Drinking Water Pump Station Design and Operation for Energy Efficiency [Project #4308]

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OBJECTIVES

Water utilities are increasingly focused on energy-efficient and environmentally sustainable solutions because of rising energy costs, energy security and reliability concerns, and greenhouse gas (GHG) emissions from energy usage. It is important that pump stations, which are major contributors to energy usage in drinking water systems, are designed and operated in a cost-effective and energy-efficient manner. The objective of this guidebook is to provide water utilities and water treatment practitioners with energy-efficient design and operational strategies for new and existing pump stations. The guidebook was developed to address the following topics:

- Pump design practices for energy efficiency
- Motor design practices for energy efficiency
- Variable frequency drive (VFD) applications for energy efficiency
- Piping, fittings, and valve impacts on energy efficiency
- Pumping system operation and control for energy efficiency
- Real-time pump efficiency monitoring tools and applications
- Life cycle cost (LCC) assessments of alternatives
- Energy savings and GHG emissions estimation protocols

BACKGROUND

Within a water utility, more than 90% of energy consumption can traced to water supply and distribution pumping. This energy consumption is also the single most significant contributor to greenhouse gas emissions. Thus, in order to minimize the energy consumption, the associated GHG emissions, and the overall operating cost of a water utility, the pumping systems need to be designed and operated in an energy-efficient manner. However, energy-efficient practices are often overlooked in pump design and operation. The traditional approaches to design and operations that lead to lower pumping system efficiency include:
• Overly conservative pump station flow and head design criteria
• Designing for a future demand that is not required today, and may never be needed
• Failure to define the flow criteria and the time duration of pump operation (e.g., no application of flow or water level exceedance data)
• Failure to optimize pump selection and design the pumps to operate within their preferred operating region (POR) for the most frequently-occurring flows
• Misapplication of throttling valves, by-pass flow control valves, or pressure-reducing valves to control flow and pressure
• Misapplication of constant speed and variable speed drives
• Utilization of overly conservative friction factors in estimating head loss, and utilization of unwarranted “safety margins” to design head of the pumps
• Reliance on theoretical “spreadsheet” calculations
• Designing based on optimizing pump efficiency at a single design point instead of considering the time of operation, efficiency, and energy consumption at all operating points along the pump characteristics curve
• Lack of pumping system data acquisition and monitoring instruments for existing pump stations to allow for benchmarking energy use over the actual operating conditions
• Lack of guidelines on how to optimize pumping system efficiency using lessons learned from case studies of new and existing pumping systems
• Overly complicated designs that utilize more energy than necessary to meet a performance specification

When the total life cycle cost of the pumping system equipment (e.g., pump, motor) is considered, the initial purchase price constitutes only a small fraction (typically less than 10%) of the life cycle cost compared to the energy costs (70% and greater). However, pumping system equipment is often procured based on a competitive low bid price without properly evaluating its energy consumption. In the case of existing pumping stations, pump efficiencies are often substantially lower than their originally installed efficiencies due to worn wear rings, worn impellers, and tuberculation build-up inside the pump. In consideration of the above-mentioned issues, this guidance manual was developed to provide a holistic approach for designing and operating a drinking water pump station in an energy-efficient manner.

APPROACH

The following tasks were performed in order to address the objectives of this project:

• A literature review summarized the current state-of-knowledge relative to energy-efficient pump station design and operations.
• A utility survey and a number of case studies were conducted to identify water industry needs, collect useful data from ongoing utility energy efficiency studies, and fill in the knowledge gaps identified in the literature review.
• This guidebook provides guidance specific to energy-efficient design and operation of drinking water pumping systems.
A software tool was developed as a companion to the guidebook to compare annual energy consumption, GHG emissions, and life cycle cost analysis of different design alternatives.

RESULTS AND CONCLUSIONS

Areas for potentially significant energy improvements were identified that will help pump station designers and operators increase pump station efficiency while concurrently reducing annual operating costs and GHG emissions. Major energy improvements and recommendations are presented below:

- Life Cycle Cost Evaluation: When discussing energy improvements and GHG reductions, the decision-making process should focus on energy consumption cost, and, by extension, operating costs. By implementing a life cycle cost analysis, which includes costs for purchasing, installing, operating, and maintaining equipment over its lifetime, the most cost-effective option can be determined. This should be the principal method for cost-based alternative analysis and prioritization.

- System Design: Pump systems that are designed using overly conservative assumptions of flow, pipe friction factor, and head margins result in oversized pumps, which operate at a lower wire-to-water efficiency. Consider sizing the pump and/or impeller for the near-term flows with provisions to modify the pump for future flows.

- Pump Selection: Pump systems that are designed based on optimizing pump efficiency at a single design point instead of considering the time of operation at all operating points can lead to an inefficient selection of pumping equipment. Single design point methods fail to consider that many pump systems’ operating points vary in service, to the extent that the single duty point will fail to identify the best life cycle design and pump selection. Pump design and selection should always favor pump selections and combinations that deliver the lowest life cycle cost, which is usually the most efficient option. In the case of multiple operating points, the selection process should consider the annual energy use where the number of hours of each operating point is taken into account.

- Number and Pump Size Determination: Pump systems that are designed to meet present and future flow demands are often designed with larger and fewer pumps operating over a wide range of flows. Pump systems are usually designed with efficiencies optimized for the highest expected flow requirement and under scenarios that are not expected to occur for many years into the future. The result is that the pumping system will be inefficient at the present operating conditions. Even when those future scenarios occur, the system will only achieve respectable efficiencies in the peak demand scenarios, which do not occur often. Consider station designs that are scalable, such that they achieve respectable efficiencies in the mid-term and can be economically adapted to higher duties only as the need occurs. Variable speed drives are often the most economical way to achieve efficiency across the short, medium, and long terms. Pumps that are ill suited to the short to medium-term duties will have a poor service life.

