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Evaluating Irrigation Pumping Systems [1]

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Inefficient irrigation pumping systems waste fuel and increase the cost per unit of water delivered. As fuel and electrical power costs increase, the cost of operating an inefficient pump increases even more.

Efficiency of a pumping system is defined as a ratio of the work being done by the system to the power or energy being supplied to it. If, for example, 50 hp is being put into a pump system and the actual work being done only requires 25 hp, then the pumping efficiency is 25 hp/50 hp = 0.5 or 50 %.

Normally, power input is measured in terms of fuel (or electrical power) consumption. Work output is measured in terms of the flow rate and pressure produced by the system. Therefore, the efficiency computed is that of the entire pumping system, which includes (1) the efficiency of fuel conversion in an internal combustion engine or electric motor, (2) friction losses in belt or gear drives, if any, (3) the pump efficiency, and (4) friction losses in the suction line, discharge column, and discharge head. The efficiency calculated including all of these components is often referred to as the pumping plant efficiency.

The pumping plant is designed to deliver water at the desired rate and pressure necessary for application. The work output is called water horsepower and is calculated from :

$$\text{Water Horsepower} = \frac{Q \cdot H}{3960}$$

where Q = flow rate (gpm), and
H = total pumping head produced
(ft, where 1 psi = 2.31 ft of water).

calculated from .

Water horsepower depends on the rate that water is lifted and the height to which it is lifted. Water does not need to be physically lifted to that height, but only to have potential to reach that height if it were released. This is the total pumping head or simply, total head produced. The horsepower required to be delivered to the pump to produce the required water horsepower is called brake horsepower. Brake horsepower is defined by equation 2.

$$\text{Brake Horsepower} = \frac{\text{Water Horsepower}}{\text{Pump Efficiency}}$$

equation 2. .

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PUMPING PLANT TESTS

In the field, the performance of irrigation pumping systems can be checked by measuring pumping plant performances. The University of Nebraska Department of Agricultural Engineering has developed standards for fuel consumption for pumping plants. This was done in conjunction with the Nebraska Tractor Test and manufacturer's performance data. Standards were developed based upon water horsepower (WHP) produced, because WHP is a characteristic of all pumps. In Table 1, performance standards are shown for the different fuels most commonly used for irrigation systems. These figures are not the highest theoretically obtainable. Rather, they are those that can reasonably be expected from a well designed, well maintained, pumping plant. It is possible to obtain a performance rating which exceeds the standards and has a rating of over 100% of the standard.

Table 1 presents performance standards for both power units and pumping plants. Power unit performance standards are given in terms of power produced (in horsepower hours, hp hr) per unit of fuel consumed (in gallons, gal, or kilowatt-hours, kwh). These figures represent the effectiveness of a typical power unit in converting fuel or electrical power to mechanical power.

Pumping system performance standards are given in units of water horsepower-hours (whp hr) per gal or kwh. They include allowances for normal pump efficiencies, drive losses, and friction losses in the discharge column and discharge head. Pumping system performance standards are expressed in terms of units of fuel consumed because they can be easily measured, whereas mechanical power input to a pump can be measured only with specialized instrumentation.

A pumping plant test requires the physical properties that determine pumping plant performance be measured. Pumping rate, pumping lift, pressure at the discharge outlet, and the amount of fuel consumed over a period of time must be measured while the pump is operating at its normal load. The engine and pump speed should also be measured to ensure that the manufacturer's recommendations are being followed.

Water Horsepower Determination

In the field, water horsepower is calculated using Equation 1 . Flow rate, Q, must be accurately measured. An impeller meter, orifice meter, or other measurement device may be used. Flow rates must be converted to gallons per minute for use in Equation 1 .

Total pumping head must also be accurately measured. This includes a measure of the pressure produced at the pump discharge (pressure head) and the vertical distance the water is lifted from its source (aquifer, lake, river, etc.) to where the pressure is measured (pumping lift) (Figure 1).

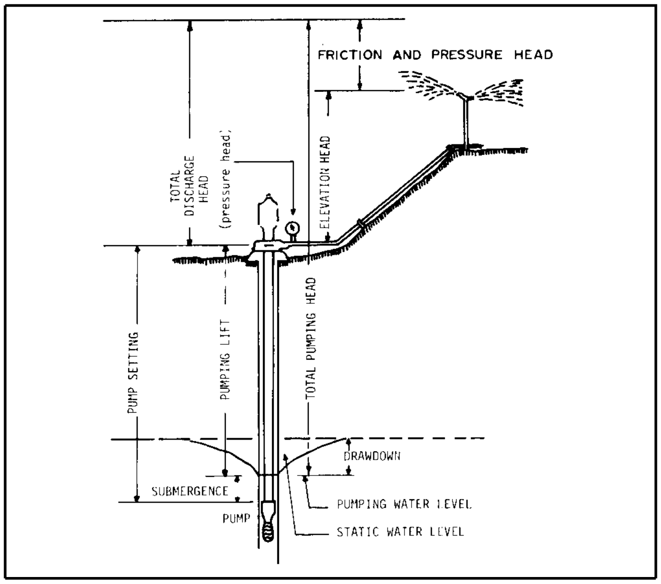

Figure 1 .

