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Irrigation Pumping Plant Efficiency

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by J.L. Chávez, D. Reich, J.C. Loftis, and D.L. Miles*

Quick Facts

- Most irrigation pumping plants have excessive operating costs because they are often in need of repair, poorly matched to the pumping load, or incorrectly plumbed using more power or fuel than they should.
- Pumping plant performance can be evaluated from field tests to determine if changes are needed.
- Some problems can be corrected with simple adjustments while others require expensive repairs.

Rising energy costs have increased the cost of pumping to the point that many farmers are finding irrigation to be unprofitable or only marginally profitable.

Fortunately, however, pumping costs are an item that farmers have some degree of control. Pumping costs often are higher than they need be for two reasons: 1.) more water is pumped than is necessary, and/or, 2.) the pumping plant operates inefficiently. This fact sheet considers only the second problem; inefficient pumps.

Common Causes and Remedies

Field testing programs in Colorado, Wyoming, Nebraska, Texas, Louisiana and other states have shown that overall pumping plant or 'wire-to-wire' efficiencies for electrically driven pumps average 45 to 55 percent, as compared to a realistically achievable efficiency of 72 to 77 percent. This implies that around 25 percent of the electrical energy used for pumping is wasted due to poor pumping plant efficiencies alone. Therefore, farmers can reduce energy costs by raising pumping plant efficiencies from present average levels to potential efficiencies. Farmers are advised that pumping plants should attain at least 65 percent efficiency and every new pumping plant should be tested to determine the pumping plant overall efficiency.

There are many reasons for poor pumping plant efficiency. Some of the more common causes of unsatisfactory performance and their remedies are as follows:

1. **Impellers that are out of adjustment are** the easiest and least expensive problem to correct . Both pumping rates and efficiency are reduced because energy is used to pump water that is recirculated around the impellers instead of being pumped into the irrigation system. Impeller adjustment is especially critical with semi-open impeller pumps. Impellers may be out of adjustment because of improper initial adjustment or because of wear. To avoid pump damage, only experienced pump people should attempt to make impeller adjustments.

   Field adjustments include: a) for semi-open impellers, all impellers in the bowl assembly must be running in close proximity (0.003 – 0.007 in) to the next lower bowl. Thus, careful adjustment in the field is required. Shaft stretch determines the final position of the impellers. Also, it directly varies with discharge head. Therefore, it has to be set to a proper specification to perform well at a given discharge head. Multi-stage units may require that the impellers be trimmed (reduction in diameter) to obtain proper fitting and clearance in the assembly bowl. For enclosed impellers, with a principal seal that is parallel to the centerline of the shaft, a close axial adjustment is not necessary. Therefore, this type of impeller is suited for operation under variable head conditions. Capacity (*see terms definition in the "Useful Definition" section at the end of the document*) and horsepower requirements can be controlled by raising the impeller until the skirts are out of the wear rings.
2. **Pump bowls designed for a higher pumping rate** than the well can supply is one of the most common reasons for poor pumping plant efficiency. Overestimating well yield often results from poor testing of the well after drilling. If well testing was inadequate, the yield of the well may have been less

*J. L. Chávez, Colorado State University irrigation specialist and assistant professor, civil and environmental engineering department; D. Reich, Colorado State University Extension water resource specialist, Western Region, agricultural and natural resource economics. Original manuscript by J. C. Loftis, Colorado State University professor, civil and environmental engineering; and D.L. Miles, Extension irrigation engineer. 9/2011

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than anticipated. In other cases, the pump supplier recommended oversize pump bowls in order to require fewer stages, thereby reducing initial cost. Furthermore, declining water tables in some areas have reduced well yields. In this situation, a pump may begin to cavitate (partial vacuum, low temperature boiling of pumped water that causes vibration and noise from water hammer) because it is being is forced to operate at a lower flow rate and higher lift than that for which it was designed. If for any of these reasons the pump capacity does not fit the well characteristics, a high pumping plant efficiency can be achieved only by replacing the bowls with new (not rebuilt) bowls that meet the well requirements.

