PUMPING PLANT EFFICIENCY
HOW MUCH EXTRA ARE YOU PAYING?

FOR CENTRAL PLAINS CONFERENCE

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The energy cost of operating a pumping plant is dependent on three variables: the amount of work output the pump is producing, the efficiency of the power unit and the efficiency of the pump.

In this paper we will address the question, “Could you reduce irrigation costs? The first step in answering that question is to ask the more basic question, “How much energy should your pumping plant be using?”

Power is defined as the rate of doing work. One horsepower is defined as performing 33,000 foot-pounds of work per minute (33,000 ft-lb/min). Irrigation water is assumed to weigh 8.34 lb/gal. 33,000 / 8.34= 3960. Therefore the horsepower imparted to the water, known as water horsepower (Whp) can be calculated using the equation:
Whp = gallons /min (gpm) x head (ft) / 3960.

Example 1: Find the water horsepower output of a pump supplying 800 gpm to a center pivot. The pumping water level is116 feet below the level of a pressure gauge installed on the pivot that is reads 45 PSI while operating.

Whp = 800 gpm x ((45 PSI x 2.31 ft/PSI)[a] + 116 ft) /3960
= 800 gpm x (104 ft + 116 ft) /3960
= 800 gpm x 220 ft /3960
Whp = 44.4

[a] Lift and pressure are components of the total head that the pump is working against. To convert PSI to feet of head multiply PSI by 2.31.

If the power unit for this pumping plant is consuming 4.6 gallons of diesel per hour, what is the performance of this pumping plant?

The performance of the pumping plant is found by dividing the work output (whp-h) by the units of energy consumed. The performance of this pumping plant is therefore 44.4 whp / 4.6 gal/h = 9.625 whp-h / gallon of diesel.

The University of Nebraska has conducted hundreds of tests over the years on farmer-owned pumping plants. Based on these field tests and on tests of engine efficiency in the laboratory, the University developed the Nebraska Pumping Plant Performance Criteria, (NPC). The NPC states the brake horsepower output from the engine and drive unit (hp-h) and the amount of useful work output one should expect from a pumping plant (whp-h) per unit of energy consumed.

Table 1. The Nebraska Pumping Plant Performance Criteria (NPC)

Energy Source	hp-h[a] / unit of energy	whp-h[b,c] / unit of energy	Energy Units
Diesel	16.66	12.5[d]	Gallon
Gasoline	11.50	8.6	Gallon
Propane	9.20	6.89	Gallon
Natural Gas[e]	82.20	61.7	mcf
Electricity[f]	1.18	0.885	kWh

[a] hp-h (horsepower hours) is the work accomplished by the power unit with drive losses considered. This is the horsepower imparted to the lineshaft that drives the pump impellers.
[b] whp-h (water horsepower hours) is the work accomplished by the pumping plant (power unit and pump).
[c] Based on 75% pump efficiency.
[d] Criteria for diesel formerly 10.94 revised in 1981to 12.5,
[e] Assumes an energy content of 925 BTU/cubic foot.
[f] Assumes 88% electric motor efficiency.

Once the work output (Whp-h) is known, one can use the NPC to estimate the amount of energy a pumping plant should be using. The pumping plant in Example 1 on the previous page had a work output of 44.4 Whp-h. If this diesel powered pumping plant were operating at 100% of the NPC, it would consume 44.4 Whp-h / 12.5 Whp-h/gal = 3.55 gallons of diesel per hour.

Another application of the NPC is to give the pumping plant a performance rating. Once the performance of a pumping plant is known, it can be divided by the NPC resulting in a ratio which when multiplied by 100% results in a performance rating. A rating of 100% indicates that the pumping plant is operating at the expected performance level. A rating below 100% indicates the pumping plant is using more energy for the work that it is doing than the criteria calls for. For example, a pumping plant operating at 70% of the NPC is only producing 70% of the useful work it should for the energy it is consuming.

The pumping plant in Example 1 would have a performance rating of (9.625 whp-h/gal / 12.5 whp-h/gal) x 100% = 77% of the NPC.

If a pumping plant's performance rating is less than100% of the NPC. There are two methods to estimate the amount of excess energy being consumed. One method is to subtract the energy consumption at 100% of the NPC from the actual energy consumption. For the pumping plant in Example 1 the excess energy consumption is 4.6 gal/h (actual) - 3.55 gal/h = 1.05 gal/h excess energy consumption.

