CASE STUDY

Illinois EPA Wastewater Treatment Plant Energy Assessment Program

Water Pumping Efficiency Technical Tip

Fluid pumping is a major component of many water and wastewater plants' energy consumption. For most potable water plants, pumping is the largest energy consumer, or next largest after heating. For wastewater plants, pumping is commonly the second highest energy consumer after aeration energy, though the percentage can vary widely depending on the process and plant.

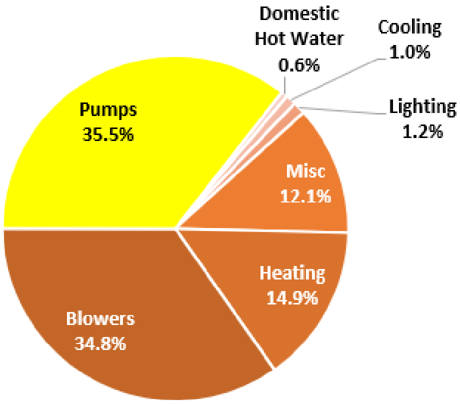

Figure 1: Wastewater Plant Energy Breakdown

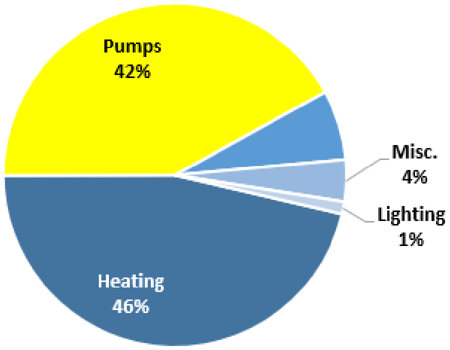

Figure 2: Potable Water Plant Energy Breakdown

Overview of Water Pumping Efficiency

Many plants are reducing energy consumption by implementing variable speed control of pumps for well and discharge pumps for drinking water plants, and pumps that push sewage into, or recycle sewage between, processes within water resource recovery and wastewater treatment plants. A common strategy for variable frequency drives (VFDs) on pumps in parallel is to run one pump until it has reached full capacity and is running at 100%, before a lag pump turns on and both modulate down to a speed matching the current flow demand.

If flow demand continues to rise, the two pumps will then both speed up to 100% before a third pump turns on and all three pumps will modulate to the same minimum required speed to match the flow. In general, good pump design will use the minimum number of pumps needed to meet flow demand, as running two pumps when one will do introduces additional inefficiencies from the pump, motor, and frictional losses. While this is a common and simple strategy for pump control, it is often not the optimal design to maximize energy efficiency at the transition point between operating one pump vs. two pumps.

Each pump and system have unique curves that relate fluid flow to resistance to flow in terms of pressure. Pump curves generally start with high pressure at zero flow, and pressure drops as flow increases. System curves usually start at lower pressure at zero flow, known as the total static head, and increase in pressure as flow increases, called the dynamic head. These two sets of curves interact to determine how pumps and systems respond to changes in flow rate. For many pumping systems, it is often beneficial to start a second pump before the first pump reaches 100% speed to maximize overall energy efficiency.

Splitting flow across two pumps can slightly reduce the dynamic head caused by higher flows in piping. One pump running at 100% speed will push 100% of its flow through the single pipe the pump is connected to, causing greater frictional resistance to flow. By running two pumps, flow is divided between two pipes, which reduces the flow rate through those pipes and the resulting frictional resistance to that flow. This reduces the total pressure in the system at the same flow rate, which reduces the power required. Figure 3 on the next page shows the difference between system curves for a single pump pushing 100% of flow through a single pipe and 2 pumps splitting the flow between 2 pipes, operating in parallel.

