PUMPING PLANT MODIFICATIONS

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We have seen a lot of activity in the past decade or so in conversion of irrigation systems, whether from open ditch to surge, furrow to sprinklers, or sprinklers to LEPA or other in-canopy spray systems. The primary motivations for such changes are to save water, reduce labor, or reduce power costs. Because it is the pumping plant that converts purchased energy (electricity, natural gas, etc) to water energy (lift, pressure, and flow rate), that motivation is the topic of this discussion. Since any conversion requires a capital investment, and possibly reallocation of other resources, we want to make sure that making the conversion results in the savings expected.

PUMP PRINCIPLES

Except for some low-lift pumps used in pipelines and for tailwater or shallow lake pumping, virtually all pumps used for irrigation in the U.S. , whether called submersible, deep well turbine, or centrifugal, are of the general type classed as centrifugal. This means that a *powerplant* (electric motor, stationary engine, tractor pto) is coupled to a rotating shaft in order to spin the *impeller* of the pump which is designed to allow water to enter this rotating cylinder near its center. The rotation of the water within the impeller results in *centrifugal force* which tends to force the water toward the outside of the spinning impeller. It is this centrifugal force which gives velocity and pressure to the water leaving the impeller, and lends its name to the type of pump. Because the nature of water movement through the impeller, the velocity (flow rate) and back pressure against the impeller are uniquely related -- the higher the back pressure, the lower the flow rate.

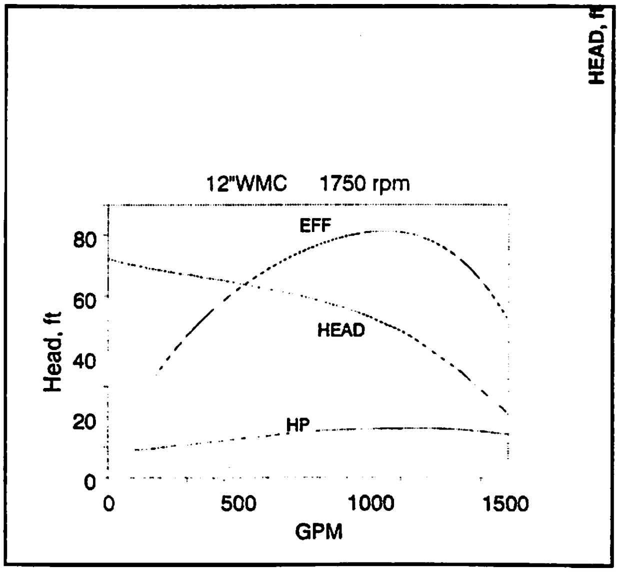

Figure 1. Hypothetical pump curve for a single stage centrifugal pump.

Each pump manufacturer tests a representative sample of each type and size pump, and publishes a graph which describes the relationships between back pressure (head), flow rate, energy conversion efficiency, and power requirement. These so called *pump curves* are an extremely important part of determining the suitability of a given pump for a particular irrigation system. Figure 1 shows a typical pump curve for a *single stage* pump. In order to get the most "bang for the buck", it is desirable to operate a pump near to its point of highest efficiency. For this model, that is about 1050 gallons per minute, at which point the pump will produce about 50 feet of *head.* Because centrifugal pumps, particularly the style intended for deep well turbine (including submersible) pumps, are designed so that the water being pumped must all flow through the pump impeller, these individual pumps *(stages)* lend themselves to being "stacked" one atop another to create a *multistage pump* typical of those used to pump groundwater for irrigation. When several stages are stacked, the resulting pump has very predictable characteristics as compared to the original pump curve. First, the flow rate will remain the same as for a single stage if the back pressure on each stage remains constant. The efficiency will change slightly, depending on the specific pump, as stages are added, but the flow rate at which maximum efficiency occurs will remain the same. The most notable factor is that the pressure (head) developed by each stage is *additive,* thus our pump in Figure 1, if manufactured into a 6 stage pump, will produce 1000 gpm at 50x6= 300 feet total head.

