ABSTRACT

Wastewater collection system owners are becoming increasingly aware of their assets, operating costs, and maintenance needs. Pump station evaluations are a critical part of system owners’ operation and maintenance plans because they provide the necessary information to plan preventative maintenance, prioritize repairs, develop CIPs, and maintain asset management databases. When conducted properly, evaluations provide a comprehensive assessment of the condition of the station.

Numerous tools and methods are available for the evaluation of pump stations; however, some methods produce incomplete or inaccurate results. In response to this deficiency, Kimley-Horn has developed a complete pump station evaluation system, the XAQ-PAC (pronounced “Zak-Pack”), which allows a complete diagnostic of a pumping system. This system tracks all parameters pertinent to the performance of the pump station—such as flow, head, volts, amps, power factor, input horse power, output horsepower, and wire-to-water efficiency—are logged simultaneously. The key component of these evaluations is a unique device specifically designed by Kimley-Horn that can be used at virtually any pump station regardless of the controls and analytical components of the pump station. The data is complemented by a comprehensive condition assessment of the site and other equipment. With the information provided through Kimley-Horn’s pump station evaluations owners gain valuable information that will enable them to more effectively plan and manage their investments in pumping infrastructure.

This paper describes the necessary evaluation metrics and methods as well as Kimley-Horn’s approach to pump station evaluations using the XAQ-PAC. Information includes statistics from over 100 pump tests conducted for 10 municipalities in three states in North Carolina, South Carolina and Virginia. This paper will also include common and isolated deficiencies observed. The information contained in these evaluations allows system owners to better understand their equipment and make more informed long-term decisions about where to invest valuable resources.

KEYWORDS

Pumps, Evaluation, Wire-to-Water Efficiency, Pump Station Evaluations, Flow, Total Dynamic Head (TDH), horse power, data logging, condition assessment

INTRODUCTION

The objective of a pump station evaluation is to provide a comprehensive review of the condition and performance of a pump station. This review is accomplished through characterizing the state or condition of each critical component of the pump station and by collecting data on the performance of the pumps. The information and recommendations provided to the Owner are used in making decisions regarding capital upgrades, rehabilitation and replacement. When possible, improvements that will lead to increased efficiency and cost savings are included as part of the evaluation. The final result of a pump station evaluation is a summary report of the data, findings, and recommendations.
Pump station evaluations are conducted in many different ways utilizing numerous tools to collect varying results. Pump station evaluations typically consist of an assessment of the condition of visible components as well performance tests on each pump to determine pump operating conditions.

**METHODOLOGY – CONVENTIONAL**

Pump station evaluations methodology may vary some depending upon the type of pump station and the equipment; however, the general procedure for evaluating a pump station is as follows:

1. **Data Collection and Review** - Available data such as; record drawings, pump curves, logged data and previous pump tests, should be obtained and reviewed prior to performing the pump station evaluation. This allows for proper planning, setup and execution of the pump station evaluation. Information such as record drawings for the pump station and force main are critical for calculating hydraulics and provide necessary information on how instrumentation will need to be set up. Pump data sheets provide pump operating conditions and are also necessary to determine what type of instrumentation will be necessary for the evaluation.

2. **Condition Assessment** - The condition assessment is typically completed by an experienced engineer or technician who follows a pre-established list of parameters for visual inspection. These parameters are usually evaluated for each pump station on a numerical scale by scoring the condition of each component. Kimley-Horn and Associates, Inc. uses a one (1) to five (5) scale with one (1) being the best and five (5) being the worst. Table 1 provides the scoring system with descriptions of what each score means.