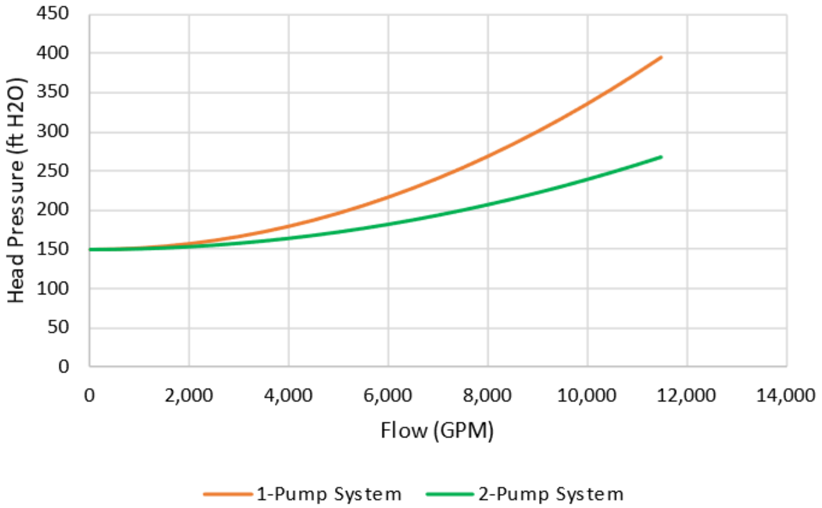

Figure 3: Single and dual-pump system curves, showing reduced head for 2 pumps operating in parallel.

Determining Optimal Staging Operations

To determine the optimal staging operation for a set of pumps, there are "smart" VFDs that are pre-programed with the head-flow curves for the pumps they control. This allows the VFD to calculate optimal speeds based on flow rate and pressure readings from the pipes the pumps are connected to. For systems that have high static head, as a pump slows down, the flow point on the pump's curve shifts to a less and less efficient point. This eventually increases the energy the pump consumes per unit of flow rather than reducing it. An example manufacturer's pump curve with impeller size curves in black and iso-efficiency curves shown in blue is shown in Figure 4, with an example system curve in green and variable speed pump curves in orange.

For most pumps, as shown in Figure 4, efficiency changes with impeller size. However, efficiency is nearly constant for any point along a pump curve due to changes in speed, at least until speed is reduced to less than 50%. In the example shown in Figure 4, the pump can only reduce speed to 73% before it reaches an unsafe operating point at surge conditions. Therefore, efficiency at any point along the pump curve is nearly the same as any point along the 100% speed curve.

