# Energy Conservation Measures for Wastewater Treatment Facilities

An Online Continuing Education Course for Engineers

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**Credit: 7 Hours / 7 PDH / 7 CPD**

# Energy Conservation Measures for Wastewater Treatment Facilities

## 1. Energy Conservation Measures for Pumping Systems

### 1.1 Introduction

Pumping operations can be a significant energy draw at wastewater treatment plants (WWTPs), in many cases are second only to aeration. Pumps are used for many applications. At the plant headworks, they may be used to provide hydraulic head for the treatment processes. Within the plant, they are used to recycle and convey waste flows, solids, and treated effluent to and from a variety of treatment processes. Pumps are also found in remote locations in the collection system to help convey wastewater to the plant.

The overall efficiency of a pumping system, also called the “wire-to-water” efficiency, is the product of the efficiency of the pump itself, the motor, and the drive system or method of flow control employed. Pumps lose efficiency from turbulence, friction, and recirculation within the pump (WEF 2009). Another loss is incurred if the actual operating condition does not match the pump’s best efficiency point (BEP)[1]. The various methods for controlling flow rate decrease system efficiency. Throttling valves to reduce the flow rate increases the pumping head, flow control valves burn head produced by the pump, recirculation expends power with no useful work, and VFDs produce a minor amount of heat. Of these methods, VFDs are the most flexible and efficient means to control flow despite the minor heat loss incurred. Table 1-1 summarizes typical pump system efficiency values – note that inefficiency in more than one component can add up quickly, resulting in a very inefficient pumping system.

**Table 1-1. Pump System Efficiency**

| Pump System Component | Efficiency | | | |
|---|---|---|---|---|
| | Range | Low | Avg | High |
| Pump | 30 – 85 % | 30 % | 60 % | 75 %[1] |
| Flow Control[2] | 20 – 98 % | 20 % | 60 % | 98 % |
| Motor[3] | 85 – 95 % | 85 % | 90 % | 95 % |
| Efficiency of System | | 5 % | 32 % | 80 % |

1. For pumping wastewater. Pump system efficiencies for clean water can be higher.
2. Represents throttling, pump control valves, recirculation and VFDs.
3. Represents nameplate efficiency and varies by horsepower. See Section 1.4 for more information

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[1] BEP is the flow rate (typically in gallons per minute or cubic meters per day) and head (in feet or meters) that gives the maximum efficiency on a pump curve.

Inefficiencies in pumping often come from a mismatch between the pump and the system it serves due to improper pump selection, changes in operating conditions, or the expectation that the pump will operate over a wide range of conditions. Signs of an inefficient pumping system include:

- Highly or frequently throttled control valves
- Bypass line (recirculation) flow control
- Frequent on/off cycling
- Cavitation noise at the pump or elsewhere in the system
- A hot running motor
- A pump system with no means of measuring flow, pressure, or power consumption
- Inability to produce maximum design flow

Wastewater utilities should consider implementing pumping ECMs as part of a long-term pump testing and maintenance program. Pumps should be tested every two to three years to ensure that they are operating efficiently. Utilities should test for flow, head, and power consumption and then calculate efficiency for each pump system. If overall system efficiency is low (less than 60 or 70 percent for centrifugal wastewater pumps, less than 72 percent for clean water pumps[2]), a more detailed evaluation is warranted. This type of program can give the plant early warning when pump components are failing and can prevent catastrophic failures. It is important that all components be evaluated and addressed holistically so that the entire system is energy efficient. State and local requirements for redundancy (e.g., the common requirement that a pump station can pump peak flows with the largest pump out of service) and safety factors may limit available efficiencies in some cases.

### 1.2 Pumping System Design

Appropriate sizing of pumps is key to efficient operation of wastewater treatment plants. Pumps sized for peak flow conditions that occur infrequently or, worse, in the future towards the end of the pump's service life operate most of the time at a reduced flow that is below their BEP. Peak flow is typically several times greater than average daily flow and can be an order of magnitude different than minimum flow, especially for small systems or systems with significant inflow and infiltration (I&I). In some systems, these projected future flows are never reached during the design life of the pump.

