Going with the Flow: Life Cycle Costing for Industrial Pumping Systems

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ABSTRACT

Industries worldwide depend upon pumping systems for their daily operation. These systems account for nearly 20% of the world's industrial electrical energy demand and range from 25-50% of the energy usage in certain industrial plant operations. Purchase decisions for a pump and its related system components are typically based upon a low bid, rather than the cost to operate the system over its lifetime. Additionally, plant facilities personnel are typically focussed on maintaining existing pumping system reliability rather than optimizing the systems for best energy efficiency. To ensure the lowest energy and maintenance costs, equipment life, and other benefits, the system components must by carefully matched to each other, and remain so throughout their working lives.

Life Cycle Cost (LCC) analysis is a tool that can help companies minimize costs and maximize energy efficiency for many types of systems, including pumping systems. Increasing industry awareness of the total cost of pumping system ownership through life cycle cost analysis is a goal of the US Department of Energy (DOE). This paper will discuss what DOE and its industry partners are doing to create this awareness. A guide book, Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems, developed by the Hydraulic Institute (HI) and Europump (two pump manufacturer trade associations) with DOE involvement, will be overviewed. This guide book is the result of the diligent efforts of many members of both associations, and has been reviewed by a group of industrial end-users. The HI/Europump Guide provides detailed guidance on the design and maintenance of pumping systems to minimize the cost of ownership, as well as LCC analysis.

DOE, Hydraulic Institute, and other organizations' efforts to promote LCC analysis, such as pump manufacturers adopting LCC analysis as a marketing strategy, will be highlighted and a relevant case study provided.

Introduction

An existing condensate pumping system at a chemical processing plant was evaluated for life cycle cost savings. (HI 2001) Based on recommendations following a systems analysis, the pump impeller was trimmed and the existing 150 horsepower (hp) motor was replaced with a 100 hp motor, resulting in an estimated $115,000 savings over the ten year projected life of the system. This 40% cost savings is due to both reduced energy consumption and reduced maintenance.

A similar systems analysis was performed on an existing water circulation tank pumping system serving a paper machine at a pulp and paper mill. (HI 2001) The analysis recommended installing a new, smaller pump in parallel to the existing pump to provide base load duty. The estimated savings of over $700,000 over the estimated 20 year system life is a 56% reduction in the life cycle cost.

These are just two examples which highlight the value of quantifying the life time savings available through systems efficiency improvements. Unfortunately, most industrial end users do not employ this life cycle analysis methodology during new system design or existing system retrofit. A new activity within the pump industry seeks to change this situation.

Pumping systems are found throughout industrial facilities worldwide. The purchase and operation of industrial pumping systems is a significant expense for facilities in most all industrial sectors. However, it is common practice for pumping system design and procurement to be based primarily upon the initial purchase cost of the equipment. This initial cost is a small part of the total cost to operate the system over its life, which can average fifteen to twenty years, depending upon its application and operating environment. Energy, maintenance, and other operating costs will far outweigh the initial costs. (see Figure 1) Therefore it makes economic sense to consider these lifetime costs when designing and procuring pumping systems. Existing systems are also candidates for life cycle analyses, since there are at least 20 times as many pumping systems in the installed base as are built each year. Many of these existing systems are not optimized for various factors, such as altered system requirements, deferred maintenance, and overly conservative design practices.

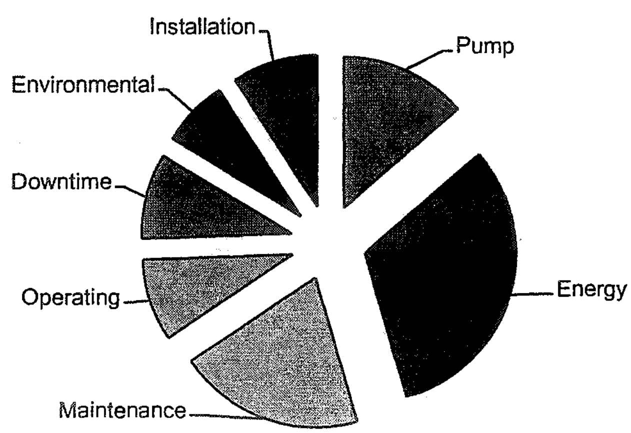

Figure 1. Example Life Cycle Costs for an Industrial Pumping System

Energy, typically electrical energy, is an important component of any examination of lifetime costs. Pumping systems in the United States manufacturing industries consume over 142 TWh per year. In the US petroleum industry, for example, 50% of the annual electricity use is for the operation of pumping systems (DOE 1998). A typical petroleum facility consumes over 10 million kWh per year on electricity for pumping, costing almost $500,000 annually, based on an industry average of $0.048 per kWh (DOE 1998)[1]. In the US forest products industry, pumping systems account for 26% of the total electricity use. A typical pulp and paper mill consumes over 4 million kWh per year on electricity for pumping, costing approximately $200,000 annually (DOE 1998).

