COMPARING IRRIGATION ENERGY COSTS[1]

Danny H. Rogers
Extension Engineer, Irrigation
Biological & Agricultural Engineering
237 Seaton Hall
Manhattan, KS 66506
785-532-5813 FAX 785-532-6944
E-mail: drogers@bae.ksu.edu

Mahbub Alam
Extension Agricultural Engineer
Southwest Area Extension Office
4500 East Mary
Garden City, KS 67846-9132
620-275-9164 FAX 620-276-6028
Email: malam@oznet.ksu.edu

Irrigated agriculture in Kansas is an energy intensive activity. Therefore the selection of the irrigation fuel source is a significant decision. This bulletin provides information on how to compare energy sources when alternatives exist from an operating cost viewpoint. It also provides some discussion on comparing alternative fuel pumping plants from an initial investment cost standpoint.

Nebraska Pumping Plant Performance

In order to compare fuel or energy costs, pumping conditions must be comparable. The Nebraska Pumping Plant Performance Criteria (NPC) provides just such a basis. The criteria were developed in the early 1960s and are recognized throughout the United States as the standard for comparison. Such a comparison of potential fuel or energy, however, is only a portion of the problem. The cost of equipment, maintenance costs, convenience, ease of automation, and other costs such as the horsepower demand charge of some electrical power suppliers should also be considered and only part of these factors have dollar values that can easily be attached.

Table 1 lists the NPCs necessary for a direct energy comparison. The values give an indication of the pump output (water horsepower-hour) per fuel input (kWh, mcf, or gallon). Natural gas is listed twice to reflect that this fuel source may have a variable energy content.

Water horsepower is a measure of the *power* input to the water and can be determined from total head and flow rate. *Water horsepower-hour* is a measure

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of the *work or energy* input to the water and is equivalent to developing one water horsepower for one hour.

The data was developed over a period of time and represents what a well-designed and properly maintained irrigation pumping plant should be capable of doing. Part of the data on engines was developed from the Nebraska tractor test program and the remainder from a variety of sources including years of irrigation pump testing. NPC is a compromise between the most efficient pumping plant possible and the average pumping plant. Therefore some pumping plants can actually exceed the criteria. In fact, tests in Nebraska indicate that about 15 percent of the systems will exceed the criteria.

The purpose of this bulletin is to use NPC to compare energy costs of comparable systems. NPC is also used to evaluate performance of pumping plants, but that use is not covered in much detail here. Refer to K-State bulletin *Evaluating Pumping Plant Efficiency*, L-885, for a more thorough example.

Comparing Energy Costs

Table 2 is developed from the last column of Table 1 and will allow for easy comparisons. This table compares the water horsepower-hour output of the various pumping plant alternatives. The energy source for comparison in each column of figures is listed with a value of 1. For example, in column 2 the value 1 is listed for electricity. Thus, natural gas, diesel and propane are being compared to electricity. One mcf of natural gas (925 BTU per cf) will produce 69.72 times as many water horsepower-hour output as 1 kWh of electricity. Diesel will produce 14.12 times as many water horsepower-hour output per gallon as 1 kWh.

All that is needed to find the comparable energy cost of the alternative energy is a cost for the original energy source. If the electrical rate is $0.08 per kWh , then the comparable energy cost for:

Natural Gas (925 BTU)
=
$0.08 x 69.72 = $5.58/mcf
Natural Gas (1,000 BTU)
= $0.08 x 75.37 = $6.03/mcf
Diesel = $0.08 x 14.12 = $1.13/gal
Propane = $0.08 x 7.79 = $0.62/gal

The interpretation is straightforward. If electricity cost $0.08 per kWh, you could afford to pay $5.58 per mcf for natural gas (925 BTU), $1.13 per gal for diesel fuel or $0.62 per gal for propane. These prices will vary from place to place. Thus, you need to use Table 2 and the prices in your area. Table 3 can be used for a quick reference for typical average prices.

The ***bold italicized*** value is the figure for comparison in each column. Natural gas prices vary from place to place and depend upon the situation. Some well head natural gas prices may be as low as $1.50 per mcf with adjacent users paying more than $5.00 per mcf.

Estimating Fuel Cost

The data of Table 1 will determine what energy costs should be if equipment is performing NPC. You need to know the amount of water used and the total "head" on the pump. Head is measured in feet of water or psi (pounds per square inch) and results from the lift from the well and the pressure of the water at the exit from the well. The lift is the distance from the water level in the well while pumping to the centerline of the outlet pipe. The discharge head is the gauge pressure at the outlet times a conversion factor of 2.31 feet per psi. These two terms may be called the Total Dynamic Head (TDH) or merely head.

