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Updating the Nebraska Pumping Plant Performance Criteria

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INTRODUCTION

Irrigation water is removed from groundwater storage using deep well turbine pumps powered by electric motors or diesel, gasoline, propane, ethanol, or natural gas internal combustion engines. For best operating efficiency irrigation power units are selected to specifically meet the requirements of the irrigation system that include how deep the water in the well is under pumping conditions, the water pressure required at the pump outlet, and the system flow rate. Since each component of the irrigation pumping plant (pump, motor, and right angle gear drive) is a mechanical device, wear and tear can reduce its operating efficiency making the motor use extra power to pump the water. As some components of the irrigation system are replaced, such as replacing a sprinkler package, the original pumping plant may no longer match the new requirements. These factors cause the energy use efficiency of irrigation pumping plants to be lower than optimum.

The evaluation of pumping plants to establish pumping plant performance dates back into the 1950's when researchers at the University of Nebraska were unable to directly compare the operation of an electrically powered pump installation to that powered by a diesel or other internal combustion engine. The solution to this issue was to develop performance criteria for each energy source that would be based upon the amount of work (water horsepower-hours) operators could expect if the system were well-designed and well-maintained. This performance criterion was referred to as the Nebraska Pumping Plant Performance Criteria (NPPPC) that is cited by irrigation design engineers worldwide (Scheusener and Sulek, 1959). Defining the original criteria involved manufacturer's and Nebraska Tractor Test data and field evaluations of pumping installations. Since 1959, the diesel fuel standard was updated by Fischbach and Dorn, (1981).

The 3-state area has approximately 110,000 active irrigation wells (2008 Ag Census). The University of Nebraska conducted a statewide pumping plant efficiency study in the late 1970's. In this study, they tested 180 farmer-owned pumping plants. When the performance ratings of all pumping plants tested were

tallied, the average pumping plant in the study was found to be operating at 77% of the NPPPC . Some pumping plants were found to be very efficient, and 15% of the systems tested actually exceeded the NPPPC.
Engineers from Minnesota, North Dakota and South Dakota were involved in irrigation pumping plant efficiency tests during 1978, 1979 and 1980. Performance characteristics were determined for 249 electric powered installations. The average performance rating was 77% of the NPPPC.

More recent tests confirm that pumping plant performance ratings remain well below the NPPPC. Pumping plant evaluations conducted on 244 units in Texas during the early 1990’s (Fipps and Neal, 1995). In their work, diesel powered units averaged 80.4%, natural gas engines averaged 87.5% and electric motors averaged 72.5% of the NPPPC. Hla and Scherer, (2000) reported on 37 units tested in North Dakota and found the average performance rating for center pivot based systems was about 80% of the NPPPC.

Based on Nebraska Tractor Test data, significant improvement has been made in the brake horsepower output per unit of fuel for internal combustion engines. However, pumping costs continue to increase due to rising fuel costs which have overshadowed improvements in pumping plant components. That said, more efficient irrigation pumping plants still could save an average of 25-30 percent of the energy used to pump irrigation water through properly matching and adjusting the pump and motor to current operating conditions. In Nebraska alone, improvement in pumping plant performance will reduce energy costs by up to $40 million per year.

Frequently cited causes of pumping plant inefficiency are the following:

1. The pipeline is valved back at the well to meet pressure requirements;
2. Well screen is plugged due to mineral incrustation and/or iron bacteria resulting in extra pumping lift;
3. Worn pump impeller due to wear from pumping sand or extended use;
4. Improper impeller adjustment on deep well turbine pumps;
5. Alteration of the irrigation application system without redesigning the pumping plant;
6. Mismatched system components such power unit too large ;
7. The power source may not be operating at the specified speed (rpm) for maximum efficiency;
8. The engine may need a tune-up; and
9. Improperly sized discharge column.

Nebraska survey results indicate that 32.7% of the power units used to pump irrigation water are diesel engines, 42.6% are electric motors, 17% are natural gas engines, 7.6% are powered by propane and 0.02% are powered by gasoline engines (USDA, 2004). The average irrigation system in Nebraska operates for 774 hours, pumping water at a rate of 839 gallons per minute, from a depth of 143 feet, with a pump outlet pressure of 42 pounds per square inch. Based on the NPPPC, the average system would require 57.4 kilowatt-hours of electricity per hour of operation or 44,464 kilowatt-hours per year. The equivalent annual energy use would be 3149 gallons of diesel fuel, 5,712 gallons of propane, or 6,380 MCF of natural gas. Assuming an average performance rating of 80% of the NPPPC, if the performance rating were improved by 10% percent, the average annual energy savings would be equivalent to 5,560 kilowatt-hours of electricity. When multiplied by 92,000 wells in Nebraska, the potential savings could reach nearly $100 million per year in energy savings.