Perhaps it is important at this point to briefly discuss the relationship between pressure and head. We are all familiar with the depth of water in the well, usually expressed in feet. We also recognize that an irrigation system (particularly sprinklers) may develop a water pressure inside the pipeline, usually expressed in pounds per square inch (psi). Hydraulically, these two phenomena are the same, with a simple conversion to relate the two: 1 psi equals 2.31 feet head. Thus, our pump in Figure 1 will either lift that 1000 gpm 50 feet or else it will discharge the water at the level of the pump with a pressure of 50/2.31= 21.6 psi (or any combination of lift and pressure between the two).

Another factor influencing the back pressure on a pump, therefore the total *head* against which it operates, is head due to friction in the connecting pipelines between pump and water outlet. All these components of head required to deliver a given amount of water can be added together to produce a curve similar to the pump curve, as indicated by Figure 2. This complex interaction between lift, pressure, and flow rate determines the operating point of the pumping plant. In fact, it is precisely at the point where the system head curve intersects the pump head curve that the pump will operate. When an irrigation system undergoes modification of almost any sort, either the system head curve or the pump head curve, and therefore the point at which they intersect, will change. If this change is significant, it may result in a low efficiency, and either more or less water and pressure than anticipated.

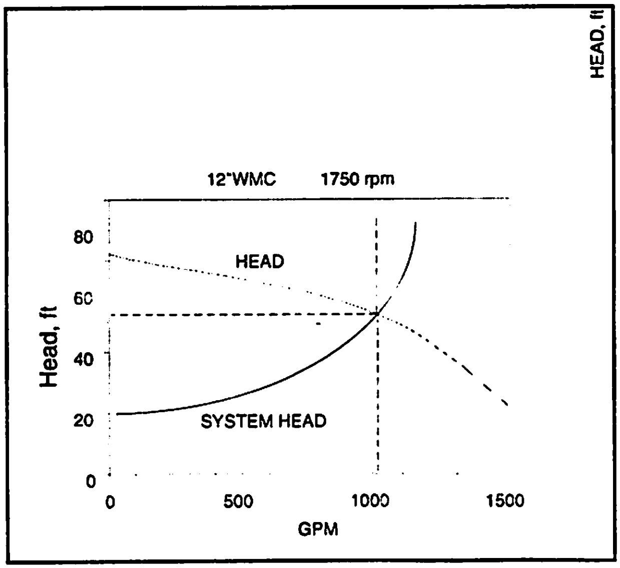

Figure 2. Pump curve with superimposed system head curve to show operating characteristics.

CHANGES TO THE SYSTEM HEAD CURVE

Changes to the system head curve can come from many situations, both intended and not. For example, the *friction head* increases with the velocity of water in the pipe. In fact it increases as the square of the velocity. Thus, if the diameter of a pipe is reduced from 10" to 8" to save initial costs, the velocity of water in the pipe will increase by more than 50%, and the friction loss by almost 2.5 times! As a result, the system head curve turns up more steeply , lowering the flow rate and increasing pumping head. In a long pipeline, that extra head can amount to significant extra power costs over the life of the pipe. Converting from the open discharge of furrow irrigation from an open ditch to buried pipe, or even a sprinkler, results in obvious changes in the system head curve. It is important to note that although putting a valve on the pump discharge will lower the operating pressure downstream from the valve, it only increases the system head curve, and should **never** be considered an alternative for matching pump discharge to desired irrigation system pressure.

In many areas of the High Plains, groundwater levels fluctuate, either due to changing influence of a nearby stream or neighbor's well, or to mining of the groundwater. Regardless of the reason, such fluctuations have a direct influence on the system head curve. Most often, the water table drops, increasing the system head curve, with a corresponding decline in flow rate from the pump.

Probably the most common change in system head curve for center pivot irrigation systems occurs when the irrigator decides to convert the system from high or moderate pressure sprinkler heads to some form of low pressure system, such as LEPA or in-canopy spray systems. This results in lowering the pressure component of the system head curve. As can be seen from Figure 2, lowering the system head curve while leaving the pump curve unchanged will *increase* the pumping rate (which may lead to problems of breaking suction in marginal wells), and usually will end up with a higher pressure than intended. These changes may reduce energy bills, but the maximum impact will not be achieved unless the pump is changed to match the new system curve.

