2,000 hours per year, with a basic interest rate of 10 percent The following example explains the use of the nomograph for comparing relative fuel costs. Assume an irrigation well is to be equipped with a power unit delivering 100 horsepower after derating, and the well will be pumped 2,000 hours per year. Natural gas is available at $5.00 per Mcf.

What is the total power cost? To solve, enter the nomograph on the vertical line labeled "Natural Gas" and go to the point marked $5.00. Next, locate the pivot point (+) at the right center of the figure. Using a straight edge, draw a line from the point indicating $5.00/Mcf through the "pivot point" to the vertical line, "Total Cost" and read $0.059/ HP-hr (note dashed line).

For the 100 HP engine, the total power cost for natural gas would be:

$0.059/HP-hr X 100 HP = $5.90/hr

$5.90/hr. x 2,000 hr./yr. = $11,800.00/yr.

The nomograph can also be used to determine fuel prices that give comparable total power cost. To do this, locate the unit price of the particular fuel and draw a straight line through this unit price and the pivot point extending across all scales. Now prices for other fuels can be estimated. For example: What prices for L.P. gas, diesel, and electricity are competitive with natural gas at $6.50/Mcf? Note that L.P. gas at $0.61 per gallon, diesel at $1.16/gallon, and electricity at $0.088/kWh are all competitive with natural gas at $6.50 per 1,000 cubic feet.

Adjusting Data to Your Situation

The data shown on the nomograph are based on certain assumptions. To estimate more specific power costs, substitute specific information into the appropriate equations from the cost categories section and calculate the cost for a particular situation.

Fuel consumption rates can vary considerably between different makes of engines, as well as between different models of the same make. There is very little variation in energy consumption between brands of electric motors so long as motor type, size, and loading are the same. Most engine manufacturers publish fuel consumption data on their line of engines. The gear ratio used in right-angle gear heads should be chosen so that the pump can operate at its rated speed while keeping the engine operating speed at the point where its fuel consumption is most efficient. If a specific fuel consumption curve is not available for your engine, a good rule-of-thumb is that most economic fuel consumption occurs at the speed where the engine produces its maximum torque. Fuel efficiency tests are usually performed on "bare" engines (no accessories) with the engine tuned for peak performance. Under field conditions, the fuel consumption rate will be greater; however, the relative ranking of engines should not change much. With all other considerations (price, power output, durability, availability of service, and repairs) being comparable, selecting the engine with the lowest fuel consumption rate can reduce total power costs for irrigation pumping.

Considerations other than Fuel

Fuel selection should not be based on price alone. Also consider the following: Is the fuel available in the area? Is the supply dependable? Is the price relatively stable? Also, are trained mechanics available for working on power units equipped for the specific fuel? Answering "no" to anyone of these questions could indicate that another fuel may be more desirable.

Power Unit Performance

Theoretically, a new diesel engine may have a performance efficiency as high as 32 percent in converting the chemical energy of its fuel into mechanical energy. Natural gas and L. P. gas engines may have efficiencies as high as 28 percent, and gasoline engines as high as 27 percent. As engines age, these performance efficiencies can be reduced significantly by component wear and poor tuning. It is advisable to keep records of hours of operation, fuel use, and water applied in order to evaluate how the performance of your pumping plant has changed with time. These records may detect abnormally high fuel consumption and poor efficiency. If a problem is indicated by the fuel use records, testing can be done to determine if the drop in efficiency is due to the engine or the pump. Appropriate corrective measures, such as a tune-up or overhaul, can then be taken.

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Comparative Energy Costs for Irrigation Pumping

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One major cost of pumping irrigation water is the cost of energy. Increasing energy prices require irrigation farmers to consider future availability as well as price when comparing energy alternatives.

Derating Power Units

Making power cost comparisons between different makes and models of engines and/or between different fuel options is desirable. By expressing power costs in terms of cost per horsepower-hour (HP-hr), it is possible to make a quick, reliable comparison. Calculations should be based on derated horsepower (HP) and not on the manufacturers advertised maximum horsepower. Derating considers the differences between field operating conditions and the manufacturer's testing conditions, which can affect engine performance.

