ASME EA-2G–2010

(ANSI Designation: ASME TR EA-2G–2010)

Guidance for ASME EA-2, Energy Assessment for Pumping Systems

AN ASME TECHNICAL REPORT

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Guidance for ASME EA-2, Energy Assessment for Pumping Systems

A TECHNICAL REPORT PREPARED BY ASME AND REGISTERED WITH ANSI

ASME
SETTING THE STANDARD

Three Park Avenue • New York, NY • 10016 USA

Date of Issuance: September 24, 2010

This Guide will be revised when the Society approves the issuance of a new edition. There will be no addenda or written interpretations of the requirements of this Guide issued to this edition.

The American Society of Mechanical Engineers
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FOREWORD

This guidance document provides technical background and application details in support of the understanding and application of ASME EA-2, Energy Assessment for Pumping Systems. This guidance document provides background and supporting information to assist in applying the standard. The guidance document covers such topics as rationale for the technical requirements of the assessment standard, technical guidance, application notes, alternative approaches, tips, techniques, rules of thumb, and example results from fulfilling the requirements of the assessment standard. This guidance document was developed to be used as an application guide on how to utilize ASME EA-2.

ASME EA-2 provides a standardized framework for conducting an assessment of pumping systems. A pumping system is defined as one or more pumps and those interacting or interrelating elements that together accomplish the desired work of moving a fluid. A pumping system thus generally includes pump(s), driver(s), drives, distribution piping, valves, sealing systems, controls, instrumentation, and end-use equipment such as heat exchangers. Assessments performed using the requirements set by ASME EA-2 involve collecting and analyzing system design, operation, energy use, and performance data and identifying energy performance improvement opportunities for system optimization. These assessments may also include additional information, such as recommendations for improving resource utilization, reducing per-unit production costs, reducing life cycle costs, and improving environmental performance of the assessed system(s).

ASME EA-2 provides a common definition for what constitutes an assessment for both users and providers of assessment services. The objective is to provide clarity for these types of services that have been variously described as energy assessments, energy audits, energy surveys, and energy studies. In all cases, systems (energy-using logical groups of equipment organized to perform a specific function) are analyzed through various techniques such as measurement, resulting in the identification, documentation, and prioritization of energy performance improvement opportunities.

This Guide is part of a portfolio of documents and other efforts designed to improve the energy efficiency of facilities. Initially, assessment standards and guidance documents are being developed for compressed air, process heating, pumping, and steam systems. Other related existing and planned efforts to improve the efficiency of facilities include

(a) ASME Assessment Standards, which set the requirements for conducting and reporting the results of a compressed air, process heating, pumping, and steam assessments

(b) a certification program for each ASME assessment standard that recognizes certified practitioners as individuals who have demonstrated, via a professional qualifying exam, that they have the necessary knowledge and skills to apply the assessment standard properly

(c) an energy management standard, A Management System for Energy, ANSI/MSE 2000:2008, which is a standardized approach to managing energy supply, demand, reliability, purchase, storage, use, and disposal and is used to control and reduce an organization's energy costs and energy-related environmental impact

NOTE: ANSI/MSE 2000:2008 will eventually be superseded by ISO 50001, now under development.

(d) an ANSI measurement and verification protocol that includes methodologies for verifying the results of energy efficiency projects

(e) a program, Superior Energy Performance, that will offer an ANSI-accredited certification for energy efficiency through application of ANSI/MSE 2000:2008 and documentation of a specified improvement in energy performance using the ANSI measurement and verification protocol

The complementary documents described above, when used together, will assist organizations seeking to establish and implement company-wide or site-wide energy plans.

Publication of this Technical Report that has been registered with ANSI has been approved by ASME. This document is registered as a Technical Report according to the Procedures for the Registration of Technical Reports with ANSI. This document is not an American National Standard, and the material contained herein is not normative in nature. Comments on the content of this document should be sent to the Managing Director, Technical, Codes and Standards, ASME.

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Proposing Revisions. Revisions are made periodically to the technical report to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the technical report. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this technical report. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Attending Committee Meetings. The EA Committee holds meetings or telephone conferences, which are open to the public. Persons wishing to attend any meeting or telephone conference should contact the Secretary of the EA Standards Committee.

GUIDANCE FOR ASME EA-2, ENERGY ASSESSMENT FOR PUMPING SYSTEMS

1 GENERAL

1.1 Scope

This guidance document provides an application guide on how to utilize ASME EA-2, Energy Assessment for Pumping Systems. This guidance document provides background and supporting information to assist in applying the Standard.

1.2 Purpose

ASME EA-2 does not provide guidance on how to perform a pumping system energy efficiency assessment, but sets the requirements that must be performed during such an assessment. EA-2 was written in a form suitable for a standard, with concise text and without examples or explanations. This document was developed to be used in conjunction with the standard to give basic guidance on how to fulfill the requirements of the standard. This document is only a guide and does not set any new requirements. ASME EA-2 can be used with or without this document.

2 INTRODUCTION TO PUMPING SYSTEMS

2.1 Overview

Pumping systems are used widely worldwide to provide cooling and lubrication services, to transfer fluids for processing, and to provide the motive force in hydraulic systems. In fact, most manufacturing plants, commercial buildings, and municipalities rely on pumping systems for their daily operation. In the manufacturing sector, pumping systems represent 27% of the electricity used by industrial systems. In the commercial sector, pumping systems are used primarily in heating, ventilation, and air-conditioning (HVAC) systems to provide water for heat transfer and water pressure boosting of domestic potable water. Municipalities use pumping systems for water and wastewater transfer and treatment and for land drainage. Since pumping systems serve such diverse needs, they range in size from fractions of a horsepower to several thousand horsepower.

Pumping systems are essential to the daily operation of many facilities. This tends to promote the practice of oversizing pumps to ensure that the needs of the system will be met under all conditions. Intent on ensuring that the pumps are large enough to meet system needs, engineers who design pumping systems often overlook the cost of oversizing pumps and add more pump capacity than is necessary. Unfortunately, this practice results in higher-than-necessary system operating and maintenance costs. In addition, oversized pumps typically require more frequent maintenance than properly sized pumps. Excess flow energy increases the wear and tear on system components, often resulting in valve damage, piping stress, and excess system operation noise.

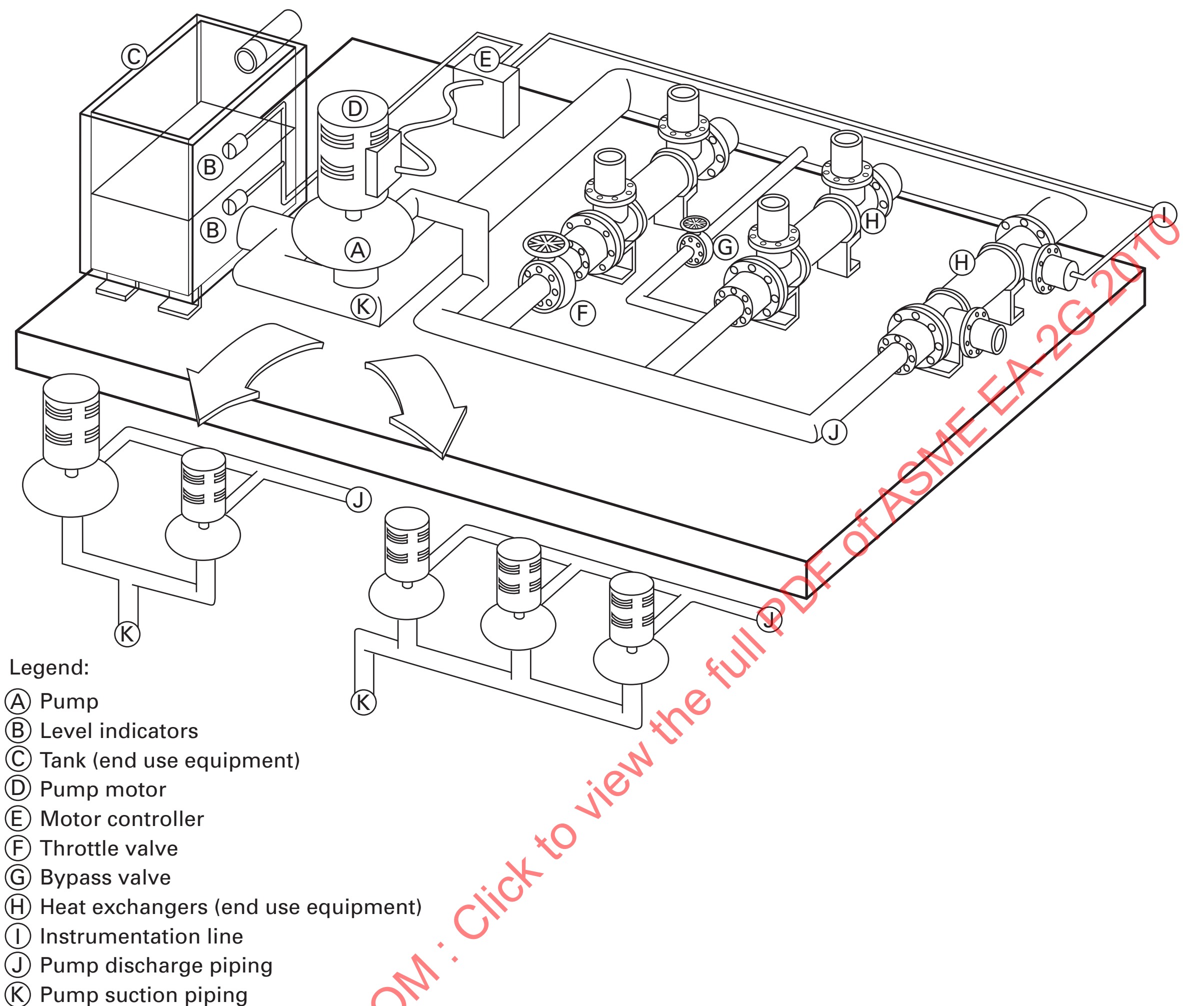
It is important to keep in mind that pumping systems are often parts of larger systems, such as complex industrial processes or HVAC systems. Therefore, potential impacts on the larger systems should be considered when evaluating pumping systems.

2.2 Components

Typical pumping systems contain five basic components: pumps, prime movers, piping, valves, and end-use equipment (e.g., heat exchangers, tanks, and hydraulic equipment). A typical pumping system and its components are illustrated in Fig. 1.

2.2.1 Pumps. Although pumps are available in a wide range of types, sizes, and materials, they can be broadly classified into the two categories: positive displacement (PD) and centrifugal. These categories relate to the manner in which the pumps add energy to the working fluid. Positive displacement pumps move a set volume of liquid per revolution or stroke, and pressure is developed as the liquid is forced through the pump discharge into the system. Centrifugal pumps work by adding kinetic energy to a fluid using a spinning impeller. As the fluid slows in the discharge passage of the pump, the kinetic energy of the fluid is converted into pressure. Centrifugal pumps include axial (propeller), mixed-flow, and radial types.

Fig. 1 Example Pumping System (Courtesy U.S. Department of Energy)



GENERAL NOTE: For source information, see reference [3] in Nonmandatory Appendix A.

Many factors are involved in the selection of appropriate pump technology. Primary among these are fluid characteristics and process requirements, but economics and experience also play important roles. Certain applications can be served by either positive displacement or centrifugal pumps, but since low viscosity fluids, for which centrifugal pumps are ideally suited, dominate process, commercial, and waste/water applications, centrifugal pumps are more common. When properly applied they are simple, safe to operate, and provide acceptable operating life.

Centrifugal pumps are also available in high flow rate designs and in systems that may be oversized, therefore making them prime candidates for energy assessments. Positive displacement pump designs are typically flow rate limited, and although a variety of fluids can be handled by available configurations, they are most frequently applied on viscous or specialty fluid applications. They further vary from centrifugal pumps by having the characteristic of constant flow rate at constant speed, and in properly designed systems require some pressure limiting device. Performance characteristics are best considered within the technology subcategories that are

(a) rotary: screw, gear, vane, lobe, flexible member, progressing cavity

(b) reciprocating: piston, diaphragm

Positive displacement pumps traditionally have high operating efficiency. However, proper system design using many techniques common to centrifugal pumping systems will provide energy reduction. Many PD applications are low power, but others have operating hours and power levels high enough to justify energy assessments.

