Agricultural Pumping Efficiency Program

Specifying An Efficient Pump

Helping California Agriculture...

Put More Power Through the Pump!
The Agricultural Pumping Efficiency Program (“Program”) has two overall objectives: 1) get high-efficiency pumping equipment in the field and 2) manage that equipment so that its potential efficiency is realized. Knowing the factors involved in specifying an efficient pump to meet required operating conditions is an important part of good overall management practices.

**IMPORTANT!**
Information contained in this brochure is for educational purposes only. Always consult your pump dealer for actual numbers and specifications.

### What is the Program?

The Agricultural Pumping Efficiency Program is a statewide educational and incentive program designed to improve water pumping efficiency and promote energy conservation in agriculture. The Program includes these key components:

- Subsidized Pump Efficiency Tests
- Incentive Rebates for pump retrofit or repair
- Education

*The educational message has four parts:*

1. Know how to specify an efficient pump
2. Know how to maintain an efficient pump
3. Know how much water has to be pumped
4. Know how much water has been pumped

This brochure addresses the first educational message, “know how to specify an efficient pump.”
The Pumping Plant as an Energy Converter

Agricultural water pumping plants are energy converters. This conversion is a two-step process:

1. The power source of the pumping plant takes electrical energy or the energy embedded in a fossil fuel (diesel, natural gas, gasoline, propane) and converts it to mechanical energy. This is most commonly rotating (e.g. turbine water pumps) or reciprocating (e.g. fertilizer injectors) energy.

2. The pump itself takes the mechanical energy and turns it into fluid energy - moving water at a certain flow rate and pressure.

The major concern is how efficient the pumping plant is in converting the input energy to fluid energy.

Definition of Concepts and Terms

This brochure introduces some concepts and terms that can help you specify an efficient pump. Among these concepts are:

**The basic horsepower equation** - this equation determines how much horsepower is needed for pumping.

**Input horsepower** - the horsepower input to a pumping plant in the form of electricity, diesel fuel or natural gas.

**Water horsepower** - the combination of water flow and total dynamic head developed by the pump. Note that 2.31 feet of head equals 1 pound-per-square-inch (1 psi) pressure.

**Total dynamic head (TDH)** - the total amount of head (another term for pumping pressure) developed by the pump. Note that 2.31 feet of head equals 1 pound-per-square-inch (1 psi) pressure.

**The operating condition** - the combination of flow and pressure (total dynamic head) developed by the pump.

**The pump performance curve** - a graph showing the different combinations of flow rate and total dynamic head available from a pump.

**Overall pumping plant efficiency (OPE)** - a measure of how much water horsepower is produced by the pumping plant from the input horsepower. It is the combination of three efficiencies:

- **Bowl efficiency** - the efficiency of the pump itself.
- **Motor efficiency** - the efficiency of the electric motor or engine.
- **Transmission efficiency** - a measure of losses that occur in transmission shafts, chains, pulleys, and v-belts.
As equation (1) indicates, input horsepower depends in part on the combination of flow and pressure developed (Flow X TDH). Operating condition is the special term used for the combination of flow and pressure (total dynamic head).

If you are asked, "What is the pump's operating condition?" the engineer wants to know what combination of flow and pressure is being (or needs to be) developed.

**The Basic Horsepower Equation**

The reason for this concern is found in the equation that relates horsepower to water flow rate and total dynamic head (pumping pressure when the pump is operating).

1. \[ HPin = \frac{\text{Flow} \times \text{TDH}}{39.60 \times \text{OPE}} \]

*Where:*
- \( HPin \) = required input horsepower
- \( \text{Flow} \) = pump flow rate in gallons per minute
- \( \text{TDH} \) = total dynamic head in feet of water head (ft) or pounds per square inch (psi)
- 39.60 = constant
- \( \text{OPE} \) = overall pumping plant efficiency

**Example:**
- \( \text{Flow} = 1,000 \text{ gpm} \)
- \( \text{TDH} = 50 \text{ feet} \)
- \( \text{OPE} = 65\% \)

The required input horsepower is:

\[ HPin = \frac{\text{Flow} \times \text{TDH}}{39.60 \times \text{OPE}} \]
\[ = \frac{1,000 \times 50}{39.60 \times 65} \]
\[ = 19.4 \text{ HP} \]

Thus, if a pumping plant has an overall pumping efficiency of 65% it will require 19.4 horsepower input to the plant to pump 1,000 gallons per minute at 50 feet of head.

It stands to reason that the higher the OPE, the lower the required input horsepower. The more efficient the pumping plant, the lower your energy bill and usually the initial cost of the pumping plant.