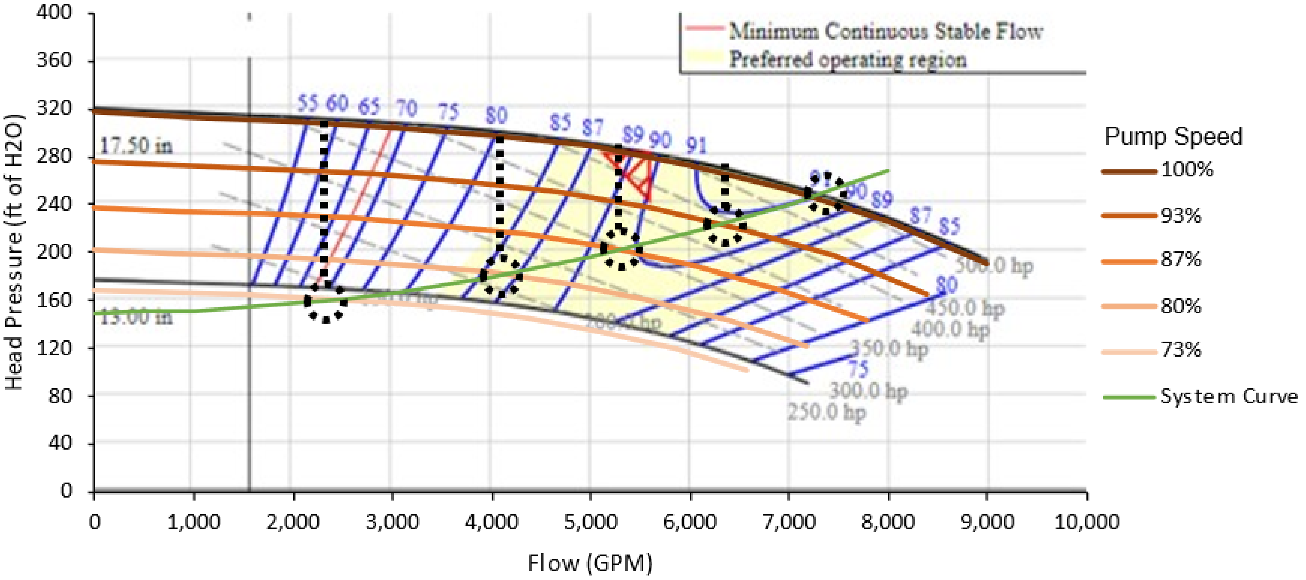

Figure 4: Pump and system curves showing pump efficiency curves.

In Figure 4 above, for this specific pump curve and system curve combination, maximum flow is close to peak pump efficiency, at around 7,300 gallons per minute (GPM), 245 ft of head, and 91% efficiency (top right dashed circle). This equates to a pump horsepower of about 500 HP. At 93% speed, peak efficiency is achieved at around 6,300 GPM, 220 ft of head with about 91.5% efficiency and pump horsepower of about 380 HP (Note: draw a vertical line from the system and 93% pump speed curve intersection up to the 100% speed curve to find the approximate pump efficiency). As the pump continues to reduce in speed, efficiency will continue to drop until around the surge condition at 73% speed, where the pump efficiency is about 60% and has a pump horsepower of about 170 HP (bottom left dashed circle). The dashed circles on the chart in Figure 4 indicate the operating point for each pump speed curve along the system curve. The dashed lines from each operating point back up to the 100% pump speed curve in the figure above show the approximate efficiency of the pump at each operating point. As you can see, trying to plot the efficiency of various operating points for a variable speed pump along a system curve can make for a very cluttered diagram!

An easier way to visualize the interaction between the pump curve, system curve, and efficiency is to plot a specific energy curve. For each point on the system curve where the variable speed pump curve intersects, a specific energy consumption can be calculated. Specific energy is determined by dividing the power input of the pump by the measured flow rate and can be listed in terms of kilowatt-hours per million gallons (kWh/MG) or horsepower per gallon per minute (HP/GPM). For the pump and system curves in Figure 4, the specific energy is plotted against flow in Figure 5. This plot indicates that this single pump consumes the least specific energy at around 3,750 GPM with a specific energy of about 0.0515 HP/GPM, or 2,300,000 kWh/MG.

