APPLICATION NOTE

An In-Depth Examination of an Energy Efficiency Technology

Agricultural Pumping Efficiency Improvements

Summary

Pumping water for irrigation is the largest use of on-farm agricultural energy in California. Growers are fully aware of the need for increasing overall efficiency of their pumping plant (pump and motor combination), but they do not always know how to achieve it. This Application Note describes some specific measures.

Overall pump system efficiency depends on the efficiency of the motor, the pump, and the design of the piping layout. This Note focuses on improvements most directly related to the pumping plant rather than piping. And, this Note primarily addresses electric motor-driven pumps, but gas and diesel engines are used as pump drivers as well.

The single greatest contributor to pump inefficiency is an oversized pump. If a pump is selected based on some anticipated future condition, such as degraded (scaled) pipe or a higher projected flow to meet increased crop requirements, it will deliver excess fluid at a higher head than necessary when new. A throttling valve on the pump discharge is often set to turn down the flow when the pump is oversized. Impeller trimming, pump speed changes, and parallel or series pumping are more energy-efficient ways to reduce the energy waste associated with oversized pumps.

Pumping plant efficiency improvements can also be made by directly increasing the efficiency of the motor or pump directly. Motor efficiency can often be increased by replacing a standard-efficiency motor with a high- and premium-efficiency motor. Pump efficiency

can be improved by replacing worn or damaged impellers.

How This Technology Saves Energy

A pump converts mechanical energy into pressure energy to move liquids by applying that pressure energy, or ***head***[1], to the liquid. In a centrifugal pump, the driver, in most cases an electric motor, rotates an impeller, which imparts energy to fluid directed into the center, or eye, of the impeller. The fluid is then acted upon by centrifugal and rotational forces which increase its velocity. The pump casing is designed so that the uniformly increasing area of its volute produces the maximum conversion of velocity energy of the fluid into pressure energy. Figure 1 shows the centrifugal pump components and fluid flow pattern.

To better understand how to improve pump system efficiency, a brief overview of pump operation, terminology, and pump and system curves is provided.

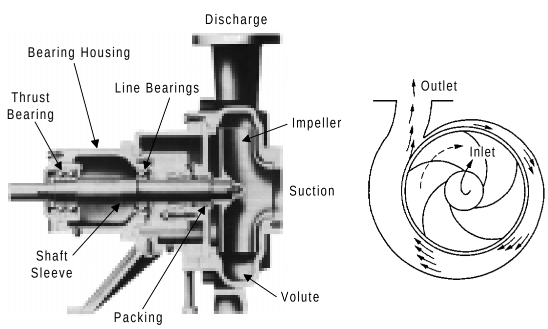

Figure 1: Components and Operation of a Centrifugal Pump *(Sources: Chemical Engineering and ASHRAE)**

[1] Bold-Italic words are defined in the section titled Definition of Key Terms.

System Curves

Figure 2 depicts a typical pumping system and the system head curve, or system curve. This is the graphical representation of the head required at all flows to satisfy the system function. The three components of total system head are static head, design working head, and friction head. Static head is the vertical difference between the system's point of entry and its highest point of discharge. Design working head is that head which must be available at a specified location to satisfy design requirements. Friction head is the head required by the system to overcome the resistance to flow in pipes, valves, fit-

