IRRIGATION MANAGEMENT SERIES

Reading Pump and Engine Performance Curves

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Pump and engine performance curves are important tools in the design and analysis of pumping stations. The pump curve provides information on the pump's ability to produce head and flow capacity along with information on pump efficiency and brake horsepower requirements. The engine performance curve will help insure proper loading of the engine to obtain the best possible fuel economy.

Pump Performance Curve

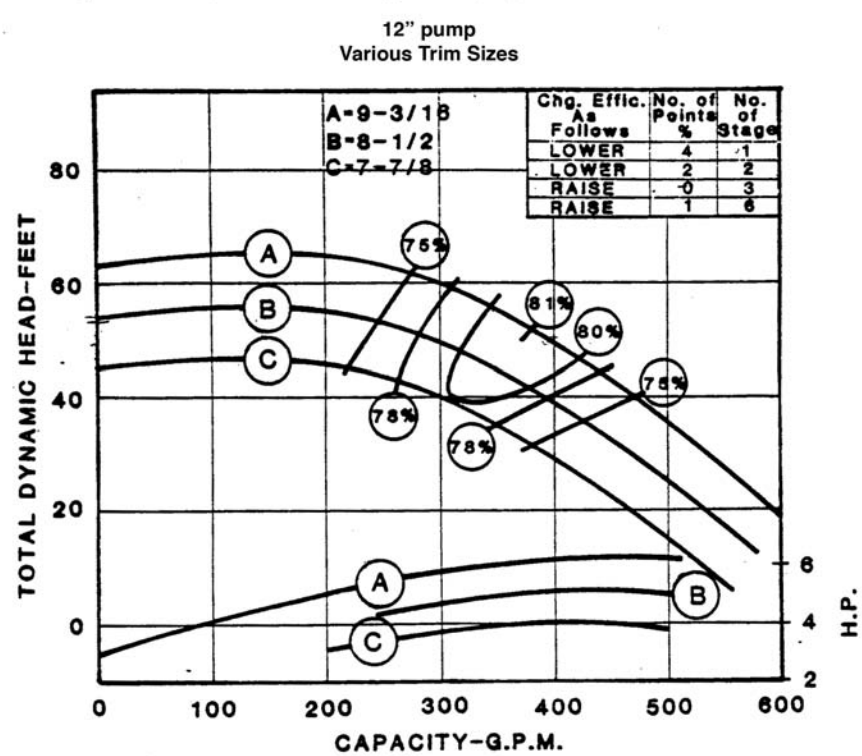
A typical performance curve for a pump is shown in Figure 1. The curve can be confusing to read since it shows information on different impeller trim sizes. The total dynamic head is read from the left vertical axis. The pump flow capacity is read from the horizontal axis and pump efficiency is shown within the chart. Brake horsepower requirements are shown below the head-discharge curve. Brake horsepower is the actual amount of work performed on pumping the water at a given head and flow capacity plus the additional amount of work required due to pump inefficiency.

Head and Capacity Relationship

The most important part of the pump performance graph is the head-capacity curve, which shows the relationship between the total dynamic head and the capacity for a given pump. A given pump can produce only a certain flow (capacity) for a given head, and vice versa. The example pump performance curve in Figure 1 shows that this pump with a 9-3/16 inch impeller trim (marked as curve A) can produce a total dynamic head of 60 feet and pump 300 gpm (gallons per minute). If a given field needed 400 gpm of capacity, this pump could then generate only 50 feet of total head.

Most pumping plants have head requirements in excess of the capability of a single bowl or stage of a pump. Pressure or head increases are accomplished by combining stages of a given pump in a series. Additional stages of the pump are added together until the total dynamic head requirements of the pumping system are met. Total dynamic head includes head requirements due to pumping lift, elevation changes, friction losses, and system operating pressure. So, if 250 feet of total dynamic head is required

Figure 1: Example Performance Curve for a pump with various trims.



with a desired pumping rate of 400 gpm, then five stages of this pump would be required. Adding stages increases pressure; it does not increase flow capacity. If capacity were to be changed significantly, the selection of a different pump would be required.