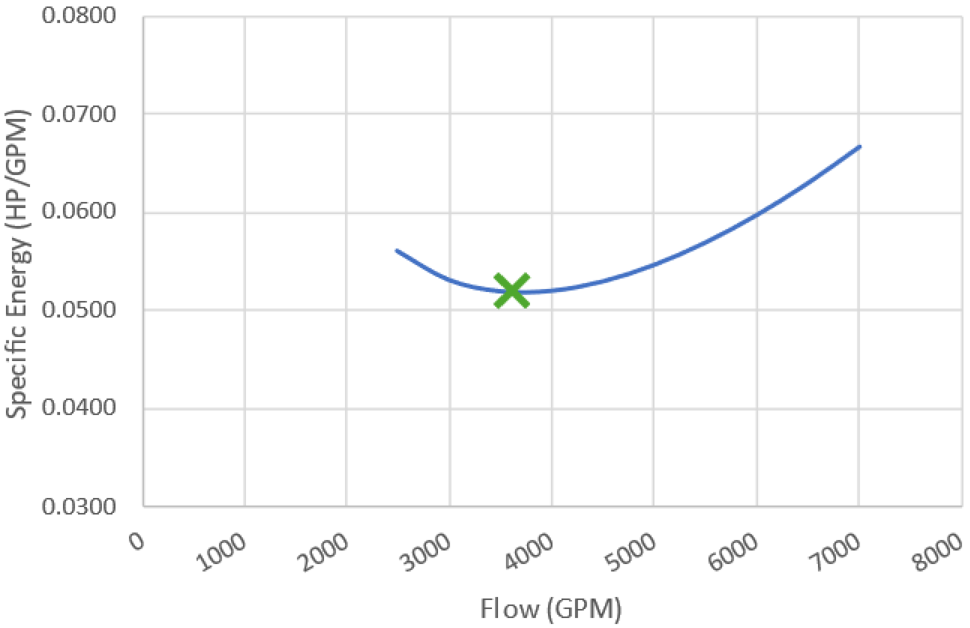

Figure 5: Specific energy curve for safe flow range in Figure 4.

So, what happens in a lead/lag pump situation where we have two pumps working together to meet variable flow rates? As we noted above in Figure 3, when a second pump is in operation, the frictional head pressure in the system is reduced since flow is split across a larger combined pipe cross-sectional area. This means there is potential to reduce specific energy consumption by turning on the second pump before the lead pump reaches 100% flow. In our example, we have two pumps of the same design as the pump in Figure 4 applied to the system curve from Figure 3. Figure 6 on the following page shows the single and dual-pump curves at full flow with their associated system curves.

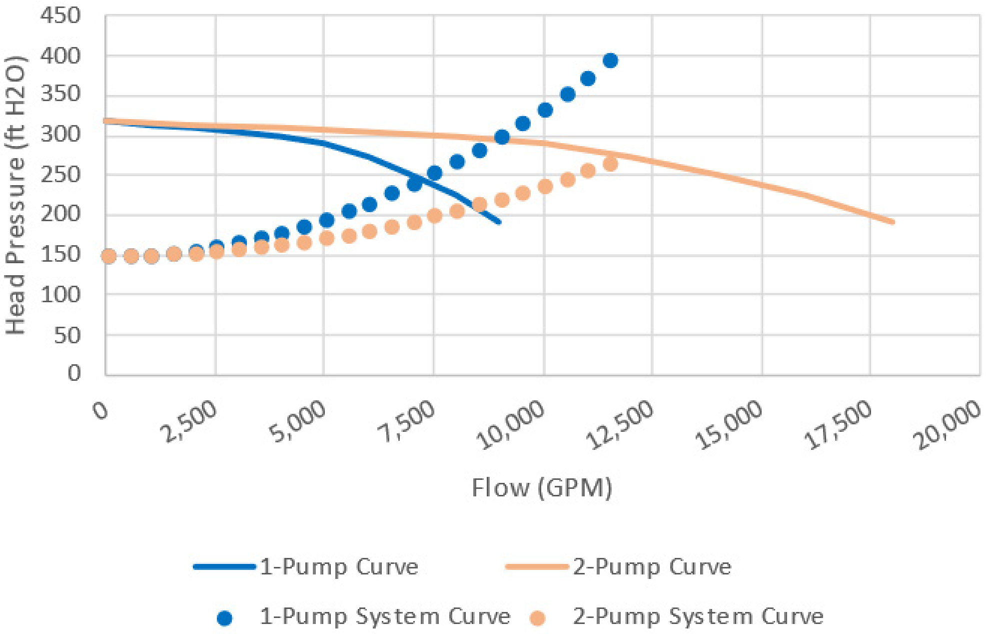

Figure 6: Combined lead-lag pump and system curves.