Pressure regulators present a unique challenge to the pump designer. Pressure regulators are designed specifically to have a variable pressure loss so that the downstream pressure (and therefore the flow rate when a fixed size nozzle is installed in a sprinkler head) remains constant. Therefore, the system head curve for a pressure regulated sprinkler system is almost vertical when the system is operated at a pressure which allows the regulators to function. If the system head curve turns vertical before intersecting the pump curve, then any head (and the power required to produce it) between the two points is wasted. Although pressure regulators are useful in assuring uniformity of water flow when topography changes across a field, the entire irrigation system should be designed so that the pressure regulators have the minimum line pressure to operate at the critical point in the field.

CHANGES TO THE PUMP CURVE

A common change to the pump curve that occurs over time is due to *wear*. Particularly if the well produces sand, the impellers will be abraded, resulting in rough surfaces, reduced effective diameter, and recirculation of water within the *bowl*, all of which reduce both the rate of water flow and the pressure developed. Changes to the pump curve can best be detected by conducting a pump test, a service provided by many utilities, consultants, pump dealers, and sometimes by public agencies.

A related, very useful, but intentional change to the pump curve can be achieved by disassembling the pump, placing the impeller in a lathe, and reducing its diameter. This *trimming* reduces the pump discharge, head produced, and power consumed, all very predictably. If the operating characteristics of a pump need to be changed a small amount and it is in otherwise good condition, trimming the impellers may be the best way to match system and pump curves.

The manufacturer's pump curve is published for a specific speed, and many pumps are rated for a range of speeds. When electric motors are used as a power source, the speed of the pump is not readily changed. Most vertical shaft deep well turbines operate at 1750 rpm, and submersibles at 1750 or 3500 rpm. Changing the pump speed is not a practical method of changing the pump curve. However, when power is provided by a combustion engine (or older belt drive electric motors), it can be relatively easy to change speed in order to change pressure and flow rate, for example when the water table drops or after changing to a low pressure sprinkler package. While such speed changes are perfectly acceptable, the operator should be aware that significant changes in speed of the pump may have a large effect on pump efficiency and the expected reduction of power costs. Changing the speed may also have an adverse effect on the engine. If changing the pump speed is a viable means of matching the pump to irrigation system, then it may be desirable to change the gearhead so that both pump and engine can run at their optimum speeds.

Some irrigators attempt to match operating pressure with design pressure by adjustment of the pump impeller clearance. On semi-enclosed impeller pumps, one side of the pumping chamber is formed by the stationary bottom section of the bowl. By tightening the nut on top of the line shaft, one can increase the clearance between impeller and bowl, which does reduce the pressure developed. One must consider, however, why this pressure is reduced. Increasing bowl clearance simply allows a part of the water pumped to recirculate and be pumped again -- representing wasted energy. In deep-set vertical shaft turbines, stretch of the lineshaft may be very significant as the pump goes from turned off to developing full pressure. Misadjustment of the impellers can cause serious damage to the pump from allowing the impeller to drag on the bowl -- either top or bottom.

When relatively large changes in operating pressure are made, such as adding a sprinkler to a well previously used for irrigation by gated pipe, or for converting a 65 psi impact head center pivot to a 25 psi LEPA system, a viable option may be to retain an otherwise good pump and simply change the number of stages. Particularly when a stage or two can be dropped from a pump, this can be a very satisfactory method of matching system to pump curve.

The cost of whatever changes need to be made to a pump to make it match the irrigation system must be weighed against the perceived benefit from modifying the irrigation system. It is entirely possible to renozzle a sprinkler system intending to reduce the operating pressure, thus power costs, but end up with a system discharging a higher flow rate at higher pivot pressure than designed, with a lowered pump efficiency, poorer water distribution on the field, and resulting in **higher** power costs to make the same crop!