<table>
<thead>
<tr>
<th>Score</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Appear to be new or in like new condition and are properly installed. Failure is unlikely in the foreseeable future.</td>
</tr>
<tr>
<td>2</td>
<td>Component has minor defects and is unlikely to fail for at least 20 years.</td>
</tr>
<tr>
<td>3</td>
<td>Components have moderate defects. Deterioration may continue, but not for 10 to 20 years. Appear to be in fair condition with signs of deterioration that can or will lead to decreased functionality and/or failure.</td>
</tr>
<tr>
<td>4</td>
<td>Component has severe defects with the risk of failure within the next five (5) to 10 years. These items are typically recommended for rehabilitation or replacement in the near future.</td>
</tr>
<tr>
<td>5</td>
<td>Component has failed or is likely to fail within the next five (5) years. These items are typically recommended for immediate rehabilitation or replacement.</td>
</tr>
</tbody>
</table>

**Table 1 – Condition Assessment Scoring System**

Typical components included in a condition assessment are: site features, wetwells, structures, pumps, piping, valves, hardware, misc. mechanical devices, control panel, RTU, generator, wiring, conduits and misc. electrical.
3. **Pump Performance Test** - Pump performance tests are a critical component of a pump station evaluation. Conducting a performance test requires the use of multiple specialized tools and methods for collecting data and sometimes can require several people to operate. Below is a list of data that is necessary for a thorough evaluation of a centrifugal pumps performance.

- TDH in PSI or Ft of head (derived from suction and discharge pressures)
- Pump output in GPM
- Electrical input power in horse power including, current draw for each phase in amps, voltage for each phase in volts, power factor for each phase

The above parameters can be used with the equations below to calculate input horsepower, output horsepower and WTW efficiency.

\[
HP_{\text{in}} = \frac{E \cdot I \cdot PF \cdot 1.73}{746}
\]

\[
HP_{\text{out}} = \frac{Q \cdot TDH \cdot SG}{3960}
\]

\[
WTW = \frac{HP_{\text{out}}}{HP_{\text{in}}}
\]

Traditional pump performance testing methodology includes utilization of handheld tools and onsite instrumentation for data collection. For submersible sewage lift stations it is common to use a draw down test with a tape measure to calculate flow rate which can be highly inaccurate depending upon the circumstances. In general, limitations in measurement accuracy and human error often prevent accurate and/or thorough performance testing results. Some pumping system owners have SCADA and instrumentation such as pressure gauges, transducers and meters that allow for direct measurement of the performance parameters. However, these systems are often not installed or are inoperable and frequently have limitations such as:

- Frequency of data collection
- Reliability of sensors
- Dampening/averaging algorithms miss variations in measurements
- Loss of calibration
- Loss of signal
- Not installed on each pump
- Only provide part of the information required

Often pump station instrumentation and human measurements are insufficient to accurately measure individual pump performance. With some data sets the information is collected with minutes between measurements meaning that conditions can change significantly between the measurements. For example, if a power measurement is taken minutes after the flow and/or TDH measurements then the resulting WTW efficiency may not be accurate because of the time delay and changes between the readings. Since so many measurements must be taken to measure the performance of the pumps, a comprehensive system is necessary that can log data much more frequently than is humanly possible or than instrumentation is typically set up to log. For this reason Kimley-Horn developed the XAQ-PAC. The XAQ-PAC is an instrument capable of removing all of the human error and logging data
very quickly to capture changes in the conditions simultaneously across all parameters being measured. The XAQ-PAC is described in more detail later in the report.

4. Analysis of Results – Once all data is collected it should be reviewed and compared against the anticipated results based on the original design or calculations. If no design conditions are available, calculations of the systems hydraulics must be completed to determine the theoretical operating condition of the pumps. Any deviations between the measured results and theoretical or design values should be explained in the final report.

5. Conclusions and Recommendations - With any pump station evaluation conclusions can be drawn from the collected data. Conclusions will consist of the most significant observations and discoveries about the station. It is important to remember during the conclusions and recommendations step of the pump station evaluation process that Owners will likely use the recommendations to plan future improvements to the station. Only items that increase the station's efficiency, reduce likelihood of failure, save money or increase safety should be included in the recommendations.