For existing treatment plants, utilities should evaluate the operation of existing pumps and identify opportunities for energy reduction. A good starting point is to determine the efficiency of existing pumping systems, focusing first on pumps that operate for the most hours and have potential problems as identified by the bullet list in Section 1.1 (presence of bypass lines,

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[2] E-mail communication from Ken Henderson, September 8, 2010.

throttled valves, etc.). Plants should collect performance information on the flow rate, pressure, and delivered power to the pumps. Field measurements may be necessary if the plant does not regularly record this information. Pump and system curves can then be constructed to

determine the actual operating points of the existing system. Operating points more than 10 percent different than the BEP signal room for improvement.

To improve efficiency, utilities should consider replacing or augmenting large capacity pumps that operate intermittently with smaller capacity pumps that will operate for longer periods and closer to their BEP. When replacing a pump with a smaller unit, both the horsepower and efficiency change. A quick way to estimate the annual energy cost savings is to approximate cost before and after the improvement and determine the difference using the following equation:

$$\text{Annual Energy Savings (\$)} = [hp_1 \times L_1 \times 0.746 \times hr \times E_1 \times C] - [hp_2 \times L_2 \times 0.746 \times hr \times E_2 \times C]$$

*Eq. 1-1*

Where:

$hp_1$ = horsepower output for the larger capacity pump
$hp_2$ = horsepower output for the smaller capacity pump
$L_1$ = load factor of larger capacity pump (percentage of full load / 100 - determined from pump curve)
$L_2$ = load factor of smaller capacity pump (percentage of full load / 100 - determined from pump curve)
hr = annual operating hours
C = energy (electric power) rate ($ / kWh)
$E_1$ = efficiency of the larger capacity pump
$E_2$ = efficiency of the smaller capacity pump

See Example 1-1 for how the Town of Trumbull saved more than $1,500 per year by adding a small pump to one of its existing sewage pumping stations. When applied correctly, replacement of standard drives with VFDs can also yield significant improvements (see Section 1.3 for additional discussion).

For greenfield plants and/or new pump stations, utilities should consider and plan for staging upgrades of treatment capacity as part of the design process. For example, multiple pumps can be specified to meet a future design flow instead of one large pump so that individual pumps can be installed as needed, say at year zero, year ten, and year twenty. The State of Wisconsin’s Focus on Energy best practices guidebook (Focus on Energy 2006) estimates that staging of treatment capacity can result in energy savings between 10 and 30 percent of total energy consumed by a unit process.

***Example 1-1 Town of Trumbull, CT, Improves Efficiency at Reservoir Avenue Pump Station***

BACKGROUND: Wastewater from the Town of Trumbull, in southwestern CT, is collected and conveyed to a WWTP in Bridgeport via ten sewage pump stations. One of these, the Reservoir Avenue Pump station, consisting of two 40-hp direct-drive pumps designed to handle an average daily flow of 236 gallons per minute (gpm). Each pump was operated at a reduced speed of 1320 rpm at 50.3 feet of total dynamic head (TDH) with a duty point of approximately 850 gpm. A bubbler-type level control system was used to turn the pumps off and on. One pump can handle the entire peak inflow (usually <800 gpm) with the second pump operating only during peak flow conditions.

ENERGY EFFICIENCY UPGRADES: To reduce energy use, the town installed a new 10-hp pump and modified the system control scheme. The new pump handles the same volume as the original pump but operates for a longer time between standby periods. In addition, the speed control was eliminated and the original pumps, when used, are run at full speed of 1750 rpm. This allowed the impellers of the original pumps to be trimmed from 11.25 inches in diameter to 10 inches. The original pumps are used for infrequent peak flows that cannot be handled by the new 10 hp pump. Under normal operating conditions, the operating point for the new pump is 450 gpm at 40.7 TDH compared to 850 gpm at 50.3 feet of head for the whole system. Improvements were made to the lighting and control systems resulting in additional energy savings.

ENERGY SAVINGS: Annual energy savings were 17, 643 kWh from modifying the pumping system. Total energy savings were 31,875 kWh/yr, or approximately $2600/yr based on a rate of 8¢/kWh. Total implementation costs were $12,000, resulting in a simple payback of 2.6 years.