Pumps are generally selected so that the operating point on the performance curve is to the right of the peak efficiency point. Any declines in groundwater and normal wear processes would then tend to push the pump towards higher efficiency, resulting in better performance over a larger period of time than if the original selection was to the left of maximum efficiency.

Efficiency

The pump performance curve also gives information on pump efficiency. The efficiency curves intersect with the head-capacity curve and are labeled with percentages. Each pump will have its own maximum efficiency point. Figure 1 shows this pump's maximum efficiency is 81 percent for operating conditions of approximately 380 gpm with impeller trim A. When operating at 300 gpm and 60 feet of head, efficiency is approximately 78 percent. When operating at 50 feet of total head and 400 gpm efficiency is approximately 80.5 percent.

The pump performance curve also features an efficiency adjustment chart to account for changes in efficiency that occur as the number of stages change. Pump efficiency improves with additional stages since the friction losses that occur are shared. If only a single stage pump is used then this example efficiency chart indicates the pump efficiency read from the chart should be reduced by 4 percent. When three stages are used, the readings can be taken directly from the chart. When six stages are used, chart readings can be increased by 1 percent. Some manufacturers record efficiency on the chart for single stage pumps and give increases with stages. Others do as shown in this example.

Brake Horsepower

The pump performance curve will give information on the brake horsepower required to operate a pump at a given point on the performance curve. The brake horsepower curves run across the bottom of the pump performance curve. Like the head-capacity curve, there is a brake horsepower curve for each different impeller trim. Continuing with the previous example, a pump with an impeller trim A operating at 50 feet of head and 400 gpm would require approximately 6.2 horsepower. The addition of stages increases horsepower by an equal amount.

Impeller Trims

Pump performance curves generally show performance for various impeller diameters or trims. Manufacturers will put several different trim curves on a pump performance curve to make pump specification easier, although this sometimes makes the pump performance curve more difficult to read.

Operating Speed

Occasionally manufacturers will provide pump performance curves that will show the effect of changing operating speed or rpm. Figure 2 shows the same 12-inch pump model with trim A operating at 1770, 1470, and 1170 rpm. The curve lines marked A in Figures 1 and 2 are identical. The general effect of reducing speed is a reduction of capacity and head. Pump efficiency can be unaffected with head and capacity changes if the new pumping conditions are proportional to the speed changes. However, most often a specific head or discharge is required that forces the pump to operate at some other point in the curve. This means efficiency will be changed.

The manufacturer cannot be expected to provide a performance curve for every conceivable operating speed and trim. The effect of speed and trim changes can be determined through the use of mathematical relationships, sometimes known as affinity laws. However since the trim of the pump cannot be easily altered after installation, only the affinity laws for speed will be discussed.

The affinity law associated with the rotational speed or rpm of a pump is that discharge is proportional to the ratio of rotational speed; head is proportional to the square of the rotational speed ratio; and brake horsepower (BHP) is proportional to the cube of the rotational speed ratio. These relationships can be stated

Equations 1, 2 and 3 and Examples

$$1)\ \text{Final Discharge} = \left(\frac{\text{Final RPM}}{\text{Initial RPM}}\right) \times \text{Initial Discharge}$$

$$2)\ \text{Final Head} = \left(\frac{\text{Final RPM}}{\text{Initial RPM}}\right)^2 \text{ x Initial Head}$$

$$3)\ \text{Final BHP} = \left(\frac{\text{Final RPM}}{\text{Initial RPM}}\right)^3 \text{ x Initial BHP}$$

$$1)\ \text{Final Discharge} = \left(\frac{1470}{1770}\right) \times 400 = 332 \text{ gpm}$$

$$2)\ \text{Final Head} = \left(\frac{1470}{1770}\right)^2 \text{ x } 50 = 34.5 \text{ feet}$$

$$3)\ \text{Final BHP} = \left(\frac{1470}{1770}\right)^3 \text{ x } 6.2 = 3.4 \text{ BHP}$$

Figure 2: Example Performance Curve for a pump with various speeds.

