ABSTRACT

Large pump systems can provide significant ongoing opportunities for energy optimization. Tailored energy monitoring approaches are needed to alarm inefficient pump conditions and provide real-time diagnostic tools. An ideal energy monitoring approach directs operations and maintenance efforts toward strategies that provide the maximum energy reduction, while minimizing unnecessary maintenance on pump system components that are operating efficiently.

Many pumping facilities measure flow, pressure, and power consumption, but few take full advantage of the energy management value of this data. An initial energy audit can identify pumps that are experiencing long-term wear problems or are operating at an inefficient condition on the pump curve due to a change in operating conditions relative to design conditions. Following the initial audit and optimization work, pump operating data can be used to monitor long-term pump wear and efficiency degradation, and to provide detection of increases in pump energy use due to plugging or other abnormal conditions.

Pump operating data can be configured into a simple energy dashboard to alert plant engineering and management when pumping equipment is operating inefficiently. An energy trending system has been developed to allow plant engineering staff to set a pump performance target that adapts to varying flow conditions, and to monitor energy performance relative to the target.

A diagnostic system using discharge pressure and pump speed data was also developed to assist in determining whether pumps are using extra energy because they are fouled or because the piping is obstructed. This system compares day-to-day operating data with actual pump data from known optimized performance conditions. This approach to using operational and energy management data to provide clear energy performance and diagnostic trending is a powerful tool for improving energy awareness and optimizing energy performance in large pumping systems.

KEYWORDS  Pump Energy, Energy Monitoring, Energy Dashboard
INTRODUCTION

Many facilities monitor pump operating conditions, including energy inputs. However, in facilities with numerous large motors and variable load conditions it can be difficult to synthesize the data in a meaningful way to identify impaired equipment that is wasting energy. For example, raw power consumption may be monitored, but if flows and pressures vary, the resulting changes in power consumption can obscure underlying energy performance issues. Efficiency monitoring is sometimes used to mitigate this effect (Bunn, 2008), but a pump can operate efficiently while still wasting energy due to adverse head or excess flow conditions.

The goal of the pump energy monitoring system is to perform the following energy management functions:

- Identification of power consumption trends over time, detecting short-term or long-term loss of efficiency
- Quantification of efficiency loss due to pump component wear
- Identification of wasted energy due to increased system pressure restrictions
- Identification of wasted energy due to abnormal flow conditions
- Comparison of efficiency between pumps so that run hours can be biased toward the most efficient pump(s)

Two different energy monitoring systems focused on these goals are described in the following sections. Each monitoring system is tailored to detect the energy-wasting circumstances encountered within the specific pump installation. The first pump monitoring system was configured for a pump station serving an interceptor that conveys paper mill wastewater to a wastewater treatment plant. The second pump monitoring system serves an effluent pumping complex located within a large wastewater plant.

METHODOLOGY

Pump Station Energy Monitoring

An energy investigation was conducted on the three 500 hp pumps at the Western Lake Superior Sanitary District (WLSSD) Knowlton Creek Pump Station (KCPS Pump 1) near Duluth, Minnesota. Key findings from this investigation included the following:

- The pumps are prone to fouling by debris. In most cases the pumps continue to run, but the pump impairment consumes excess electricity overcoming the obstruction as shown in Figure 1.

- One impeller had a broken vane.

- The force main can be obstructed by air pockets when the air release valves (ARV) are plugged.
• Pump fouling and pump wear are observable in the pump operating data.

Based on these findings, it became clear that WLSSD could only achieve sustainable pump energy reductions if they had a monitoring system that could be used to alert staff to fouled pump and obstructed forcemain conditions.

KCPS instrumentation includes amp metering and a shaft tachometer for each pump. Flow and pressure metering is performed on the common discharge piping as the force main leaves the pump station (Figure 2).
Establishing Pump Power Performance Target  The key to the WLSSD KCPS power monitoring system is establishing an achievable “optimized” pump power performance target that is flow-paced over the range of pump station flow rates. In other words, as the pump station flow rate increases and decreases, the pump power performance target increases and decreases. Efficient pump performance will register at or below the power performance target and inefficient pump performance will register above the power performance target.