Further, some applications have flow and fluid characteristics that warrant consideration of PD versus centrifugal technology based on comparison of system efficiencies.

Centrifugal pumps have a variable flow/pressure relationship. A centrifugal pump acting against a high-system pressure generates less flow than it does when acting against a low-system pressure. A centrifugal pump's flow/pressure relationship is described by a performance curve that plots the head (pressure) as a function of flow rate. Understanding this relationship is essential to sizing a pump properly and designing a pumping system that performs efficiently. For more information, see references [2] and [3] in Nonmandatory Appendix A.

2.2.2 Prime Movers. Most pumps are driven by electric motors. Although some pumps are driven by direct current (dc) motors, the low cost and high reliability of alternating current (ac) motors make them the most common type of pump prime mover. Energy-efficient motors are standard in today's marketplace, and "premium efficiency" motors are widely available in common sizes and enclosures. In high run-time applications, improved motor efficiencies can significantly reduce operating costs. However, the assessment's focus should typically be on a systems approach, where attention to systems issues such as component sizing, piping configuration, and maintenance practices typically identifies the greatest energy savings opportunities. A high efficiency motor usually operates at a higher speed than an older, less efficient motor. The pump might therefore create higher pressure and flow and consume more energy if no other changes are made to the system. When changing to a more efficient motor, system effects should therefore be taken into account.

Steam turbines and other devices, although much less common, are also used to power pumping systems.

2.2.3 Piping. Piping is used to contain the fluid and carry it from the pump to the point of use. The critical aspects of piping are its dimensions, material type, and cost. Since all three aspects are interrelated, pipe sizing is an iterative process. The flow resistance of a pipe at a specified flow rate is highly dependent on pipe size, and decreases as the pipe diameter gets larger. For example, increasing pipe diameter by 10% can result in a pressure drop of more than 60%. However, larger pipes are heavier, take up more floor space, and cost more than smaller pipe. Similarly, in systems that operate at high pressures (for example, hydraulic systems), small-diameter pipes can have thinner walls than large-diameter pipes and are easier to route and install.

Small-diameter pipes restrict flow, however, and this can be especially problematic in systems with surging flow characteristics. Smaller pipes also operate at higher liquid velocity, increasing erosion effects, wear, and friction head. Increased friction head affects the energy required for pumping.

2.2.4 Valves. The flow in a pumping system may be controlled by valves. Some valves have distinct positions, either shut or open, while others can be used to throttle flow. There are many different types of valves; selecting the correct valve for an application depends on a number of factors, such as ease of maintenance, reliability, leakage tendencies, cost, and the frequency with which the valve will be open and shut.

Valves can be used to isolate equipment or regulate flow. Isolation valves are designed to seal off a part of a system for operating purposes or maintenance. Flow-regulating valves either restrict flow through a system branch (throttle valve) or allow flow around it (bypass valve). A throttle valve controls flow by increasing or decreasing the flow resistance across it. In contrast, a bypass valve allows flow to go around a system component by increasing or decreasing the flow resistance in a bypass line. A check valve allows fluid to move in only one direction, thus protecting equipment from being pressurized from the wrong direction and helping to keep fluids flowing in the right direction. Check valves are used at the discharge of many pumps to prevent flow reversal when the pump is stopped.

2.2.5 Seals and Sealing Systems. The point at which the shaft penetrates the pump casing, known as the stuffing box, provides a leak path that must be sealed. This area is normally sealed using packing or mechanical seals. For systems in which fluid leakage is not a significant concern, packing is usually used because it is much less expensive and requires less sophisticated maintenance skills. Mechanical seals provide superior sealing, but they are typically more expensive and harder to repair or replace. Most pumps sold today are provided with mechanical seals.

Auxiliary systems are sometimes necessary to control the environment in which the seal operates. Seals in general are energy efficient devices, but the systems used to control their operating environment may be worth investigating to identify energy saving opportunities in some applications. ASME B73.1 and API 682 standards cover typical sealing system arrangements found in industry. Energy consumption of sealing systems can vary widely depending on the type.

2.2.5.1 Packing. There are two basic types of packing problems: overtightening and improper installation. Packing typically requires some leakage in order to remain lubricated and cooled. If packing rings are over tightened, friction between the packing and shaft will generate excessive heat, which can destroy the packing and possibly damage the shaft.

Since packing comes in direct contact with the pump shaft, it wears over time, increasing the leakage rate. Consequently, the packing gland must be periodically tightened to squeeze the packing against the shaft and keep leakage to an acceptable level. Improper packing installation leads to uneven compression of the packing rings (overtightening of one, insufficient tightening of others) or an overly loose fit between the packing and shaft. This often results in excessive leakage, which in turn can cause housekeeping problems (such as wet floors), high ambient moisture levels, and, if the fluid is toxic, contamination problems. If the fluid is expensive, leakage also has a direct economic cost.

2.2.5.2 Mechanical Seals. Mechanical seals are typically used in applications that call for superior sealing. The effectiveness of mechanical seals is highly dependent on correct installation and a continuously clean operating environment. Mechanical seals have two primary failure mechanisms: degradation of the face material and loss of spring or bellows tension, which allows the faces to separate more easily. Degradation of the seal face is usually caused by debris that wedges into a seal face and causes damage. To minimize the risk of this type of damage, mechanical seals are often serviced by special flushing lines that have filters to catch debris. Seal faces are held together by a force that is usually provided by springs or bellows. However, compressive properties are often lost because of fatigue, fouling, and/or corrosive environments, which degrade spring and bellows materials. To minimize fatigue loads on mechanical seals, the seal must be precisely aligned so that spring movement is minimal during each shaft revolution. For more information on mechanical seals, see reference [6] in Nonmandatory Appendix A.

2.2.6 End-Use Equipment. The essential purpose of a pumping system may be to provide cooling, to supply or drain a tank or reservoir, or to provide hydraulic power to a machine. Therefore, the nature of the end-use equipment is a key design consideration in determining how the piping and valves should be configured. There are many different types of end-use equipment, and the fluid pressurization needs and pressure drops across this equipment vary widely. For heat exchangers, flow is the critical performance characteristic; for hydraulic machinery, pressure is the key system need. Pumps and pumping system components must be sized and configured according to the needs of the end-use processes.

2.3 Principles

2.3.1 Design Practices. Fluid systems are usually developed to support the needs of other systems. For example, in cooling system applications, the heat transfer requirements determine how many heat exchangers are needed, how large each heat exchanger should be, and how much flow is required. Pump capabilities are then calculated based on the system layout and equipment characteristics. In other applications, such as municipal wastewater removal, pump capabilities are determined by the amount of water that must be moved and the height and pressure to which it must be pumped. The pumps are sized and configured according to the flow rate and pressure requirements of the system or service.

After the service needs of a pumping system are identified, the pump/motor combination, layout, and valve requirements must be engineered. Selecting the appropriate type of pump and its speed and power characteristics requires an understanding of its operating principles.

The most challenging aspect of the design process is cost-effectively matching the pump and motor characteristics to the needs of the system. This process is often complicated by wide variations in flow and pressure requirements. Ensuring that system needs are met during worst-case conditions can cause designers to specify equipment that is oversized for normal operation. In addition, specifying larger than necessary pumps increases material, installation, and operating costs. Designing a system with larger piping diameters can be cost effective when pumping energy costs are considered over many years of service. Reference [12] in Nonmandatory Appendix A provides additional information on piping configurations and pipe sizing.

2.3.2 Fluid Energy. For practical pump applications, the energy of a fluid is commonly measured in terms of head. Head is usually expressed in feet or meters, which refers to the height of a column of system fluid that has an equivalent amount of potential energy. This term is convenient because it incorporates density and pressure, which allows centrifugal pumps to be evaluated over a range of system fluids. For example, at a given flow rate, a centrifugal pump will generate two different discharge pressures for two different-density fluids, but the corresponding head for these two conditions is the same.

The total head of a fluid system consists of three terms or measurements: static pressure (gauge pressure), height (or potential energy), and velocity head (or kinetic energy).

Static pressure, as the name indicates, is the pressure of the fluid in the system. It is the quantity measured by conventional pressure gauges. The height of the fluid level has a substantial impact on the static pressure in a system, but it is itself a distinct measurement of fluid energy. For example, a pressure gauge on a vented tank reads atmospheric pressure. If this tank is located 50 feet (ft) above the pump, however, the pump would have to generate at least 50 ft of static pressure [for tap water, the gauge would have to read 21.7 pounds per square inch (psi)] to push water into the tank.

Velocity head (also known as "dynamic head") is a measure of a fluid's kinetic energy. In most systems, the velocity head is small in comparison to the static head. For example, the flow velocity in cooling systems does not typically exceed 15 ft/sec, which is roughly equivalent to 3.5 ft of head [if the system fluid is water, this velocity head translates to about 1.5 psi gauge (psig)]. The velocity head of a fluid must be considered when selecting pressure gauges, when designing a system, and when evaluating a reading from a pressure gauge, especially when the system has varying pipe sizes. A pressure gauge downstream of a pipe reduction will read lower than one upstream of the reduction, although the distance may only be a few inches.

2.3.3 Fluid Properties. In addition to being determined by the type of system being serviced, pump requirements are influenced greatly by fluid characteristics such as viscosity, density, particulate content, and vapor pressure. Viscosity is a property that measures the shear resistance of a fluid. A highly viscous liquid consumes more energy during flow because its shear resistance creates heat. Some fluids, such as cold lubricating oil (at less than 60°F), have viscosities that prevent centrifugal pumps from moving them effectively. As a result, the range of fluid viscosities over the operating temperatures of a system is a key system design factor. A pump/motor combination that is appropriately sized for oil at a temperature of 80°F may be undersized for operation at 60°F.

The quantities and properties of particulates in a system fluid also affect pump design and selection. Some pumps cannot tolerate much debris. And, the performance of some multistage centrifugal pumps degrades significantly if seals between stages become eroded. Other pumps are designed for use with high-particulate-content fluids. Because of the way they operate, centrifugal pumps are often used to move fluids with high particulate content, such as coal slurries and wastewater.

The difference between the vapor pressure of a fluid and the system pressure is another fundamental factor in pump design and selection. Accelerating a fluid to high velocities — a characteristic of centrifugal pumps — creates a drop in static pressure. This drop can lower the fluid pressure to the fluid's vapor pressure or below. At this point, the fluid "boils," changing from a liquid to a vapor. Known as cavitation, this effect can severely impact a pump's performance. As the fluid changes phase during cavitation, tiny bubbles form. Since vapor takes up considerably more volume than fluid, these bubbles decrease flow through the pump.

The damaging aspect of cavitation occurs when these vapor bubbles return to liquid phase in a violent collapse. During this collapse, high-velocity water jets impinge onto surrounding surfaces. The force of this impingement often exceeds the mechanical strength of the impacted surface, which leads to material loss. Over time, cavitation can create severe erosion problems in pumps, valves, and pipes.

Other problems that cause similar damage are suction and discharge recirculation. Suction recirculation is the formation of damaging flow patterns that result in cavitation-like damage in the suction region of an impeller. Similarly, discharge recirculation is the formation of damaging flow patterns in the outer region of an impeller. These recirculation effects usually result from operating a pump at a flow rate that is too low. To avoid this type of damage, many pumps are listed with a minimum flow rating. Operators must be particularly cautious in speed-regulated systems with high static head, to avoid operating the pump in inefficient regions of the system curve.

2.3.4 System Types. Like pumps, pumping system characteristics and needs range widely, but they can be classified in general as either closed-loop or open-loop systems. A closed-loop system recirculates fluid around a path with common beginning and end points. An open-loop system has an input and an output, as fluid is transferred from one point to another. Pumps that serve closed-loop systems, such as a chilled water system, typically do not have to contend with static head loads unless there are vented tanks at different elevations. In closed-loop systems, the frictional losses of system piping and equipment are the predominant pump load.

In contrast, open-loop systems often require pumps to overcome static head requirements as a result of elevation and tank pressurization needs. A mine dewatering system is one example; it uses pumps to move water from the bottom of a mine up to the surface. In this case, static head is the dominant pump load.