Pressure head must be measured with a reliable pressure gauge. A calibrated gauge should be installed for purposes of this measurement only. A gauge that has been in the field for several years may not be reliable for a pump efficiency test. The gauge should allow pressures to be read to the nearest psi. Pressure head must be calculated by multiplying gauge pressure (psi) by 2.31 ft/psi.

Pumping lift must be measured as a component of the total pumping head. Pumping lift is measured as the vertical distance from the pumping water level at its source to the discharge point at which the pressure gauge is located. It is important that this elevation be measured while the pump is operating because the water level in the aquifer may be considerably lower during pumping. Water elevations may be measured by any of several methods. One method consists of lowering a rusty steel measuring tape between the well column and casing. A water mark will remain on the rusty tape and allow it to be read immediately upon retrieval.

A second commonly used technique involves locating the water elevation by allowing it to complete an electrical circuit (Figure 2). A battery and ammeter are connected in series. One electrical lead is connected to the well casing; the second is lowered into the well. When the lead contacts the groundwater, the electrical circuit is completed and a current flow is indicated on the ammeter. Depth to water is obtained by measuring the electrical lead length. Similar results can be obtained by using a portable ohmmeter and measuring resistance changes when the circuit is completed.

Pumping lift should be measured to the nearest foot. Total head, H, is calculated as the sum of the pressure head and elevation head, Finally, water horsepower is calculated by multiplying the measured flow rate (gpm) by the total head (ft) and dividing by 3960 (Equation 1).

Fuel Consumption Determination

To assess pumping plant performance, fuel use must be determined. For electric power units this can be accomplished with any of several types of portable instrumentation to measure voltage, current flow, and power factor while the system is operating. It can also be measured with acceptable accuracy using the electric company's kilowatt-hour (kwh) meter. The number of kilowatt hours consumed during an accurately measured period of time can be used to calculate the rate of power consumption in kwh/hr. To increase accuracy, a period of time of at least one hour should be used to evaluate electrical power consumption. The kwh meter should be read before and after the test period. The rate of power consumption is then calculated as the difference in kwh meter readings divided by the elapsed time.

For internal combustion engines, gallons of fuel consumed must be measured during an accurately monitored pumping period. This can be accomplished by several methods. For diesel and gasoline engines, fuel consumption can be monitored using a specially constructed graduated cylinder connected to the engine's fuel line. The time for a given amount of fuel to be consumed can be accurately measured with a stopwatch. It is important that the engine be fully loaded and at the correct operating temperature if this technique is to be used. A three-way valve is useful for this purpose. During warmup, fuel is consumed directly from the bulk fuel tank at the well site. To begin the test, the graduated cylinder is switched into the fuel line and the stopwatch is started as the fuel moves past an upper reference point on the cylinder. Timing continues until the fuel level reaches a lower reference point. Fuel use rate is calculated from the known volume of fuel consumed divided by the elapsed time. If performed with care, this method is the most accurate method of determining the fuel use rate. Care must also be taken to avoid allowing dirt to enter the fuel line as this can cause engine operational problems, especially with the injectors of diesel engines. If it is not possible or desirable to inject directly into the fuel lines, fuel consumption rates can be measured by depletions from the bulk storage tank. If the fuel tank is symmetrically shaped, consumption rate can be obtained by measuring fuel levels before and after an extended pumping period. Volume of fuel consumed will be obtained from the differences in depth before and after the pumping period, and from a knowledge of the cross sectional area of the tank. Such a tank can be calibrated by measuring fuel depth before and after an accurately measured volume is added to the tank.

Unfortunately, fuel tanks are often not regularly shaped (i.e. a cylindrical tank laying horizontally), and in such cases it is difficult to estimate volume of fuel consumed from measured reductions in liquid level in the tank. If a flow meter is used to measure the amount of fuel pumped into the tank when it is refilled, that reading can be used to evaluate the fuel consumption rate if pumping times are also accurately recorded. An "hours of operation" meter may be a part of the instrument panel of the engine. If so, it may be used to totalize hours of operation.

Fuel consumption rates can also be calculated monthly or annually based upon fuel purchase records. Engine operating time must still be accurately recorded, preferably with an hour meter on the engine. Long term record evaluations such as these are not as desirable as using previously described techniques, because long term fuel storage efficiency becomes a factor to be considered. Vented tanks lose some fuel to vaporization which results in an apparent decrease in the calculated pumping plant performance rating.

Fuel consumption rates for LP-Gas (Propane), which must be stored in tanks under pressure, can best be measured from the supplier's records. Pressure gauges indicating percentage of fuel remaining in the tank may not be sufficiently accurate to evaluate the pumping plant performance. Rather, the fuel supplier's record of gallons required to refill the tank and an accurate record of pumping time must be used in the calculation of performance ratings.