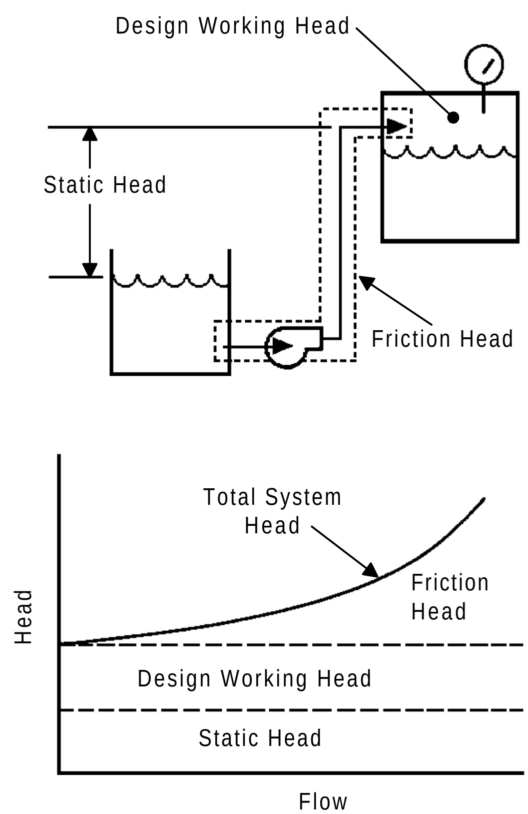

Figure 2: Pump System Curve

tings and mechanical equipment.

Pump Curves

Pump manufacturers provide pump head-capacity curves, or pump curves, that predict pump performance, which can be shown as a single-line curve depicting one ***impeller*** diameter (Figure 3) or as multiple curves for the performance of several impeller diameters in one casing (Figure 4). To meet the wide variety of needs, manufacturers will produce different-sized impellers to be used inside a single casing. This keeps costs down by reducing the number of needed casings, but sacrifices some efficiency.

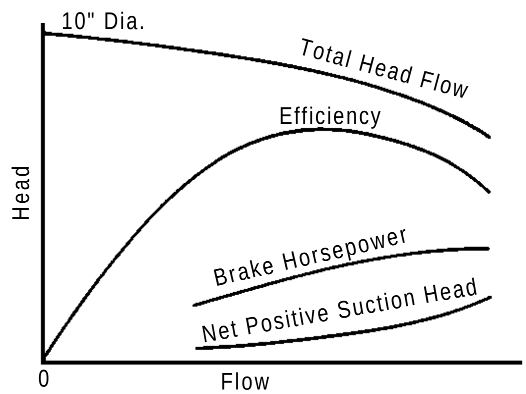

Figure 3: Single Line Pump Curve
*(Source: Peerless Pump)***

A pump operates over a range of head and flows for a given speed and impeller diameter. Change either and a given pump will operate on a different curve. It is characteristic of centrifugal pumps that, for any given speed, as flow through the pump increases, its head decreases. The pump design point is the point on the curve where maximum efficiency is attained. Lines forming a concentric pattern around the design point indicate areas of equal efficiency.

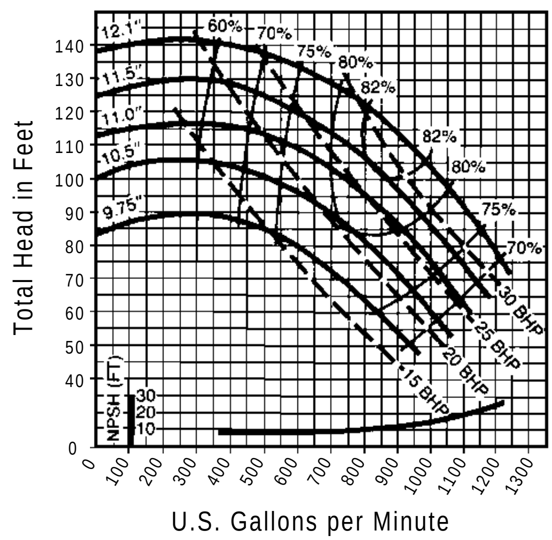

Figure 4: Multiple Pump Curves

A system curve can be developed and overlaid on the pump curve. The intersection of the pump head-capacity curve and the system curve will be the operating point for the pump (Figure 5). This condition represents the point at which pump head matches system head as defined by the system piping configuration.