2.3.5 Flow Control. Flow control is essential to system performance. Sufficient flow ensures that equipment is properly cooled and that tanks are drained or filled quickly. Sufficient pressure and flow must be guaranteed to satisfy system requirements, creating a tendency to oversize pumps and the motors that run them. Because systems may contain flow control devices to regulate system temperature and protect equipment from over-pressurization, pumps that are oversized can burden these flow control devices with high-energy dissipation loads.

There are four primary methods for controlling flow through a system or its branches: throttle valves, bypass valves, pump speed control, and multiple pump arrangements. The appropriate flow control method depends on the system size and layout, fluid properties, the shape of the pump power curve, the system load, and the system's sensitivity to flow rate changes.

The most common way to control flow is to use a throttling valve. The valve restricts the flow passage and thereby creates a pressure drop. This means that the pump operating point moves up on the pump curve. There will be extra losses when the flow is forced through the valve and the pump efficiency will also change as the operating point changes. These two effects can be substantial, and the system efficiency can be very poor as a result.

Bypass lines allow fluid to flow around a system component. A major drawback of bypass valves is their detrimental impact on system efficiency. The power used to pump the bypassed fluid is wasted. In static-head-dominated systems, however, bypass valves could be more efficient than throttle valves or systems with variable speed drives (VSDs).

Pump speed control includes both mechanical and electrical methods of matching the speed of the pump to the flow/pressure demands of the system. VSDs, multiple-speed pumps, and multiple pump configurations are usually the most efficient flow control options, especially in systems that are dominated by friction head, because the amount of fluid energy added by the pumps is determined directly from the system demand. Pump speed control is especially appropriate for systems in which friction head predominates.

Both VSDs and multiple-speed motors provide efficient system operation by driving pumps at different speeds according to system needs. During a period of low system demand, the pump is operated at low speeds. The primary functional difference between VSDs and multiple-speed motors is the degree of speed control available. VSDs typically modify the speed of a single-speed motor through mechanical or electrical methods, while multiple-speed motors contain a different set of windings for each speed. VSDs are practical for applications in which flow demands change continuously. For more information on variable speed pumping, see references [3] and [16] in Nonmandatory Appendix A.

Multiple pump arrangements typically consist of pumps placed in parallel in one of two basic configurations: a large pump/small pump configuration, or a series of identical pumps placed in parallel. In the large pump/small pump case, the small pump, often called the "pony pump," operates during normal conditions. The large pump is used during periods of high demand. Because the pony pump is sized for normal system operation, this configuration operates more efficiently than a system that relies on the large pump to handle loads far below its optimum capacity. For more information on this type of pumping system configuration, see reference [3] in Nonmandatory Appendix A.

With a series of identical pumps placed in parallel, the number of operating pumps can be changed according to system demands. Because the pumps are the same size they can operate together, serving the same discharge header. If the pumps were different sizes, the larger pumps could dominate the smaller pumps and could cause them to operate less efficiently unless care is taken when programming the system operating scheme. If the proper pumps are selected, each pump can operate closer to its best efficiency point. An added flow control benefit of parallel pumps is that a system curve remains the same whether one or several pumps are operating; what changes is the operating point along this system curve. In systems dominated by friction, parallel pump configurations should be avoided, since the operating point for each pump will move up its curve as more pumps are started, which in turn will lead to inefficient operation of all the pumps.

Multiple pumps in parallel are, however, well suited for static head-dominated systems where starting or stopping additional pumps will not significantly affect system pressure. Another advantage is system redundancy; one pump can fail or be taken off line for maintenance while the other pumps support system operation. When identical parallel pumps are used, the pump curves should remain matched. Therefore, operating hours should be the same for each pump, and reconditioning should be done at the same time for all of them. For more information on this configuration, see references [3] and [5] in Nonmandatory Appendix A.

2.3.6 System Operating Costs. Pumps have varying efficiency levels. The operating point of centrifugal pumps at which their efficiency is highest is known as the best efficiency point (BEP). BEP efficiencies range widely, from 35% to more than 90%, and they are a function of many design characteristics. Operating a pump at or near its BEP not only minimizes energy costs, it also decreases loads on the pump and maintenance requirements. However, a high pump efficiency does not guarantee a high system efficiency.

The cost of over-sizing pumps extends beyond energy bills. Excess fluid power must be dissipated by a valve, a pressure-regulating device, or the system piping itself, which increases system wear and maintenance costs. Valve seat wear, which results from throttling excess flow and from cavitation, creates a significant maintenance problem and can shorten the interval between valve overhauls. Similarly, the noise and vibration caused by excessive flow creates stress on pipe welds and piping supports; in severe cases, this can erode pipe walls. The internal forces on an impeller of a throttled pump will also increase, leading to shorter seal and bearing lives. Note that, when designers try to improve a pumping system's reliability by over-sizing equipment, the unanticipated result is usually lower system reliability. This is caused by both the additional wear on the equipment and low-efficiency operation.

Energy is often the dominant component of system operational costs, but depending on the application, other factors such as maintenance can be the overriding costs. Organizations should consider the total "lifetime" cost of owning and operating pumping systems. Life cycle costs typically include the initial purchase costs, installation and commissioning, energy costs, operating costs (system supervision), maintenance costs, down time, environmental costs, and decommissioning and disposal costs. Comparing estimates of the life cycle costs of alternative system optimization recommendations is a financially sound approach to decision-making for pumping system projects. For more information on life cycle cost analysis, see reference [8] in Nonmandatory Appendix A.

3 OVERVIEW OF THE STANDARD: HOW TO USE ASME EA-2

ASME EA-2 is organized in sections, which are briefly described in paras. 3.1 through 3.7.

3.1 Section 1: Scope and Introduction

This section includes the scope for the standard, limitations of the standard, and an introduction on how to use the standard that includes information on the systems approach and the system engineering process. No guidance is provided for this section of the Standard.

3.2 Section 2: Definitions

This section includes definitions of terms used in the standard. No guidance is provided for this section, and these definitions are repeated in section 2 of this document.

3.3 Section 3: References

This section lists documents that are referenced in the standard. No guidance is provided for this section of the Standard.

3.4 Section 4: Organizing the Assessment

This section outlines the requirements on how to organize an assessment including identification of assessment team members and responsibilities, requirements for preliminary data collection and analysis, and requirements on the development of assessment goals and a plan of action. It also covers general issues necessary for smooth execution of the assessment, such as management support, access to the facility, and communication issues. To best utilize assessment team members' time, certain tasks such as preliminary data collection and evaluation should be performed before the start of the assessment proper. A plan for the assessment work should also be developed, and the pumping systems assessment team is responsible for ensuring that the plan conforms to the requirements of the Standard. Guidance is provided in section 4 of this document.

3.5 Section 5: Conducting the Assessment

This section outlines the requirements on how to conduct an assessment (the implementation phase of the plan of action).

Pumping systems vary tremendously between different types of industries and facilities. A municipal system might contain 10 pumps, whereas a large paper mill might have several hundred pumps installed. Some facilities have a large number of pumping systems, and it is unrealistic to assess all pumping systems during one assessment. Additionally, it may not be cost-effective to assess certain systems, such as small capacity systems or systems that run infrequently. It is therefore essential that a prescreening be made of the installed systems so efforts can be concentrated where the savings potential is greatest.

Prescreening is used as a tool to find those systems that have the largest potential for savings and improvement. The standard describes how to sort out such systems from a list of all systems present in a facility. The concept of different assessment levels is also introduced in section 5. The specific work that is associated with each level is clearly described in the standard.

The standard describes information to collect during different phases of the assessment (i.e., the prescreening, the walk-through, and data collection). It also covers the need to determine and understand the functional requirements of each pumping system undergoing a Level 2 or 3 assessment and how to set the proper system boundaries.

The section lists all parameters that need to be measured to calculate the system efficiency and discusses data collection methodology. It also discusses the need to understand system requirements and system boundaries.

Guidance is provided in section 5 of this document.

3.6 Section 6: Analysis of Data From the Assessment

This section outlines the requirements on how to analyze the data collected during an assessment, including the development of a baseline profile. The section presents the basic energy reduction opportunity calculation methods. It also briefly discusses the possibility of turning equipment off that is not needed and lists other common system changes to optimize system performance. Guidance is provided in section 6 of this document.

3.7 Section 7: Reporting and Documentation

This section outlines the requirements on how to structure the assessment report. Guidance is provided in section 7 of this document.

4 GUIDE TO ORGANIZING THE ASSESSMENT

Section 4 identifies action that must be performed up front to ensure a successful assessment. Sections 4.1 through 4.4 address the responsibilities of the different parties that are engaged in the assessment process and general conditions that have to be met. It is important that each participant be aware of what is expected from him/her to make sure that the different parts of the assessment are carried out.

4.1 Identification of Assessment Team Members

There is no additional guidance for this clause.

4.1.1 Required Personnel Responsibilities. Potential assessment team members to fill the functional roles identified in the standard could include those presented in paras. (a) through (c)

(a) Authorized Manager. An authorized manager accepts overall responsibility and has final decision-making authority. Responsibilities include allocating resources necessary to plan and execute the assessment.

Resources include items such as funding, availability of company personnel at the plant site and, as necessary, requisitioning internal work orders, and supplies. The manager should also allocate and authorize the participation of outside contractors and consultants, and, as necessary, facilitate the participation of any necessary outside personnel including contracts, scheduling, confidentiality agreements, and statement of work. For complex systems it may be necessary to have a cross-functional assessment team with expertise from different fields and members from operations and process engineering.

(b) Assessment Team Leader. Plant management demonstrates commitment to the assessment goals, objectives, and activities by appointing a system assessment team leader familiar with the processes, systems, and equipment related to pumping systems used in the plant. The assessment team leader should be familiar with operating and maintenance practices for the pumping system equipment (or should have access, during the assessment, to people who are) and should be empowered to obtain necessary support from plant personnel and other individuals and organizations during the assessment.

The assessment team leader should

(1) be knowledgeable (or know who is) about the systems in question and have contact with the system operations and maintenance personnel.

(2) be fully devoted to the assessment during the assessment process.

(3) understand the nature of the assessment.

(4) identify the facility support personnel required to complete the assessment.

(5) ensure that the assessment team members have access to relevant information and tools ahead of the assessment.

(6) be responsible for logistical issues and on site planning for the assessment such as office space and other types of equipment that might be needed.

(7) provide a preliminary list of the pumping systems at the facility together with basic information about these systems.

(8) if possible, perform any necessary prescreening.

(9) if possible, identify a potential list of projects for investigation.

(10) ensure that safety, health, and environmental requirements are met and documented according to site requirements.

(11) provide any expert from outside of the organization with any appropriate confidentiality agreements. Any agreements must be reviewed, signed, and returned prior to entering the site.

At very large facilities, no one individual is expected to be familiar with all systems. The assessment team leader should know where to go and/or which individual(s) to contact to get data such as the necessary design, operating, and maintenance information needed for the assessment.

(c) Pumping Systems Expert. This individual — either a corporate or plant employee or outside consultant — should have the requisite qualifications, background, experience, and recognized abilities to perform the assessment activities, data analysis, and report preparation.

4.2 Facility Management Support

There is no additional guidance for this clause.

4.3 Communications

(a) Initiation Meeting. Lines of communication required for the assessment should be established between the assessment team members at an early stage so that proper preparation and prescreening activities can take place ahead of the assessment on site.

To ensure that these preparatory and prescreening activities are successfully completed, an initiation meeting should occur just prior to the commencement of the assessment. The purpose of this meeting is to

(1) introduce the assessment team members

(2) identify the goals and expectations of the assessment

(3) review information collected in the preparatory and prescreening activities

(4) establish the work schedule

(b) Tools and Methods. At this initiation meeting, the assessment team members should discuss the tools and methods to be used. The tools in the form of computer programs, etc. should be distributed to the assessment team members ahead of time so that they have time to get acquainted with the tools. The assessment team should establish

(1) the measurement, metering, and diagnostic equipment required

(2) the time periods for on-site assessment

(3) the daily schedule(s) for the on-site assessment

(4) frequency and type of communication on status of assessment

4.4 Access to Resources and Information

There is no additional guidance for this clause.

4.5 Assessment Goals and Scope

There is no additional guidance for this clause.

