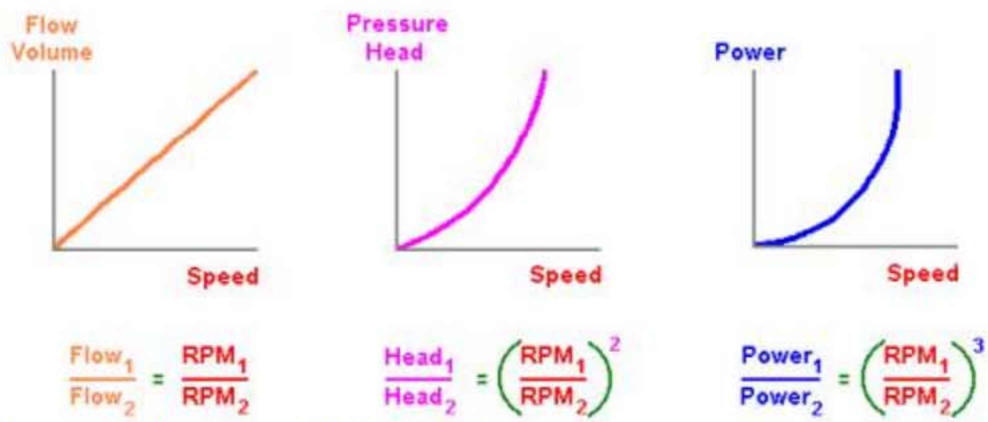

Figure 5. Illustration of Affinity Laws

The second curve shows that head varies as the square of speed. At 50% speed, rate of flow will be 50%, but the head is only 25% based on this relationship.

The third curve shows the power required for a particular flow requirement. where energy varies as the cube of speed. If speed is set to 50% of full speed, the rate of flow will be 50%, head will be reduced to 25%, and we consume only 12.5% of the full speed power. Therefore, the potential for energy savings as the flow requirement changes is tremendous. During non-peak loads in a plant, the drive reduces the speed of the pump motor to meet the lower demand, thus reducing the horsepower and overall electricity usage. When demand increases, the VFD adjusts the speed of the motor to accommodate the larger load. This operation has even greater impact during peak load time because with constant speed operation, it is quite costly to start a 100 hp motor due to peak demand penalties that arise from high in-rush amperage. A VFD is a soft starting device and will not allow the motor to exceed its full load amp rating. What this means to the operating plant is that the utility company will charge less for starting the larger horsepower turbine pumps with VFDs installed. Starting the pump motors with across the line starters can create in-rush current of over 600% of rated full load amps.

Figure 6 illustrates how pump horsepower at full speed with the use of a throttling valve compares to a pump connected to a VFD. The blue (upper shaded) area is the required hp for a pump operating across the line with a flow control valve versus the gray (lower shaded) area which is the hp required when operating the same pump with a VFD. With the use of drives the valves can often be eliminated to not only reduce the overall friction loss in the system but also decrease the number of the mechanical devices, each requiring its own procurement, installation, and maintenance costs. If the valves are operated pneumatically, the compressed air requirements to operate the valves can be eliminated as well.

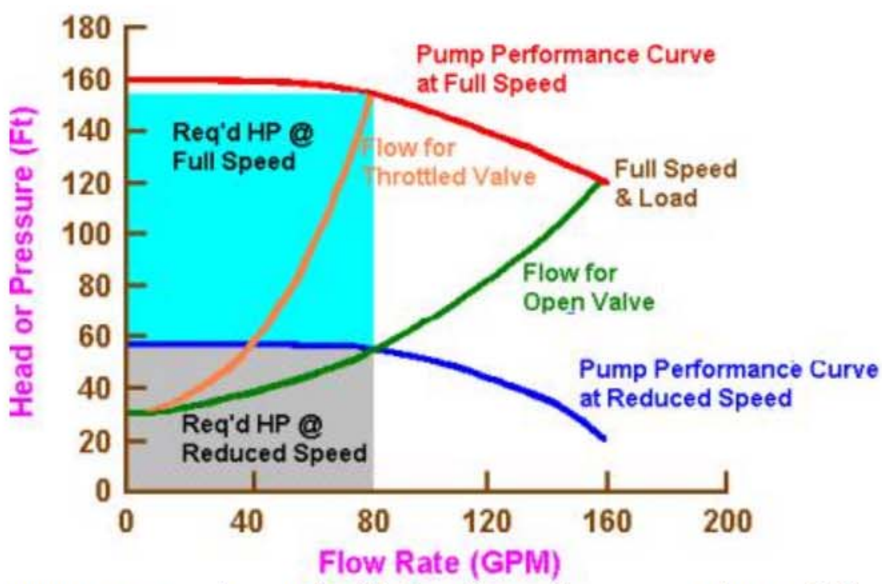

Figure 6. Speed control with throttling valve compared to variable speed control.

As drives are now more reliable and easier to use in plant SCADA systems, they are clearly becoming a significant source for realized energy savings and reduction in operating expenses for the pump system. Many electric utilities provide incentives and energy rebates to facilities that upgrade with energy efficient motors and variable speed drive systems.

Additionally, 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.

Consideration of component upgrades such as VFDs and higher efficiency pumps and motors is just one aspect of a systems approach to pumping system optimization. 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. The references provided following the conclusion of this paper are suggested for addition reading on the systems approach.

V. Conclusion

The overall energy consumption of a water treatment plant is a significant portion of operating authorities' budgets. For water systems owned and operated by the local municipalities, taxpayers bear the burden of unnecessary operating expenses. To focus on real energy savings within the plant it is vital to understand the pumping system network. Knowing the true system requirements at peak and non-peak loads and understanding the benefits of efficiency for the pump and motor play key roles in minimizing energy consumption. Properly applying speed control can also contribute to significantly reducing peak operating cost and improving overall system response. Applying a systems approach to pumping systems optimization and using life cycle cost analyses will benefit all parties involved with the water treatment plant. The idea of "green thinking" should be part of the system just as much as the quality of water that is produced.

VI. Acknowledgements

Some of the data contained in this document was obtained from an actual water treatment plant, which should be recognized for its time and dedication to clean water:

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Additional information on the application of life cycle costing methodologies can be found in Reference 2.

Additional information on identifying pumping systems optimization opportunities can be found in Reference 4.

VII. References

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