The efficiency of agricultural pumping plants can be improved by:

- **Replacing a standard-efficiency motor** with a high- or premium-efficiency motor

- **Improving pump efficiency** by adjusting or replacing worn impeller(s) or bowl(s)

- **Reducing total dynamic head** by changing impeller diameter or motor speed, or by using multiple pumps

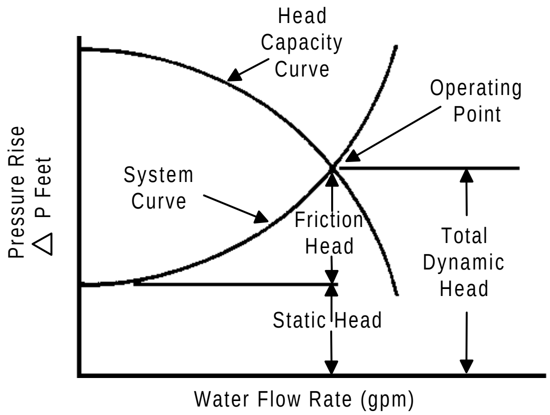

*Figure 5: System Curve and Pump Curve (Source: Peerless Pump)***

Types of Energy Efficiency Measures

Pumping plants can be optimized by a number of measures discussed in this section. As stated earlier, this Application Note focuses on measures directly related to the pumping plant and its operation; piping system characteristics are beyond its scope. And, this Note primarily addresses electric motor-driven pumps, but gas and diesel engines are used as pump drivers as well.

Improve Motor or Pump Efficiency

Pump system efficiency can be improved directly by increasing the efficiency of the motor and/or pump. The following specific actions can be taken:

- **High-Efficiency Motors:** Agricultural pumps normally run 3,000 hours or more annually. The 3 to 5 percent increase in motor efficiency of a high- or premium-efficiency motor can provide quick paybacks.

- **Replacing or Repairing the Pump Impeller and/or the Pump Bowl:** A retrofit of the impeller and bowl assembly of a pumping plant, and the optimal placement of the bowls relative to water levels, can improve pump system efficiency.

- **Pump Adjustment:** Proper adjustment of the impeller relative to the bowl assembly will minimize the clearance between impeller and bowl and maximize the quantity of water pumped.

Decrease Total Dynamic Head

Oversized pumps are the single largest source of energy waste in pumping systems. The situation arises in the design process. Engineers add pressure losses to the system head to allow for scaling and fouling of piping that occurs over time; margin is also added to ensure that the pump selected will deliver the required flow. After installation, the system head may be less than anticipated, especially early on. If pump selection is based on some anticipated future condition, such as "old" pipe or a higher projected flow to meet increased crop requirements, it will deliver excess fluid at a higher head than necessary. If allowed to operate at an excessive flow, the pump "runs out on its head-flow curve" until system resistance matches the pump head. As the pump operates further to the right on the curve, operation becomes less predictable and more unstable. Motor overloading or ***cavitation*** may occur as a result. A valve on the pump discharge is often set to turn down the flow. The extra head is then taken as a pressure drop across the valve. Figure 6 depicts this situation on a system curve.

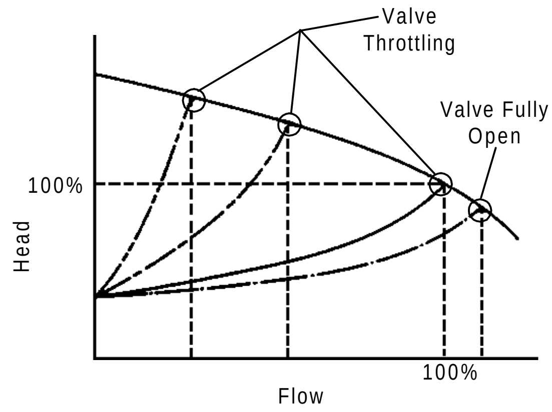

Figure 6: Effect of Pump Throttling
*(Source: Peerless Pump)**

There are several more energy-efficient ways to reduce the total dynamic head and minimize overpumping:

- **Impeller Trimming:** One way is to change the impeller size. This can be done by trimming the existing one or replacing it. Pump manufacturers normally build their pump bodies to accept a range of impeller diameters. Changing this diameter raises or lowers the entire pump curve. Practically speaking, impeller trimming is limited to a 20% reduction in diameter.

