PUMPING PLANT EFFICIENCY, FUEL OPTIONS AND COSTS

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Energy costs have a major impact on production costs in agriculture. Irrigated agricultural has additional energy sensitivity due to the cost of pumping irrigation water. As pumping energy costs increase, irrigators have been exploring energy options. While changing energy sources can sometimes be economical option, it can require large up-front investment costs with little guarantee that the alternative energy source will remain cost competitive. Before changing energy sources, irrigators should evaluate the performance of their current pumping plants, as wear and changes in pumping conditions over time can cause substantial loss in pumping plant efficiency. This results in the increased use of fuel for the same or less amount of water pumped.

The irrigation fuel or energy bill is composed of two parts. The first is related to pumping plant performance and the second is related to crop irrigation management.

Total fuel bill = Pumping cost/Unit Volume of Water x Volume Applied

The pumping cost per unit volume of water depends on well efficiency, pumping plant efficiency and fuel cost. The major influences on the total volume applied are related to management issues, such as irrigation schedule for the crop selected and the irrigation system efficiency. Reducing the total volume applied reduces the fuel bill proportionately, so if the amount of water applied is minimized with good irrigation scheduling and high application efficiency, the fuel bill will be minimized based on pumping volume. Good irrigation management practices and high system efficiency are the subject of other presentations. The focus of this discussion will be on the pumping cost per unit volume of water.

Pumping Cost Per Water Volume

The major factors that influence the pumping cost per volume are: pumping plant efficiency and TDH (total dynamic head), which is the total hydraulic resistance against which the pump must operate. Well efficiency is also a factor, but it is largely determined by design and construction factors that were used during the drilling and development processes. Many wells would produce a greater flow with less drawdown if the screen, gravel pack and development procedure had been better designed, but little can be done to improve the efficiency of a poorly constructed well. Many wells would also benefit from treatments to remove incrustations on well screens or treatments to control biological growths that can also clog well screens. If the water's entry into the well through the screen is restricted, more drawdown is needed to produce a given flow.

Performance evaluations indicate that many irrigation pumping plants use more fuel than necessary as compared to a properly sized, adjusted and maintained pumping plant. For example, a 1990 study in Kansas (Table 1 and Table 2), found pumping plants performance ratings ranging from 15 to 120 percent of the Nebraska performance Criteria (NPC). Irrigation pumping energy requirements can be estimated using the NPC shown in Table 3. The NPC is a guideline for a performance of a properly designed and maintained pumping plant. Some pumping plants will exceed this criteria, but most will not.

In that study, the average pumping plant used about 30 percent more fuel than necessary. Obviously, some are much worse and others actually exceeded the NPC. Causes of excessive fuel use include:

1. Poor pump selection. Pumps are designed for a particular discharge, head and speed. If used outside a fairly narrow range in head, discharge and speed, the efficiency is apt to suffer. Some pumps were poor choices for the original condition, but changing conditions such as lower water levels or changes in pressure also cause pumps to operate inefficiently.
2. Pumps out of adjustment. Pumps need adjustment from time to time to compensate for wear.
3. Worn-out pumps. Pumps also wear out with time and must be replaced.
4. Improperly sized engines or motors. Power plants must be matched to the pump for efficient operation. Engine or motor loads and speed are both important to obtain high efficiency.
5. Engines in need of maintenance and/or repair.
6. Improperly matched gear heads. Gear head pump drives must fit the load and speed requirements of the pump and engine.

Pumping plant performance evaluations can be obtained by hiring a consulting firm or contractor to take the measurements, but many farmers are reluctant to spend money to find out if something is wrong. Energy costs, however, can represent a significant portion of the production cost for a crop. The following procedure can help an irrigator analyze irrigation fuel or energy bills to see if they are reasonable for the pumping conditions and price of fuel.

If this estimate indicates low pumping plant efficiency, then hiring a firm to repair or replace the pumping plant may be justified. The irrigator needs to know 1) acres irrigated, 2) discharge rate, 3) total dynamic head, 4) total application depth, 5) total fuel bill, and 6) fuel prince/unit in order to make such an estimate.

The following procedure is outlined in the K-State Research and Extension Bulletin L-885, “Evaluating Pumping Plant Efficiency Using On-farm Fuel Bills”. The procedure is also available as a computer software program, FuelCost, available via the web at www.ozent/ksu.edu/mil. The procedure uses the NPC as the basis for the fuel use estimate.

Step 1: Determine Water Horsepower
Water horsepower (WHP) is the amount of work done on the water and is calculated by
WHP = TDH (GPM)/3960
where:
GPM - discharge rate in gallons per minute
TDH = total dynamic head (in feet) = Pumping Lift (ft) + Pressure (psi) x 2.31
TDH is usually estimated by adding total pumping lift and pressure at the pump. Since pressure is usually measured in PSI, convert PSI to feet by multiplying PSI x 2.31 (see conversions in Table 4).

