Pumping System Design

Santee Cooper® POWER

Pumps are the largest single application of electric motors. In industrial facilities in the U.S., pumps and fans account for more than 25 percent of electricity consumption. Energy usage by pump and fan systems can be reduced by 20 to 50 percent through improved efficiency. Most of the potential energy savings lies in the application of the equipment, including properly designing the system in the first place, rather than in higher-efficiency equipment.

This pamphlet focuses on designing pumping systems for improved energy efficiency and better performance. Retrofits of existing systems also offer significant opportunities for improved efficiency, but the design phase presents the biggest opportunity to achieve the greatest energy efficiency and the lowest overall system costs.

Fat, Straight Pipes and Smaller Pumps

The conventional approach to designing a pumping system is to use a standard engineering guide to select the size of the pipe based on the expected flow rate. Designers normally avoid specifying larger pipes than necessary in order to reduce the initial material cost of the pipes. However, the energy used by pumping systems to overcome pipe friction increases greatly with smaller pipes. In fact, pumping energy increases with roughly the inverse of the fourth power of the pipe diameter. (See sidebar.) For example, cutting pipe diameter in half will increase the required pumping energy by about 2^4, or 16-fold.

Figure 1 (next page) shows the annual costs of pumping water to sustain a flow rate of 600 gallons per minute (gpm) through 1,000 feet of pipe, given different pipe sizes. Using a 10-inch (in.) pipe would result in annual pumping costs of about $200, whereas pumping costs for an 8-in. pipe would be about $450, and costs for a 6-in. pipe would be about $1,700. Clearly, significant increases in energy costs result when smaller-diameter pipes are selected for a system.

Calculating Pumping Power and Costs

The pumping power required to overcome friction losses can be determined by using the following equation:

H = QP/(constant)(pump efficiency)

Where H = pumping power in horsepower; Q = flow rate in gallons per minute; and P = friction pressure losses (pressure drop in inches water gauge).

Also, P = $fLV^2/2Dg$ and V = Q/A,

Where L = pipe length in feet; V = average fluid velocity in feet per second; D = pipe inner diameter in inches; g = the gravitational constant (32.2 ft/sec^2); A = area of pipe = (pi)D^2/4; and f is the friction factor, which for laminar flow in smooth pipes can be stated as:

f ~= 16 (pi)(kinematic viscosity)D/Q

Therefore, H = 128 Q^2 (kin vis)L/[(pi) $\mathbf{D^4}$g(constant)(pump efficiency)]

In other words, *for a given required flow rate (Q), the pumping energy is proportional to the inverse of the fourth power of the pipe diameter* (with laminar flow conditions).

Turning to costs, in general, the estimated pumping energy costs to overcome piping friction losses can be calculated as follows:

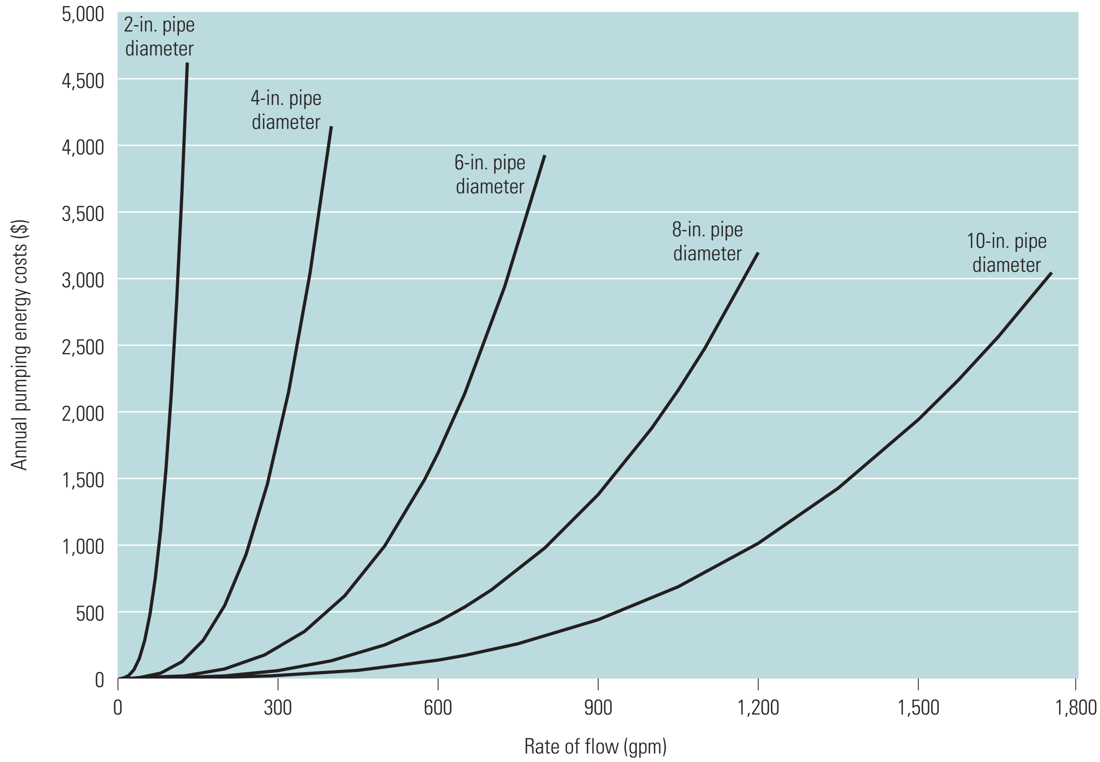
Energy cost ($/y) = Pumping horsepower (from the equation above) x (Number of hours/y) (0.746 kilowatts/hp) ($/kilowatt-hour)

Unfortunately, even when designers consider increased energy costs when assessing the higher initial cost of larger pipes, many of them—and the engineering design manuals they rely on—often overlook the additional cost reduction that comes from being able to use a smaller pump with larger pipes. And that might lead a designer to specify a smaller pipe size and, therefore, a larger pump, missing an opportunity to truly optimize overall costs.

In addition to using fatter pipes, it is possible to specify other elements of pumping systems in ways that will create additional

Figure 1: Pumping energy costs and pipe diameter

To sustain a given flow rate (measured in gallons per minute), pumping energy costs will increase significantly when smaller-diameter pipes are used. For our calculations, we estimated costs for sustaining a flow rate of 600 gallons per minute through 1,000 feet of clean schedule-40 iron pipe for water at 70° Fahrenheit. Our other assumptions included an electricity rate of $0.05/kilowatt-hour, 8,760 hours of operation per year, and combined pump and motor efficiency of 70 percent.



Note: in. = inch; gpm = gallons per minute

Source: Platts; data from U.S. Dept. of Energy, Office of Industrial Technologies

energy savings. As shown in **Figure 2** (next page), these savings combine to produce total savings greater than the sum of the individual measures. The trick is to methodically work backwards from the needed output—the desired fluid flow.

To fully optimize the design of the piping and pump system, the designer should seek answers to the following questions:

- How much flow, with what time-varying patterns, is required to achieve a well-controlled, efficient process?
- How big should the pipes be? We suggest considering the largest pipe size that will still allow the minimum recommended fluid velocity for a given application. (Often a minimum fluid velocity is recommended in order to avoid a build-up of sediment in the piping system.)
- How short, smooth, and "sweet" can the pipes be while delivering the required flow? Designers typically choose a convenient location for the pumps first, and then lay out the pipes to connect the pumps with the rest of the equipment. Laying out the pipes *first* and then choosing the best location for the pumps allows for straighter, shorter piping, which significantly reduces friction losses (although not as dramatically as choosing a larger-diameter pipe). For example, with 4-in. diameter pipe, adding a 90-degree bend is equivalent to adding about 30 in. of additional straight piping (about 7 to 8 times the pipe diameter for a 90-degree bend).
- How big and with what performance curve should the pump be specified to deliver the desired flow pattern, and how efficient can the pump be made over that operating range? If you are specifying a new