4.6 Initial Data Collection and Evaluation

4.6.1 Initial Facility Specialist Interviews. There is no additional guidance for this clause.

Table 1 Energy Unit Cost Summary

Energy Type	Energy Units	Total Cost	Average Unit Cost
Annual electric energy	kWh	$	...
Electric demand (peak)	kW	$	...
Miscellaneous electric costs (e.g., power factor penalty, fixed facility charges, etc.)	...	$	...
Annual natural gas	MMBtu	$	...
Other fuels	MMBtu	$	...

4.6.2 Energy Project History. There is no additional guidance for this clause.

4.6.3 Primary Energy Cost. This section discusses the importance of understanding how the facility is being billed for energy costs. This information is essential to calculate a payback timeframe for a project and is usually based on 12 mo of recent billing data. A review of the utility rate schedule is also helpful for more detailed information. An example of an energy unit cost summary is shown in Table 1. Miscellaneous electric costs include service fees or other charges that are not included in the demand or consumption unit costs.

It is important to be aware of "time of use" rates that vary energy unit costs during the day or "block" energy rates that charge different kilowatt hour rates for energy used. For this type of rate schedule the marginal energy cost could be used for energy saving calculations. Facilities often have policies governing these calculations; for example, the average total per unit energy cost is equal to the total billed cost over a given period divided by the energy consumed in that given period.

4.6.4 System Data. To assess a system, it is imperative to understand the required function of the system. This is sometimes referred to as the ultimate goal of the system, which describes all the necessary and desirable functions of the system. The assessment team must understand normal operating conditions as well as operation under extreme and upset conditions, knowing the limits within which the system is designed to operate, and understanding how the operating conditions are distributed over time. Information about these parameters is often available in facility computer monitoring systems, or can often be obtained from engineers and operators familiar with the system.

Some facilities may not have accurate records, and the facility personnel may be unable to supply the needed information. The assessment team should then monitor the system over some period of time in order to establish the demands on the system.

A pumping system assessment considers the overall efficiency of an existing operating system or a new system design. The system is typically made up of several components that may include, but are not limited to, the pump(s), driver(s) (including the power supply system), variable speed control, piping and all valve types, fittings and suction, and discharge sources such as tanks, heat exchanger, boilers, etc. It is necessary to understand the subsystem's role relative to the total plant process. The system boundary can be very complex as the subsystems may be part of a larger plant system.

The overall design of the system has a major influence on system efficiency. Pump efficiency is determined by the pump's operating point on its curve, whereas the system efficiency requires comparing the power necessary to fulfill the system demand to the input power to the system.

There are usually large differences among optimum efficiency of a component (such as a pump or motor), operating efficiency of the same component, and system efficiency. When system efficiency is calculated, the fluid power necessary to fulfill the process demand, not the fluid power produced by the pump, should be used. For example, if a pump is operated near its best efficiency point, the efficiency calculated on the basis of the pump output may be very high. However, if a significant portion of the discharge pressure is throttled away in a control valve, the overall system efficiency could be low in spite of high pump efficiency. This is because the system efficiency in this case is not calculated using the pump discharge head, but the head downstream from the control valve, which is the pressure the process (system) requires. In such a case, a pump replacement, impeller trimming, different speed motor, and/or the addition of variable speed control are among the potential solutions that can be explored. Before any measurements and calculations are made, it is thus necessary to define the system and determine where measurements should and can be made.

The pumping system assessment determines the efficiency of the system as a whole rather than component efficiency. To do this, the assessment team first has to determine the system demand. For a simple throttled system, the system demand is the head and flow downstream of the throttling valve. For a bypass controlled

Table 2 Assessment Level Overview

Activities	Level 1 Assessment	Level 2 Assessment	Level 3 Assessment
Prescreening opportunities	Required	N/A	N/A
Walk through	Optional	Required	Required
Identify systems with potential saving opportunities	Required	Required	Required
Evaluate systems with potential saving opportunities	Optional	Required	Required
Snapshot type measurement of flow, head, and power data	Optional	Required	N/A
Measurement/data logging of systems with flow conditions that vary over time	N/A	N/A	Required

GENERAL NOTES:
(a) Verify and use data from plant historical information where applicable.
(b) The table appeared as Table 1 in ASME EA-2.

system it is the flow that is not bypassed and the appropriate pressure. The true system demand can be difficult to determine for more complex systems.

System demand can vary due to process/production requirements as well as seasonal changes.

In the case of pumping systems, input power is the power delivered to the system. If a variable frequency drive (VFD) is included in the system, it should be the power delivered to the VFD. For a system with no VFD, the input power is the power delivered to the motor.

Factors outside the investigated system may influence the system or its operation. Such factors could originate from the ultimate goal of the system.

4.7 Site-Specific Goals

There is no additional guidance for this clause.

4.8 Assessment Plan of Action

The process of developing a Plan of Action insures that all participants understand responsibilities for the entire assessment process.

4.8.1 Identification of Other Assessment Team Members Required. There is no additional guidance for this clause.

4.8.2 Assessment Scheduling. There is no additional guidance for this clause.

4.8.3 Key Personnel Interviews. There is no additional guidance for this clause.

4.9 Goal Check

There is no additional guidance for this clause.

5 GUIDE TO CONDUCTING THE ASSESSMENT

5.1 Introduction

The assessment work generally starts with a kick-off meeting where all involved get together and lay out the tasks for the duration of the assessment. The first item to agree upon is the scope and overall goals of the assessment. The scope of the assessment should define the portion(s) of the facility that are to be assessed. Ideally, a list of all systems at the plant, together with basic information about these systems, should be available at this meeting.

It is common to start with criteria for selecting which pumping systems to assess and then review all the systems to make a preliminary selection of systems for analysis. Systems could be re-listed and prioritized after estimated savings opportunities, control methods, yearly energy cost, or some combination of the above. The main objective of prescreening is to identify the systems that should be assessed and list them in a preliminary, prioritized order.

It also must be noted whether the pump system is part of a larger system and what constraints this might introduce (i.e., it might be impossible to optimize the pump system without optimizing the larger system). Savings in the pump system could sometimes result in added cost at another part of the process. In such cases it is important that the assessment team has cross-functional members or specialists that understand other parts of the larger system.

5.2 Assessment Levels

The assessment procedures have been separated into three different levels depending on the complexity of the systems. See Table 2.

Three levels are defined, since the complexity and difficulty of an assessment varies from system to system depending on the variability of the system operating parameters. The three different assessment levels are described in paras. 5.1 and 5.2 of the standard.

5.2.1 Level 1 Assessments. There is no additional guidance for this clause.

5.2.2 Level 2 Assessments. There is no additional guidance for this clause.

5.2.3 Level 3 Assessments. There is no additional guidance for this clause.

5.3 Walk Through

After the prescreening has been conducted and systems have been selected for further investigation, the assessment normally starts with a visual examination of each pumping system to be assessed according to Level 2 or Level 3. This should entail walking the systems from start to finish, ensuring the information provided to the assessment team reflects the configuration of the existing system(s). See para. 5.3 of the standard.

It is vital to make extensive notes during the walk through.

5.4 Understanding System Requirements

(a) Collecting Information. It is necessary to collect as much information about the system and its components as possible, such as

(1) P&ID, system layout including static head

(2) operational information (operating times, flow variations, constant or variable, etc.)

(3) pump and motor data (name plate data as well as operating data)

(4) control methods

(5) installed measurement equipment

(6) design parameters

(7) available pressure taps

(8) pipe dimensions

(9) pumped fluids and their properties

(b) Identification of Existing Conditions. The walkthrough and the information to be collected is described in detail in para. 5.3 in the standard and repeated here. The assessment team should identify any existing conditions that are often associated with inefficient pumping system operation. These conditions include indicators such as

(1) pumping systems where significant throttling takes place. It is also recommended to collect other pertinent information such as valve positions (percent open), suitable measuring points, etc.

(2) pumping systems with recirculation of flow used as a control scheme.

(3) pumping systems with large flow or pressure variations.

(4) multiple pumping systems where the number of operated pumps is not adjusted in response to changing conditions.

(5) systems serving multiple end uses where a minor user sets the pressure requirements.

(6) cavitating pumps and/or valves.

(7) high vibration and/or noisy pumps, motors, or piping.

(8) pumps with high maintenance requirements.

(9) systems for which the functional requirements have changed with time, but the pumps have not.

(c) Low Efficiency. There can also be other reasons for low efficiency that are not readily discovered during a Level 1 assessment. These potential issues include

(1) wear on pump impellers and casings that increase clearances between fixed and moving parts (if available, this information can be provided by plant staff)

(2) clogged pipelines or pumps (usually requires historical data to be discovered)

(d) Other Items. Other items that should be noted include

(1) valve position, and verifying proper valve operation, if possible.

(2) pump and drive motor nameplate information.

(3) operating schedules to develop load profiles.

(4) head/capacity curves (if available) from the pump manufacturers.

(5) motor rewind policies and practices used by the facility. If best practices for rewinding motors are not followed, the motor losses could be larger than indicated by the manufacturers' data.

The assessment team should also note the system flow rate and pressure requirements, pump style, operating speed, number of stages, specific gravity, temperature, and viscosity of the fluid being pumped. (Note that spot checks of in situ flow rates may only represent one point in time where demand varies on a continuous basis).

5.5 Determining System Boundaries and System Demand

Understanding how flow rate requirements vary over time is a crucial element in optimizing fluid systems. It is very common for pumping systems to be over-sized; that is, that they are capable of delivering a higher flow rate or head than what is really needed by the process. The reasons for this vary, but common reasons are that the system is designed for "future needs," an anticipated increase in flow rate requirement in the future, or that the designer added safety factors when selecting the pump and other system components. Over-sizing pumping systems leads to excessive losses and power consumption. Therefore, analysis to determine actual requirements should be a part of any assessment.

In some cases the pump system is part of a larger system and the influence of changes to the pump system on the larger system has to be understood before the pump system can be optimized. In such cases the assessment team must interact with or add specialists that understand the larger system.

5.6 Information Needed to Assess the Efficiency of a Pumping System

There is no additional guidance for this clause.

5.6.1 Driver Information. There is no additional guidance for this clause.

5.6.2 Pump Information. There is no additional guidance for this clause.

5.6.3 Fluid Properties Information. There is no additional guidance for this clause.

5.6.4 Measured Data. There is no additional guidance for this clause.

5.6.5 System Functional Baseline. There is no additional guidance for this clause.

5.7 Data Collection Methodology

The basic data needed to evaluate operating efficiency is

(a) power
(b) flow
(c) pressure

It is critical to keep in mind that *the pumping system* is being assessed, not just the pump, and that the efficiencies of the components could be very good at the same time as the system efficiency is low. It is therefore imperative that the true system demand be used for the evaluation and not current operating data.

For example, if a pump delivers 100 psi (689 kPa) and operates at peak efficiency, but is throttled and the pressure drop across the throttling valve is 50 psi (345 kPa), then half of the delivered power is lost in the valve and the system efficiency is low.

Section 5.7 of the standard describes the data collection methodology. It describes the different information and parameters that have to be measured.

The standard does not require that a specific tool or computer program be used for the evaluation of the system efficiency. There are several tools that are available from governments, private companies, and other organizations. Tools undergo continuous improvements, and specifying a special tool would hamper the development of such tools. The only demand set by the standard is that the tools should be transparent so that the methodologies and results can be understood by the users and duplicated at a later point in time.

Flow rate requirements can be constant or variable. For systems with constant flow rate requirements, it is fairly simple to address these issues. The pumping system should be designed to deliver what is necessary and not more. If future expansion is expected, an example of a better solution is to add a larger impeller once the higher flow rate is required.

Systems with variable process needs are more complicated to assess. Examples of systems with varying flow rate demands are seasonal loads (chilled water, associated tower water, etc.), industrial processes with variable output, potable water, and wastewater systems. The first task is to estimate the expected variation or, in an existing system, to measure the variation over a specific period of time. Common ways of showing the demand are illustrated in Figs. 2 and 3.

The first task is to understand the variation expected or, in an existing system, to measure the variation over a specific period of time. A suitable way of showing the demand is shown in Fig. 4.

The number of flow intervals to develop a reasonable baseline will typically vary between four and ten intervals depending on data availability (for pump systems with varying flow). An example of data presentation is shown in Table 3.

Power and head measurements for each flow interval can be determined by re-creating each flow interval condition and taking pressure and power measurements or, when this is not possible, estimated from an existing pump curve.