The second method for finding the excess energy consumption is to subtract the performance rating of the pumping plant from 100% divide by 100% to convert to a decimal and multiply the difference by the actual fuel consumption. For the pumping plant in Example 1, the performance rating was 77% of the NPC. 100% - 77% = 23%. 23% / 100% = 0.23. 0.23 x 4.6 gal/h = 1.06 gal/h excess energy consumed.

Nebraska conducted a statewide pumping plant efficiency study in 1980-81. In this study, they tested 180 farmer-owned pumping plants. As one might expect, the performance ratings of the pumping plants varied considerably. Some pumping plants were found to be very efficient. In fact, 15% actually exceeded the NPC.

The fact that some pumping plants exceeded the criteria indicates the criteria is a reasonable target for all pumping plants. The 85% of the pumping plants tested in the study which fell short of the criteria were using more energy per unit of work output (whp-h) than the criteria calls for. A few were found to be consuming over twice the amount of energy than was called for by the NPC.

When the performance ratings of all pumping plants tested were tallied, the average pumping plant in the study was found to be operating at only 77% of the NPC . Stated differently, the average pumping plant was using (100% / 77% = 1.3) times as much energy as expected. These test results compare with average ratings of 76% and 77.8% found in two earlier Nebraska studies and 78% found by a consulting firm in Kansas in the late 1970s.

When the efficiency of a pumping plant is not what it should be, the problem can either be in the power unit or in the pump or both.

Adjustments

Internal combustion power units on irrigation pumps can have the same problems as those in cars and trucks. Many had improperly adjusted air/fuel mixtures or spark timing. When indicated, the technicians performed adjustments to the air/fuel mixture and spark timing on spark ignition engines. No adjustments were attempted on diesel engines and none are possible on electric motors.

The decision of whether to make pump adjustments was based on the an examination of how closely the output of the pump matched the manufacturer's

pump curve. If the pump was operating on the curve, no adjustment was necessary.
When tests were run on wells that were being over-pumped (pumping air), pump adjustments were made when the rotational speed of the pump could be reduced (internal combustion engines) but not made if the speed could not be reduced (direct coupled electric motors).

Following the initial pumping plant tests, 57% were determined to potentially benefit from adjustments that could be made in the field. Pumping plants that received adjustments were then retested. Adjustments either to the engine or pump or both resulted in 14% average savings in energy costs compared to the initial test results on those units receiving adjustments.

Aside from the direct savings resulting from in-field adjustments, technicians were able to calculate the feasibility of making repairs beyond the field adjustments. On some pumping plants, major repairs or even replacement of the pump could be paid for in only a few years using projected savings in energy costs.

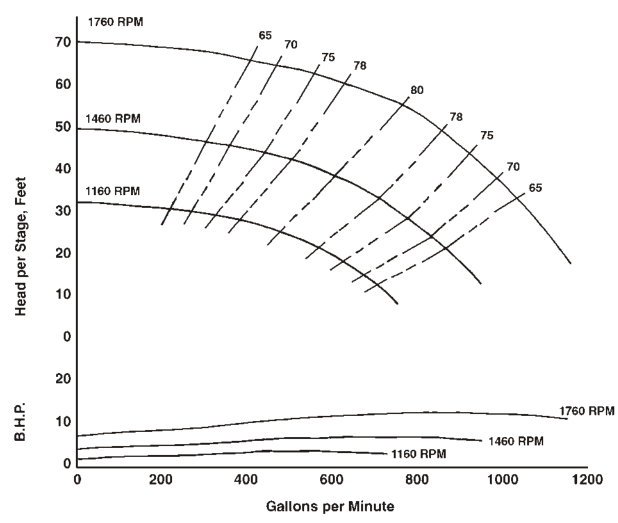
What Causes Poor Pump Performance?

The three main causes for poor pump performance are: (1) pump designs that are poorly matched to the job they are currently doing (as when the operator has switched from gated pipe to a center pivot sprinkler or has switched from a high pressure to a lower pressure sprinkler package), (2) pumps that had worn impeller vanes and/or internal seals as a result of pumping sand, (3) impellers that were not properly adjusted within the pump bowls.