Natural gas consumption rates can be monitored with sufficient accuracy using the gas meter at the pumping plant site. An accurate record of pumping time must be maintained to calculate pumping plant performance ratings.

Calculation of Pumping Plant Performance

An example set of field data is presented to illustrate the procedure for calculation of pumping plant performance:

Pump Discharge Rate, Q = 600 gpm

Pumping Lift, Le = 70 ft

Discharge Pressure, P = 60 psi

Pump Speed = 1750 rpm

Fuel Consumed (Diesel) = 4.0 gal

Pump Test Duration = 1.0 hr

1. Check Pump Speed:

Pump speed should be measured with a portable tachometer to assure that the pump is being operated according to its specifications. The design pump operating speed should be stamped on a plate attached to the pump discharge head.

In this example, the measured pump speed (1750 rpm) was found to be very nearly the required pump operating speed (1760 rpm). If it were not, speed must be adjusted before continuing.

2. Calculate Total Pumping Head (H):

H = Pumping Lift (ft) + Discharge Pressure (ft)

H = 70 ft + 60 psi 231 ft/psi

H = 70 ft + 139 ft = 209 ft

3. Calculate Water (Output) Horsepower, WHP
:

$$\mathrm{WHP} = \frac{Q \cdot H}{3960}$$

$$\mathrm{WHP} = \frac{600\ \mathrm{gpm} \cdot 209\ \mathrm{ft}}{3960}$$

$$\mathrm{WHP} = 31.7\ \mathrm{hp}$$

Horsepower, WHP .

4. Calculate Pumping Plant Performance :

$$\text{Performance (whp} \cdot \text{hr/gal)} = \frac{\text{WHP} \cdot \text{Test Duration (hr)}}{\text{Fuel Consumed (gal)}}$$

$$\text{Performance} = \frac{31.7\ \text{hp} \cdot 1.0\ \text{hr}}{4.0\ \text{gal}}$$

$$\text{Performance} = 7.9\ \text{whp} \cdot \text{hr/gal}$$

Performance .

5. Calculate Pumping Plant Performance Rating,

: 6. Calculate Fuel Wasted per Hour: Fuel Wasted/Hour = Current Fuel Consumption Rate (1 - PR)100%

Fuel Waster/Hour = 4.0 gal/hr (100% - 71.6%)

Fuel Wasted/Hour = 1. 1 gal/hr

In this example, the actual pumping plant performance of 7.9 whp hr/gal is only 71.6% of the performance standard for diesel powered pumping plants. For the size of unit described, 1.1 gal/hr of diesel fuel is wasted because the pumping plant is not operating efficiently in its current condition. Whether this reduction in performance is significant enough to justify having the pumping unit repaired depends upon the expected repair cost and the number of hours of pump operation per year. In general, if the repair cost can be regained by savings in operating costs over a 2-3 year period of time, then it will be economically feasible to have the repairs made. The actual repayment time can only be calculated using a detailed economic analysis including the expected performance increases, fuel cost, and the repair costs amortized over that period of time.

CAUSES FOR SUBSTANDARD PERFORMANCE

Substandard performance in the pump can be caused by several factors. The pump could be mismatched for present conditions. The pump may not have been properly selected or the operating conditions may have changed. The water table could have dropped or a new pipe line could have changed the pumping head requirement. The power source may not be operating at the specified speed (rpm) for maximum efficiency.

The impellers could be out of adjustment. Qualified repairmen can adjust the impeller clearance with the bowl for the greatest efficiency. If the impeller is badly worn or corroded, adjustment will not help. Cavitation occurs in pumps that attempt to operate at flow rates greater than the well can supply. This pits the impellers and ruins them.

The engine may be loaded improperly. An internal combustion engine operates most efficiently at 75-90% of its continuous horsepower rating at its design speed. Electric motors operate best at 100-110% of their nameplate rating. Overloading an internal combustion engine can seriously shorten engine life as well as increase fuel costs.

The engine may need a tune-up. The ignition, timing, and carburetion should be adjusted on spark ignited engines. Diesel engines require fuel injection timing. Adjustments should be made by a qualified specialist to ensure maximum efficiency under the operating conditions. Electric motors generally do not need adjustment over their lifetime. Parts that are excessively worn should be replaced. Compression tests can be run to check for the need to overhaul an internal combustion engine.

Poorly designed pumping systems result in low performance ratings. This could be caused by such factors as an undersized suction pipe, restrictions in the intake strainer, or improperly sized discharge column. Misalignment of the drive shaft also decreases performance ratings. Excessive wear is a sign of this.

SUMMARY

Pumping plant performance ratings can be determined in the field by comparing fuel consumption rates for a measured output horsepower of the system with the Nebraska performance standard. The Nebraska standard was established to demonstrate what could reasonably be expected of pumping plants during operation.

The procedure for evaluating in-field performance of a pumping plant has been outlined. The procedure and an example demonstrating the fuel wasted by operating an inefficient pumping system has also been presented. Finally, causes for substandard performance of irrigation pumping plants have been discussed.

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