The information in Figs. 2 through 4 can be rearranged to a show a **duration curve** that illustrates the variation of flow rate requirements over a year. The flow duration diagram in Fig. 5 shows the number of hours during a year the flow rate requirement exceeds a certain level. The peak flow rate that is required is the intercept with the y-axis. Since the x-axis represents time, and the y-axis represents flow rate in Fig. 5, the area below the curve equals the volume pumped during one year. The advantage of this diagram is that it clearly shows the demands from the system, both regarding maximum flow rate, average flow rate, and the variations.

It is fairly common that systems are optimized for maximum flow rates. While it is, of course, important that the system can deliver the maximum required flow rate at a reasonable efficiency, from an economic point of view, it is more important that systems are optimized for the flow rates at which they are going to operate most of the time. For example, it could be cheaper from a life cycle cost perspective to have one pump set for handling the maximum flow rates and another to handle average flow rates.

Figure 6 shows the flow demand variation during a year for a hypothetical wastewater pump (the total

Fig. 2 Example of Hourly Flow Demand in a Building

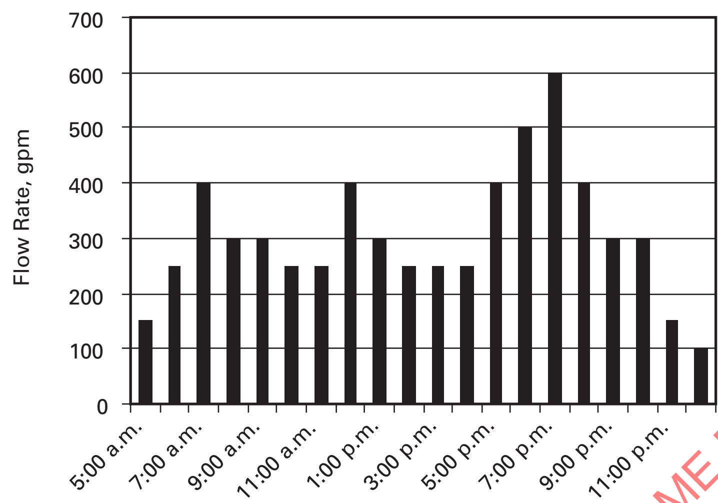


Fig. 3 Example of Annual Variation of Flow Rate Demand

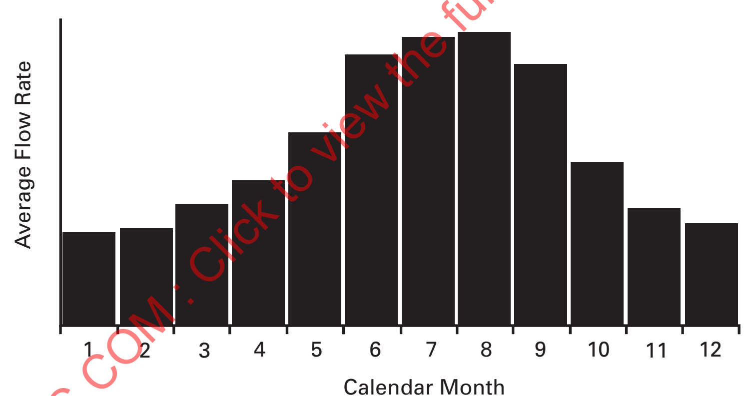


Table 3 Example Flow Duration Summary Table

Flow Interval	Flow Rate, gpm (m^3/h)	Annual Hours
–	–	–
–	–	–
–	–	–
–	–	–

GENERAL NOTE: Dashes represent sample data.

Fig. 4 Example of Daily Variations of Flow Rate Demand

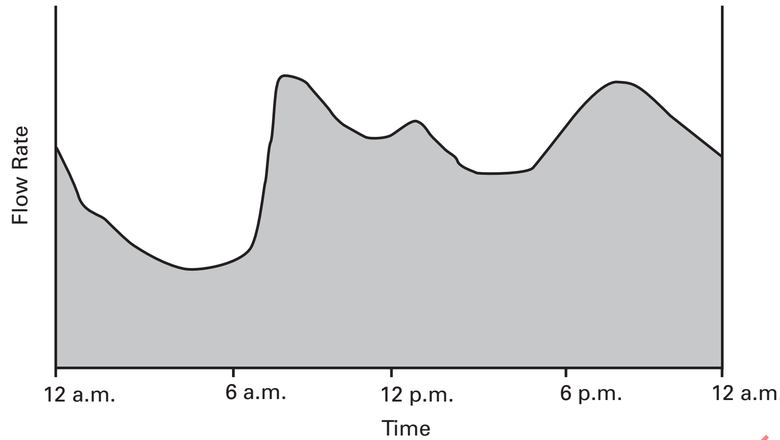
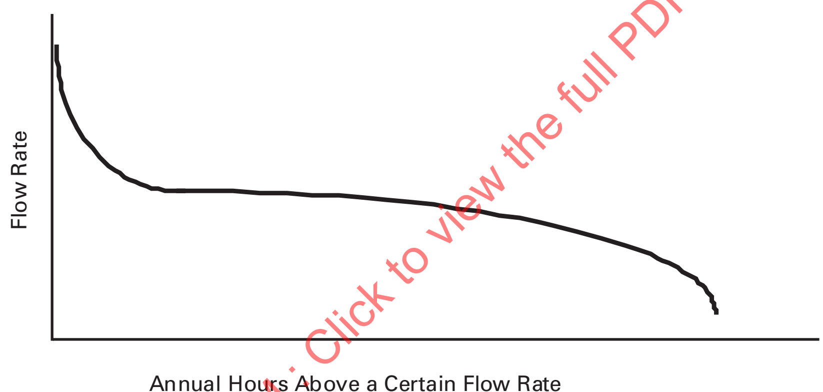


Fig. 5 Typical Annualized Duration Curve



volume is equal to the area under the curve). The pump needs to operate less than 2,500 hr/yr at the peak flow rate to move this volume.

In Fig. 7, a smaller pump is added to the system. In this case the large pump is only running about 200 hr/yr, whereas the smaller pump runs for a bit more than 5,000 hr at a lower flow rate. The advantage of this arrangement is that the typical flow rate will be efficiently handled by the smaller pump, which requires significantly less energy to operate. The frictional losses in the system are reduced at the lower flow rate, thus reducing energy use. From a life cycle perspective, the energy cost savings over time can often justify the cost of the additional pump.

5.7.1 System Information. There is no additional guidance for this clause.

5.7.2 Measurement of Pump and Motor Operating Data. Electrical power [kilowatts (kW)] should be measured at each operating point with a true RMS power meter. If only amperage can be measured, the Pumping System Assessment Tool (PSAT) software tool available from the U.S. Department of Energy can be used to estimate kilowatts. Table 11 is an example data collection form for electrical measurements.

5.7.3 Pressure. There is no additional guidance for this clause.

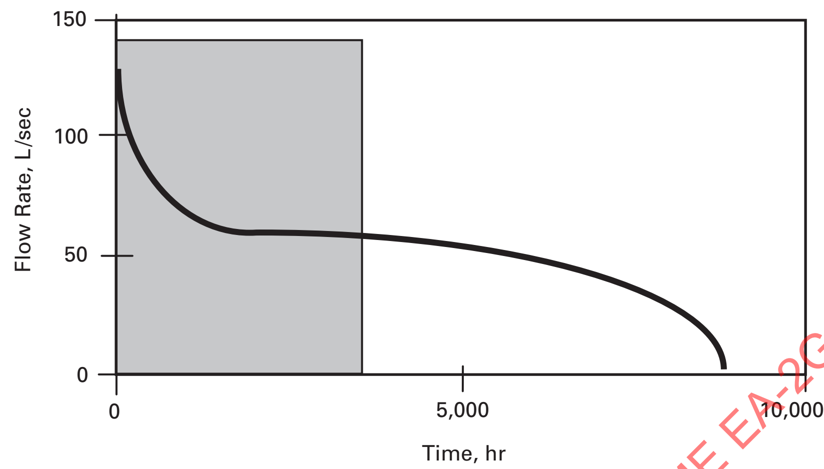
5.7.4 Flow. There is no additional guidance for this clause.

5.7.5 Motor Input Power. There is no additional guidance for this clause.

5.8 Cross Validation

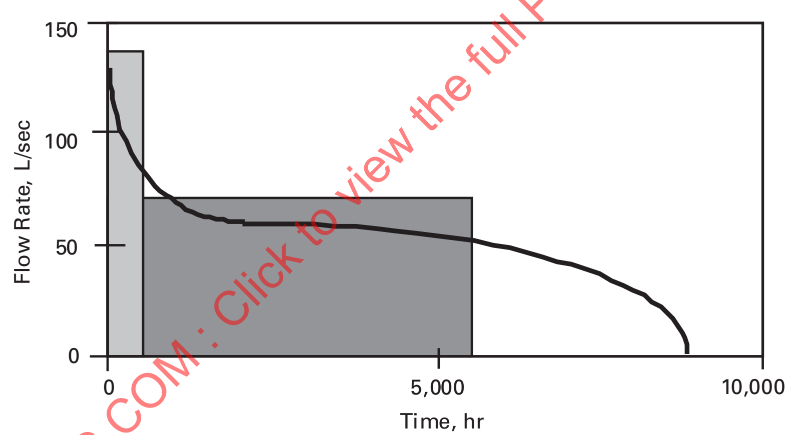
Cross validation of measured data is necessary, both as a means to check the data collected for validity and as a means to obtain data that is otherwise difficult to

Fig. 6 Flow Rate Duration Diagram



GENERAL NOTE: The shaded area equals the area below the curve.

Fig. 7 Flow Rate Duration Diagram Using Two Pumps — One Large and One Small



obtain. There are a number of ways to verify data. Some examples include

(a) verifying that the flow, pressure, and power measurements agree with the pump curve data. If there is reasonable agreement between measurements of the power used (absorbed power), pressure or flow compared to the pump curve, then the data are probably correct. A mismatch between measured data and pump curve data indicates that inaccurate data has likely been obtained. If, for example, power and pressure data agree, then flow rate can be estimated from the pump curve.

(b) verifying measurements that can be accomplished through the use of multiple instruments. For example, pressure measurements can easily be verified with an alternate pressure instrument or gauge. Electrical power can be calculated from amperage measurements using a tool like the U.S. Department of Energy's PSAT.

(c) for flow measurements taken with a clamp-on ultrasonic flow meter, alternative measuring methods such as verifying the flow rate with a simple pump down test (if the pump suction or discharge tank can be isolated).

(d) pump curves, which are helpful to verify that the flow and head determined from pressure measurements are within the proper tolerances. Although the operating point can be much different than the original design point, it can still help detect obvious measurement errors.

Some basic considerations for collecting accurate data include taking the time to verify data as measurements are being taken, making sure instrument settings are correct, and taking detailed notes.

5.9 Wrap-Up Meeting and Presentation of Initial Findings and Recommendations

There is no additional guidance for this clause.

6 GUIDE TO ANALYSIS OF DATA FROM THE ASSESSMENT

6.1 Common Causes and Remedies for Excessive Energy Use

It is important that a thorough understanding of system requirements be established before the application of any analysis technique. This includes distinguishing between system design specifications and actual process requirements before evaluating energy savings opportunities.

It should be understood that once a physical change is made to the system, the system curve will likely change, resulting in different system requirements and the need for another iteration of system analysis. Each time the system is modified there is the potential to redefine optimal operation for that system.

6.1.1 Reduce System Head. There is no additional guidance for this clause.

6.1.2 Reduce System Flow Rate. There is no additional guidance for this clause.

6.1.3 Ensuring That Components Operate Close to Best Efficiency. Throttling a pump often causes the pump to move away from its BEP and operate at a less efficient point on its curve. In addition, control valves can also be subject to stem friction from sealing mechanisms. This can result in variations from set points and therefore contribute to operation outside the desired BEP region. The use of low friction sealing materials and consistent compression load methods can alleviate this problem.

6.1.4 Change Pumping System Run Time. There is no additional guidance for this clause.

6.2 Basic Energy Reduction Opportunity Calculations

ASME EA-2 provides the fundamental equations needed to evaluate pumping system performance. This section of the guidance provides several examples to demonstrate the use of these equations.