3. **Damaged impellers** also will result in poor performance. Three common causes of impeller damage are cavitation (also resulting in reduction of discharge and deterioration of other pump parts), sand pumping (due to well filter failure or design problems) and improper impeller adjustment. Sometimes only the impellers need to be changed, but more often the permanent solution is to replace the entire bowl assembly. If this is done, it is likely that a different model of pump bowls should be used to fit present well conditions.
4. **Incorrect power unit selection** is another major cause of low efficiency. This is much more important for engines than for electric motors. While the efficiency of electric motors does not vary greatly with loading, it should be noted that over-loaded motors have shorter lives, are less dependable and are more expensive to maintain. On the other hand, because of graduated energy costs, underloaded motors often increase the cost per kilowatt of power used. Incorrect engine selection is a major cause of low efficiencies among the natural gas pumping plants. Many are overloaded. Automotive-type V-8 engines often are used for applications where heavy-duty industrial engines should be used. Operating speeds of the smaller engines are increased so that they will produce adequate power. As a result, they wear out rapidly and require much more fuel.
5. **Failure to perform required maintenance**, including tune-ups, is often a cause of low efficiency in engine-driven pumping plants. Electric motors, on the other hand, usually operate efficiently. In the case of **semi-open impellers**, close adjustment is necessary for proper operation. Thus, if variation in required discharge head occurs then the pump could be damaged. The higher thrust requirement may affect the lift of the thrust bearings, therefore fast bearing wearing can be expected. Monitoring the pumping unit pressure head and flow discharge is critical to assure proper operation and a longer unit life span. **Enclosed impellers,** on the other hand, will have increased bearing life with up to 30 percent less thrust (large discharge head variation/demand). The lower thrust allows using smaller shafting, which affects the cost of the initial installation and on maintenance.
6. **Differences in operating conditions.** Finally, a change in operating conditions from those for which a pumping plant was designed will result in a drop in efficiency. Three common situations that result in increased pumping lifts and total discharge head (Figure 1) or pressures are a drop in water table elevation, converting from open discharge to a pipeline, and changing from surface irrigation to sprinkler/trickle (pressurized) irrigation. On the other hand, a reduction in operating pressure results when center pivot sprinklers are converted from high pressure to low pressure in an attempt to save energy. Usually the pump will operate less efficiently under the new lower pressure conditions than it did under high pressure. As a result, anticipated savings in energy costs may not be realized.
7. **Poor plumbing, horizontal axis/centrifugal pumps** have a range window of pressure and flow rate conditions for the inlet and outlet of the pump for optimum efficiency. Some pumps require inlets constantly flooded, others need sufficient back pressure on the outlet. If a pump is not operating in optimum conditions water hammer and cavitation are common symptoms along with frequent replacement of impellers and seals. Consult with your pump vendor on pump suitability and always examine installation instructions carefully before purchasing accompanying pipework.

Field Pump Evaluation

Since some power suppliers offer field evaluation of electrical pumping plant performance at very reasonable cost, many farmers can easily determine whether or not their pumps are operating properly. Internal combustion engine driven plants are more difficult to test since both the engine and the pump should be evaluated. A few private consultants and pump suppliers are equipped to perform this service.

A field pump evaluation involves measuring several operating characteristics of the pump. These include:

- depth to water before pumping, (static water level, Figure 1),
- depth to water during pumping (dynamic water level or static pumping level, Figure 1),
- Net Positive Suction Head (NPSH), for horizontal axis/centrifugal pumps, is the suction head the pump has available (always less than atmospheric pressure). This will determine how much head deficit the suction side of the pump can overcome. Make sure you account for friction losses in pipe, valves and elbows.
- pump total dynamic discharge head or pressure (TDH),

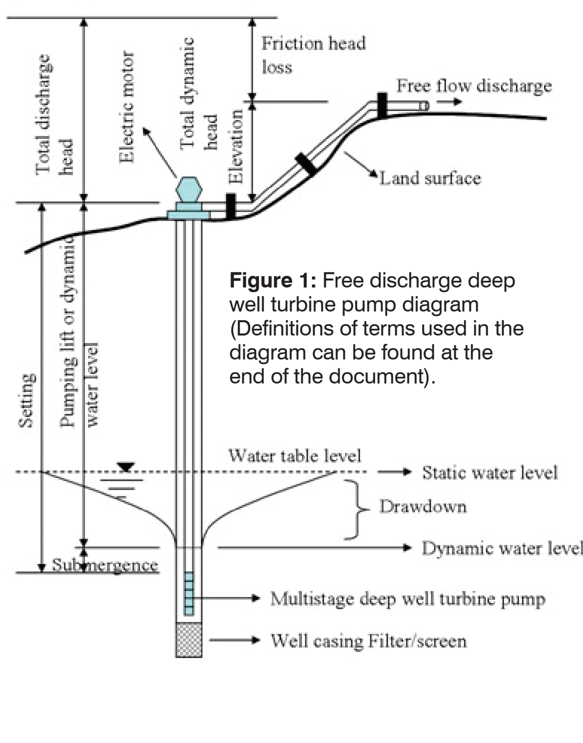

Figure 1: Free discharge deep well turbine pump diagram (Definitions of terms used in the diagram can be found at the end of the document).