Energy efficiency is generally not a motivating factor for decision-makers in industry (Pye and McKane 1999). Plant and corporate management personnel are typically bound by the profit motive when considering the investment of capital funds. Additionally, plant personnel may have limited capital funds available for efficiency projects. Decision-makers are more attuned to activities that directly translate to the bottom line, such as projects to increase productivity. Fortunately, the majority of energy efficiency projects provide non-energy benefits in addition to the energy cost savings, such as:

- reduced maintenance costs
- increased productivity
- reduced costs of environmental compliance
- reduced production costs
- reduced waste disposal costs
- improved product quality
- improved capacity utilization
- improved reliability, and
- improved worker safety

Far more compelling to facility decision-makers are potential projects with quantifiable "efficiency" or "productivity" improvements. Such proposals must be supported by a financial analysis that includes both the energy and non-energy costs and benefits (savings). Analyses can be in terms of net present value, internal rate of return, or life cycle cost, all of which take into account the time value of money.

Some pump manufacturers are considering life cycle cost analysis to be the single largest driver in the United States pumping equipment market over the next ten years. These manufacturers expect the end user emphasis will move from pump features and lowest price to lifetime performance and manufacturer service and support. One manufacturer expects life cycle marketing and education to influence as much as $565 million per year in system replacement and new installations within the next five years.

Increasing Awareness of LCC

The Hydraulic Institute, an association of US pump manufacturers, in cooperation with Europump, an association of national pump manufacturing associations in Europe, has produced Pump Life cycle Costs: A Guide to Life Cycle Cost Analysis for Pumping Systems (HI 2001). This guide explains in-depth life cycle costing for pumping systems and provides substantial technical guidance on designing new pumping systems as well as assessing improvements to existing systems. The guide also includes examples of manual calculation of LCC and a software tool to assist in LCC calculation.

[1] Based on 1997 data.

The Hydraulic Institute has a downloadable version of an Executive Summary of the Guide on its web site (www.pumps.org). Individual Hydraulic Institute member companies also are promoting the Guide and the life cycle methodologies to their customers.

Europump and its member organizations are using the debut of the Guide as an opportunity to develop awareness of life cycle costing. For example, the British Pump Manufacturers Association, a Europump member, hosted a one-day workshop built around the Guide.

The US Department of Energy's BestPractices program plans to promote use of the life cycle cost approach by facilitating collaboration between the Hydraulic Institute and industrial end use associations. The BestPractices program will work with the DOE Federal Energy Management Program to include life cycle costing as a tool for purchasing agents at federal facilities. BestPractices has also placed the Executive Summary of the Guide on its web site (www.oit.doe.gov/bestpractices/).

The BestPractices program has promoted the systems approach to industry for energy efficiency analysis for many years. The MotorMaster+ software tool includes a straightforward LCC module to assist in motor purchase decision-making. BestPractices workshops on Asset Management for Motor Systems and the Pumping System Assessment Tool (PSAT) incorporate discussions on LCC analysis.

The BestPractices program is leveraging its resources to promote life cycle costing through its Allied Partners, in particular with Hydraulic Institute member companies. Several of these companies are requiring key staff to become qualified as users for the PSAT software training. Several plan to become qualified instructors who will then be able to build life cycle costing awareness among end users as they provide the PSAT instruction to their customers. Perhaps most importantly, pump manufacturers are beginning to bring life cycle costing into sales and marketing discussions with customers.

Although not developed specifically for pumping systems, a new standard was published in 2000 by the International Organization for Standardization. ISO 15663, Petroleum and natural gas industries – Life cycle costing, attests to the increased realization by industry of the need to consider the life time costs of ownership for equipment.

A Systems Approach

When a system is considered for optimization, a "systems approach" is highly recommended. A systems approach, which analyzes both the supply and demand sides of a pumping system and how they interact, shifts the focus of the analysis from individual components to total system performance, i.e., looking at the forest, not just the trees. The potential energy and cost savings through a systems approach to optimization almost always outweigh the sum of the savings through component optimization.