- Drive Type Determination: When making a determination between different drive types, it may be easy for a designer to conclude that variable speed drives will always provide an energy-savings advantage over constant speed drives. However, a variable speed drive will not save energy unless the application, control strategy, sizing, and operational scenarios are tailored to improve specific energy consumption. To determine the most cost-effective
option, it is the best design practice to apply the energy use evaluation principles and life cycle analysis methodologies presented herein.

- Impeller Material Selection and Surface Roughness: Pump performance curves indicated in most manufacturers’ catalogs are based on impellers made of cast iron or bronze materials. Stainless steel impeller materials usually have 1 – 2% lower efficiencies than cast iron or bronze materials because of casting shrinkage. In addition, the surface roughness of the impeller, which can be improved by polishing or coating, also has an effect on efficiency. Consider these factors along with their associated life-cycle costs when determining the impeller design.

- Loss in Efficiency Due to Wear and Tear: Lack of testing and monitoring of pump performance could leave wear and tear items unnoticed. Wear and tear on a pump can reduce pump system efficiency and increase specific energy consumption. Increased clearance between wear rings due to wear can reduce pump efficiency from 1 – 10%. Repair of surfaces in contact with water can improve efficiency from 0.4 – 7%, depending on the size of pump. Consider adjusting or replacing wear rings to maintain original clearance between wear rings to restore original pump efficiency.

- Intelligent Controls: Pumps are normally controlled by flow, pressure, level, time clock, or via SCADA systems. There are new products available that are programmed to have the “intelligence” to monitor, calculate, and decide how to sequence or run the pumps so that they operate at the lowest specific energy consumption. Other control systems can be configured to upload the system curve and the pump curves. These systems can also be configured to receive the flow or pressure demand set point by the system, and “intelligently” look for the right combination (number, size, and speed) of pumps to operate at the best possible specific energy consumption. Designers and manufacturers are encouraged to implement these innovative methods.

- Efficient Motors: Premium-efficiency motors should be utilized instead of high-efficiency motors. Premium- or ultra-efficiency motors have even better efficiency than high-efficiency motors.

- Pump System Control Modifications: Pumping system control optimization is important for energy efficiency. For example, in an existing pump station with VFD, system efficiency can be significantly improved by providing a closer matchup of an existing pump to a new duty point or by migrating the duty point to one that has a better specific energy consumption. However, an energy benefit analysis between constant speed and variable speed options should be conducted based on the system demand characteristics in order to determine if a VFD is warranted.

- Energy Consuming Valves: Throttling and bypass of flow should be avoided, as it wastes energy and is rarely the most economical solution when a full range of options is available. Also, consider replacing fittings and isolation valves that have a high-pressure drop with ones that produce lower pressure drop.

- Pipe Size: An increase in pipe diameter of the distribution system can be an energy-efficient option to decrease pumping energy costs. However, trade-offs between energy savings and other economic considerations (e.g., capital investment) need to be assessed.

- Pump System Monitoring: Consider implementing real-time monitoring to map trends in specific energy consumption and schedule maintenance or replacement of pump equipment. Real-time monitoring can also reveal important system events, like when debris...
from a water main break has collected in the suction pipework of a pump, or a valve has partially closed due to vibration.

- **Water Distribution System:** The distribution system network should be analyzed using advanced hydraulic models in order to identify energy losses in different parts of the network. The concept of water network energy efficiency should be implemented to achieve the most energy-efficient system possible.

- **Energy Recovery:** Energy recovery technologies (e.g., hydro turbine, pump as turbine) should be considered to recover energy that is currently being wasted by throttling valves and pressure reducing valves.

- **Scheduled Maintenance and Repair:** Scheduled pumping system repair and maintenance should be conducted to restore efficiencies to near brand new condition. Then, the pumps should be monitored regularly to determine when the next pump refurbishment is required.

Specific information (percent energy savings) for each of the above-mentioned strategies is provided in this guidebook based on published literature, utility survey data, and information derived from case studies.

**RECOMMENDATIONS AND APPLICATIONS**

The guidebook describes best practices for the energy-efficient design and operation of pump stations. It discusses conventional problems responsible for inefficient energy consumption and identifies benefits and applicability of real-time monitoring principles and tools. The software tool developed in this study can be used to compare multiple alternatives for a new or existing pump station based on annual energy consumption, GHG emissions, and life cycle cost analysis. Both the guidebook and the software tool were informed by the extensive literature review and data gathered from the case studies conducted at a number of water utilities. Utilization of this guidebook and software tool should assist a utility in assessing and improving the energy efficiency of their pumping systems in order to achieve the following goals:

- Achievement of design function with the lowest possible energy use
- Operation of pumps at the best efficiency point (BEP) without any significant off-set
- Energy use minimization through application of variable speed drives when appropriate
- Design of facilities to enable periodic pump performance testing to achieve continuous energy efficiency improvements
- Investment decision-making based on life cycle cost analysis

**MULTIMEDIA**

The report includes a software tool that can be used to evaluate different design and operational alternatives based on annual energy consumption, GHG emissions reduction, and life cycle cost analysis. The tool can be found on the WRF Website on the 4308 project page under Project Resources/Web Tools.