- **Pump Speed Changes:** Another way to reduce a pump's output is to reduce its speed. This may not be as simple as changing the impeller diameter. Because most pumps are driven directly off the shaft of their motor, to change the speed of the pump you must change the speed of the motor.

Induction motors, the most common, operate at synchronous speeds which are multiples of the frequency of the 60 Hz AC power delivered, perhaps 1800 or 3600 RPM. To alter the speed of an AC induction motor it would be necessary to either:

1) Change to a motor with a different speed.

2) Change to a two-speed motor.

3) Install a ***Variable Speed Drive*** (VSD) to control the frequency of the power delivered to the motor. VSDs are useful for controlling pumps with variable demands.

- **Parallel and Series Pumping:** Parallel pumping can reduce energy requirements when flow requirements change in distinct steps. Series pumping also can improve energy efficiency. Both are popular choices because they meet additional criteria such as high reliability, backup capability, low maintenance, and low first cost.

The following example illustrates the benefits of series pumping. Assume 10 units of water have to be pumped up a constant slope. The required total dynamic head is 100 feet to move water to the highest part of the system, but that part only uses 3 units of water. Using only one pump station requires that *all 10 units* of water be pumped with a head of 100 feet. It may be economical to use two pumps, one to pump all the water at 60 feet of head and another to add 40 feet for the three units required at the highest point.

Applicability

The nature of system flow requirements can significantly impact the applicability of different measures to reduce the total dynamic head. Table 1 indicates the applicability of the different measures.

Field Observations to Assess Feasibility

This section discusses steps to take in the field to identify situations where energy efficiency improvements can be made.

Eff. Measure	System Flow Requirements		
	Constant	Distinct Steps	Highly Variable
Impeller sizing	X		
Motor speed	X		
2-Speed motors		X	
Parallel pumping		X	
Series pumping		X	
VSDs			X

Table 1: Measure Applicability Matrix

Related to Applicability

The following information is needed to evaluate a pump:

- **Record pump nameplate data** such as design head and flow, impeller size (if listed), speed, make and model number.

- **Record the motor nameplate data.**

- **Record the pressure gauge reading(s).** Gauges are often installed with the system for balancing.

- **Walk the system** to identify problems in the areas in pump noise, layout configuration, valve type and throttling, and required static head. Possible problems with any pump or system change should be identified.

- **Obtain the pump curves** (if available). By using these curves a preliminary evaluation can generally be done without measuring the actual gpm. If the pressure (head) is known, simply read the flow off the pump curve. Keep in mind that the pump curves are only representative of the model. Large pumps should be tested because small differences in performance can add up to large energy costs. Worn pumps will operate at a lower efficiency than the curves would suggest; they should be fully tested, or simply replaced with an efficient, appropriately sized model.

- **Consider and evaluate for changes** in the motor, the pump, and the system.

Related to Energy Savings

The applicability of motor and pump efficiency improvements and the potential for energy savings depend on the efficiency of the existing motor and pump. Table 2 provides typical ***Overall pumping Plant Efficiency (OPE)*** values for various size motors. The OPE accounts for both motor and pump efficiency and can be obtained with a standard pump test.

Related to Implementation Cost

- **High-speed pumps** are often more efficient in small sizes. The potential for cavitation increases, however, and higher speed may mean more frequent maintenance.