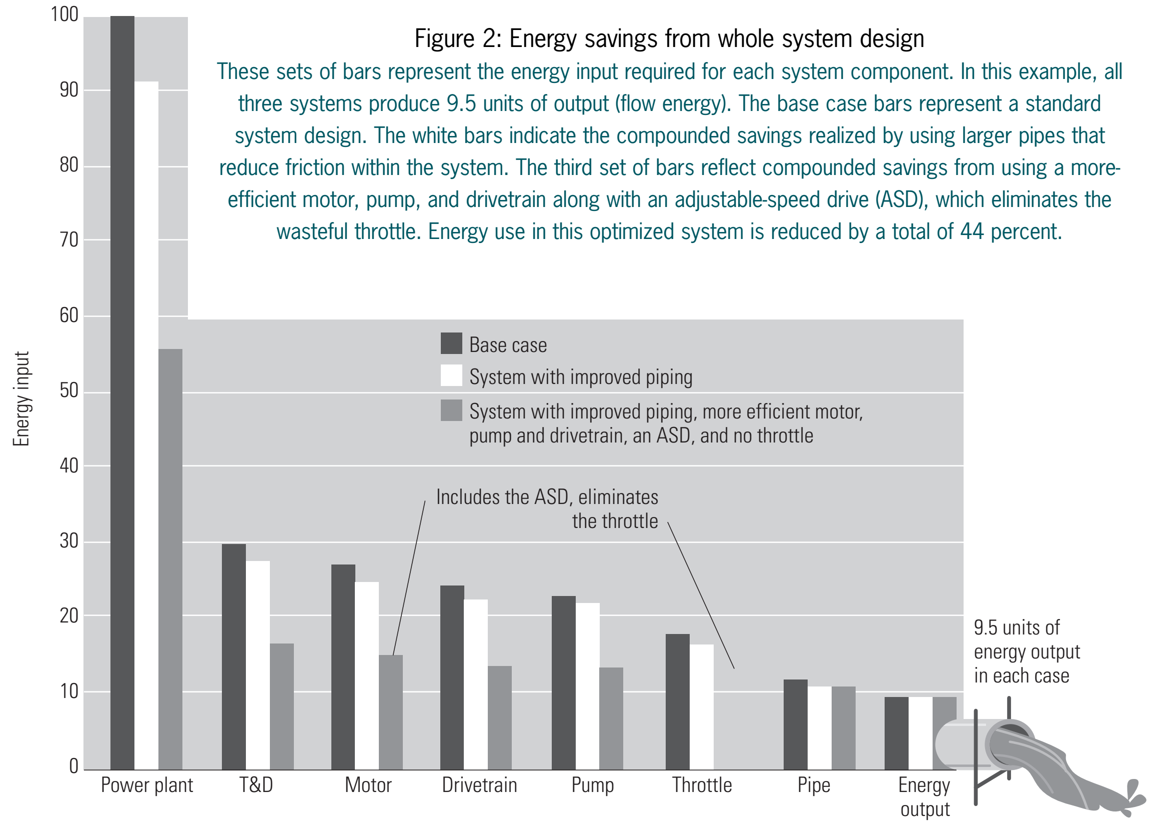


Figure 2: Energy savings from whole system design

These sets of bars represent the energy input required for each system component. In this example, all three systems produce 9.5 units of output (flow energy). The base case bars represent a standard system design. The white bars indicate the compounded savings realized by using larger pipes that reduce friction within the system. The third set of bars reflect compounded savings from using a more-efficient motor, pump, and drivetrain along with an adjustable-speed drive (ASD), which eliminates the wasteful throttle. Energy use in this optimized system is reduced by a total of 44 percent.

Source: Platts

pump, it is usually most cost-effective to choose one with a motor that has a NEMA Premium efficiency rating (from the National Electrical Manufacturers Association), rather than one that meets the minimum federal efficiency standards set forth in the Energy Policy Act of 1992 (EPACT standards).