(a) Comparing Existing and Optimal Energy Use. In the first example, the calculated electric power is compared to actual existing power. This calculation is useful for determining potential power reduction when a pumping system is not operating at optimal flow rate and head conditions.

The hydraulic power added by the pump to the fluid system is shown in eq. (1).

(U.S. Customary Units)

$$P_w = \frac{QHs}{5{,}308}$$

(SI Units)

$$P_w = \frac{QHs}{367} \tag{1}$$

where

H = total dynamic head at flow rate Q, ft or m
P_w = hydraulic power supplied by the pump, kW
Q = flow rate, gal/min or m^3/h
s = specific gravity, dimensionless

The electrical power required to support the pumping system operation is shown in eq. (2).

$$P_e = \frac{P_w}{\eta_P \eta_M \eta_D} \tag{2}$$

where

P_e = electrical power input, kW
η_D = drive (belt, adjustable speed, gear, etc.) efficiency
η_M = motor efficiency when supplying the power required by the pump at flow rate Q
η_P = pump efficiency at operating flow rate Q

Pumping systems are deemed to be operating at the optimal performance level when the system functional requirements are being met with

– minimum practical flow rate
– minimum practical head
– minimum practical run time
– maximum commercially available component efficiencies

The optimal hydraulic power added to the system by the pump is the value calculated with the minimum practical flow rate and head values inserted into eq. (1), and the optimal electric power is calculated [per eq. (2)] using the optimal hydraulic power and the best available pump, motor, and drive efficiencies.

The calculated electric power can be compared to actual existing power, even if the pump is not operating at the optimal flow rate and head conditions, to determine potential power reduction.

As prescribed in the standard, the assessment shall establish a baseline of total annual energy use for the pumping system(s) assessed.

In the first example, the calculated electric power is compared to actual existing power. This can be done

Fig. 8 Simplified Flow Diagram for Examples 1 and 2

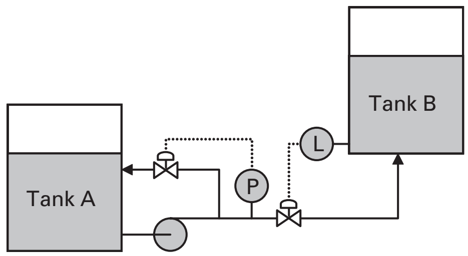


Table 4 Existing Versus Optimal Analysis Results (Example 1)

Condition	Flow Rate, gpm (m^3/h)	Total Dynamic Head, ft (m)	Pump Efficiency	Motor Efficiency	Electric Power, kW	Pump and Motor Combined Efficiency	Annual Energy, MWh	Annual Cost, $1,000
Measured	2,000 (454)	150 (46)	N/A	N/A	87	0.65	533	27
Optimal	1,500 (341)	100 (30)	0.86	0.94	35	0.81	214	11
Potential savings	500 (114)	50 (15)	...	...	52	...	319	16
Ratio of optimal power/measured power	...	...	...	...	0.40	...	...	...

even when the pump is not operating at the optimal flow rate and head conditions, to determine potential power reduction.

(1) Example 1. A system transfers liquid from Tank A to Tank B, and employs a recirculation line to maintain constant pump discharge pressure as well as a level control valve that maintains constant level in Tank B. The pump is directly driven by a motor (without gear, belt, or variable speed drive).

– The system fluid has a specific gravity of 1.0, and the plant average electric cost rate is USD0.05/kWh

– Measured pump flow rate: 2,000 gpm (454 m^3/h)

– Measured pump total dynamic head: 150 ft (46 m)

– Measured electric power: 87 kW

– Optimal flow rate: 1,500 gpm (341 m^3/h) [measured flow rate minus 500 gpm (114 m^3/h) recirculation flow]

– Optimal pump total dynamic head: 100 ft (30 m) [measured pump total dynamic head minus 50 ft (15 m) head loss across the receiving vessel level control valve]

– The system operates at the above conditions 70% of the time.

Calculate the potential power, energy, and cost savings for optimal pump and motor efficiencies of 86% and 94%, respectively, and compare the optimal power to the existing (measured) power.

(b) Excess System Energy Use. Calculations of excess hydraulic power related to flow rates and head higher than required to satisfy the system functional requirements are useful in determining the savings opportunities. A proven methodology for calculating excess power follows.

The actual measured pump output hydraulic power is proportional to the product of the flow rate, head, and fluid specific gravity:

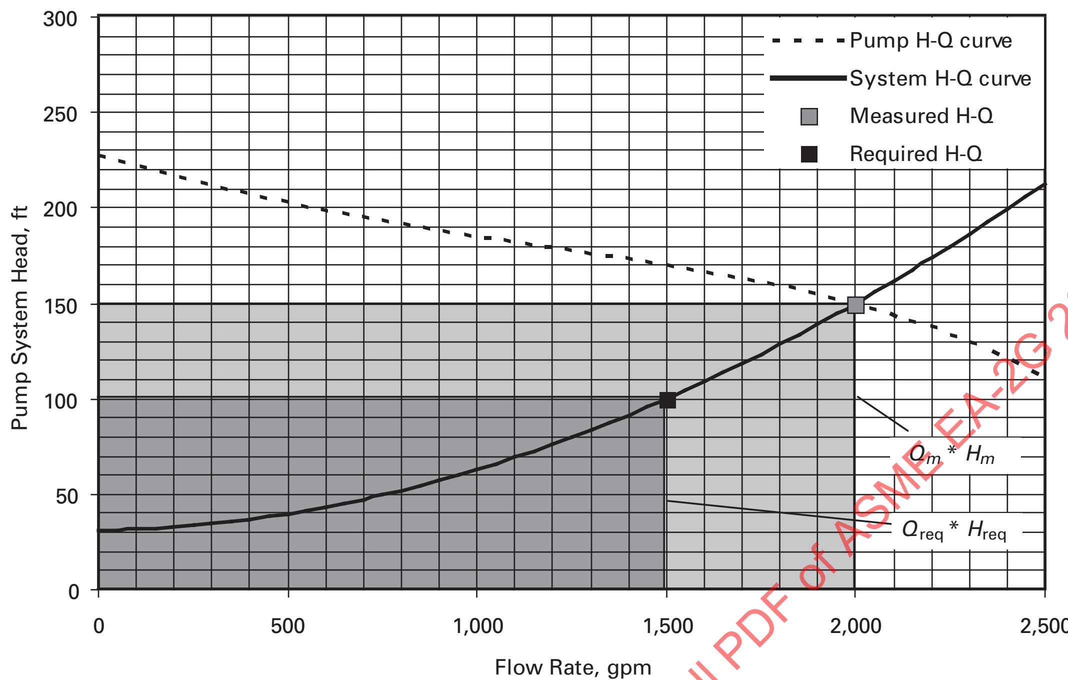
(U.S. Customary Units)

$$P_{wm} = \frac{Q_m H_m s}{5{,}308} \text{ (gpm, ft, kW)}$$

(SI Units)

$$P_{wm} = \frac{Q_m H_m s}{367} \text{ (m}^3\text{/h, m, kW)}$$

Fig. 9 Provided Versus Required Flow



where

H_m = measured head
P_{wm} = hydraulic power at measured conditions
Q_m = measured flow rate
s = specific gravity

However, if the head and/or flow rate *required* to meet the system functional requirements is less than that being provided by the pump (with the difference being caused by throttling, bypassing, or simply excess handling more flow than is required), the optimal, or required hydraulic power is equal to the product of the *required* flow rate and head on the unthrottled, unbypassed system curve.

(U.S. Customary Units)

$$P_{wreq} = \frac{Q_{req} H_{req} s}{5{,}308} \text{ (gpm, ft, kW)}$$

(SI Units)

$$P_{wreq} = \frac{Q_{req} H_{req} s}{367} \text{ (m}^3\text{/h, m, kW)}$$

It is helpful to illustrate hydraulic power graphically as being proportional to the size of a rectangle defined by the measured and required flow rate and head values, as shown in Fig. 9.

If the actual powers associated with these two rectangles are calculated, the difference, or excess fluid power will be

(U.S. Customary Units)

$$P_{w_{xs}} = \frac{\left[(Q_m H_m) - (Q_{req} H_{req})\right] s}{5{,}308} \text{ (gpm, ft, kW)}$$

(SI Units)

$$P_{w_{xs}} = \frac{\left[(Q_m H_m) - (Q_{req} H_{req})\right] s}{367} \text{ (m}^3\text{/h, m, kW)}$$

Alternatively, the excess can be graphically illustrated in the context of excess flow rate and head as shown in Fig. 10. In this figure, H_{xs} and Q_{xs} refer to the excess head and excess flow rate, respectively.

In this paradigm, the excess hydraulic power is

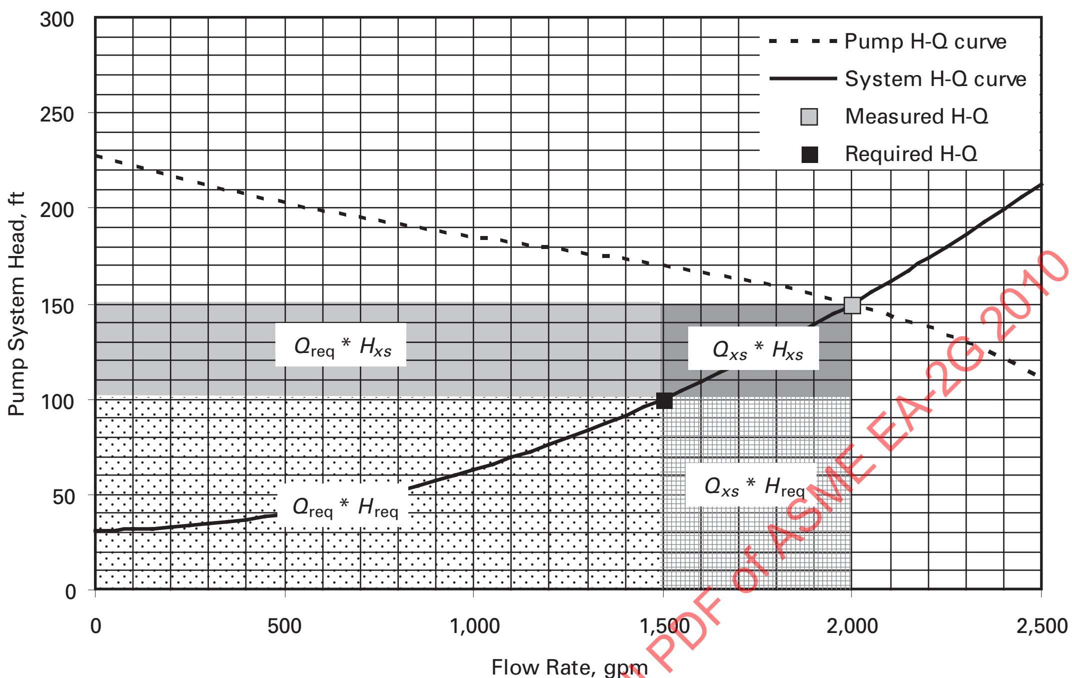
(U.S. Customary Units)

$$P_{w_{xs}} = \frac{\left[(Q_{req} H_{xs}) + (Q_{xs} H_{req}) + (Q_{xs} H_{xs})\right] s}{5{,}308} \text{ (gpm, ft, kW)}$$

(SI Units)

$$P_{w_{xs}} = \frac{\left[(Q_{req} H_{xs}) + (Q_{xs} H_{req}) + (Q_{xs} H_{xs})\right] s}{367} \text{ (m}^3\text{/h, m, kW)}$$

Fig. 10 Required Energy Use and the Different Types of Excess Energy Use



where

$P_{w_{xs}}$ = hydraulic power associated with Q_{xs}, and H_{xs}, which are the flow rate (gallons/minute or meters^3/hour) and head (feet or meters) values that are in excess of the values needed to satisfy system functional requirements. In other words, $H_{xs} = H_m - H_{req}$ and $Q_{xs} = Q_m - Q_{req}$.

