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Converting Center Pivot Sprinkler Packages: System Considerations

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This NebGuide points out some of the system-oriented factors that should be considered when changing sprinkler packages on a center pivot irrigation system.

Irrigators using existing center pivots may be interested in changing sprinkler packages to take advantage of new sprinkler technology, overcome a poor design on the original package, reduce energy requirements or simply to replace worn sprinklers on an older machine. Whatever the reason, there may be multiple benefits in changing the sprinkler package on an existing center pivot. If done properly, most systems will use less energy as a result of changing from a high operating pressure to medium or low pressure. Other systems may realize an increase in application efficiency by changing to a sprinkler package that has lower evaporation losses. Systems with insufficient capacity may actually show crop yield increases as a result of this increased application efficiency.

In any case, there are considerations that should be investigated before converting to a new sprinkler package. The new sprinkler package should be appropriate for the soil and topographical characteristics of the site. The information presented here deals with the irrigation system issues that should be addressed when changing a sprinkler package. The irrigation system includes the center pivot, the power unit and pump and their components. Since these components must work together efficiently, changing the operation of any component changes the way the other components operate.

Effect of Pressure Reductions on System Components

Reducing the operating pressure of a center pivot system may have many positive effects, but there are some trade-offs. When the overall system pressure is reduced, problems may arise that can be corrected by changing some equipment; however, in some cases it may not be economical to make these changes.

One potential problem associated with reducing the system pressure involves operation of the end gun. Systems with existing end guns may not have adequate pressure to operate the end gun after the pressure reduction. End-gun booster pumps can be installed to allow continued use of the original end gun. Some systems could require the addition of a booster pump and a smaller end gun. Others may require that the end gun no longer be used. An end-gun booster may have additional power and maintenance requirements. Removing the end gun will decrease the irrigated acreage. These costs should be considered when changing the operating pressure of a center pivot.

When converting to a low-pressure system, some irrigated acreage may be lost even if end guns are not used. The high pressure system may have additional throw from the outermost sprinkler in the range of 50 to 75 feet. Replacing this package with a low to medium pressure system with a wetted radius of 15 to 35 feet will result in loss of irrigated acreage. For example, if the wetted radius was reduced by 40 feet on a 1,320-foot center pivot, the irrigated acreage would be reduced by 7.5 acres.

Another consideration is the impact of reduced operating pressure on water application uniformity. Medium to low pressure sprinklers will be more sensitive to pressure variation due to field elevation changes than high pressure sprinklers. To overcome this sensitivity and ensure that the uniformity of application is not sacrificed, many systems will require pressure regulators on each sprinkler.

Changing Operating Pressure — Internal Combustion Units

Figure 1 illustrates how changing the operating pressure can affect pump performance. The relationship between pressure developed by each stage and gallons per minute of output is shown by the solid lines. For each of the three pump speeds shown, the pump will operate somewhere along the solid lines as long as the speed does not change. When the speed changes, the pump operates on a new performance curve. The dotted lines, which are roughly perpendicular to the solid performance curve lines, indicate the pump efficiency at that point. Pumps can operate below and/or to the left of the performance curve

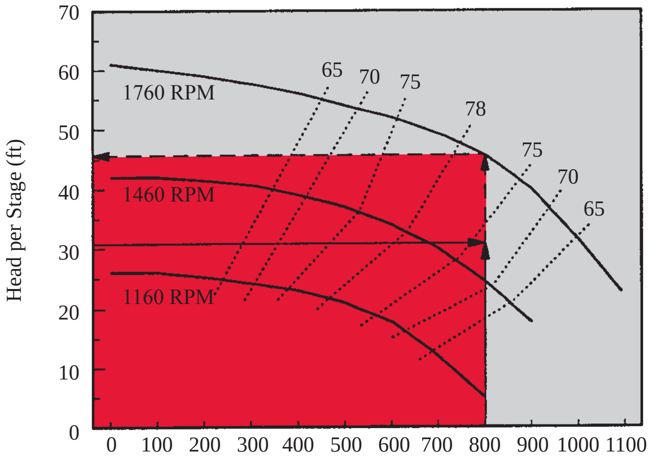

Figure 1. Pump curve showing the effect of decreasing the engine speed.

