INVESTIGATION OF FACTORS AFFECTING ENERGY FOR IRRIGATION PUMPING

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ABSTRACT

Nineteen irrigation pumping plants from five counties in Oklahoma were tested for their efficiency of operation. Most were powered with natural gas while a few operated on electricity. Average pump efficiency was found to be about 62 percent. Newly installed pumps should operate at an efficiency near 70 percent. Average engine efficiency was found to be about 20 percent. Average overall efficiency was found to be about 13.9 percent, while an efficiency of 15 percent or higher is desirable. Higher efficiencies can be achieved by exercising more care in the design of pumping plant installations. For existing systems, higher efficiencies can be achieved with careful maintenance and proper operation.

An ongoing program of the type conducted under this project would give Oklahoma's irrigation farmers the means required for determing the conditions at which their pumping plants operate most efficiently.

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INTRODUCTION

In Oklahoma, energy for irrigation accounts for 27 percent of all energy used on the farm, excluding fertilizers. Considering that only 7 percent of the cultivated land in the state is irrigated, one can see why the rising cost of fuel is of such great concern to the state's irrigation farmers. Dwindling supply and escallating cost of fuel along with falling groundwater levels are being experienced by a large number of irrigation farmers in Oklahoma. In the years ahead, marginal pumping operations may find the economic dividing line shifting against them, and heavy investments in distribution systems may become economically unsound operations (1).

Energy and U.S. Agriculture (2) lists Oklahoma irrigation energy use at 8,705 billion BTU'S per year. Using the fuel distribution from this report and current fuel prices, the calculated fuel cost for irrigation in Oklahoma is approximately 20.5 million dollars per year. The primary fuel used is natural gas. A 1979 survey of Oklahoma irrigation (3) lists the total number of irrigation wells as 6,733. Of the total acres irrigated with groundwater, 65 percent use natural gas for pumping. Therefore, emphasis was placed on pumping plants fueled with natural gas. Of the total acres irrigated by groundwater, over 54 percent are located in the three panhandle counties of Oklahoma, where most of the tests were conducted.

Irrigation pumping plants were tested for their efficiency of operation. The engine and pump efficiencies were measured separately in order to better locate the source of inefficiency. According to Abernathy and Cook (4), natural gas engines should be 20 to 24 percent efficient, pumps should be 60 to 70 percent efficient. The overall efficiency of pumping plants in good condition should be 15 percent or higher.

METHODS

Research conducted under this project consisted of measuring the pumping efficiency of a number of irrigation pumping plants. The variables measured at the well site consisted of fuel consumption of the power plant, torque and rotational speed of the shaft driving the pump, quantity of water being pumped, pumping lift and system operating pressure. From this data, we calculated the fuel efficiency at the power plant, the pumping efficiency of the pump, the combined or overall efficiency of the pumping plant, and the fuel use per acre-foot of water pumped.

The research was conducted with the assistance of OSU County Extension Offices, who helped in locating pumping installations and arranging with cooperators for performing the tests.

Fuel consumption was measured using a differential pressure measuring device. The Annubar unit was installed in the gas line between the gas company's meter and the carburetor using flexible hoses. An assortment of hoses and pipe fittings were required because of the variation between the different installations. The Annubar unit measured the velocity head and the static pressure of the gas flowing in the line. This pressure differential was displayed on a portable pressure meter to which the Annubar was connected. The pressure measurements, displayed in inches of water, were then converted to flow in cubic feet per hour using a flow conversion chart provided by the meter manufacturer. The fuel consumption data and the heating value of the gas were used to calculate the fuel horsepower going into the engine with the following equation:

$$\text{HP (fuel)} = \frac{\text{fuel consumption (MCF)} \times 990{,}000 \text{ (BTU/MCF)}}{2545 \text{ (BTU/HP)}}$$

For vertical hollow shaft electric-driven pumps, there is no provision for measuring the power delivered to the pump from the motor. Electric motor efficiencies range from about 85 to 92 percent and vary little over the life of the motor. To determine fuel use of electric-powered systems, the voltage and amperage in the power line to the motor was measured. From these quantities, a value of horsepower was calculated with the following equation:

$$\text{HP (elec.)} = \frac{\text{Voltage} \times \text{Amperage}}{745.7\ \frac{\text{Watts}}{\text{Horsepower}}}$$