The pump power performance target was set based on historic pump flow and power data under clean pump and unobstructed force main conditions (Figure 6). A curve fit of the historic data was used to derive an equation that can be used to continuously generate an “optimum” power performance target based on the current station flow rate. For KCPS Pump 1, the curve fit equation for the pump performance target based on the measured station flow rate (MGD) is:

$$\text{Power Performance Target (kW)} = 0.2717 \times \text{Flow}^2 + 0.4799 \times \text{Flow} + 99.637$$

Note that the “Power Performance Target” is established based on operating data from the apparent best-performing pump, Pump 1, during its most efficient operating period. As depicted in Figure 2, recent operating data appear to indicate that Pump 2 and Pump 3 are less efficient than Pump 1. By using the best performing pump to set the power performance target, prolonged used of less-efficient pumps will be discouraged since their poor performance relative to the best pump will be detected by the power monitoring system.

Figure 3. Amp Metering Data Indicates That Pump 1 is the Most Efficient of the KCPS Pumps
The power performance target is compared to the corresponding real-time SCADA power reading to calculate the “Percent of Target” parameter used for energy monitoring and trending:

\[
\text{Percent of Target} = \frac{\text{SCADA Power Reading (kW)}}{\text{Power Performance Target (kW)}}
\]

Figure 5 illustrates the “percent of target” calculation for a sample data point taken from the 7/24/10 data set.
The “percent of target” parameter will allow WLSSD staff to easily assess pump energy performance. For example, if the pump power reading for a given hour is equal to the optimized pump performance target, the percent of target parameter will read 100 percent and pump energy performance will be considered on-target. If the percent of target parameter rises to 110 percent, the pump is using 10 percent more power than it should under current flow conditions, and remedial action should be taken. Experience may show that the alarm condition should be set lower than 110 percent to promote more timely operations response to poor pump performance.

High “percent of target” readings do not indicate that the pump system is experiencing high flow. Since the “percent of target” is based on a power performance target that corresponds with the current real time flow rate, the “percent of target” is always normalized for actual flow conditions. As a result, future increases in flow to the KCPS could drive station electrical consumption up without a corresponding increase in the “percent of target” parameter. The overall intent of the monitoring system is to track whether the KCPS pumps are operating in an energy efficient condition, regardless of short-term or long-term changes in pump flow rates.
The “percent of target” parameter also directly gauges improvements in pump performance. If future pump rebuilds or other efficiency improvements occur, the “percent of target” parameter should fall below 100 percent. For example, if the “percent of target” parameter is reduced to 95 percent following a pump improvement, this will indicate that pump energy consumption has been reduced by 5 percent relative to optimized conditions in 2010.

To demonstrate the utility of the “percent of target” power parameter concept, the method was applied to historic KCPS pump operating data. Data sets were received for the following periods for each of the three pumps:

- Before pump inspection and debris clearing
- Following pump inspection and debris clearing
- Following force main ARV cleaning

Trend data for the “percent of target” power parameter quantifies both the magnitude and duration of the energy efficiency improvement gained by these maintenance activities. Unfortunately, the data indicate that these particular pump energy improvements were modest and short-lived. For example, Figure 6 shows a 2-3 percent power reduction following the cleaning of Pump 3 in April 2010, lasting approximately 10 days. Presumably the pump was then re-fouled by new debris, causing power consumption to return to pre-cleaning levels. WLSSD is currently re-installing diminutor equipment to address this re-occurring pump fouling issue.

Energy alert and alarm conditions should be established using the “percent of target” parameter. Initially, 105 percent is suggested for the alert set point and 110 percent is suggested for the alarm condition. If the “percent of target” parameter is below 105 percent the pump system’s energy performance is considered to be acceptable and no alarm or alerts are generated. Figure 6 depicts the proposed goal, alert, and alarm set points. During the April-May time period shown in this trend Pump 3 was predominantly operating in the alert condition, with a couple of short-lived deviations above the 110 percent alarm threshold. Since these particular excursions were relatively short (1-2 days), no operator response would have been required. As noted previously, Pump 3 is currently less efficient than the benchmark pump (Pump 1), so “percent of target” values above 105 percent are typical for this pump.
Figure 7 indicates there was little discernable power reduction following the ARV cleaning in October 2010. Pump 1 operated near the “percent of target” efficiency goal of 100 percent both prior to the ARV cleaning (August 2010 data) and following the ARV cleaning (November 2010 data). Memo Section 4.2 below describes the use of the “percent of target” approach for pressure and pump speed as an adjunct to power “percent of target” trending. This additional monitoring step can help target maintenance activities such as ARV cleaning so that they occur only when force main restriction is detected through use of the pressure “percent of target” metric. Using this technique will minimize unproductive maintenance and maximize power reduction.
Pressure and Speed Performance Targets. A diagnostic system using discharge pressure and pump speed data was also developed to assist the WLSSD in distinguishing whether the KCPS pumps are using extra energy because they are fouled, or because the discharge piping is obstructed. Table 1 summarizes the general approach to using SCADA data to identify the root cause of energy inefficiency.