Step 2: Calculate hours of pumping
H_R = D (Ac) / (GPM/450)
where:
H_R = Hours of pumping
D = Depth of applied irrigation water (inches)
Ac = Acres irrigated
GPM = discharge rate in gallons/minutes
450 = a conversion constant (see Table 4)

Step 3: Estimate hourly NPC fuel use
FU = WHP/NPC
where:
FU = Hourly fuel use using the Nebraska criteria
WHP = Water Horsepower from Step 1
NPC = Nebraska Performance Criteria (Table 3)

Step 4: Estimate seasonal NPC fuel cost
SFC = FU x H_R x Cost
Where:
SFC = Seasonal Fuel Cost if the pumping plant was operating at NPC
H_R = Hours of operation from Step 2
Cost = $/Fuel Unit

Step 5: Determine excess fuel cost
EFC = AFC - SFC
where:
EFC = Excess Fuel Cost (in dollars)
AFC = Actual Fuel Cost (in dollars)
SFC = Estimated Seasonal Fuel Cost using NPC (in dollars)

Step 6: Calculate annualized repair cost
ARP = INVEST X CRF
where:
ARP = Annualized Repair Cost
INVEST = Investment required to repair or upgrade pumping plant
CRF = Capital Recovery Factor (Table 5)

The excess fuel cost may be thought of as the annual payment to cover the cost of a pumping plant upgrade or repair. Repair costs can be annualized by using capital recovery factors (CRF). If the annualized repair cost for the interest rate and return period selected is less than the excess fuel cost, the investment in repair is merited.

This procedure is an indicator of your total pumping plant performance. It does not indicate the source of the excessive fuel use, but pumping plant tests in Kansas have generally shown that poor performance is generally due to the pump. The low efficiency may be due to excessive pump clearance, worn impellers, or changes in pumping conditions since the pump was installed.

Figure 1 provides an example farm problem. The example farm results in an annualized repair cost of $3811 and an excess fuel bill of $4014. Since $3811 is less than $4014, the investment in repair of the pumping plant would be merited. The excess fuel use could be divided by the CRF (example $4014/.3811 = $10,533) to indicate the amount you could afford to spend in upgrading the pumping plant.

Figure 1: Example Farm Problem

Acreage:	130 acres
Pumping Life:	330 feet
System Pressure:	22 psi
System Discharge Rate:	600 gpm
Total Irrigation Application:	16.5 inches per acre
Fuel Type: Natural Gas	Price $9.00 per MCF
Total Fuel Bill:	$16500

Step 1: Determine Water Horsepower
WHP = TDH x (GPM)/3960
= (300 + 22 x 2.31) x (600)/3960
= 53.2 WHP

Step 2: Calculate Hours of Pumping
HR = D(Ac)/GPM/450
= (16.5) (130)/(600/450)
= 1609 hrs.

Step 3: Estimate Hourly NPC Fuel Use
FU = WHP/NPC
= 53/61.7
= 0.86 MCF/Hr

Step 4: Estimate Seasonal NPC Fuel Cost
SFC = FU x Hr x Cost
= 0.86 x 1609 x 9
= 12486

Step 5: Determine Excess Fuel Cost
EFC = AFC-SFC
= 16500 - 12486
= 4014

Step 6: Calculate Annualized Repair Cost
Estimate of pump repair: $10,000
Desired CRF using 3 years and 7% interest
from Table 3: CRF = 0.3811
ARC = INVEST x CRF
= 10,000 (0.3811)
= $3811

The water horsepower equation, shown in Step 1, establishes that the power needed to lift water is proportional to the amount and the total head requirement. Reducing either will reduce water horsepower requirement and therefore reduce fuel use. However, each pumping plant, if properly designed, will operate most efficiently at a given head-discharge relationship. Once installed, changes in head on discharge requirements could result in a loss of pumping efficiency. K-State Research and Extension Bulletin L-886, “Reading Pump and Engine Performance Curves”, is available in hard copy at your county Extension office or via the web at www.oznet.ksu.edu/mil, will provide additional information on this subject.

Irrigation Energy Source Options

Natural gas has been the dominate energy source for irrigation in Kansas as historically it was readily available and relatively inexpensive in much of the major irrigated areas. This unfortunately may no longer be true and irrigators have been examining other energy source options, which are primarily diesel, propane, and electricity.