The NPPPC is based upon the assumption that the pump efficiency is 75% and on the energy contained in fuel for internal combustion engines. Likewise, the assumed efficiency of an electric motor is 88%. Other assumptions are included in the footnotes in Table 1. Based on these assumptions, the existing pumping plant performance criteria are listed in Table 1.

Table 1. The current Nebraska Pumping Plant Performance Criteria (NPPPC).

Energy Source	**Energy Unit**	**Bhp-hr/unit (1)**	**Whp-hr (2)/unit (3)**
Electric	Kilowatt-hr	1.18(5)	0.885
Diesel	Gallon	16.6	12.5(4)
Natural Gas	1000 cu. Ft.	88.9(7)	66.7
Propane	Gallon	9.2	6.89
Gasoline(6)	Gallon	11.5	8.66

1 Horsepower hours (bhp-hr) is the work accomplished by the power unit including drive losses
2 Water horsepower hours (whp-hr) is the work produced by the pumping plant per unit of energy at the NPPPC
3 The NPPPC are based on 75% pump efficiency
4 Criteria for diesel revised in 1981 to 12.5 whp-hr/gal
5 Assumes 88% electric motor efficiency
6 Taken from Test D of Nebraska Tractor Test Reports. Drive losses are accounted for in the data. Assumes no cooling fan
7 Manufacturers' data corrected for 5 percent gear-head drive loss and no cooling fan. Assumes natural gas energy content of 1000Btu per cubic foot.

PERFORMANCE TESTING

The key factors affecting pumping plant performance are typically recorded using a procedure developed by the University of Nebraska (Schroeder and Fischbach, 1982). The test involves accurate measurement of pump discharge pressure, pumping water level, water flow rate, and fuel consumption. These data are entered into Equation 1 to determine the water horsepower-hours produced by the pumping plant. When divided by the fueled consumed during the testing period, the outcome is the pumping plant performance.

$$\text{WHP} - \text{HR} = \frac{[(\text{Pressure} * 2.31) + (\text{Lift})] * \text{Flow Rate}}{3960} \qquad 1)$$

where:

WHP-HR	=	water horsepower-hours of work produced by the pumping plant
Pressure	=	pump outlet pressure, psi
Lift	=	water level in the well during pumping, ft.
Flow Rate	=	pump flow rate measured at the outlet, gpm

Figure 1 shows a schematic of a pumping plant with some performance variables that are recorded during a pumping plant test.

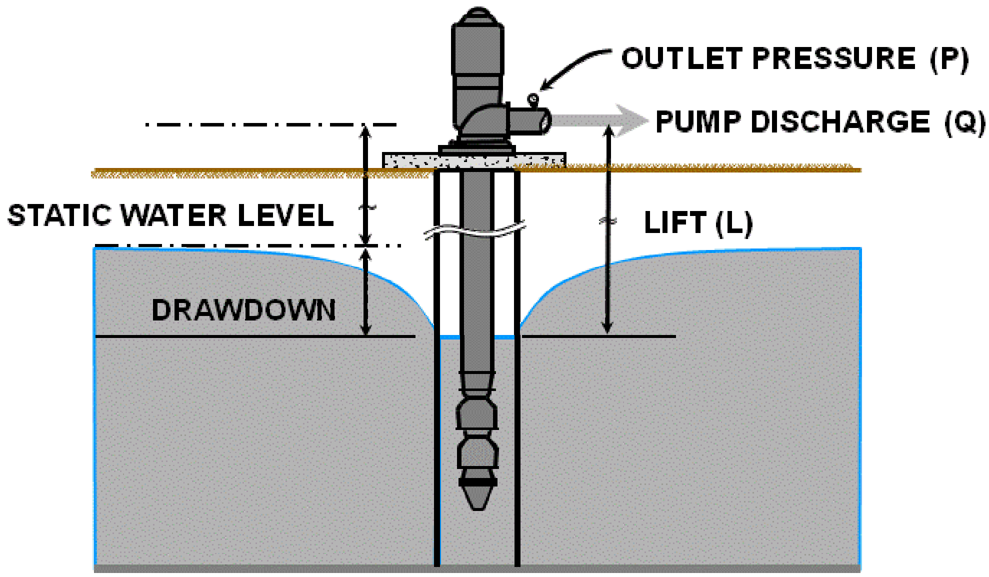

Figure 1. Schematic of factors affecting the pumping plant performance of a deep well turbine pump powered by an electric motor.