## 1.3 Motors

The cost of running electric motors can be the largest fraction of a plant's total operating costs. The Water Environment Federation (WEF) estimates that electric motors make up 90 percent of the electric energy consumption of a typical wastewater treatment plant (WEF 2009). Inefficient motors, operation outside of optimal loading conditions, and mechanical or electrical problems with the motor itself can lead to wasted energy at the plant and are opportunities for savings.

The percent energy savings resulting from replacing older motors with premium motors is modest, typically between 4 and 8 percent (NEMA Standard MG-1. 2006). Savings can be higher when energy audits reveal that existing motors achieve very low efficiencies, or when existing motors are oversized and/or under loaded. Many plants have coupled motor replacements with upgrades from fixed speed to variable speed drives for significantly higher energy savings. In general, upgrading motors is a conventional ECM that has been practiced at wastewater treatment plants for some time. Because the focus of this course is innovative rather than conventional technologies, this section contains only a brief overview of material.

### 1.1.1 Motor Efficiency and Efficiency Standards

Motor efficiency is a measure of mechanical power output compared to electrical power input, expressed as a percentage.

$\text{Motor efficiency} = P_m/P_e$
*Eq. 1-2*

Where:

$P_m$ = mechanical power output of the motor in Watts
$P_e$ = electrical power input to the motor in Watts (WEF 2009)

No motor is 100 percent efficient – all motors experience some power loss due to friction, electrical resistance losses, magnetic core losses, and stray load losses. Smaller motors generally experience higher losses compared to larger motors.

The United States Congress, in the Energy Policy Act (EPACT) of 1992, set minimum efficiency standards for various types of electric motors manufactured in or imported to the United States. Minimum nominal, full-load efficiencies typically range from 80 to 95 percent depending on size (i.e., horsepower) and other characteristics. Motors manufactured since 1997 were required to comply with EPACT standards and to be labeled with a certified efficiency value.

The National Electrical Manufacturers Association (NEMA) premium efficiency standard has existed since 2001 (NEMA 2006) as a voluntary industry standard and has been widely adopted due to its power (and thus cost) savings over EPACT 1992 compliance standards. The 2007 Energy Act raised efficiency standards of motors to NEMA premium efficiency levels and set new standards for motors not covered by previous legislation.

Submersible motors are commonly used in wastewater treatment plants. They serve specialized applications in environments that are not suited for NEMA motors. There is currently no efficiency standard for submersible motors and their efficiency is less than NEMA motors. Additionally, their power factor is usually lower. Their selection is usually driven by the application, though some applications have alternatives that use NEMA motors. Efficiency should be considered in the evaluation of alternatives in these applications as it affects the life-cycle cost used in the selection process.

Operating efficiency in the field is usually less than the nominal, full-load efficiency identified by the motor manufacturer. One reason for this is the operating load. As a rule of thumb, most motors are designed to operate at between 50 and 100 percent of their rated load, with maximum efficiency occurring at about 75 percent of maximum load. For example, a motor rated for 20 horsepower (hp) should operate between 10 and 20 hp and would have its best efficiency around 15 hp. Larger motors can operate with reasonable efficiency at loads down to the 25 percent range (USDOE 1996). Motors operated outside of the optimal loading lose efficiency. Other factors that reduce efficiency in the field include power quality (I.e., proper voltage, amps, and frequency) and temperature. Motors that have been rewound typically are less efficient compared to the original motor.

Accurately determining the efficiency of motors in service at a plant i hallenging because there
is no reliable field instrument for measuring mec everal methods are
available, however, to approxim se field measurements
and technical data in th ncy. Section 1.1.2
provides additional info

### 1.1.2 Motor Manage

Wastewater utilities shou ium motors instead
of rewinding older units w improvements at
the plant (see the text bo Motor replacement
is best done as part of a pl in program
development is to create a ry should contain
as much information as po eplate
information, and field mea , and operating
speed under typical operati plant managers
should conduct a motor rep place now and
which are reasonably efficie ilure.

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