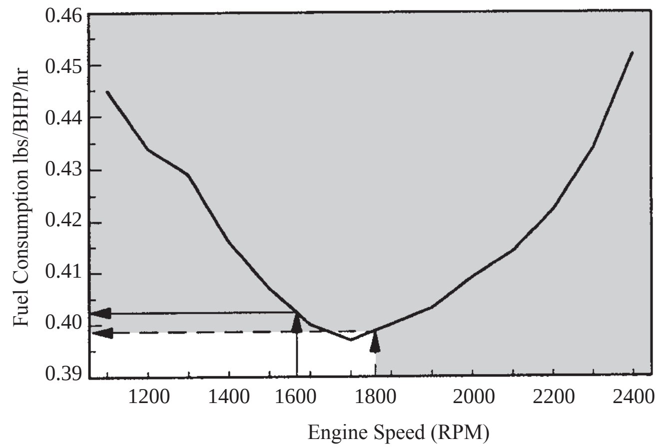

Figure 2. Engine performance curve, showing the effect of engine speed on efficiency.

if they are worn or out of adjustment. Keep in mind that the speed used on a pump curve (*Figure 1*) is pump speed, not engine speed. Pump and internal combustion engine speed will be equal only if 1:1 gears are used in the gear head, or if the driver and driven pulleys in a belt drive system are of equal diameter. The operating pressure of the pump may be reduced by reducing the engine speed. Reducing the engine speed will reduce both flow rate and operating pressure unless the center pivot has been altered to apply the same flow at the new lower pressure.

The application amount will remain the same with the lower pressure system if the flow rate and travel speed of the center pivot are not changed. The application rate (the rate at which water is added to any point on the soil surface) will probably increase because the lower pressure system will have a smaller wetting pattern. If the wetting pattern is smaller and the pump flow rate is unchanged, the application rate will increase.

One potentially negative effect of changing the engine speed is that the pump efficiency may decrease. This could mean that a lower percent of the energy delivered to the pump drive shaft is effectively converted to water movement. If this change in efficiency is large, reductions in energy use associated with reducing the pressure may be offset by the increase in energy use associated with the decrease in pump efficiency. As a result there may be no overall savings in energy costs. In fact, the energy costs may increase. A possible solution to this problem is to replace or modify the pump bowls and/or impellers. The pump curve should always be evaluated prior to any change to ensure that the new settings are satisfactory.

Another consideration when changing the engine speed is that the engine performance (fuel use) may change. Internal combustion engines are designed for maximum efficiency at a given speed. Deviation from that speed will decrease the engine efficiency, as shown in *Figure 2*. If the decrease in engine efficiency is significant, the pump gear head (or pulley diameters if belt drives are used) should be changed so that the engine runs at a speed near the minimum fuel consumption level.

Changing Operating Pressure — Electrical Units

Many electrically powered pumps are driven by vertical hollowshaft motors that are directly coupled to the pump lineshaft. There is no way to change the rotational speed of the pumps when using these motors.

Several options are available to reduce the operating pressure of center pivots that have electrically driven pumps. One option is to continue to use the original pump and design the sprinkler package to deliver more gallons per minute at a lower pressure. When looking at *Figure 1*, we would follow the pump curve downward to the right. The result is that pump efficiency will be reduced and the capacity of the well, peak application rate of the sprinkler, and other factors will limit how far this option can be taken. Another option is to pull the pump and remove one or more stages from the bowl assembly. This is a viable option only if the pump design is well matched to the volume to be pumped through the new sprinkler package. If the impellers or the bowl assembly are worn, this would be a good time to have the pump redesigned.

Another alternative would be to pull the pump and trim the impeller diameters to meet the new conditions. This has much the same effect on the head and capacity of the pump as operating the impeller at a lower rotational speed. Depending on the pump and operating conditions, it may be necessary to remove some bowls and trim others to meet the new conditions. In some cases it may be necessary to replace the pump with one that is designed to operate with the new conditions.

Using the old, higher horsepower electric motor to drive the pump would not be an operational problem since electric motors only draw the current required by the load. A potential problem with over-sized electric motors is that utility companies assess a demand charge based on the horsepower rating of the motor. An over-sized motor will therefore be assessed a high demand charge unless the utility company uses a demand meter instead of the nameplate horsepower.

An option with single phase motors is to change to one that operates at a lower speed. Again, the pump curve should be checked for potential pump efficiency problems associated with the new pump speed. This may be a more expensive option, but the lower operating speed may extend the life of the pump. The demand charge would not be a problem in this case, since the lower speed motor would have a lower horsepower rating, and thus a fair demand charge.

If a belt drive system is used, the pulley diameters could be changed to adjust for new pressure and flow rate conditions. In this case, the pump curve should be checked for the new pump efficiency, and the demand charge problem may occur.

Runoff Potential

It cannot be over-stressed that many low to medium pressure systems may generate a runoff problem that could overshadow the positive effects of the sprinkler package conversion to reduced pressure. Runoff is influenced by application rate, which is influenced by wetted diameter. The wetted diameter of low to medium pressure systems is often considerably less than that of high pressure systems. In some cases converting to lower pressures may generate unacceptable runoff amounts.

Cost Considerations

There are many cost-related factors that must be considered when making a change in sprinkler packages. *Table I* summarizes the potential costs and benefits associated with the change. For any system, the benefits should outweigh the costs before the conversion is made.

Other economic factors to consider are related to the projected life of the system and its components. There is more incentive to change sprinkler packages if the current sprinklers already need to be replaced due to wear. Also, any new sprinklers placed on an older center pivot may be salvaged and transferred to a new system if the center pivot itself is replaced.