**XAQ-PAC**

The XAQ-PAC is a custom built microcontroller based electronic device developed by Kimley-Horn for measuring the performance of centrifugal pumps. The XAQ-PAC uses an array of sensors to monitor all of the parameters necessary for measuring and calculating pump performance. All parameters are logged and displayed in real time simultaneously as the test is being performed.

The XAQ-PAC is a portable device that is set up on a site with the necessary sensors and each pump is operated under typical system conditions while the data is logged. During the operation of the pumps the engineer performing the test is free to make observations and does not have to record any data. A typical XAQ-PAC installation sketch for a submersible sewage pump station is shown below.

![Figure 1 – Typical XAQ-PAC Setup](image-url)
As shown in Figure 1 the major components to the typical set up for a submersible sewage lift station are as follows:

**Pressure Transducer:** This is typically set up on the discharge piping of the pump as close to the pump as feasible so that as much friction loss can be measured as possible. Any losses between the pump and the pressure transducer must be calculated based on the flow rate and the Hazen-Williams equation.

**Level Transducer:** This device is typically suspended over the liquid in the wetwell to measure the distance to the wetwell for calculating the volumetric displacement of the fluid. The volumetric displacement is used in conjunction with a time stamp to calculate a flow rate.

**Voltage Probes:** Three voltage probes are connected inside the pump control panel to each phase of the pumps power leads. The voltage probes collect voltage signals for the XAQ-PAC to use in calculating True RMS voltage levels as well as the frequency of the signals and the power factor.

**Current Transducers:** Three current transducers are connected inside the pump control panel on each phase of the pump power leads. The current transducers provide the current usage signals necessary for calculating the True RMS current usage as well as the power factor.

Additional inputs are available for sensors such as flow meters, tachometers etc.

**RESULTS**

**Condition Assessments**

Data collected from over 50 wastewater pump station condition assessments across three (3) states indicates that in most cases the older the pump station the worse the condition. Wastewater pump stations constructed before the year 2000 consistently scored at or above a three (3) in the majority of the component categories. Wastewater pump stations constructed after 2000 generally had low scores in most categories with the exception of hardware. When corrosive metals are used in wetwells or other structures exposed to sewer gases they corrode quickly. Based on field observations the average life expectancy of non stainless components such as bolts, hangers, brackets etc. is about 15 years. Stations older than 15 years also frequently exhibited signs of corrosion on the walls of wetwells with aggregate showing and becoming increasingly worse with age and concentrations of hydrogen sulfide gas. Electrical issues are common among stations older than 15 years. Based on our observations over time sewer gasses, moisture and frequent repairs result in failing and disorganized equipment. Components that are easily accessible without entering a confined space are generally better maintained with scores at or below a three (3).

**Pump Performance Evaluations**

The XAQ-PAC has been in use for almost two (2) years and has been used to measure the performance of over 100 pumps. Some of the most common deficiencies that we have observed are:

- Pumps operating near shutoff head or to the far left of the curve
- Undersized pumps/motors
- Force main headloss issues
- Installed pumps differing from record data

Figure 4 illustrates a pump data sheet with test results exhibiting all four of the common issues mentioned above.

Logging data continuously allows the engineer analyzing the data to see trends and irregularities in the data. Drawdown and rate of rise tests with irregular slopes should not be used in calculating flow rates unless the rate of change can be factored into the calculations. Factoring in rate of change is impossible...
without logging data frequently enough to accurately capture the rate of change. Making measurements by hand or by transferring readings from a display to paper cannot be completed fast enough to capture sufficient data for accurately describing rate of change during pump tests. Figure 3 shows liquid levels changing linearly indicating that there was minimal change in inflow and outflow during the tests. The inflection points where the pressures rise from static indicate where a pump was switched on and the distance from the transducer to the liquid level increased. Figure 3 also shows the surge wave in the force main as indicated by cyclic fluctuating pressure levels after the pumps are switched off. This type of cycle can be indicative of force mains with transition zones, malfunctioning ARVs and other problematic hydraulics. The test performed in Figure 3 had a drawdown of over 6.5 Ft. The measurement accuracy of the level transducer is ±0.25” meaning that a test with a drawdown of 6.5 Ft had an overall flow rate accuracy of 0.3%. The time accuracy is to the 100th of a second.