An acre-foot (ac-ft) (ac-ft) of water is 43,560 cubic feet. Each cubic foot weights 62.4 pound. Thus, the total energy needed to lift 1 acre-foot of water to a height of 1 foot would be:

$$43{,}560\ ft^3 \times 62.40\ lbs/ft^3 \times 1\ ft = 2{,}718{,}144\ ft\text{-}lbs$$

One horsepower is $33{,}000\ ^{ft\text{-}lbs}/_{min}$ so
one horsepower-hour (hp-hr) is:

$$33{,}000\ ^{ft\text{-}lbs}/_{min} \times 60\ ^{min}/_{hr} = 1{,}980{,}000\ ^{ft\text{-}lbs}/_{hr}$$

This is the amount of energy expended when moving the water, the horsepower (hp) requirement is often designated as water horsepower (whp) to indicate output horsepower done to the water. The energy needed to pump one acre-foot of water at a head of 1 foot is:

Electricity

$$2{,}718{,}144\ ^{ft\text{-}lbs}/_{ac\text{-}ft} \div 1{,}980{,}000\ ^{ft\text{-}lbs}/_{whp\text{-}hr} = 1.373\ ^{whp/hr}/_{ac\text{-}ft} \text{ per foot of lift}$$

Then using the values from Table 1, the amount of each energy source needed to pump one acre-foot of water at a head of 1 foot be determined as shown below.

$$\frac{1.373\ whp\text{-}hr/ac\text{-}ft/ft}{0.885\ \frac{whp\text{-}hr}{kWh}} = 1.55\ kWh/ac\text{-}ft/ft$$

The results of all the fuel sources are shown in Table 4.

Each of these numbers represents the fuel input required (kWh, mcf, or gallon) per foot of head for each acre-foot of water pumped. Multiply these numbers by the total head in feet to get the fuel input per acre-ft of water for a particular lift. This number can then be multiplied by the acre-feet of water required to determine the fuel required. Fuel cost can then be estimated by multiplying the fuel requirement by the fuel price.

For example, natural gas with a energy content of 925 BTU per mcf, fuels a center pivot that covers 130 acres with 18 inches (1.5 feet) of water per season. The lift is 150 feet, the pressure is 45 psi and gas costs $3.75 per mcf. What is the estimated fuel use cost?

1. Determine head:

45 psi x 2.31 ft/psi	= 104 ft
+ lift	= 150 ft
total dynamic head	= 254 ft

2. Multiply Table 4 value by head.
   .0223 mcf/ac-ft/ft x254 ft = 5.66 $^{mcf}/_{ac\text{-}ft}$

3. Multiply Step 2 by the water used pumped.
   a. 130 acres x 1.5 feet = 195 ac-ft
   b. 5.66 $^{mcf}/_{ac\text{-}ft}$ x 195 ac-ft = 1,104 mcf

4. Multiply Step 3 by fuel cost.
   1,104 mcf x $3.75/mcf = $4,140

If the cost for fuel exceeded $4,140, then the pumping plant was not performing up to the Nebraska Performance Criteria. If the actual cost was $6,475 then:

$$\frac{4{,}140}{6{,}4{,}75} x100 = 64\%$$

or the pumping plant was operating at 64 percent of NPC and wasting 36 percent of the energy or $2,335 annually. If the well lift or the amount of water delivered from the well is not measured, the estimates will be less reliable. If the pump is badly worn, substantially less water maybe being pumped. Similarly, if the water level is not checked, it may be lower. The only sure way is to have the pumping plant checked, but an estimate using the above approach can be quite revealing. The procedure above compares cost of performance on the basis of energy source only.

The most economical energy source, however, is not necessarily the one with the lowest energy equivalent cost. The capital investment in equipment also needs to be considered. The following example will help illustrate this point.

Example: An irrigator is trying to decide whether to use electricity or diesel as an energy source. He can buy an appropriately sized electric motor for $3,500 and it would cost $15,000 to bring in three phase power. There is a diesel engine and right angle drive available for $20,000. He decides to use investment costs based on 5 years return period and 12 percent interest.

Electricity costs \$.06 per kW-h. Diesel costs \$0.80 per gallon. He estimates use at 1,000 hours per year. Pump discharge is 800 gpm. Pumping lift and pressure requirements are 300 feet of total dynamic head.