For example, a survey of only the components of a pumping system may reveal opportunities for an energy efficient motor, replacement of a leaking valve, and adjustment to the energy management system to precisely align the pump operation hours to the schedule of the end-use process. This may result in a 20% reduction in energy costs. In comparison, analysis of the pumping system using a systems approach could identify a varying load profile that could best be met through a two-pump arrangement or adjustable speed drive, resulting in a 50-60% savings.

The results of a systems approach to analysis will vary from system to system and from facility to facility. One common problem, however, is oversized pumping systems, including both the pumps and system components. (Bower 1999) Anecdotal evidence indicates that about 75% of all pumping systems are oversized. This inefficient condition may result from conservative design, design for anticipated system capacity increases, or a decrease in the output demand. Typical indications of an oversized system include frequent on/off cycling, highly throttled valves, or heavy reliance on bypass lines. Possible improvements are to trim the existing pump impeller, install a smaller impeller, remove stages of the pump (if a multi-stage pump), replace with a smaller pump, or reduce the pump speed. An engineering analysis can identify practical alternatives, and a life cycle analysis can then be employed to determine the most economical option. Proper sizing results in not only improved energy efficiency, but also has a positive effect on other factors in the life cycle cost equation. A properly sized system operates close to its Best Efficiency Point, resulting in lower maintenance costs, longer equipment life (increased mean time between failure), and reduced downtime expenses.

End users frequently install variable frequency drives (VFDs) to control motors on pumping systems with variable loads. The VFDs often result in substantial energy and maintenance savings, but it is important to note that not all applications are appropriate for VFDs, particularly systems with substantial static head. (Hovstadius 1999) A systems analysis will typically identify whether a VFD is appropriate for a particular application. Flow control alternatives such as impeller trimming and multiple pump arrangements may be more effective and more economical. A life cycle cost analysis comparing the alternatives will identify the lowest cost solution. A good example of such an analysis is given in the HI/Europump Guide, and is also in the Guide's Executive Summary, available from the DOE BestPractices' and Hydraulic Institute's web sites (www.oit.doe.gov/bestpractices/ and www.pumps.org).

Proper system sizing and the use of variable frequency drives are just two examples of the efficiency improvement opportunities commonly seen in industrial pumping systems. DOE's *Improving Pumping System Performance: A Sourcebook for Industry*, (DOE 1999) provides a more detailed description of these and other system opportunities.

The BestPractices program offers a guideline for prescreening pumping systems which provides guidance in applying the systems approach to pumping system evaluation. (Tutterow et al. 2000) The Pumping System Assessment Tool (PSAT) software, developed and available through BestPractices, complements this prescreening guideline.

Overview of Life Cycle Costing

A greater understanding of all the components that make up the total cost of pumping system ownership will provide insights into opportunities for significantly reducing energy, maintenance, and other operational costs. LCC analysis is a management tool that can help companies realize these opportunities. The analysis takes into consideration the costs to purchase, install, operate, maintain, and dispose of all components of the system. Determining the LCC of a system involves following a methodology to identify and quantify all of the components of the LCC equation. When used as a comparison tool between possible design or overhaul alternatives, the LCC process will identify the most cost-effective solution within the limits of the available data.

In applying the evaluation process, or in selecting pumps and other equipment, the best information concerning the intended output and operation of the plant must be established. If bad or imprecise information is used then a bad or imprecise assessment will result. The LCC process is a way to predict the most cost-effective solution; it does not guarantee a particular result but allows the plant personnel to make a reasonable comparison between alternate solutions within the limits of the available data.

Pumping systems often have a lifespan of 15 to 20 years. Some cost elements will be incurred at the outset and others will be incurred at various times throughout the lives of the different solutions being evaluated. It is therefore necessary to calculate a *present* or *discounted* value of the LCC to accurately assess the different solutions.

To make the most of an LCC analysis, it is best to evaluate alternative system solutions. For a majority of facilities, the lifetime energy and/or maintenance costs will dominate the life cycle costs. Therefore, it is important to determine the current cost of energy and the expected annual energy price escalation for the estimated life, along with expected maintenance labor and material costs. Other factors, such as the life time costs of down time, decommissioning, and environmental protection, can often be estimated based on historical data for the facility. In some processes, down time costs can be more significant than the energy or maintenance elements of the equation. Therefore, careful consideration should be given to productivity losses due to down time.