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Incorrect power unit selection is another major cause of low efficiency. This is much more important for engines than for electric motors.

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- pump flow rate, and
- rate of electrical energy or fuel consumption.

From these measurements, both the water horsepower, or rate of useful work done by the pump, and input horsepower equivalent, or rate of energy used by the motor or engine, are calculated. Overall pumping plant efficiency is the water horsepower divided by the input horsepower equivalent (see Equation 1.)

Knowing the pumping (discharge) rate, total pumping (dynamic) head, and pump efficiency, one can compute the input power required using Equation 1 below. Published efficiency curves for turbine pumps do not include such losses as line-shaft bearing and gearhead friction. The manufacturer's reported efficiency for these pumps is for a specific number of stages. It is necessary to adjust the reported efficiency upward or downward, depending on the number of stages.

Generally, there is only one peak pump efficiency, which occurs at a specific pumping rate. However, most pumps do not operate at the peak efficiency, which is around 87 percent. Depending on variations on the TDH and flow discharge the pump efficiency may be lower than the peak.

Pump efficiency (E_{pump}, Equation 1) is the ratio of the output work (called water power or water horsepower, WP) the pump exerts to the water in relation to the required power (input power) of the driving unit, which is also called break power (BP), or break horsepower.

$$E_{pump} = WP/BP = (Q \times TDH / 3960) / BP \qquad (1)$$

where:

WP = water power, in units of horsepower (hp), and
Q = pumping rate, gallons per minute (gpm)
TDH = total dynamic head (ft)
BP = motor/engine break horsepower (hp)

Note: 1 horsepower (hp) = 0.746 kW if one wishes to express power in kW units instead. If units are in kW to obtain WP or BP in hp units multiply the number of kW by 1.341.

The overall pumping plant efficiency (E_{pplant}, Equation 2) is the product of the pump efficiency ($E_{pump,}$ as a decimal number) and the motor efficiency (or engine, $E_{motor,}$ as a decimal number) multiplied by 100. For electrical motors, the typical E_{motor} range is between 80 to 90 percent.

$$E_{pplant} = E_{pump} \times E_{motor} = (Q \times TDH / 3960) / P_m \qquad (2)$$

where:

P_m = input power to the motor (hp)

The E_{pplant} or wire-to-water efficiency maximum value range is 72 to 77 percent, with a minimum acceptable value of 65 percent. If the pump is operating below an E_{pplant} of 65 percent then provisions must be made to improve performance to save energy and attain adequate designed hydraulic TDH and Q levels.

Cost vs. Savings From Repair or Replacement

Once it has been found that a pump is not performing up to par, the next step is to consult a reputable pump supplier to determine the cost of repair or replacement. If it is necessary to pull the pump, these costs will be substantial.

How does one decide whether pump repair or replacement will pay off? There are certain conditions under which pump bowls will almost certainly need to be replaced.

- The potential well yield is adequate, but the pump will not supply the required flow rate at the required pressure.
- The water table has declined dramatically; this was not anticipated in the original pump selection.
- A major change in the irrigation system has occurred, either from surface irrigation to sprinkler irrigation or vice versa, or from high pressure to low pressure sprinklers.

In other cases, the decision of whether to spend money on a pump is not so clear. Compare the potential savings from increased efficiency to the cost of pump improvements. The results of a pumping plant efficiency test as described earlier can be used to make this comparison. Tables 1 and 2 simplify the necessary calculations for electrically driven pumps.

Example 1

A certain pump supplies a center-pivot system on the High Plains that irrigates 120 acres of corn and applies a gross depth of 20 inches of water during the crop growing season. A pump efficiency test finds that the current overall efficiency is only 40 percent and that the total pumping head is 300 feet. What are the potential savings from improving the pump efficiency to 65 percent if the cost of electricity is $0.08 kWh?