If we plot the specific energy curves for two cases, one where the lead pump runs up to 100% speed before the lag pump is activated, and one where the transition between single pump and dual pump operation is optimized, we get a specific energy plot like the one below in Figure 7. The specific energy is noted in terms of kWh/MG to show the total energy impact for optimizing control. Note in Figure 7 that the non-optimized switchover from 1 pump to 2 pumps happens at about 7,000 GPM, but the optimized switchover happens at about 6,000 GPM, or when Pump 1 is at about 85% of its full speed. The small hatched triangle between 6,000 and 7,000 GPM represents, on average, a specific energy savings of 167,000 kWh/MG.

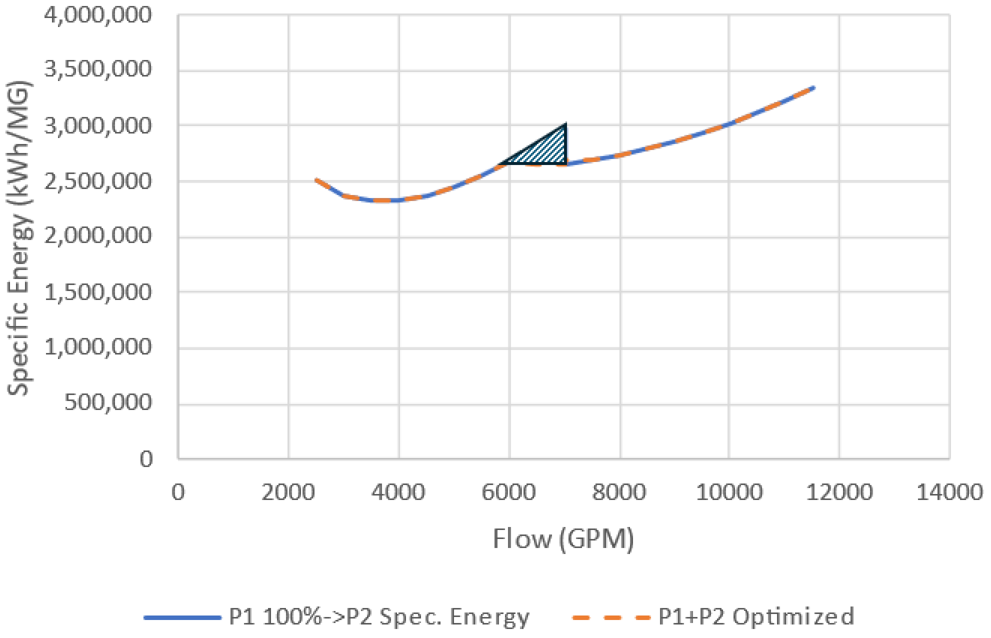

Figure 7: Specific energy use for unoptimized and optimized pump staging.

This example is based on pumps installed at a large 24 MGD plant with 500 HP motors, but the principles can apply to smaller systems as well. A similar analysis for a smaller pump system using 40 HP pumps in a lift station netted potential energy savings of 5,300 kWh/MG, not an insubstantial amount of energy.

For operators that already have VFDs but aren't sure if they can estimate their system curve accurately, they can manually estimate optimal operation for a pump system by calculating the specific energy of the pumps at various speeds and pump combinations. Power for the pumps can be determined from reading the amp draw from a VFD and multiplying that value by the voltage for the pump to get wattage. Flow readings can be obtained from the flow meters already in the plant for monitoring. From this data, operators can approximate the specific energy curves for the pump/system combination unique to their plant. Supervisory control and data acquisition (SCADA) software trending of these points will allow a plant to estimate the specific energy for various flow rates. By experimenting with different change-over speeds for single to multiple pumps, plants can gradually build out a specific energy curve like that shown in Figure 7 and determine if they're operating as efficiently as possible.

Pump optimization savings opportunities are highly specific to each plant, so potential savings vary widely in the industry. Get started today with optimizing your pump systems by reaching out to SEDAC for an energy assessment or help starting your own

Learn more about the program and apply now for your no-cost energy assessment now!
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