Shaft rotational speed is a useful surrogate gauge of pump efficiency since it is easily measured. If a pump is worn or plugged it speeds up to compensate for the performance impairment. However, a pump speed increase can also be the result of a high pump head condition. Thus, if pump speed must be considered in tandem with pump head to discern the cause of the speed increase. A pump speed increase without a concurrent pressure increase indicates likely pump impairment.

The pressure and speed diagnostic system uses a curve-fitting approach similar to the power monitoring approach described previously. Pressure and speed performance targets are based on optimized condition data for pressure and speed as shown in Figures 8 and 9.
Table 1
SCADA Conditions and Root Causes

<table>
<thead>
<tr>
<th>SCADA Condition</th>
<th>Root Cause(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High pump power consumption</td>
<td>Force main obstruction, pump impairment, pump wear</td>
</tr>
<tr>
<td>High pump speed</td>
<td>Force main obstruction or pump impairment</td>
</tr>
<tr>
<td>High pump head</td>
<td>Force main obstruction</td>
</tr>
<tr>
<td>High pump speed without high pump head</td>
<td>Pump wear or impairment</td>
</tr>
</tbody>
</table>

Figure 8. System Curve Data Used To Set Diagnostic Pressure Performance Targets
RESULTS

Figure 10 adds the pressure and speed parameter trends to the power “percent of target” trend presented previously in Figure 6. From these additional trends we can see that the pump cleaning allowed the pump to meet the flow requirements at a lower speed (until the fouling condition returned and the pump speed increased in tandem with the increasing power). Since the pressure trend was relatively steady during this time it is clear that the power reduction was associated with the pump cleaning and not a change in pressure conditions. Conversely, later in the month a 2-day spike in power corresponds to an increase in both pressure and speed, indicating that this spike was largely the result of increased pump pressure (in this case the result of the wet well level being temporarily reduced, increasing the pump’s static head).
Examining another period of historical data revealed some interesting trends. Figure 11 depicts the “percent of target” power trend for Pump 1 in July and August 2010. A prolonged period of excess power use in late July began following a pump cleaning and ended with a series of step-wise reductions in power in early August. The shape of the step-wise reductions includes a short upward spike followed by a dramatic downward step to an improved “percent of target” power condition. This step pattern repeats three times, with each step improving the pump’s power performance. What caused the high power condition and what could cause this step-wise improvement in energy consumption?

Figure 12 depicts the pressure trends for the same time period as the power trend in Figure 11. By comparing the power and pressure trends it can be seen that the increase in power consumption around 7/21/10 was the result of an increase in pump pressure. Elevated pressure conditions such as those shown in Figure 12 can be caused by either high static head conditions or high frictional losses due to forcemain obstructions. High static head is typically caused by a low wet well level. During the high pressure period from 7/24/10 to 7/28/10 at 3:00 pm and again from 8:00 am until 4:00 pm on 7/29/10 the station wet well level was 5.5 ft instead of the normal level of 9.5 ft. The 4 ft change in wet well level would be expected to increase the system pressure by about 7-8 percent at normal flow conditions, so the “percent of target” metric...
would similarly increase by 7-8 percent. During the 7/29 low wet well level period the percent of target rose to 107 percent as expected. During the 7/24 to 7/28 period the force main pressure seems to have also increased, since the increase in pressure “percent of target” is more than would be expected by just the wet well level change.

The end of the increased pressure condition coincides with a power and speed spike (Figure 13). Review of the raw operating data reveals that this power spike coincides with a rapid increase in flow, from 18.8 MGD at 4:00 am to 22.2 MGD at 4:30 am as the pump was stopped and restarted and the wet well level was reset to its normal level. There are two subsequent decreasing power steps which also correspond to similar abrupt flow rate increases. This data pattern implies that there may have been a clearing of force main air pockets or solids accumulations as a result of these episodes of abrupt flow increase.

Figure 11. “Percent of Target” for Power Elevated in Late July, Then Reduced in Early August
Figure 12. Percent of Target for Pressure Elevated due to Low Wet Well and Excess Forcemain Pressure
Initial Implementation Findings  WLSSD engineering staff adopted the benchmarking target energy monitoring approach for ongoing use within their plant SCADA system. Figure 14 shows a screen shot of the recent “Percent of Target” trends. In this data set duty is cycled twice between Pump 2 to Pump 1. Pump 1’s energy performance (shown in blue) is superior to Pump 2’s energy performance (shown in pink). In addition, there is a slight trend toward high forcemain pressures causing increased power consumption, despite efforts to clear air relief valve in early May.