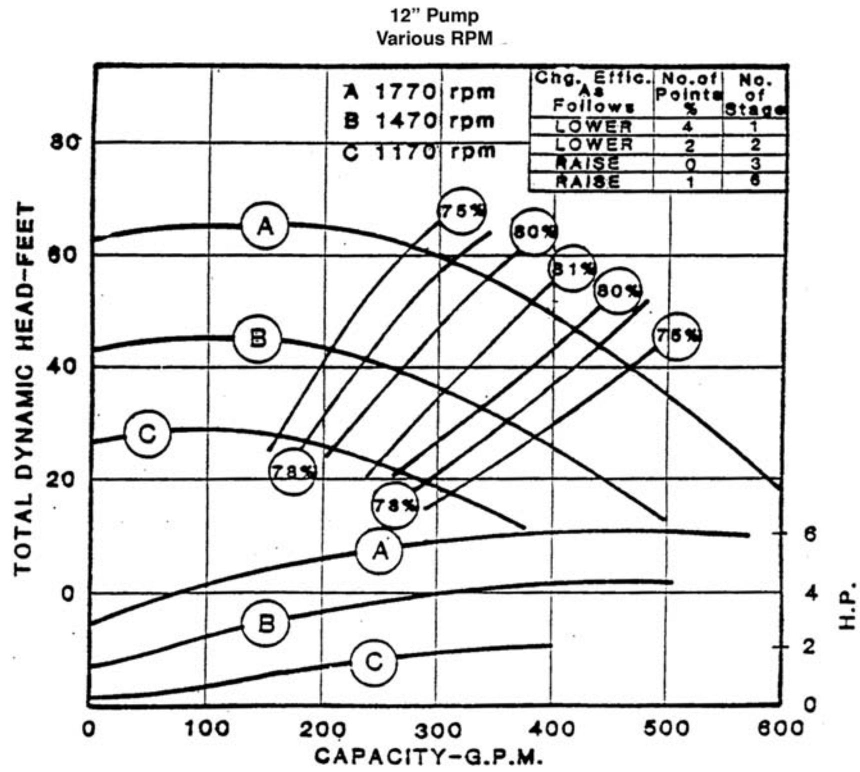
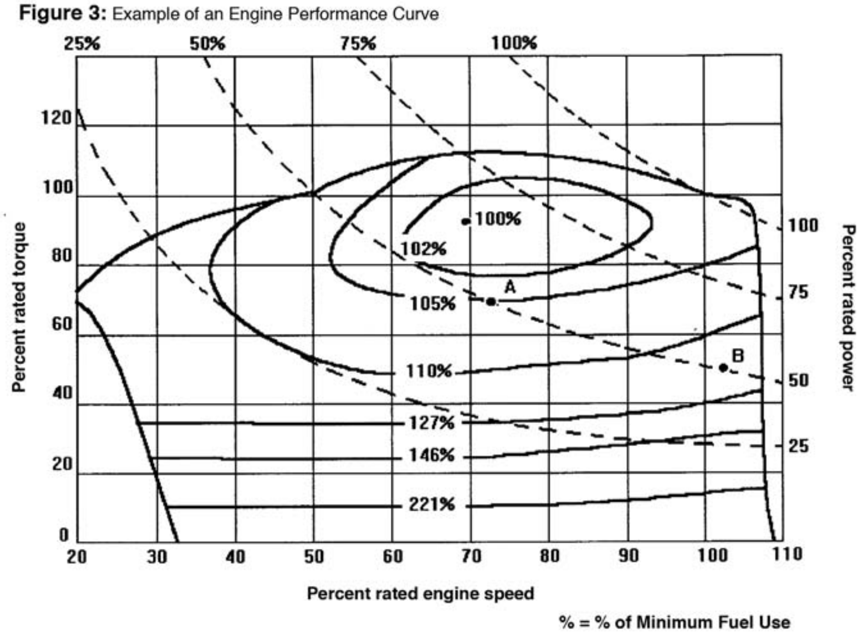


Figure 3: Example of an Engine Performance Curve



mathematically as shown in Equations 1, 2 and 3 at left.