By applying either estimated or assumed component operating efficiencies, the corresponding excess electrical power ($P_{e_{xs}}$) for each system-level excess can be calculated as

$$P_{e_{xs}} = \frac{P_{wxs}}{\eta_P \eta_M \eta_D}$$

It should be noted that $P_{e_{xs}}$ as calculated above implicitly assumes that the optimal pump, motor, and drive efficiencies will be unchanged at the two fluid conditions. This is obviously a simplifying assumption, since all three efficiency parameters are a function of performance characteristics of the existing and optimal pump, motor, and drive combinations.

Excess power should be multiplied by the operating time in hours to get the excess electrical energy, E_e:

$$E_{e_{xs}} = TP_{e_{xs}}$$

where

T = the operating time (hours) at the excess flow or head condition

Note that unlike the protocol in para. 6.2.1, the excess system energy method does not require measurement of existing electric power, although if it is measured, the combined motor, pump, and drive efficiencies can be determined. In cases where assumed component efficiencies are used, the assumed values should be conservatively high to ensure that the excess power is not overstated. Note that an additional cause of excess energy use may be operating systems at times when they are not needed.

The excess system energy method does not require measurement of existing electric power. However, if it is measured, the combined motor, pump, and drive efficiencies can be determined. In cases where assumed component efficiencies are used, the assumed values should be conservatively high in order to ensure that the excess power is not overstated. Also, note that excess energy use can come from operating equipment for more time than needed. Example 2 illustrates this concept.

(1) Example 2. Estimate the hydraulic and electrical power waste for the system shown in Fig. 7 using conservative motor and pump efficiencies of 95% and 87%, respectively.

– Operating flow rate, Q: 2,000 gpm (454 m^3/h)
– Excess flow rate, Q_{xs}: 500 gpm (114 m^3/h)
– Operating head, H: 150 ft (46 m^3/h)
– Excess head, H_{xs}: 50 ft (15 m)
– Assumed motor efficiency: 0.95
– Assumed pump efficiency: 0.87

Table 5 Power Waste-Based Analysis Results (Example 2)

	Waste, kW	Waste, kW, Electric	Annual Energy, MWh	Annual Cost, $1,000
Waste calculation, excess Q	14	17	105	5
Waste calculation, excess H	19	23	140	7
Combined waste, both	28	34	208	10

Note that the waste-based estimate of this example is less than the existing versus optimal estimate of the first example. This is due to the conservatively assumed motor and pump efficiencies. Also, the two waste calculations cannot be added. See Fig. 10.

Information regarding optimum component efficiency at different duty points can be obtained from the National Electrical Manufacturers Association (NEMA) (motors) and the Hydraulic Institute (pumps). This information also is available in the PSAT software program developed by U.S. Department of Energy.

Many times it can be practical to estimate valve losses to get an estimate of potential saving opportunities in a system. The U.S. Department of Energy's PSAT program comes with a "Valve tool" that easily estimates such opportunities.

Sealing systems can be another cause of excessive energy consumption. The excess energy related to the use of inappropriate seals or seal support systems, which may consume large amounts of plant utilities, can be expressed as:

$$E_{excess} = \Sigma \, (E_{cooling} + E_{heating} + E_{evaporation})$$

where

$E_{cooling}$ = the energy required to re-heat the process due to temperature loss through intentional cooling of a seal chamber or seal support system (where a different seal or seal support system could operate without cooling)

$E_{evaporation}$ = the energy required to remove seal flush fluids downstream in the process to restore product integrity (where a different seal or seal support system could operate without flushing or at a lower flush flow rate)

$E_{heating}$ = the energy required to raise the temperature in a seal chamber or seal support system (where a different seal or seal support system could operate without heating)

To a lesser extent but potentially significant in larger equipment and complex multiple-seal arrangements, the excess energy from friction due to suboptimal selection of the seal or sealing system can be expressed as

$$E_{excess} = E_{friction1} - E_{friction2}$$

where

$E_{friction1}$ = the frictional energy consumed by an older technology, suboptimal sealing system

$E_{friction2}$ = the frictional energy consumed by an optimized sealing system

7 GUIDE TO REPORTING AND DOCUMENTATION

7.1 Final Assessment Report

There is no additional guidance for this clause.

7.2 Report Contents

In some cases an Introduction Section may be inserted before the Executive Summary to provide background information on the assessment process, acknowledging the facility staff that assisted with the assessment, and organizations that participated in sponsoring the assessment.

7.2.1 Executive Summary. The executive summary should emphasize the objective (which states the goals) of the assessment, the analysis of the results (including recommendations), and energy savings.

A project summary table should be a part of the Executive Summary, and should include a list of the recommended projects and unit energy savings. Optionally, a determination of project economics can be presented by classifying the recommendation by simple payback in years (when estimated costs are included for Level 2 or 3 assessments). The unit energy savings should be expressed in kilowatt hours (kWh) for electric consumption savings, kilowatts (kW) for electric demand savings (when applicable), and million British thermal units (MMBtu) for fossil fuel savings. An example of the table is shown in Table 6. For more detailed high level evaluations, a life cycle cost analysis with additional savings data should be included in the project summary table.

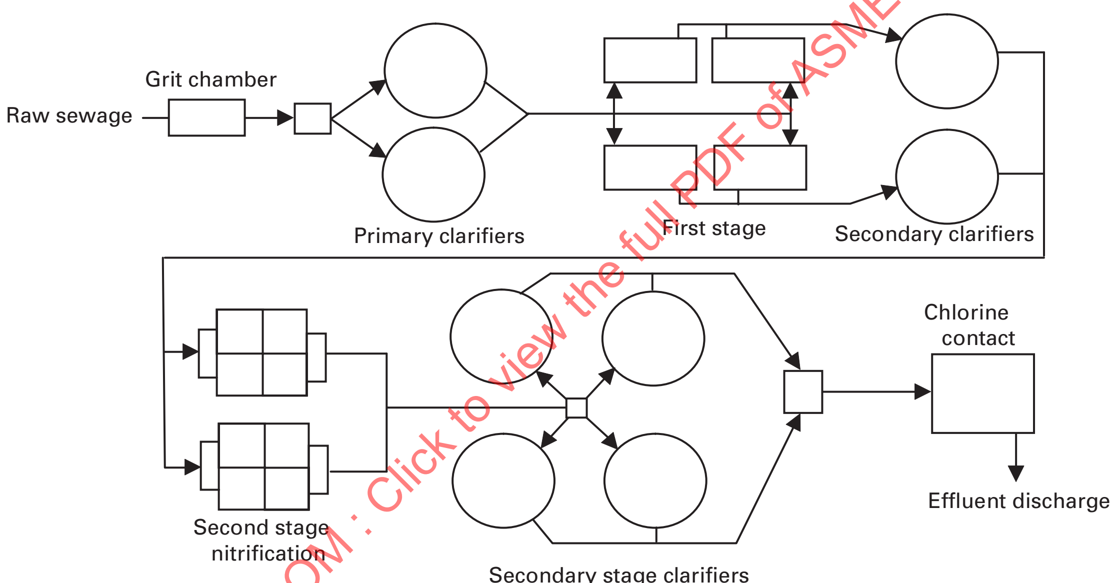
The recommendations listed are typically classified as Operation and Maintenance Measures (OMMs) or

Table 6 Example Project Summary Table Format for a Level 2 or 3 Assessment

Energy Savings Opportunity Summary Information					
	First Year Annual Savings			Cost/Payback (Optional)	
Recommendations/Identified Opportunities	kWh	kW	USD	Estimated Cost	Simple Payback, y
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–

GENERAL NOTE: Dashes represent sample data.

Fig. 11 Example of Process Diagram



as Energy Conservation Measures (ECMs). The recommendations should be prioritized based on facility staff acceptance and cost effectiveness. Consideration must also be given to projects that may be easily implemented versus improvements that may not be easily pursued until plant production lines are down for maintenance.

This section may also include a discussion of the facility's energy utilization, energy cost index, and environmental benefits associated with each recommended project.

7.2.2 Facility Information. A description of the facility, facility purpose, and significant energy systems should be included in this section. Typically, this consists of a general overview of the facility operation, facility production figures (if applicable and available), and a simple process flow chart of the major energy use systems in the facility. An example of a process diagram for a wastewater facility is shown in Fig. 11.

The description of each process should be limited to a basic description that is suitable for readers who may not be familiar with the production/treatment process with an emphasis on how pump systems are used within each process. However, it is not necessary to provide an in-depth discussion of how each process works.

For nonproduction facilities, such as a commercial building or campus, figures and descriptions of the plumbing and HVAC systems should be included. Relationships between the specific building systems and any district energy (heating or cooling) systems should be included in the description. Also, information about auxiliary systems, such as cooling tower water treatment, should be included.

Facility energy unit costs used for energy calculations should also be presented in this section as discussed in para. 4.6.3. Pie charts or graphs that provide an overview of how energy use is allocated for each process

Table 7 Equipment Nameplate Data

	Motor				Pump	
	HP, kW	RPMs	Nameplate Efficiency	FLA	Rated Flow and Head	Rated Efficiency
Pump #1	_	_	_	_	_	_
Pump #2	_	_	_	_	_	_
Pump #3	_	_	_	_	_	_

GENERAL NOTE: Dashes represent sample data.

system or by types of equipment can be included if this information is available.

Existing or ongoing energy-related projects performed by facility staff can also be presented in this section. This can include a general discussion of various energy initiatives, or more specific project descriptions with documented savings.

7.2.3 Assessment Goals and Scope. There is no additional guidance for this clause.

7.2.4 Description of System(s) Studied and Significant System Issues. This section should include a description of the specific system(s) on which the assessment was performed. The primary goal of this section is to provide a detailed review of the systems based on site observations, facility staff input, and available process data. This should include a description of system operation and how it varies based on production or seasonal requirements, pump/motor system data, and system assumptions that could affect baseline energy use. Depending on the assessment level, the discussion of system operation can be extensive and should be supported by graphs, tables, and system schematics.

(a) Pump/Motor Equipment Data. General nameplate data for each pump/motor for the system reviewed can be presented in tabular form as shown in Table 7.

Similar general equipment specification information for variable speed drives, gear reducers, or engine drives (for engine driven pumps) should also be included.

(b) Description of System(s) Studies in Assessment and Significant System Issues. A general overview of system and process requirements provides an understanding of how pump capacity and head are matched to system requirements. An example of how a plant water system is distributed for a 30 million gallons/day (MGD) wastewater plant is shown in Fig. 11. This estimated flow balance reveals that pump flow increases significantly when additional flow is used for the gravity thickener system in the summer.

7.2.5 Assessment Data Collection and Measurements. This report section should include a discussion of pumping system data collection methods and assumptions. For a Level 1 assessment, there should be less quantitative data, since the focus is to prioritize potential energy savings opportunities. Relevant data should include

(a) defining system requirements and a determination of how system operation changes during the year (drawings, system process data).

(b) pump total operating head, component frictional head losses, and system curve development (through the use of existing gauges, portable pressure transducers, or based on suction/discharge tank elevations). If applicable, report measured suction and discharge vessel vapor pressure. Table 8 identifies common pressure measurement methods. Understanding of the data can often be enhanced by including a simple schematic of the pumping system elevations. See Fig. 12.

(c) electrical energy use data (use of portable or existing instrumentation).

(d) determination of pump operating hours and flow intervals (plant historical data, staff input, data loggers).

(e) predicting pump performance (generic or shop test pump curves, field data).

(f) a discussion of data accuracy and the need for verification before the recommended projects are approved.