The use of a torque measuring device enabled the horsepower developed by the engine to be determined. This being the same power delivered to the pump allowed the engine and pump efficiencies to be evaluated separately. Torque measurement was accomplished by installing a torque sensor in the drive shaft between the engine and pump. By checking with irrigation equipment dealers in the state, we found the most commonly used drive shaft sizes to be the series 41 and series 56 shafts, 36 inches in length. These shafts were purchased and modified to accomodate the torque meter. The drive shafts have little adaptability to various lengths; and therefore, many installations could not be tested. The torque meter also incorporated an RPM measuring unit. The RPM was usually verified using either an engine tachometer or a handheld tachometer at the pump gear head. When measuring RPM at the gearhead, the gearhead ratio was used to compute the shaft RPM. Using the shaft rotational speed and the torque measurement, engine horsepower was computed using the following equation:

$$\text{HP (engine)} = \frac{\text{Torque(inch-pounds)} \times \text{Speed(RPM)}}{63024}$$

The quantity of water being pumped was measured using one of two types of flow meters. On open discharge systems, a standard 10" flow meter was used.

The meter was connected to the irrigation pipe or to a hydrant using hose clamps and a flexible canvas sleeve. In pressure systems, an Annubar flow sensor was used. All of the high pressure installations tested were center-pivot systems. The sprinkler head nearest the pivot was removed and replaced with the Annubar unit. The pressure differential measured by the flow sensor was displayed on the meter in inches of water. This reading was converted to GPM with a conversion chart developed from calibration tests conducted in the laboratory. A pressure guage was installed in the high pressure systems.

Pumping lift was determined using an electric well sounding device. Much care had to be used with this procedure since the probe had to be lowered into the well on a cable. Knowing the pumping rate and the head against which it is pumped, the following equation was used to calculate water horsepower:

$$HP(water) = \frac{Q(gpm) \times TDH(ft)}{3960}$$

At several installations, we found the pump base to be sealed, thus having no place for the depth sounding probe to enter the well casing. Several times the probe became lodged down in the well. The cable apparently spiralled around the pump column or the probe caught between the pump column and well casing. A few probes were lost and in one instance 100 feet of cable was left in the well. In no case did the presence of equipment in the well interfere with the operation of the pump.

Once all of the separate horsepowers were determined, it was possible to determine the operational efficiency of the plant. The engine efficiency was calculated as the ratio of engine horsepower to fuel horsepower. Pump efficiency is the ratio of water horsepower to engine horsepower. And overall efficiency is the ratio of water horsepower to fuel horsepower.

RESULTS

The results of the research are tabulated in the Appendix of this report. Data have been reported by the county in which the pumping plants are located. The data include pumping lift, quantity of water being pumped, fuel horsepower, engine horsepower, water horsepower, engine efficiency, pump efficiency, overall efficiency, fuel consumption, and fuel use in BTU per acre-foot of water pumped. The power plants were classified according to the type of fuel used, and the pumps were classified as either free discharge or sprinkler. All of the sprinkler type systems tested were center-pivots. Most of the pivots operated with a system pressure in the range of 50 to 65 psi, while a few had been converted to low pressure and operated at around 35 psi. All of the free discharge pumps fed furrow irrigation systems distributed with gated pipe.

Nineteen pumping plants were tested in five Oklahoma counties. These counties are Beaver, Caddo, Cimarron, Kingfisher, and Texas. Most of the wells were located in areas of relatively high pumping lift. In parts of the state where water tables are higher, such as Kingfisher county, many of the pump bases are sealed for increased efficiency and provide no means for entering the well to measure lift. The average pump efficiency for all of the pumps tested was slightly over 62 percent. The lowest efficiency for a pump was 27.9 percent while the highest was 80 percent for a new installation. Only 3 pumps were found to have an efficiency less than 60 percent.

If the pumps tested are representative of all those in the state, it appears that Oklahoma's irrigation pumps are in fairly good condition. The cause of low efficiency on one pump tested was found to be a loss of water due to leaks in the underground distribution system. The apparently low efficiency was misleading, because the inefficiency was not due to poor pump performance; but due to the reduced quantity of water measured at the flow meter. Repairs to the system will significantly increase the efficiency without increased fuel use.

Average efficiency of all the natural gas engines tested was found to be about 20 percent. The best energy efficiency was 28 percent and the lowest was 4.6 percent with most falling in the range of 18 to 22 percent. There appears to be a potential for raising the efficiencies of the engines to a somewhat higher level. Some engines tested were in need of major repairs, while the efficiencies of most could be raised a few percent by minor adjustments and proper maintenance. Overall efficiencies of the pumping plants powered with natural gas averaged about 13.9 percent, while the average for electrically powered pumping plants was 63.6 percent.