**The Operating Condition - the Combination of Flow Rate and Total Dynamic Head**

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If you are asked, "What is the pump's operating condition?" the engineer wants to know what combination of flow and pressure is being (or needs to be) developed.
Turbine pumps can operate over a range of operating conditions. Pump manufacturers know this and publish **pump performance curves**.

The pump performance curve is a graphical depiction of the range of operating conditions in which a particular pump can deliver. Figure 1 is an example of such a curve.

**FIGURE 1 - Simple pump performance curve showing relation between pump flow (gpm) and Total Dynamic Head (TDH) measured in feet.**

Given that pumps can operate over a wide range of **operating conditions**, why would one pump be chosen over another? The answer lies in the **bowl efficiency**. As previously noted, pumping plants are energy converters. The power plant (either an electric motor or internal combustion engine) converts electrical energy (or the energy contained in diesel, natural gas, propane, or gasoline) into rotating mechanical energy. The pump then converts this mechanical energy into moving water at a certain pressure.

Just as the power plant has a certain efficiency in converting the electric or fuel energy, the pump has a certain efficiency in converting the mechanical energy to moving water. This efficiency is termed **bowl efficiency**.

The bowl efficiency varies over the range of operating conditions due to the physics of how water moves through the pump. More or less friction and heat losses due to turbulence have to be overcome at different flow rates.
Pump manufacturers know this also and supply this information on a pump performance curve. Figure 2 is an example of a complete pump performance curve.

**FIGURE 2 - Published pump performance curve with bowl efficiency, required pump input power and required net positive suction head are also shown.**

The lines in Figure 2 are explained as follows:

- The green lines indicate the TDH-Flow Rate Curve. This indicates the range of operating conditions that the pump will operate within. Note that four curves are given depending on the diameter of the impeller (4.50” - 5.25”). The diameter of the impeller is called trim.
- The red lines indicate the bowl efficiency at any operating condition.
- The blue lines indicate the brake horsepower required at the pump for any one operating condition. The four lines correspond to the four impeller diameters.
- The brown line indicates the Net Positive Suction Head (NPSH) that is required at each pump flow.
**IMPORTANT!**

NPSH is a very important factor in the actual engineering design and installation of the pumping plant. Insufficient NPSH can result in cavitation. Cavitation occurs when a vacuum is formed in the pump bowl, air bubbles are created that implode (collapse) violently against the impeller (making a loud rumbling noise). This can cause pitting of your impeller, decreasing efficiency and lead to pump failure.

**Keys to Specifying an Efficient Pump**

The keys to specifying an efficient pump are:

1. Knowing the required operating condition or conditions.
2. Choosing a pump that runs at the highest efficiency at those conditions.

For example, you would probably not choose the pump shown in Figure 2 if you had to pump 100 gallons per minute at 32 feet of head. Note that it only runs at 60% bowl efficiency (Point A) at this condition. However, you might choose this pump if your required condition was 250 gpm at 28 feet. Then the bowl efficiency is a very good 80% (Point B).

**Specifying a Stable Operating Condition**

Required operating conditions can be stable or vary throughout a season or for longer periods of time. An example of a predictable and stable operating condition would be a booster pump, drawing from a reservoir, supplying a well-engineered micro-irrigation system.

The key aspect of a stable operating condition is to make sure that all pressure requirements are identified correctly. Figure 3 is a schematic of a stable operating condition situation.

Note the components of the total dynamic head shown in Figure 3:

1. Suction pipe friction - loss of pressure as the water moves through the suction pipe.
2. Suction lift - the distance water has to be lifted to the pump.
3. Screen losses - there will be a drop in pressure as the water moves through the inlet strainer.
4. Discharge pipe friction - there will be a pressure loss as water moves through the pipe on the discharge side.
5. Elevation lift - water has to be lifted to a higher elevation.
6. Operating pressure - there is a certain amount of pressure required to run the irrigation system.

The key in a stable operating situation is to make sure that all variables are identified and quantified correctly.

**What to Do with a Variable Operating Condition**

An example of a widely varying operating condition would be a water well with a pumping water level that fluctuates depending on the time of year. Usually it will be much lower in the summer when it, and any surrounding wells, are pumping the most. The problem could be compounded in the situation where the well might be supplying a flood irrigation system one day, and then a booster pump for a portable sprinkler system the next.

Pumping plant designers recognize seasonal fluctuations. A common solution is to choose a pump that operates "to the right" of optimum efficiency during the early part of a season. As the water table drops (with a concurrent increase in required total dynamic head), the pump operating condition moves into the optimum efficiency. An example of this is seen in Figure 4.

**FIGURE 3 - Schematic of a stable operating condition.**
The pump is chosen so that it operates at point A during the early part of a season. Note that it is only producing about 45 feet of total dynamic head, but 1,700 gpm. As the water table drops, and the total dynamic head requirements increase, the operating condition will move up to point B. Now the pump is providing the required increase in total dynamic head, 65 feet, but flow is only 1,200 gpm - enough to sufficiently water the crop during the hottest part of the season.