- What would the most advantageous size and efficiency be for the mechanical drivetrain that transmits torque to the pump? Of the motor? Of the motor controls? And of electrical supplies for the motor and its controls?
- What control sequences and staging of pumps will result in the most efficient overall performance? For example, replacing a throttling valve with an adjustable-speed drive is a smart decision in many cases. Or it may make sense to use two or more smaller pumps instead of one large pump. Both pumps can be operated in parallel during peak demand periods, and then just one pump can be operated during low-demand periods. Energy savings result from running each pump at a more-efficient operating point and from avoiding the need to throttle a large pump during low-demand periods. Another alternative is to use one variable-speed pump and one constant-speed pump.

Life-Cycle Costs

How can a designer evaluate the cost-effectiveness of all these options? Ideally, life-cycle costs of several alternative designs should be considered. The life-cycle cost is the total lifetime cost (over a period of, say, 15 years for a typical piping/pumping system) to purchase, install, maintain, operate, and ultimately dispose of the equipment and other components of the system.

Software available from the Hydraulic Institute makes this type of calculation easy, once the alternatives have been mapped out and appropriate costs for components have been estimated. The required inputs to the software include initial investment and installation costs for the systems being analyzed; the annual hours of operation, the average power required, and the price of electricity; and annual maintenance costs, repair costs, and estimated downtime.

For a typical midsize industrial pump, the initial cost of the pump only accounts for about 10 percent of the pump's total life-cycle cost. Energy will account for about 50 percent and maintenance for about 35 percent of the total. A key step in this type of evaluation is to consider the alternatives as a *system*, taking into account the interactions among components and design elements.

Summary

The design phase of developing new piping and pumping systems affords a great opportunity to improve system performance while also generating large cost savings. By starting with the end-use needs and working backwards through the system, energy savings can be compounded, and by considering the life-cycle costs of the pumping system as a whole, overall costs can be dramatically reduced. And if you choose a simpler piping layout and opt for better controls, you could also improve reliability and overall performance.

Case Study: Interface Facility in Shanghai

In 1997 Interface, a major carpet producer, was building a new factory in Shanghai, China. In the first draft of the design for one of the factory's industrial processes, which was created by a well-known western engineering design company, 14 pumps with a total capacity of 95 horsepower were specified. Then Interface brought in Jan Schilham, one of its own engineers from Holland, to take a fresh look at the process design. Applying methods he had learned from efficiency expert Eng Lock Lee, Schilham produced a design that only required a total of 7 horsepower—a 92 percent reduction. Schilham's design employed two of the important principles discussed in this pamphlet: (1) choosing fatter pipes and smaller pumps, and (2) laying out the pipes *before* positioning the pumps. The fatter pipes and straighter, simpler layout dramatically reduced the required pumping energy as well as resulting in a lower total capital cost. In this case, Schilham found that the capital cost fell more quickly for the pumping and drive equipment than it increased for the larger pipes. The simpler piping layout also required less floor space and allowed quicker construction, more-reliable operation, easier maintenance, and better performance.

Resources

The Hydraulic Institute's life-cycle assessment tool is available free at www.pumps.org/public/pump_resources/energy/lcc (accessed 11/21/03).

See also the Executive Summary of "Pump Life-Cycle Costs: A Guide to LCC Analysis for Pumping Systems" (2001) by the Hydraulic Institute, DOE Industrial Technologies Program, and Europump, which is available from www.oit.doe.gov/bestpractices/pdfs/pumplcc_1001.pdf (accessed 11/20/03). Note that the full report is only available in print (for a fee).

Additional information can be found in the Hydraulic Institute's "7 Ways to Save Energy," available from www.pumps.org/public/pump_resources/index2.html (accessed 11/20/03).

This pass-through also draws on information found in "Reduce Pumping Costs Through Optimum Pipe Sizing," by the U.S. Department of Energy's Industrial Technologies Program. This document is available online from www.oit.doe.gov/bestpractices/motors (accessed 11/20/03).

The Interface case study is from Paul Hawken, Amory Lovins, and Hunter Lovins' *Natural Capitalism* (Little, Brown and Co.: Boston, 1999), pp. 116–117.