Additional information recorded during the test include the number and type of impellers, pump speed of rotation, power-take-off torque, motor manufacturer, and motor model number. Where necessary, an electric current meter is used to record incoming power in each leg of 3-phase power line. Recent Nebraska tests have included monitoring gas emissions from the engine exhaust to gain additional insight into how well the engine is adjusted.

In the winter of 2008-2009, we received a grant through the Water Energy and Agriculture Initiative to conduct pumping plant evaluations across the state of Nebraska with the overall goal of helping to reduce the energy consumption by irrigation pumping plants powered by electricity, natural gas, propane, gasoline, ethanol, and diesel fuel.

Specific objectives are to:

1) Identify pumping plant components that do not match current operating requirements;
2) Determine the potential maximum brake-horsepower output per unit of energy for new irrigation power plants;
3) Develop a revised Nebraska Pumping Plant Performance Criteria for diesel, natural gas, propane, electricity, ethanol, and gasoline power units.

Testing protocol varied slightly depending on the type of power unit and the ability to install instrumentation to the system. However, the general protocol is listed below.

Irrigation Pumping Plant Test Sequence:

1. Record information about pump and motor on the data sheet that was not available via the well registration or producer. Contact well driller if necessary to identify pump impellers.
2. Record static water level in the well if system has been shut down for several hours.
3. Install monitoring equipment including: engine/motor and pump speed, engine exhaust gas analyzer, pump outlet pressure, ultrasonic flow meter, and fuel use with scale or electric meter.
4. Start the pumping plant and bring the system to normal operation speed. Allow to run for a minimum of 30 minutes.
5. Switch engine fuel source to the test can on the scale.
6. Manually record all data onto data sheet to start the test sequence. During the test period record the outlet pressure, motor and pump rpm, flow rate (instantaneous and totalizer), fuel use rate, pumping water level and exhaust gas concentrations a minimum of once every 5 minutes for a minimum of 30 minutes.
7. Manually calculate system performance to ensure the accuracy of recorded data.
8. Save data files in separate file folder on the laptop.
9. If the test is acceptable, turn off the motor/engine and remove equipment.

Special Considerations:

1. The pumping plant evaluation must be conducted with all conditions nearly constant throughout the testing sequence. Recorded information during the test sequence should change less than the following:

Pump speed	± 0.5%
Pumping water level	± 1%
Fuel use rate	± 0.5%
Pump flow rate	± 1%

2. Pumping water level, flow meter, fuel use, and engine exhaust gases should be recorded nearly simultaneously.

3. Engine speed should not be changed once the test has been initiated since engine speed impacts flow rate, outlet pressure, and fuel use rates.
4. At least one test sequence should be conducted with and without power use by the center pivot, volume gun, or other irrigation system components.

Initial year testing began in July of 2009 and the results of the tests are presented in Table 2. Nearly all of the units tested were less than 3 years old. Though at least one unit in each of the energy sources was above the NPPPC, overall results indicated that extra energy is still being used to pump irrigation water in Nebraska. The electric units were the closer to the NPPPC than the other power types.

Table 2. Average test results for pumping plant tests conducted in 2009.

Energy Type	Flow Rate gpm	Pumping Level feet	Outlet Pressure psi	Energy Use Rate Unit/hr	Performance Whp-hr/unit	% of NPPPC %
Electric	794	146	37	46.1	0.84	95
Diesel	668	105	46	35.6	10.8	82
Propane	513	39.5	52	3.58	5.77	84
Ethanol	1689	191	1	9.3	8.89	??

SUMMARY

A new pumping plant testing program is under way to update the Nebraska Pumping Plant Performance Criteria for all energy types. Average pumping plant test results conducted previously in Nebraska and elsewhere have been near 80% of the NPPPC. Tests conducted on relatively new installations in 2009 produced results that ranged from 82% for Diesel powered units to 92% for electric units. The project will continue in 2010 and the update of the NPPPC will be based on data collected by the UNL and other entities across the country.

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