The LCC equation, as defined in the HI/Europump Guide (HI 2001), is:

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d$$

where

C_{ic} = initial cost, purchase price (pump, system, pipe, auxiliary)
C_{in} = installation and commissioning
C_e = energy costs
C_o = operating cost (labor cost of normal system supervision)
C_m = maintenance cost (parts, man-hours)
C_s = down time, loss of production
C_{env} = environmental costs
C_d = decommissioning

BestPractices suggests the following steps as a general guideline when analyzing an existing pumping system:

- Assemble a complete document inventory of the items in the pumping system;
- Determine the flow rates required for each load in the system;
- Look for heavily throttled valves;
- Look for frequent pump starting and stopping;
- Listen and feel for excessive vibration;
- Listen for excessive noise; and
- Identify pumps with high maintenance costs.

Since the systems are usually in operation during the analysis, there is a limit to the amount of testing possible. In lieu of detailed testing, accurate models of the system layouts can be developed to allow consideration of system alternatives. Assuring the accuracy of the models is critical, and requires a certain degree of expertise in this area. The prescreening guideline and PSAT software described earlier can assist in this modeling process.

Case Study

Some industrial facilities have begun to use the systems approach and life cycle cost analysis to identify opportunities and to realize substantial savings. A chemical manufacturing plant sought to minimize the lifetime cost of its pumping systems. Technical staff from a pump manufacturer applied a "smart pumping system" (Stavale et al. 2001) for a cooling tower application at this plant to demonstrate the technology and validate the life cycle savings potential. The chemical plant specified stringent requirements for any new system, including 50,000 hour mean time between failure, 10,000 start-stops, and run dry capability, among other performance parameters.

The cooling tower pumping system serves a hydrogen purification plant. The system was installed in August, 1999 and includes an ASME B73 8x10-13 centrifugal pump driven by a 100 horsepower, 1780 rpm electric motor. The pump is capable of 2,800 gallons/minute at 120 feet of head.

The installed system consists of a standard centrifugal pump, a variable speed drive, instrumentation, a microprocessor, and special software. The software interacts with instrumentation signals to sense process conditions. This "smart pumping system" detects and prevents the pump from operating under damaging conditions, such as inadequate Net Positive Suction Head (NPSH), dry running, or operating against a closed suction or discharge valve. The system is also capable of recognizing and adjusting to changing operating conditions and allowing normal pumping operation to resume following system transients. The control described here occurs if the user has selected "alarm and control" mode. The user also has the option of "alarm and fault" (automatic system shut-off) mode and "alarm only" mode.

A low flow monitor detects a dry running condition, and operation below minimum flow or against a closed suction or discharge valve. If flow cannot be maintained, the user again can select between "alarm and control", "alarm and fault", and "alarm only" modes.

The "smart pumping system" also includes safeguards to protect against high pressure, high temperature, excessive electrical current, and excessive speed. Self-diagnostic features compare the pump performance to the "as new" performance of the system, sounding an alarm when actual performance degrades past a certain value.

Case Study Life Cycle Cost Estimates

Although the software, microprocessor, and instrumentation were added up-front costs, the total installation cost was actually slightly lower than the cost of a standard pumping system installation of this size. This is in large part because typical system components such as a control valve, external flow meter, separate starter, and recirculation line piping were not needed. Also, the design avoided the added expense of purchasing an oversized pump and motor.

The calculated total life cycle cost savings are $268,650, as shown in Table 1. The estimates are based on a 15 year equipment life. The energy costs assume electricity at $0.06 per kWh, with 24 hour per day operation. Maintenance cost calculations assume an 18 month mean time between failure (MTBF) for the conventional system, and a 27 month MTBF for the installed system.

Table 1. Total Life Cycle Costs

Life Cycle Costs	Conventional System	Installed System
Initial Costs	$20,600	$19,800
Installation Costs	$83,000	$53,750
Energy Costs	$636,900	$410,700
Pump Maintenance Costs	$25,000	$16,600
Other Maintenance Costs	$6,000	$2,000
Total Life Cycle Costs	**$771,500**	**$502,850**

The chemical plant has been pleased with the new system, and is currently installing a second system for another cooling tower. To date, the actual savings measured closely match the savings calculated during the LCC analysis.

Conclusions

Industrial pumping systems are significant consumers of not only energy, but also of financial resources required for the maintenance and operation of these systems. Significant opportunities exist for reducing life time system costs, but go unrealized since engineering and procurement practices tend to consider only the initial system costs. Life cycle cost analysis is a proven methodology for identifying the lowest life time costs of alternative design or retrofit options. Efforts are under way to increase the awareness of life cycle costing as a viable means of evaluating pumping systems, including DOE promotion of a "systems approach" to realizing opportunities, and the publication of the HI/Europump Guide to life cycle cost analysis for pumping systems.

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