One must be particularly cautioned against reducing the pumping rate of already marginal wells because one is converting to an irrigation system perceived to be more efficient than the old one. Although one can sometimes reduce the electrical demand charge by sizing down a pump, reduced flow rate *always* results in increased risk of water stress for the crop. The irrigator must weigh this benefit of reduced power charges against the cost of failure if precipitation is not as high as anticipated. Because of the cost of pulling a pump, and the time it takes if required during the growing season, such changes should be considered permanent.

EXAMPLE SAVINGS

As an example of how important it is to match the pump to the irrigation system, lets consider a very realistic scenario. You now have a well that lifts 900 gpm from 150 feet depth and delivers it to a 126 acre center pivot at 45 psi. The pivot is equipped with an over-canopy spray system which has an acceptable uniformity coefficient of 80%. In western Kansas, lets assume you need 15 inches of water applied to the crop root zone to make a crop with your goal of limiting signs of water stress to less than 10-15% of the field. Your current pump has been in the ground for 15 years, and currently tests at 55% wire-to-water efficiency. You use electricity to pump and pay an average of $0.07 per kwh. The 80% uniformity coefficient means that you need to pump about 40% more water than needed by the crop to maintain 85-90% of the field well watered, thus you need to pump 15" x 1.4 = 21" water per season, or 2646 acre-inches. At 900 gpm, you will have to irrigate a total of 1323 hours. The total head is 150' + 2.31(45 psi) = 254'. At 55% pumping plant efficiency, your motor will be loaded at 105 horsepower or 78.3 kw (HP = [gpm x feet head]/[39.6 x efficiency %]). Your total electrical consumption for the season is 103,590 kwh @$0.07 which runs $7250 per year.

You have been convinced that if you convert to a low pressure in-canopy spray, you can save both water and power bills. If you convert, you can run 22 psi at the pivot, will have a 90% uniformity, and 95% application efficiency. If the pumping plant is matched correctly, it can have an efficiency of 70% (about 107% of Nebraska Standard). In this ideal situation, you will only have to pump 10% more than the crop needs to satisfy the water stress requirements with a 90% uniformity system, for a total of 16.5" or 2079 acre-inches. At 900 gpm, this represents only 1039 hours irrigation. At a total head of only 201 feet, and with a 70% efficient pumping plant, your motor will draw only 65 horsepower (maybe you can reduce some demand charges, too). Total power consumption will reduce to 50580 kwh and will cost $3540. With an $8000 investment, you have reduced your operating costs by $3710 per year, a pretty attractive payback. Remember, however, that this scenario requires you to also modify the pumping plant.

Say you decide to just make the changes to the sprinkler, and let the pump go for now. All heads are changed, spacing changed, and longer drops added. To work at the lower design pressure and the original 900 gpm, each nozzle will have to be slightly larger (assuming the number of heads isn't changed) than before. When you are finished, the pump delivers 1050 gpm, not 900, and runs at 30 psi pivot pressure, not 22 as designed. As a result, more water comes out the inner nozzles than intended, and the uniformity drops to 75%. This means you have to pump 60% more water than needed by the crop to maintain the water stress goal, or 24". All told, you will pump 1292 hours per year, fewer than before, but will pump 3024 acre-inches of water, about 14% more. Because your pump is operating even further from the optimum condition than before, the pumping plant efficiency is now only 50%, and the motor is loaded at 116 horsepower as compared to 105 before. The total electrical consumption is 111,900 kwh and your bill is $7834. You have invested $8000 in sprinkler upgrades hoping to save yourself $3700 per year in power, but rather you power bill has gone *up* by almost $600!

This may sound like a pretty bleak scenario, but it is a rather common one. The only way to avoid such pitfalls is to have a competent pump person test your pump before hand to compare its operation with that when it was new, and to determine what changes in the pump (possibly replacement) will be necessary to match it to the new irrigation system. Then, weigh the costs of the *whole package*, sprinkler modifications and pump improvement, with the perceived benefits.

The foregoing analysis has looked only at the changes in system operation resulting from changes in the hardware. Other speakers will talk about the tradeoffs to conversion from one type irrigation system to another, but many of those tradeoffs have implications of pumping energy costs, either positive or negative.