- **A multiple-stage pump**, because of the reduced head per stage, may be

Motor HP	Low	Fair	Good	Excellent
3-7.5	<44.0	44-49.9	50-54.9	>54.9
10	<46.0	46-52.9	53-57.9	>57.9
15	<47.1	48-53.9	54-59.9	>59.9
20-25	<48.0	50-56.9	57-60.9	>60.9
30-50	<52.1	52.1-58.9	59-61.9	>61.9
60-75	<56.0	56-60.9	61-65.9	>65.9
100	<57.3	57.3-62.9	63-66.9	>66.9
150	<58.1	58.1-63.4	63.5-68.9	>68.9
200	<59.1	59.1-63.8	63.9-69.4	>69.4
250	<59.1	59.1-63.8	63.9-69.4	>69.4
300	<60.0	60-64.0	64.1-69.9	>69.9

Table 2: Typical Overall Pumping Plant Efficiency Classifications

more efficient than a single-stage unit, though at higher initial cost.

- **Inefficient, low-cost pumps** are installed by some manufacturers to keep costs down. Rapid paybacks are often possible with their replacements.

- **A slightly over-sized pump with a trimmed impeller** can be installed where added load or scaling is anticipated. When system demands exceed the capacity of the pump, only the impeller will need to be changed.

Estimation of Energy Savings

The potential for improving the efficiency of a pumping plant is highly dependent on the age and design of the equipment and its operation. An old, worn pump and standard-efficiency motor may be operating in the vicinity of 50 percent efficiency. A new pump and premium-efficiency motor could improve overall pump efficiency to over 60 percent, a 20 percent improvement.

The following equations can be used to determine pumping power:

$$BHP = \frac{GPM \times H \times SG}{3960 \times PEFF}$$

$$KW = \frac{BHP \times 0.746}{MEFF}$$

where:

BHP = Brake horsepower at pump driveshaft

H = Total dynamic head

$PEFF$ = Pump efficiency

GPM = Flow in gallons per minute

SG = Specific gravity of the liquid (1.0 for water at 60°F)

$MEFF$ = Motor efficiency

In addition to these equations, the Affinity Laws can be used to predict changes in flow, head and horsepower as pump speed is changed. These laws may be stated as follows:

The flow rate from a pump will vary directly according to the ratio of the motor speed:

$$Q2 = Q1 \times (N2 / N1)$$

where:

$Q2$ = flow rate at the new speed

$Q1$ = flow rate at the starting speed

$N2$ = pump speed for the new condition

N1 = pump speed for the starting condition.

Head (pressure) will vary as the square of the ratio of the pump speed:

$$H2 = H1 \times (N2 / N1)^2$$

where:

H2 = pressure at the new speed

H1 = pressure at the starting condition.

Required horsepower (BHP) will vary as the cube of the ratio of the pump speed or impeller diameter:

$$BHP2 = BHP1 \times (N2 / N1)^3$$

where:

BHP2 = brake horsepower required at the new speed or impeller diameter

BHP1 = brake horsepower required at the starting condition.

Standard Savings Calculation

When improvements are made in motor or pump efficiency, the following standard calculations can be used to estimate energy savings:

Motor efficiency improvement -

$$KWH_{savings} = BHP \times 0.746 \times \left[\frac{1}{MEFF1} - \frac{1}{MEFF2}\right] \times annual\ operating\ hours$$

where:

MEFF1 = old motor efficiency

MEFF2 = new motor efficiency

Pump efficiency improvement -

$$KWH_{savings} = BHP1 \times 0.746 \times \left[1 - \frac{PEFF1}{PEFF2}\right] \times annual\ operating\ hours$$

where,

PEFF1 = old pump efficiency

PEFF2 = new pump efficiency

Cost and Service Life

Factors That Influence Service Life and First Cost

An important factor to be aware of is the variability of the system design point over time. If the system piping and/or flowrates vary with different seasons or crops, the service life of a measure to optimize the pumping system for a particular configuration and flow rate may be quite short.