The high efficiency of the electric installations is due to the inherently high energy conversion efficiency of electric motors. Efficiencies normally found with electric motors range from about 85 to 92 percent. Due to the current price of electrical energy in relation to natural gas, gas is still the more economical fuel for pumping irrigation water. Fuel use in BTU per acre-foot of water pumped was averaged for the natural gas engines and was found to be 8.219×10^6. The highest being 18.106×10^6 and the lowest being 3.199×10^6. The electrically powered pumping plants ranged from 1.049×10^6 BTU per acre-foot to 3.103×10^6 BTU per acre-foot with an average fuel use of 2.017×10^6 BTU per acre-foot. All were located in areas with similar pumping lift.

No repairs were made to any engines or pumps tested throughout the duration of the project, so no tests could be repeated to determine increased performance.

CONCLUSIONS

Most of the irrigation pumps tested under this project were found to be operating at fairly high levels of efficiency. The average overall pumping efficiency of 13.9 percent could however be increased through better engineered pumping installations. A more careful matching of engines to pumps and pumps to well conditions would, in the long term help reduce irrigation energy use. In the short term, a rigorous maintenance program along with a careful match of engine speed to optimum pump speed could help irrigation farmers reduce their fuel bills.

A continuing program of the kind initiated in this project would be of great assistance to farmers in determining the conditions at which their pumping plants operate at an optimum efficiency.

RELEVANT LITERATURE

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DATA FROM EFFICIENCY TESTS

(Pumping Plants Powered with Electricity)

Location County	Pump Lift (Ft)	Q (GPM)	H.P. Fuel	H.P. Water	Eff. % *Pump	Eff. % Overall	Fuel Use (BTU/Ac-Ft)x10^{-6}
Beaver	192	435	33	21.1	70.4	63.3	1.049
Caddo	200	784	105	68.0	71.7	64.5	3.103
Caddo	193	480	66	41.6	70.0	63.0	1.900
Averages	195	566	68	43.6	70.7	63.6	2.017

* Pump efficiencies were determined using the measured overall efficiency and an assumed motor efficiency of 90 percent.

DATA FROM EFFICIENCY TESTS

(Pumping Plants Powered with Natural Gas)

Location County	Pumping Lift (ft)	Q (GPM)	H.P. Fuel	H.P. Engine	H.P. Water	Eff. % Engine	Eff. % Pump	Eff. % Overall	Fuel Consumption (MCF/hr)	Fuel Use (BTU/Ac-Ft)x10^{-6}
Beaver	223	710	381	92.4	55.8	24.2	60.3	14.6	0.98	7.421
Cimarron	190	812	473	87.3	60.3	18.5	69.0	12.8	1.22	8.056
"	190	925	459	(*)	71.4	(*)	(*)	15.5	1.18	6.868
"	190	710	405	(*)	52.7	(*)	(*)	13.0	1.04	7.886
Kingfisher	57	690	157	44.5	36.2	28.0	80.0	22.4	0.41	3.199
"	(**)	860	649	29.8	(**)	4.6	(**)	(**)	1.67	10.449
"	(**)	892	545	43.9	(**)	8.1	(**)	(**)	1.40	8.450
Texas	218	1110	760	175.0	85.2	21.3	48.9	10.4	1.95	9.469
"	280	825	389	99.0	58.3	25.5	58.9	15.0	0.99	6.461
"	327	725	463	84.6	59.9	18.2	70.8	12.9	1.18	8.763
"	316	822	497	94.2	65.6	19.0	69.6	13.2	1.27	8.286
"	330	795	489	105.8	66.3	21.7	62.6	13.6	1.24	8.425
"	322	270	353	78.7	22.0	22.3	27.9	6.2	0.91	18.106
"	227	790	368	75.3	45.3	20.5	60.1	12.3	0.94	6.379
"	348	513	280	62.9	45.1	22.5	71.7	16.1	0.72	7.556
"	269	870	363	90.4	59.1	24.9	65.3	16.3	0.93	5.724
Averages	249	770	439	83.1	55.9	20.0	62.1	13.9	1.13	8.219

* Missing values due to malfunction of torque sensing device.

** Missing values due to inability to measure pumping lift.