There are many pump manufacturers and each manufacturer can have dozens of pump designs in their catalog. At a given rotational speed, each impeller design operates on unique head versus capacity curve. In all cases, the greater the head (ft) the pump is working against, the lower the capacity (gpm output).

As can be seen by examining a typical head/capacity curve in Figure 1, the pump's efficiency changes, depending on the operating conditions. Each pump design will have a best efficiency point at a certain head/capacity condition,

Figure 1. Typical head/capacity curve for a vertical turbine irrigation pump.



with lower efficiencies on either side of the best efficiency point. This pump achieves a best efficiency of 80% at 55 feet of head/stage and about 800 gpm at 1760 rpm.

The job of the pump installer is to select an impeller design that will operate efficiently when pumping the volume of water required for the application and while producing the total head required using some multiple number of stages.

Because no two irrigation systems or situations are exactly alike, fuel costs are hard to compare between different irrigation systems. Therefore most irrigators did not know, prior to the pumping plant test, whether a pumping plant was using too much energy for the conditions under which it was operating, even those that were using 50% more energy than the NPC in many cases.

Conduct a Short Term Pumping Plant Test

If there isn't a water meter installed on the system, a short-term pumping plant test can be run using one of a variety of devices to measure the flow rate. The pumping water level, system pressure measured at the pump discharge, and the rate of energy consumption must also be measured. Contact a reputable well driller and ask if they are equipped to run a short term pumping plant efficiency test.

Estimate Long-Term Pumping Plant Performance and Potential Energy Savings From Records

If a water meter is installed on the system and if the operator has records of total water volume pumped and fuel consumed over a period of time (a week, a month, or the pumping season) and if he/she has a measurement of the pumping water level and system pressure during the same time period, the performance rating of the pumping plant can be estimated. If the performance rating is below 100% of the NPC, the potential savings from adjustment or repair can be calculated.

The information required to estimate long term performance includes: total volume pumped (acre-inches), the lift (pumping water level), pressure at the pump discharge head (psi) and energy consumed over the period corresponding to the water meter readings.

Note: When the pressure gauge is not located at the discharge head, the elevation difference between the discharge head and the gauge must be added to the lift.

1. Whp-h = total volume pumped (ac-in) x total head (ft) / 8.75

2. Performance = whp-h (from 1.) / fuel used for the test period

3. Performance Rating = (Performance (from 2.) / NPC) x 100%

4. Potential fuel savings = ((100% - %NPC (from 3.) / 100%) x fuel used for the test period

Example: Using records to estimate long term pumping plant performance

- Test period = entire irrigation season
- System = Center Pivot Sprinkler and a diesel powered pump.
- Pumping water level = 140 feet
- Pressure at the discharge head = 40 psi
- Ac-in of water pumped (from water meter readings) = 1,500 ac-in (12 inches x 125 acres)
- Total fuel used for test period = 4,139 gallons of diesel

1. whp-h = acre-inches pumped x total head (ft) / 8.75
   = 1,500 x (140 + (40 x 2.31)) / 8.75
   = 1,500 x (140 + 92.4) / 8.75
   = 1,500 x (232.4) / 8.75
   = 39,840

2. Performance = whp-h (from 1.) / fuel used for the test period
   = 39,840 whp-h / 4,139 gallons
   = 9.625 whp-h / gallon

3. Performance Rating = Performance (from 2) / NPC x 100%
   = (9.625 whp-h / gallon / 12.5 whp-h / gallon of diesel) x 100%
   = 77.0%

4. Potential fuel savings = ((100% - %NPC) / 100%) x fuel used
   = ((100% - 77%) /100%) x 4,139 gallons of diesel
   = 0.23 x 4,139 gallons
   = 952 gallons/season

At $1.00 / gallon for diesel, the potential energy savings resulting from bringing this pumping plant up to the NPC would be $952 per year. If repairs were financed at 7% interest with annual payments, one could borrow $5,125 for repairs and pay the loan off in seven years using annual savings in energy costs.

- If the water meter totalizer registers in gallons, divide gallons by 27,154.
- If the water meter totalizer registers in acre-feet, multiply ac-ft by 12.
- If the water meter totalizer registers in cubic feet, divide cubic feet by 3,630.