![Figure 2 – Liquid Level and Pressure Graph](image)

On numerous occasions, the XAQ-PAC has provided data indicating issues that are not easily observable such as; leaking check valves, surge issues, electrical problems, worn pumping parts, clogged pumps and more. One example of an electrical problem observed on a pump was a faulty contactor on one of the phases in a motor starter. Figure 3 below shows the current for the 3rd phase being much less initially until the contactor engaged fully after a few minutes of operation. This was not observable by personnel conducting the test other than through the data, decreased pump output was also observed during this period.
A NEW SPIN ON PUMP STATION TESTING AND ANALYSIS: WHAT YOU WISHED YOU KNEW ABOUT YOUR PUMP STATION

Figure 3 – Faulty Contactor Amperage Graph

Table 2 provides a summary of the data collected with all of the pump performance tests conducted using the XAQ-PAC.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Pumps Tested</td>
<td>119</td>
</tr>
<tr>
<td>Minimum WTW Efficiency</td>
<td>10.5</td>
</tr>
<tr>
<td>Average WTW Efficiency</td>
<td>40.5</td>
</tr>
<tr>
<td>Maximum WTW Efficiency</td>
<td>72</td>
</tr>
</tbody>
</table>

Table 2 – XAQ-PAC Test Results Summary Table

In the majority of cases there are pumps that will operate more efficiently than the existing pumps. In some cases the payoff associated with reduced electrical cost from a more efficient pump can justify the replacement of pumps. Payoff periods can be as low as five (5) years in some cases. In general more efficient pumps have less failures, wear, and require less maintenance than pumps operating inefficiently. Even though it is harder to quantify than electrical savings, there is an O&M cost to be saved by upgrading to more efficient pumps in some cases also.

CONCLUSION

Pump station evaluations are a critical part of system owners' operation and maintenance plans because they provide the necessary information to plan preventative maintenance, prioritize repairs, develop CIPs, and maintain asset management databases. When conducted properly, evaluations provide a comprehensive assessment of the condition of the station.

For the most accurate results a device such as the XAQ-PAC should be used in conjunction with an experienced engineer or technician to provide the most accurate and through pump station evaluation. Using an automated performance testing apparatus like the XAQ-PAC eliminates human error and provides more accurate results than conventional performance testing methods.
ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIP</td>
<td>Capital Improvement Plan</td>
</tr>
<tr>
<td>E</td>
<td>Electrical Potential (Volts)</td>
</tr>
<tr>
<td>FT</td>
<td>Feet</td>
</tr>
<tr>
<td>GPM</td>
<td>Gallons Per Minute</td>
</tr>
<tr>
<td>HP</td>
<td>Horse Power</td>
</tr>
<tr>
<td>I</td>
<td>Electrical Current (Amps)</td>
</tr>
<tr>
<td>PF</td>
<td>Power Factor</td>
</tr>
<tr>
<td>PSI</td>
<td>Pounds Per Square Inch</td>
</tr>
<tr>
<td>RTU</td>
<td>Remote Telemetry Unit</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
<tr>
<td>SG</td>
<td>Specific Gravity (1.01 for sewage)</td>
</tr>
<tr>
<td>TDH</td>
<td>Total Dynamic Head</td>
</tr>
<tr>
<td>WTW</td>
<td>Wire To Water</td>
</tr>
<tr>
<td>XAQ-PAC</td>
<td>Exact Acquisition for Pumps And Controls</td>
</tr>
</tbody>
</table>
A NEW SPIN ON PUMP STATION TESTING AND ANALYSIS: WHAT YOU WISH YOU KNEW ABOUT YOUR PUMP STATION

Figure 4 – Pump Data Sheet