The Nebraska Performance Criteria can also be used to compare these major energy sources, assuming the pumping plants are performing at 100 percent NPC. K-State Research and Extension Bulletin MF-2360 discusses this procedure, but energy cost comparisons can also be made using FuelCost, or FuelCost on-line at www.ozent.ksu.edu/mil. Cost equivalent fuel multipliers can be developed using NPC values as shown in Table 6. Cost comparisons of for some fuel prices are shown in Table 7. For example, the equivalent fuel cost of electricity, given $8/MCF natural gas is $0.11/KW (8 x 0.0143). These comparisons are based on the unit energy content of the energy sources and do not include other costs associated with the convenience of operation, maintenance, or additional costs such as minimum service charges or peak electric demand charges.

Summary

Irrigation pumping costs increase in proportion to energy prices but some of the pumping cost may be due to poor pumping plant performance. An estimation of the pumping plant performance may be possible using on-farm records, which could help an irrigator to decide on the best course of action for future irrigated crops. Bulletins and computer software on pumping plant energy are available through K-State Research and Extension.

Information Sources

Rogers, D.H. and R.D. Black. 1993. *Evaluating Pumping Plant Efficiency Using On-Farm Fuel Bills.* Kansas State University Research and Extension Bulletin L-895. Manhattan, KS.

Rogers, D.H. and M. Alam. 1999. *Comparing Irrigation Energy Costs*. Kansas State University Research and Extension Bulletin MF-2360. Manhattan, KS.

Rogers, D.H. and W. M. Sothers. 1993. *Reading Pump and Engine Performance Curves*. Kansas State University Research and Extension Bulletin L-886. Manhattan, KS.

Rogers, D.H., F.R. Lamm, M. Alam, and G.M. Powell. 2003. *Shock Chlorination Treatment for Irrigation Wells*. Kansas State University Research and Extension Bulletin MF-2589. Manhattan, KS.

FuelCost software program to estimate pumping plant efficiency and compare energy source. Available for download at www.oznet.ksu.edu/mil

References

MacFarlane, P.A., D.O. Whittemore, M.A. Townsend, J.H. Doveton, V.J. Hamilton, W.G. Coyle III, A. Wade, G. L. MacPherson, and R.D. Black. 1990. The Dakota Aquifer Program: Annual Report, FY 89. Kansas Geological Survey Open-file Report 90-27. Lawrence, KS.

Table 1. Summary of Well and Pumping Plant Performance Testing Data from the Dakota Aquifers Program, (MacFalane, P.A., et.al., 1990)

Area	Static Level Ft.	Dynamic Level Ft.	Well Yield Gpm	NPC Rating %
Southwest	240 (70-330)	277 (160-430)	774 (170-1230)	85 (40-120)
West Central	109 (30-330)	142 (40-280)	668 (400-1050)	81 (30-115)
North Central	49 (25-100)	98 (40-155)	432 (275-860)	61 (15-110)

Table 2. Summary of Pumping Plant Performance Evaluation by Energy Source from the Dakota Aquifer Program (MacFarlane, P.A., et.al., 1990)

Quartile average						
		Ave	1st	2nd	3rd	4th
Energy	No.	%	%	%	%	%
Natural Gas	32	85.5	112.1	96.1	80.3	53.4
Electric	18	77.4	107.3	87.0	69.9	45.4
Diesel	17	69.9	97.8	81.2	66.4	34.2
Propane	4	47.3	—	—	—	—

71 total - Weighted average 77.3%

Table 3. Nebraska Performance Criteria for Pumping Plants

Energy Source	**WHP-HRS per Unit or Fuel**
Diesel	12.50 per gallon
Propane	6.89 per gallon
Natural Gas	61.7 per MCF
Electricity	0.885 per KWH (kilowatt-hour)

Table 4. Useful Irrigation Conversions

1 psi (pounds per square inch) = 2.31 feet of head

1 acre-inch/hour = 450 gallons/minute

Table 5. Selected Capital Recovery Factors (CRF)

Length of Load or Length of Useful Life Years	Annual Interest Rate (%) 5	7	10	12	15
2	.5378	.5531	.5712	.5917	.6151
3	.3672	.3811	.4021	.4163	.4380
4	.2820	.2820	.3155	.3292	.3503
5	.2310	.2310	.2638	.2774	.2983
7	.1728	.1728	.2054	.2191	.2404
10	.1295	.1295	.1627	.1770	.1993
15	.0963	.0963	.1315	.14	.1710

Table 6: Cost Equivalent Fuel Multiplier Table

Electricity	1	0.0143	0.071	0.128
Natural Gas (925 btu/cf)	69.72	1	4.94	8.96
Diesel	14.12	0.203	1	1.81
Propane	7.79	0.112	0.551	1

Table 7: Typical Cost Comparison

Electricity ($/KW)	0.08	0.11	0.14	0.23
Natural Gas ($/mcf)	5.58	8.00	9.88	16.13
Diesel ($/gal)	1.13	1.62	2.00	3.26
Propane ($/gal)	0.62	0.90	1.10	1.80