From Table 1, the potential energy savings is 24.6 kWh/ac-in pumped. The annual (or seasonal) volume pumped is (120 acres) x (20 inches) or 2,400 acre-inches. The potential savings are:

(24.6 kWh/ac-in) x (2,400 ac-in/yr) x ($.08/kWh) =$4,723.2/year

The annual cost of pump improvements can be found as follows. The annual cost of an investment is equal to the initial cost times the appropriate capital recovery factor corresponding to the life of the investment and the prevailing interest rate.

Table 2 shows the capital recovery factor for several interest rates. The 10-year economic life applies to pump repairs while the 15-year economic life applies to pump replacement.

Example 2

For the pump in the preceding example, the bowls could be replaced at a cost of $15,000 to provide an improved efficiency level of 65 percent. Is this investment worthwhile if the farmer must borrow the money at 8 percent interest?

From Table 2, the capital recovery factor for 8 percent interest and a 15-year economic life is .1168. The annual cost of the improvement is therefore ($15,000) x (.1168) = $1,752/year. Since the potential savings found earlier ($4,723/year) exceeds the cost of improvement, the investment is probably justified.

If this analysis had indicated that potential savings were significant, but

Table 1: Potential energy savings from pump improvement (kWh/ac-in pumped) assuming 65 percent efficiency after improvement.

	Present pump efficiency (%)							
H	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
50	10.5	7.7	5.6	4.1	2.9	2.0	1.2	0.5
100	21.0	15.3	11.2	8.2	5.8	3.9	2.4	1.1
150	31.5	23.0	16.9	12.3	8.7	5.9	3.6	1.6
200	42.0	30.6	22.5	16.4	11.7	7.8	4.8	2.2
250	52.5	38.3	28.1	20.5	14.6	9.8	6.0	2.7
300	63.0	45.9	33.7	24.6	17.5	11.8	7.2	3.3
350	73.5	53.6	39.4	28.7	20.4	13.8	8.4	3.8
400	84.0	61.2	45.0	32.8	23.3	15.7	9.5	4.4
450	94.5	68.9	50.6	36.9	26.2	17.7	10.7	4.9
500	105.0	76.6	56.2	41.0	29.2	19.7	11.9	5.5

TDH = Total pumping head or total dynamic head (ft).
kWh/ac-in = kilo Watt hour per acre-inch.
*To convert to metrics use the following conversion: 1 foot = 0.3048 meter.

somewhat less than the annual cost of the improvement, it would probably be advisable to have the pump tested again in a year or two. Pump wear and/or water table decline could easily result in the change being justified at that time.

One must remember that this analysis is based on an achievable E_{pplant} efficiency level of 65 percent after pump improvement. Higher E_{pplant} efficiency levels are possible (up to 77 percent), thus there could be potential for higher energy savings. However, if the 65 percent level is not realized, neither will the anticipated savings in energy costs. The farmer would be well advised to obtain a written contract from the pump supplier guaranteeing a certain level of pump performance to be achieved by the proposed pump improvements.

Useful Definitions

Static water level- The vertical distance (ft) from the center line of the discharge to the water level when there is no pumping occurring.

Static pumping level or dynamic water level. The vertical distance (ft) from the center line of the discharge to the water level when the pump is working.

Drawdown. The difference (ft) between the static pumping level and the static level.

Pumping lift. The vertical distance (ft) from the water level to the center of the discharge when the pump is running.

Setting. The distance from the column pipe connection at the discharge head to the column pipe connection at the bowl assembly.

Submergence. The distance (ft) from the pumping level to the column pipe connection at the bowl assembly.

Elevation. The vertical distance from the center line of the discharge elbow to the center line of the discharge pipe.

Friction head loss. The head (ft) needed to overcome pressure losses due to friction in the pipe and fittings.

Total dynamic discharge. The head which must be developed by the pump to overcome friction losses and elevation.

Total dynamic head (TDH). The sum of the pumping lift and the total discharge head.

Capacity. The rate of flow of water measured per unit of time.

Reference

Hoffman, G.J., R.G. Evans, M.E. Jensen, D.L. Martin, and R.L. Elliott. 2007. *Design and operation of farm irrigation systems.* 2nd Edition, American Society of Agricultural and Biological Engineers (ASABE), St. Joseph, MI.

Table 2: Capital recovery factors based on various interest rates.

	Capital recovery factors								
Interest rate:	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**	**12%**	**14%**
10-year life	.1233	.1295	.1359	.1424	.1498	.1558	.1628	.1770	.1917
15-year life	.0899	.0963	.1030	.1098	.1168	.1241	.1315	.1468	.1628