Typical Service Life

Following are the PG&E CEE program assumptions for the service life of several measures:

- Pump retrofit - 8.7 years
- Pump adjustment - 3 years
- Variable speed drives - 16 years
- High efficiency motors - 15 years

- Base-mounted pumps - 20 years
- Pipe-mounted, sump and well pumps - 15 years

Operation and Maintenance Requirements

PG&E has for years offered free tests to determine the performance of agricultural pumping plants under field conditions. Tests measure gallons per minute, input horsepower and water levels (pumping, static and discharge). From these data a Pump Test Report is prepared. If potential savings are indicated, a Pumping Plant Efficiency Comparison Report is also prepared, detailing energy and dollar savings.

Definitions of Key Terms

- **Cavitation:** The collapse of vapor pockets formed in the impeller passages because the absolute pressure at the pump suction nozzle has approached the ***vapor pressure*** of the liquid.

- **Head:** A quantity used to express the energy content of the liquid per unit weight of the liquid, referred to any arbitrary datum. In terms of foot-pounds of energy per pound of liquid pumped, all head quantities have the dimension of feet of liquid.

- **Impeller:** The heart of the centrifugal pump, it is the rotating piece housed in the casing, or volute, and driven by a motor. The impeller has spiral-shaped vanes whose diameter increases in the direction of the flow. The spiral accelerates the velocity of the water, developing pressure. Examples are shown below.

- **Induction Motor:** The most common type of AC motor, in which a primary winding on the stator is connected to the power source, while the secondary winding on the rotor carries induced current.

- **Net Positive Suction Head Required (NPSHR):** The amount of pressure in excess of the liquid's vapor pressure required to prevent vapor pockets from forming and bursting, leading to noisy and destructive cavitation. NPSHR is a characteristic of a given pump and varies with speed and flow. It is determined by the manufacturer and included on the pump performance curve.

- **Overall Pumping Plant Efficiency (OPE):** The ratio of pump output to motor input, in percent. Equivalent to the product of motor efficiency and pump efficiency.

- **Vapor Pressure:** The pressure at which a pure liquid can exist in equilibrium with its vapor at a specified temperature.

- **Variable Speed Drives:** Such drives coordinate induction motor speed to the needs of the job, using semiconductor devices and switching circuits to change the frequency of power delivered to the motor.

References to More Information

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "HVAC Systems and Equipment Handbook," 1996.

2. Chemical Engineering McGraw-Hill Publications Co., "Fluid Movers: Pumps, Compressors, Fans and Blowers," 1979.

3. Luhm, G., "Multi-Stage Pumping," PGandE Company Application Note No. 75, July 1986.

4. Luhm, G., "Centrifugal Pumps and Pump Systems," PGandE Company Application Note No. 47-56-89, May 1984.

5. Luhm, G., "Parallel and Series Pumping," PGandE Company Application Note No. 74, October 1986.

6. Pacific Gas & Electric Company, "Adjustable Speed Drives: What's in it for you," 1989.

7. Pacific Gas & Electric Company, "Agricultural Resource Guide," April 1996.

8. Peerless Pump, "System analysis for pumping equipment selection," Brochure B-4003, 1979.

9. Peerless Pump, "Handbook of Pump Engineering Data," Brochure-EM77.

Major Manufacturers

Pumps

PACO Pumps, Inc.
800 Koomey Road
Brookshire, TX
Tel (800) 955-5847
Fax (713) 934-6090

Peerless Pump Co.
1441 Peerless Way
Montebello, CA 90640
Tel (213) 726-1232
Fax (213) 726-0814

VSDs

ABB Industrial Systems, Inc.
16250 W. Glendale Drive
New Berlin, WI 53151
Tel (800) 752-0696
Fax (800) 648-2072

There are many other manufacturers of relevant equipment. A good source of manufacturers and products are grouped by type of product in *Heating Piping and Air Conditioning's* annual "Info-dex" issue (Penton Publishing, Chicago, IL; (312) 861-0880).

Further information may be obtained from: University of California Irrigation Program - Dr. Blaine Hanson, (916) 752-1130; Cal Poly Irrigation Training and Research Center - Dr. Charles Burt, (805) 756-2434.