**FIGURE 4 -** Pump performance curve with two operating conditions identified.
growing season. Note that the pump is operating near its maximum efficiency at Point B, at the time of peak pumping.

Designers also do this to compensate for predicted pump wear. Note that as the impeller wears, the pump will not operate along its original pump performance curve. Point C on Figure 4 might be the operating condition in the middle of summer after several years of use. The required 65 ft. of TDA is still being supplied and it is hoped the approximate 900 gpm is still enough to irrigate the crop.
You should also be aware of the three basic impeller designs used in agriculture turbine water pumps. These are:

- **Axial Flow** (open impeller)
- **Radial Flow** (closed impeller)
- **Mixed Flow** (semi-open or semi-closed impeller)

Each of these impeller types provides a certain range of operating conditions. The impeller type is chosen based on the required operating condition.

An axial flow pump (open impeller) is much like the propeller on a speed boat. Water moves generally in a straight line through the pump. Axial flow pumps provide very high flows but at relatively low pressures. In agriculture these impellers are often used in canal lift pumps.

In contrast, water flow through a closed impeller takes a 90 degree turn. This is the type of impeller used in the horizontal centrifugal pump. These impellers produce relatively high pressures but lower flows. Radial flow impellers are most often used for booster pumps.

The third type is called a mixed flow or semi-open impeller. In this type of pump, water goes through and out the impeller at some angle less than 90 degrees. The water flow is constrained on one side by the impeller and on the other by the bowl.
Power Source Options

Remember that the overall pumping efficiency is a combination of three efficiencies. Not only must we consider the bowl efficiency but also the transmission efficiency and the efficiency of the power plant itself.

The two main options for the power plant are the electric motor and the internal combustion engine. There are advantages and disadvantages to each. The main factor in the decision for many people is the cost of the energy, either electricity, diesel or natural gas. However, one should consider the initial cost of installation, reliability, serviceability, required maintenance and possibly government regulations. Also note that the costs for any fuel can vary greatly and fluctuate quickly.

IMPORTANT!

The mixed-flow impeller is the one type of pump where pump adjustments can make large differences in efficiency. This is because as water flows through the pump, one side of the water is constrained by the bowl. The clearance between the impeller and the bowl can be adjusted to increase efficiency. This should only be attempted by an irrigation pump professional.

Mixed Flow - Semi-open or semi-closed impeller
Submersible type motors are a type of electric motor option with additional advantages and disadvantages. These motors are used mainly in water wells. The motor is attached to the pump and both are submerged. They do not require long transmission shafts, as with the normal vertical turbine, since the power source is at the pump. Thus, transmission efficiency is higher. They also minimize above-ground hardware, which may be an aesthetic or security concern. And, in very deep wells they may be mandatory due to a crooked well.

Submersible motors may have added energy losses due to long cable lengths from the ground surface to the motor. They are by nature, less efficient than normal line-shaft motor designs.

Make sure that you do a valid lifetime cost analysis when choosing between a submersible and a standard line-shaft pumping plant.
Varying the rotational speed of a pump changes the performance curve. This may help you supply variable operating conditions with less required energy as shown in Figure 6.

**FIGURE 5 -** Pump performance curves for a pump operating at different speeds.

At Point A, operating at 1,350 rpm, the pump will supply 80 feet of head at 3,000 gpm of flow. At Point B, 900 rpm, it will only supply 30 feet of head at 3,000 gpm of flow. The efficiency of the pump at point A is 80% and at Point B, it is at 83%. Even though one of the operating conditions (in this case head) has changed, the efficiency remains relatively high.

The above example shows how varying pump speeds can aid a grower with different field elevations from set to set. In this situation, the farmer needs constant flow, but the head (pressure) condition changes depending on different elevations of each individual set.

Let’s consider another example of what operating conditions might need to be met. Assume a vegetable grower has different acreage requirements for a pressurized system throughout the season. In May, there are 160 acres requiring 4,000 gpm at 60 feet of head (Point C). However, in July, there are only 120 acres requiring 2,500 gpm at 60 feet of head - same sprinkler system, just a different set size (Point D).
Given a load profile and other energy and operating cost data, VFD manufacturers and suppliers can estimate energy and cost savings, thus identifying the economics of any situation.

There are limits to the amount of speed variance available with a VFD. And in the case of an electric motor and an internal combustion engine, engine efficiency varies with varying speed and load.
A VFD is best used where there is a consistent requirement for widely varying operating conditions. Common situations are:

- Milking systems for cows
- Municipal water systems
- Golf course systems
- Elevation changes from one set to another

Another important factor to consider when installing a VFD is power quality. VFD’s are sensitive to transient voltages, either due to the servicing utility or switching of other loads on the same supply line. Also, VFD’s can cause additional heating of motors due to harmonic currents induced by them.