These relationships could be used to develop Figure 2 using information from Figure 1. For example, at rated speed (1770 rpm) and impeller curve A, the pump curve shows 50 feet of head can be developed at a discharge of 400 gpm with a pump efficiency of 80.5 percent. Brake horsepower requirements are 6.2 hp. If pump speed is slowed to 1470 rpm, what is the effect on pumping characteristics?

Solution:

Use equations 1, 2 and 3 as shown in the examples at left. The reduction of the operating speed results in the flow capacity being reduced to 332 gpm, the head to 34.5 feet and the brake horsepower to 3.4bhp.

The results can be compared to values read from Figure 2 to see that the relationships are valid.

Engine Performance Curve

Engine performance curves can also be obtained. Anybody with a new pumping plant installation should request a copy of the performance curves for the pump and engine and be certain the gear head ratio is clearly marked on the unit and recorded with the performance curves. The irrigator is then in a much better position to evaluate the effects of system changes or water declines on pumping plant efficiency.

A typical engine performance curve or map is shown in Figure 3. The horizontal axis shows percent of rated engine speed. The left vertical axis is the percent of rated torque. The intersection of 100 percent rated torque and speed is the maximum rated power for the engine. In this example, 100,75, 50 and 25 percent of rated power is plotted. On Figure 3, points A and B are plotted along the 50 percent rated power curve. This illustrates that the same power output can be achieved using various combinations of speed and torque. Imposed on the power curves are lines that are lines of equal fuel consumption. For a given engine, the lines would be labeled with values using units such as pounds of fuel per horsepower–hour, or gallons per horsepower–hour, kilograms per kilowatt hour, or so forth. In this example case, these values were replaced with percent of minimum fuel use. The point labeled 100 percent is the area of best fuel economy.

Effects of Rotational Speed Changes on Engine Performance

Examination of points A and B from Figure 3 illustrate that the engine at point A is operating at much better fuel economy that at point B. If this situation were a tractor, operator response would be to gear up and throttle down. With a fixed gear head, this would require changing of the gear head at considerable expense.

With pump and engine performance curves, the effect of changing pump speed to accommodate new pumping conditions with the same equipment may be estimated without extensive field testing or discovery of excessive fuel use during or after the irrigation season. Changing speed to accommodate changes in pumping conditions can result in pumping water at very low efficiency. Worse case situations result in decreased water availability and increased pumping costs, although occasionally some changes can improve pumping efficiency. However, since irrigation fuel costs can represent a significant production expense, any changes in operating conditions should be analyzed in order to make certain profitability is not sacrificed.

Summary

Many factors affect the overall performance of irrigation pumping plants. All changes influence performance; however, many changes are not evaluated in terms of pumping costs and irrigation capacity unless the effects are severe enough to have an immediate and noticeable impact. Loss of pumping efficiency and capacity are common with increasing head requirements. Evaluation of this loss should be done to see if other adjustments or equipment investments would be economically beneficial.

Additional Information Sources:

L885.*Evaluating Pumping Plant Efficiency Using On-Farm Fuel Bills*.

MF2360. *Comparing Irrigation Energy Cost*.

FuelCost. A software program to estimate irrigation pumping plant efficiency. Available via the Mobile

Irrigation Lab Web site at

www.oznet.ksu.edu/mil

References:

Nebraska Performance Criteria (NPC) for Pumping Plants

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