The data in Figure 14 also show improved pump energy performance when a pump is initially started, with a general trend toward decreased performance as the pump remains on line. This effect is somewhat similar to the clearing effect observed in Figure 13 when the pump was stopped and started.
Figure 14. Energy Monitoring System Implemented in WLSSD SCADA System
PLANT WATER PUMP ENERGY MONITORING

Metropolitan Council Environmental Services (MCES) operates three 400 horsepower pumps supplying effluent water to incineration and headworks facilities at their Metro Plant in St. Paul, Minnesota. A pump audit of these pumps exposed the following energy issues:

- The pumps have lost efficiency due to wear.
- A large volume of pumped flow is being wasted due to a poorly functioning control valve on a condenser unit.
- Pump head is often maintained higher than necessary for process needs.
- Pump controls are not being used to automatically modulate pump speed for variable process conditions.
- Pumped flow is sometimes wasted via a “dump valve” due to the inability of the control system to match a reduction in flow demand.

MCES wanted a simple energy “dashboard” to monitor the energy performance of the effluent water pumps. The benefit of the dashboard would be to track improvements as the problems listed above are addressed. Similar to the WLSSD energy monitoring system, the monitoring system would also highlight any increases in daily pump energy use so that the root cause can be identified and mitigated.

The MCES pump situation differed from the WLSSD situation because MCES could realize electrical savings through water conservation and pressure optimization, whereas the WLSSD pump station’s flow and pressure were largely dependent on interceptor flow variations and force main geometry. As a result of this distinction, a simple power tracking system was proposed. This system established a fixed average daily power (kW) benchmark. Daily average pump power use is compared to the benchmark to track whether average daily power is increasing or decreasing relative to the benchmark. By establishing a fixed kW target, as opposed to the flow-paced kW target used for the WLSSD pump station, efforts to reduce excess effluent water use will be credited for their energy benefits since the daily average kW will decrease relative to the benchmark as the flow rate decreases. This dashboard system will also showcase improvements due to pump overhauls and system pressure reductions.

A recent set of effluent water pump dashboard monitoring data is shown in Figure 15. The monitoring data shows a small increase in average daily pump energy use following a series of incinerator downtimes. If proposed system optimizations are successful, a future decrease in the pump energy benchmark parameter should reflect the magnitude of the energy improvement gained. For example, a wear ring replacement might decrease the benchmark parameter to 95%, indicating a 5% reduction in pump energy use. In contrast to the WLSSD system, this reduction is a direct reflection of the reduction in electrical power consumption since the benchmark is not adjusted for flow variations.
CONCLUSIONS

A benchmark-based energy monitoring system was applied to two different types of pumping systems. For the collection system pump station with variable operating conditions, the energy monitoring benchmark was configured to be flow-paced so that daily pump energy performance could easily be monitored through the single “Percent of Target” parameter. For the effluent water pumping system, a fixed energy benchmark was used so that energy reductions due to flow conservation and pressure reduction strategies would be registered and plant staff would be incentivized to drive down daily average power consumption. Either of these two approaches could be widely adopted for trending energy performance in other large pumping systems. In pumping systems that are prone to fouling or force main obstructions, similar benchmarked monitoring of pressure and pump speed can be used to identify the root cause of poor energy performance.

The following management strategies are recommended to leverage the information gathered by the energy monitoring system into long-term energy minimization:
1. Choose a flow-paced or fixed benchmark based on individual pump system operating characteristics.

2. Utilize the monitoring system for large pump systems to increase the magnitude of potential energy benefits.

3. Incorporate a means to log maintenance activities, such as pump cleaning into the pump energy monitoring system so that the benefit of these activities can be assessed via inspection of the trend data.

4. Add an energy performance alert/alarm system in SCADA to notify operations and engineering staff when abnormally high energy use is occurring.

5. Assign one person from Engineering and one person from Operations to monitor energy alerts and alarms.

6. Set goals based on the “percent of target” energy metric (e.g. reduce average 2011 “Percent of Target” by 5% from average 2010 “Percent of Target”).

7. Bias pump hours toward pumps with the best “Percent of Target” performance.

REFERENCES:

Bunn, S, Hillebrand,C., (2008) Operating pumps to maximize efficiency and to minimize your carbon footprint or Save money, Save the planet, 2008 AWWA ACE Conference Proceedings