7.2.6 Data Analysis. Outcomes from measurements taken and data analysis will be provided in this section of the report. The use of tables, schematics, and other graphical tools in the report is an effective means of conveying information to the reader. For pumping systems where system requirements vary, it will be necessary to develop flow profiles as discussed in para. 5.7. For some facilities, it will be possible to download 12 mo of hourly flow data from a process distributed control system into a spreadsheet. With this detailed information, it will be possible to determine

Fig. 12 Example Flow Balance

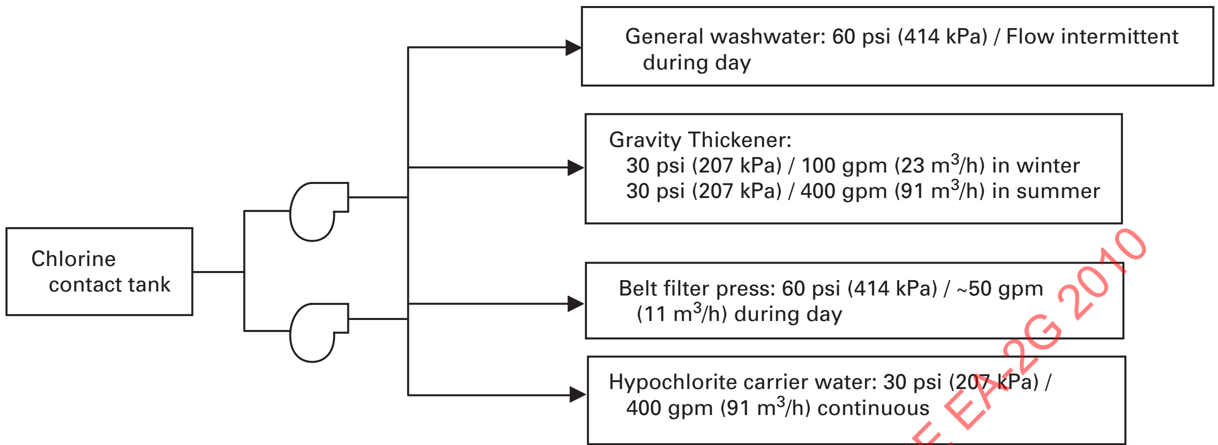


Table 8 Measurement Methods

Head Value	Methods/Assumptions
Suction tank elevation	Local reading on existing ultrasonic level control
Suction piping loss/pipe size	Minimal head loss, __ pipe size
Pump discharge losses before gauge	Minimal head loss, __ pipe size
Discharge pressure	Portable pressure instrument reading
Discharge tank elevation	Estimated based on visual observation

– total monthly flow
– number of hours for various flow ranges (flow intervals)
– how flow varies during different times of the day

An example of data collected for plant water pumps equipped with variable speed drives is shown in Table 9 and Fig. 13.

For the above example, the pump speed was adjusted as required to maintain a constant discharge pressure value of 70 psi. As noted in Fig. 13, flow increased significantly during the summer months to match process requirements.

When available, average or total process requirements that are related to pump operation in hours can be used to benchmark pumping system energy use. This may be represented by total flow pumped, manufacturing production units, system temperature or other parameters. However, other variables such as tank levels, system pressures, fluid viscosity and temperature changes that could impact pumping system energy use must also be considered.

(a) Pump Head and System Curve Development. For each flow interval, pump head must also be determined. Since pump head calculations include elevation considerations, tank levels, and pressure readings, it is useful to present this information in a simple schematic as shown in Fig. 14 with an overview of head calculation methods and assumptions.

When system head conditions have been determined for various flow rates, the flow interval table can be expanded to include this information as shown in Table 10.

(b) Electrical Measurements. Measured electrical data can be summarized in a table such as Table 11.

Fig. 13 Annual Flow Profile Example

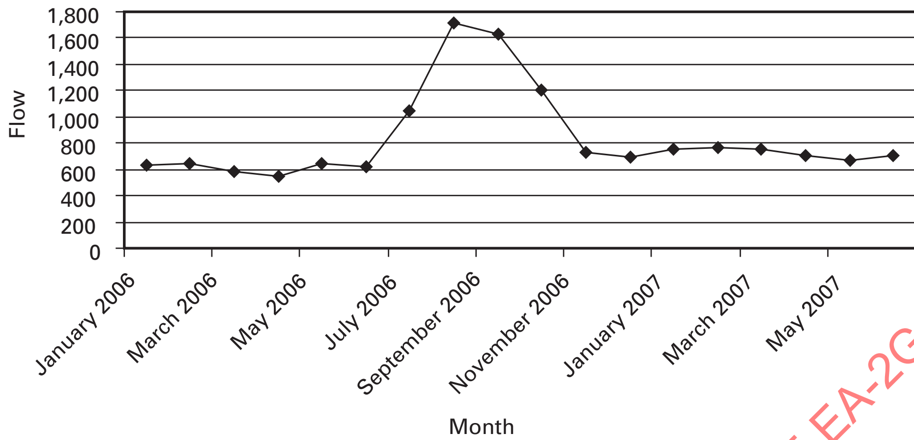


Fig. 14 Simple Pumping System Schematic

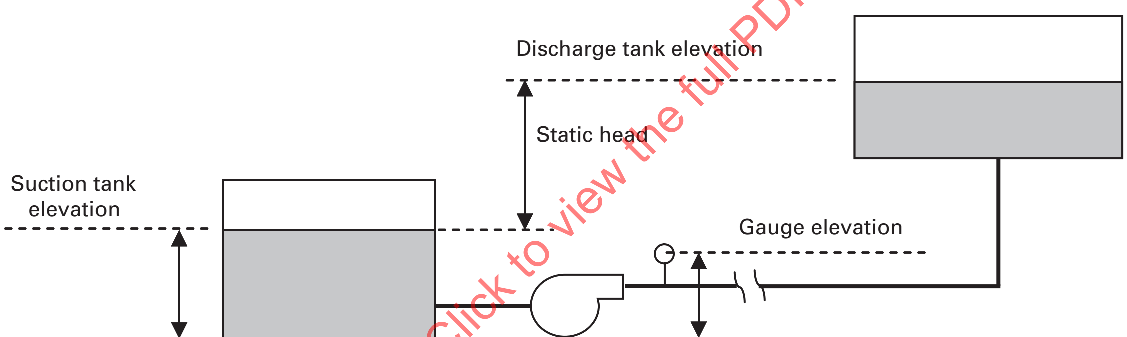


Table 9 Flow Data From Distributed Control System

Time	Flow, gpm (m^3/h)
7/1/06 12:00 a.m.	948 (215)
7/1/06 1:00 a.m.	970 (220)
7/1/06 2:00 a.m.	961 (218)
7/1/06 3:00 a.m.	945 (215)
7/1/06 4:00 a.m.	963 (219)
7/1/06 5:00 a.m.	965 (219)
7/1/06 6:00 a.m.	954 (217)
7/1/06 7:00 a.m.	962 (218)
7/1/06 8:00 a.m.	950 (216)

Table 10 Flow Interval Data

Flow Interval	Flow Rate	TDH	Annual Hours
1	–	–	–
2	–	–	–
3	–	–	–
4	–	–	–
5	–	–	–

GENERAL NOTE: Dashes represent sample data.

Table 11 Electrical Measurements

Pump	Leg	Amperage	Voltage	kW
1	1	–	–	–
	2	–	–	–
	3	–	–	–
Average/Total: 2				
	1	–	–	–
	2	–	–	–
	3	–	–	–
Average/Total: 3				
	1	–	–	–
	2	–	–	–
	3	–	–	–
Average/Total		–	–	–

GENERAL NOTE: Dashes represent sample data.

As indicated previously, every effort should be made to collect electrical measurements using a true-RMS power meter. If necessary, the U.S. Department of Energy's Pumping Systems Assessment Tool can be used to estimate power using amperage measurements. A power versus amperage relationship may also be useful when data loggers are used to evaluate energy use at different flow intervals.

(c) Operating Hours. Facilities that monitor equipment with distributed control systems can often extract operating hours and related process data from the system database for specific time periods. When these data are downloaded into a spreadsheet, a pump use profile can be used to determine a system baseline. An example of a pump operating hour summary is shown in Table 12.

If pump operating hours are not available through a process system database, it may be necessary to estimate them based on interviews with facility staff or, if pumps are cycled frequently, data loggers can also be used over a one- to two-week time period to estimate typical hours of operation.

(d) Predicting Pump Performance. Field data should be compared with the original pump curve when evaluating pump performance. Besides providing a simple comparison to verify head and flow measurements, the original pump curve (preferably based on shop or field testing) is beneficial to evaluating efficiency changes, impeller trims, and predicting pump performance when system changes are proposed.

7.2.7 Annual Energy Use Baseline. In the analysis section of the report, the pumping system energy use baseline should be established and energy savings opportunities developed. This is typically done by taking instantaneous flow, pressure, and electrical measurements and determining operating hours at varying system conditions.

For all assessment levels, the analysis for baseline development and proposed recommendations should be performed in sufficient detail to allow facility staff to understand all parts of the analysis. If software is used, the data entered into the software should be clearly defined.

Table 12 Pump Operating Hours

Month	Pump #1 Hours	Pump #2 Hours	Pump #3 Hours
Jan	–	–	–
Feb	–	–	–
Mar	–	–	–
Apr	–	–	–
May	–	–	–
Jun	–	–	–
Jul	–	–	–
Aug	–	–	–
Sep	–	–	–
Oct	–	–	–
Nov	–	–	–
Dec	–	–	–
Total	–	–	–

GENERAL NOTE: Dashes represent sample data.

Table 13 Baseline Data

	Pump ID	Flow Interval	Pump Flow Rate	RPMs	TDH	kW	Annual Hours	Estimated Annual kWh
	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–
Totals	–	–	–	–	–	–	–	–

GENERAL NOTE: Dashes represent sample data.

The supporting analysis data may include spreadsheets, diagrams, software output screen captures, and calculations. The steps, assumptions, and calculations of the analysis should be presented in a logical detailed format that can be understood by other engineering professionals for third-party verification if required.

It is important to define the flow and head values determined at the pump and how these values compare to system requirements. In some cases, these values will be similar, but in other cases where flow is recirculated to the suction tank or reduced with a discharge control valve, the data should be presented to illustrate these differences. Table 13 provides an example presentation format.

Pump efficiency calculations can be presented as shown in Table 14, and any software calculations can be summarized through screen shots from the software tools used by the assessment team.

A discussion of how the motor/drive efficiency was determined should also be included.

7.2.8 Performance Improvement Opportunities Identification and Prioritization. Improvement opportunities may be presented in terms specified in (a) through (e).

(a) Potential Savings. Include energy use, energy demand, and cost savings. The steps, assumptions, and calculations of the analysis should be presented in a logical, detailed format that can be understood by other engineering professionals for third-party verification if required.

(b) Energy Efficiency Recommendations. The amount of detail included in the energy efficiency recommendations should vary considerably for each assessment level. Recommendations are typically classified as

Table 14 Pump Efficiency Calculations

Flow Interval	Flow Rate	TDH	Motor/Drive Efficiency	Measured kW	Calculated Pump Efficiency
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–

GENERAL NOTE: Dashes represent sample data.

Table 15 Project Savings and Cost Summary

Project Summary	
Cost/Savings	**Unit**
First-year savings	kWh
Demand savings	kW
Energy cost savings (based on $/kWh)	$
Demand savings (based on $/kW summer, $/kW winter)	$
Total cost savings	$
Estimated cost	$
Simple payback	yr

Operation and Maintenance Measures (OMMs) or as Energy Conservation Measures (ECMs). The recommendations reviewed in this report section should be prioritized based on facility staff acceptance and cost effectiveness.

The presentation of each measure should be limited to a brief description of the proposed improvement and a summary of the benefits. If needed, it is also appropriate to recommend a higher level assessment before the measure is pursued. Detailed supporting data, such as energy use calculations, cost savings calculations, and economic analysis, should be referenced and included in the report appendix. An example summary table of project savings and costs is shown in Table 15.

(c) Operation and Maintenance Measures. Operation and Maintenance Measures include energy saving opportunities that can be performed for minimal costs or recommended policies and practices that may not be quantifiable but are considered efficient industry practices. Examples include reducing the number of pumps in use for parallel pumping, and pressure or level control adjustments. These measures are typically supported with simple calculations or a general explanation that supports the recommendation. An example of an energy efficient practice that may not have quantifiable savings includes the installation of pump energy monitoring equipment or controls.

(d) Energy Conservation Measures. Energy conservation measures (ECMs) include recommendations that require a more substantial capital investment that results in a simple payback that typically exceeds 1 yr. For pumping systems this may include the installation of VSDs or major pumping system modifications. An ECM should include a description of the measure, a summary of first-year energy savings, increase or decrease in operational and maintenance costs (for Level 3 evaluations), cost savings, estimated implementation costs (optional), and economic cost benefit (optional). Project economics may be presented based on simple payback (cost/savings) or use a life cycle cost analysis approach for Level 3 evaluations. Because of their nature, additional engineering design work is often required to implement ECMs and should be included in the estimated implementation cost.

(e) General Comments. This section of the assessment is used to discuss general observations of nonpumping-