Table I. Potential economic costs and benefits associated with changing sprinkler packages.

Potential Costs	*Potential Benefits*
Equipment • sprinklers • pressure regulators • drop tubes • end-gun booster pump • adding extra sprinkler fittings	**Reduced Fuel Costs** • pump operates at lower pressure • more efficient system (fewer pumping hours) • reduced demand charge
Acreage Reductions • end gun inoperable • reduced wetted diameter of end sprinklers	**Application Efficiency** • higher if runoff is not a problem
Pump Alterations • bowls and impellers • gear head or pulleys	**Increased Yields** • if pump capacity is too low
Motor Change	
Artificially High Demand Charge	

Procedure Summary

A general outline for the steps to take when deciding if a sprinkler change is warranted is given below.

1. Determine appropriate sprinklers for soil and slopes.
2. Determine operating pressure and flow rate needed for the chosen sprinkler package.
3. Determine if the pump and power plant should be redesigned for the new operating conditions.
4. Determine costs associated with any required system changes and the new sprinkler package.
5. Determine the investment that could be made and paid for with savings in operating costs or increased crop yield.

Example Calculations

An irrigator wishes to install a low pressure sprinkler package on an older high pressure center pivot. In doing so, he will need to change the system operating pressure. He has an internal combustion engine with the engine performance curve shown in *Figure 2*. The gear head on the well has a 1:1 gear ratio so the engine speed equals the pump speed. The engine drives a pump with the characteristics shown in the pump curve of *Figure 1*. Six stages are used, so all readings from the head per stage axis of *Figure 1* are multiplied by six. The initial (high pressure) settings are:

Flow Rate	800 gpm
Pressure at Pivot Point	70 psi (161.7 ft of head)
Pumping Lift and Friction Loss	114.3 ft of head
Engine Speed	1760 RPM

The new sprinkler package requires 30 psi (69.3 feet of head) at the pivot point. First, the irrigator needs to know the new engine speed required to pump 800 gpm at the new pressure. The elevation and friction losses in the column are the same, so the total head would now be 114.3 feet plus 69.3 feet, or 183.6 feet. This is 30.6 feet of head per stage. Following the solid arrows on *Figure 1* leads to a point that is approximately one-third of the distance from the 1,460 RPM curve to the 1,760 RPM curve, when measured perpendicularly. The new pump speed would be approximately 1,460 plus one-third times the difference between 1,760 and 1,460, or 1,560 RPM.

Having both the old (dashed arrows) and new (solid arrows) points on the pump curve (*Figure 1*), the difference in fuel consumption resulting in the change may now be calculated. The pump efficiencies are estimated in *Figure 1* based on position relative to the dotted lines.

The fuel consumption rate is read from *Figure 2*. The brake horsepower for either case is determined as:

$$BHP = \frac{total\ head\ (ft) \times gpm}{3960 \times pump\ efficiency\ (decimal)}$$

For the high pressure system, (pump efficiency from *Figure 1* = 76%) this is:

$$BHP = \frac{276 \; x \; 800}{3960 \; x \; 0.76} = 73.4 \; hp$$

Fuel consumption for the high pressure system at 1,760 RPM is 0.398 lb/BHP/hr (dashed arrows, *Figure 2*). Thus the fuel consumption rate for the high pressure system was:

$$Fuel\ Consumption = \frac{0.398 \; lb}{BHP \bullet hr} \; x \; 73.4 \; BHP = 29.2 \; lb/hr$$

For the low pressure system, the brake horsepower is (pump efficiency from *Figure 1* = 74%):

$$BHP = \frac{183.6 \; x \; 800}{3960 \; x \; 0.74} = 50.1 \; hp$$

Fuel consumption for the low pressure system at 1,560 RPM is 0.402 lb/BHP/hr (solid arrows, *Figure 2*). Thus the fuel consumption rate for the low pressure system will be:

$$Fuel\ Consumption = \frac{0.402 \text{ lb}}{BHP \bullet hr} \; x \; 50.1 \; BHP = 20.1 \; lb/hr$$

Thus the difference in fuel consumption due to the nozzle conversion will be (29.2 lb/hr - 20.1 lb/hr) or 9.1 lb/hr (about 1.3 gal/hr for diesel). This decrease in fuel consumption is the primary economic incentive for the conversion in this case and must offset the cost of the conversion when spread over the life of the new sprinkler components. In this case both the pump and engine efficiency decreased. The combined decreases were not sufficient to overwhelm the reduction in fuel consumption associated with the lower horsepower requirements. In some cases the reduction in efficiencies will cause an increase in fuel consumption, and equipment should be altered accordingly.

In this same example, another option would be to reduce the existing pump bowl assembly from six to four stages. Then the pump and engine could be run at the original speed and efficiency while consuming less fuel. The costs in this case would be associated with pulling the pump and modifying the bowl assembly.

Acknowledgments

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