Step 1: Estimate WHP Requirements

WHP = GPM x TDH/3,960 =

800 x 300/3,960 = 60.6 WHP

Step 2: Calculate Yearly Energy Bills

$$\text{WHP / NPC} \times \frac{\text{Hours of use}}{\text{yr}} \times \text{Energy Cost} = \text{Yearly Fuel Bill}$$

Electricity:

60.6 WHP÷0.885 WHP/HR÷KWH
x 1,000 hr/yr
x \$0.06/KWH = \$4,108/yr

Diesel:

60.6 ÷ 12.5 x 1,000 x \$0.80 = \$3,788/yr
Estimated Cost Difference =

\$ 4,108	Electricity
- 3,788	Diesel
\$ 320/yr	Advantage to diesel

Step 3: Investment Costs Estimation

Find the investment cost of the most expensive system minus the least expensive:

Electricity 15,000 + 3,500 =	\$18,500
Diesel	20,000
Difference	\$-1,500

Disadvantage to diesel

Use Table 5 to find a capital recovery factor (CRF) for the return period and interest rate.

CRF for 5 years 12 percent = .2774
Annual Cost for Extra Investment
1,500 (0.2774) = \$416

Step 4: Annualized Cost Comparison

Combine the annualized energy use and investment cost into one term. Be certain to add or subtract as appropriate.

Energy Comparison plus annualized
Cost Comparison
$320 + (-416) = -$96
Diesel advantage to electricity
or $96 Diesel disadvantage compared to electricity

Conclusion

Although the annual operating cost of diesel would be less, the 5-year outlook would favor electricity. Two other factors favoring electricity are convenience of operation and oil and tune-up costs of the diesel engine. Also remote operation is more feasible with electricity.

Irrigated agriculture is energy intensive, which also means it requires large capital investments for energy and related equipment. The above example illustrates a simple procedure for making a comparison of energy sources. It does not include all factors. Some factors can be examined on an economic basis. Others require judgement or personal preference to be used. Factors requiring consideration include:

1. The initial purchase price of the power unit and the associated items such as drive mechanism, fuel storage tanks, pipelines, and bringing in electrical service.
2. The expected useful life of the items in number 1.
3. Repair and maintenance costs.
4. Labor requirements to operate and maintain the system.
5. Dealer service reliability and availability.
6. Repair parts availability.
7. Future availability of the energy source.
8. Convenience of operation and automation.

Table 1: Nebraska Performance Criteria for Pumping Plants

Fuel	Pump Output
Electricity	0.885 whp-hr/kWh
Natural Gas (925 BTU/cf)	61.7 whp-hr/MCF
Natural Gas (1,000 BTU/cf)	66.7 whp-hr/MCF
Diesel	12.50 whp-hr/gal
Propane	6.89 whp.hr/gal

Table 2: Cost Equivalent Fuel Multiplier Table

Electricity	1	0.0143	0.0133	0.071	0.128
Natural Gas (925 BTU/cf)	69.72	1	0.925	4.94	8.96
Natural Gas (1,000 BTU/c\f)	75.37	1.08	1	5.34	9.68
Diesel	14.12	0.203	0.187	1	1.81
Propane	7.79	0.112	0.103	0.551	1

Table 3: Typical Cost Comparison

Electricity	***0.08***	0.05	0.05	0.06	0.08
Natural Gas (925 BTU)	5.58	***3.50***	3.5	3.95	5.38
Natural Gas (1,000 BTU)	6.03	3.78	***3.78***	4.27	5.81
Diesel	1.13	0.71	0.71	**0.80**	1.09
Propane	0.62	0.39	0.39	0.44	***0.6***

Table 4: Pumping Fuel Use Required for Lifitn 1 acre-foot of water 1 foot in height

Fuel Type	**Fuel Unit**	**Fuel Units /ac-ft/ft**
Electricity	KWH	1.551
Natural Gas (925 BTU/cf)	mcf	0.0223
Natural Gas (1,000 BTU/cf)	mcf	0.0206
Diesel	gal	0.1098
Propane	gal	0.1993

Table 5. Selected Capital Recovery Factors

Length of Loan or Length of Useful Life	Annual Interest Rate (%)				
Years	5	7	10	12	15
2	0.5378	0.5531	0.5712	0.5917	0.6151
5	0.231	0.2439	0.2638	0.2774	0.2983
7	0.1728	0.1856	0.2054	0.2191	0.2404
10	0.1295	0.1924	0.1627	0.177	0.1993
15	0.0963	0.1098	0.1315	0.1468	0.171