Always consult an expert before deciding to install a VFD.

Maintaining an Efficient Pumping Plant

Another part of the educational message of the Agricultural Pumping Efficiency Program is "know how to maintain an efficient pump." This message goes beyond the janitorial aspects of routine maintenance – that is keeping oil in the reservoir, checking the grease on bearings, or tightening packing correctly.

Maintaining an efficient pump in the field also requires that you:

1. Recognize when the required operating condition has changed.
2. Recognize when the pump itself has deteriorated.

Required operating conditions can change for a variety of reasons. The more common would be:

- A systemic change in a water table in the case of water wells.
- A change in the irrigation system - most commonly from flood irrigation to some type of pressurized system.
- A change in required set flows or pressures in a micro-irrigation system as a crop matures.

In all of these cases, the change in operating condition or the change in the condition of the pump itself can be identified by a pump efficiency test.
A pump test measures various aspects of the pump’s operation. It results in an estimate of the overall efficiency of your pumping plant and the cost of running it at the time and conditions of the test. It may also give an indication of water well performance.

Testing pumps requires both theoretical and practical training. Pump tests may be available from:

- **Public Utilities** - using either their own employees, which they train, or contract testers.
- **Pump Dealers** - using their own employees or contract testers.
- **Independent Pump Test Companies** - many of these testers have a public utility background.

To obtain a subsidized pump test under the Agricultural Pumping Efficiency Program you must use a Participating Pump Test Company. Please call or log on to our web site [www.pumpefficiency.org](http://www.pumpefficiency.org) for a current list of these companies.

A pump tester measures at least four variables for each test:

1. Water flow rate.
2. Pumping lift, or inlet pressure.
3. Pump discharge pressure.
4. Energy input to the pumping plant.

Calculations are performed with the flow, lift, and pressure measurements and the results compared to the energy input.

Regular pump testing can identify problems before a breakdown or excessive energy costs occur. This allows you to perform an objective economic analysis to identify when it is profitable to invest in a retrofit or repair. On a new pump, a test will establish a baseline of performance and verify that equipment is operating as designed.

Please refer to the brochure "Pump Efficiency Tests" available from the Program. This brochure explains pump efficiency tests in depth, especially how you can interpret both the operational results and the pumping cost analysis to determine when it’s best to pay for a pump retrofit or repair.
In Summary

The first parts of the Program’s educational message are:

1. Know how to specify an efficient pump
2. Know how to maintain an efficient pump

There is no one "most efficient pump" for all conditions. Specifying an efficient pump depends largely on correctly identifying the required operating conditions (the required combination of flow rate and pressure). Also important is recognizing when the required operating conditions are likely to change.

However, recognize that the overall pumping plant efficiency depends on three factors:

1. **Power plant efficiency** - how efficient the electric motor or engine is in using input energy (either electricity or liquid fuel).
2. **Transmission efficiency** - losses in drive shafts or V-belts, bearings, etc.
3. **Bowl efficiency** - the efficiency of the pump itself in converting brake horsepower to water horsepower.

There are many other aspects to consider also since the prime goal is lowest (lifetime) cost. You must also consider:

- First cost vs. operating costs
- Reliability
- Serviceability (fast response from supplier)
- Other factors (required payback, borrowing capacity, experience, etc.)

Just as important in specifying and installing the efficient plant is maintaining efficiency. This goes beyond the routine maintenance procedures specified by manufacturers. The plant operator must be able to recognize when either:

1. The required operating conditions have changed
2. The pump condition (efficiency) has deteriorated

*The pump efficiency test is essential in maintaining an efficient pump in the field.*

Contact the Program for more information on specifying and maintaining an efficient pump. A list of participating pump test companies that can provide subsidized tests is also available.
The Program may be terminated or modified without notice. The Program has a limited budget. Applications for retrofit/repair rebates or pump tests are accepted on a first-come, first-served basis until available funds are allocated or the ending date of the program, whichever comes first (visit www.pumpefficiency.org or call 800.845.6038 for more information).

California consumers are not obligated to purchase any full fee service or other service not funded by this program. This program is funded by California utility ratepayers under the auspices of the California Public Utilities Commission.

Important!

The Center for Irrigation Technology developed and manages the statewide Agricultural Pumping Efficiency Program. CIT is dedicated to advancing water/energy management practices and efficient irrigation technology. Located on the campus of California State University, Fresno, CIT functions as an independent testing laboratory, applied research facility and educational resource to both the public and private sectors. For more information, check the CIT link at www.pumpefficiency.org or call (800) 845-6038.

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