To derate an engine, start with the maximum rated brake horsepower (BHP) for the specific speed at which the engine will be operated and make the following deductions:

1. Deduct 20 percent for continuous load.
2. Deduct 3 percent for each 1,000 feet of elevation above sea level.
3. Deduct 1 percent for each 10°F rise of ambient air temperature above 60°F.
4. Deduct 5 percent for accessories (generator, air cleaner, heat exchanger, etc.).
5. Deduct 5 percent if a fan and radiator are used.
6. Deduct 3 percent if a right angle drive is used.

Some manufacturers rate their engines for continuous operation. In these cases, the deduction for continuous operation has already been made.

For natural gas powered engines a good rule-of-thumb to calculate a rough estimate of an engine's derated continuous horsepower output can be given by:

$$HP = \frac{\text{Displacement (cu. in.) X Engine Speed (RPM)}}{10{,}000}$$

As a rule, electric motors do not need to be derated from the horsepower indicated on the nameplate because most manufacturers base this rating on 70°F air temperatures and a 10 to 15 percent overload factor. This is a built-in service factor to compensate for varying temperature and voltage conditions. If pump power requirements fall between motor sizes, select the larger size motor. For example, if the power required is 32 HP, choose a 40 HP motor rather than 30 HP.

Useful Life

Since power costs are to be calculated in terms of cost per HP-hr or kwh, it is necessary to establish the hours of useful power plant life. Operator skill, preventive maintenance, and operating conditions greatly affect how long a power unit will remain useful.

Exact data are not available on expected irrigation engine life. Conferences with service managers at irrigation engine repair shops indicate that with proper maintenance, periodic overhaul, and operation until no longer economically repairable, the following power unit useful life can be expected:

Automotive engines - 20,000 hours
Light industrial engines - 30,000 hours.
Electric motors - 75,000 hours or 25 years (whichever occurs first).

Initial Costs

The typical initial purchase cost per horsepower derated for average Oklahoma conditions is approximately as follows:

Natural Gas and LP Gas Engines (with Gear head):
Automotive: $75 per derated horsepower.
Light industrial: $180 per derated horsepower.
Diesel Engines (with Gear head):
Light industrial: $160 per derated horsepower.
3-Phase Electric Motors (with Motor Starter):
Vertical Hollow-shaft: $90 per nameplate HP.
Solid Shaft: $80 per nameplate HP.

Cost Categories

There are four major categories involved in calculating total power unit costs. These are:

1. Depreciation
2. Repairs and maintenance
3. Taxes and insurance
4. Fuel

An economic comparison of power costs must include all four of these categories.

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Depreciation

Assuming the power unit is used for its entire useful life at a rate of 2,000 hours per year and has no trade-in value, a capital recovery factor (CRF) can be used to determine the annual cost of ownership for the prevailing interest rate. For a 5 percent interest rate, the CRF is 0.1628 for natural gas, LP gas and diesel engines (based on a 10-year engine life), and 0.1278 for electric motors (based on a 16-year engine life). The annual depreciation cost is:

$$\text{Depreciation, (\$/HP-hr)} = \frac{\text{CRF X ini. cost (\$/HP)}}{\text{Hours of use/year}}$$

Repair and Maintenance

The annual cost of repairs and maintenance (R&M) for irrigation power units can vary considerably, depending on the operating conditions, operator skill, and hours of operation. An accepted practice in estimating these costs is to use a percentage of the initial cost of the unit as the annual cost. The percentage used depends upon the type of power unit. For all internal combustion engines, a typical repair and maintenance factor (RMF) is 6 percent per year. For electric motors, the maintenance factor typically is 2 percent of initial cost per year. Annual maintenance and repair cost is:

$$\text{R\&M, (\$/HP-hr.)} = \frac{\text{RMF\% X initial cost (\$/HP)}}{\text{100\% X Hours of use/year}}$$

Taxes and Insurance

Taxes and insurance (T&I) will vary with time and the depreciated value of the power unit. Typically they will cost about 1.5 percent of the initial cost of the unit. Therefore, the annual tax and insurance cost is:

$$\text{T\&I, (\$/HP-hr.)} = \frac{\text{1.5\% X initial cost (\$/HP)}}{\text{100\% X Hours of use/year}}$$

Fuel Costs

Based on data taken from manufacturer's performance tests and Nebraska Tractor Tests, typical performance efficiencies of 30 percent for diesel engines, and 26 percent for LP gas engines should be expected for irrigation engines in Oklahoma conditions. Peak efficiencies may range higher or lower than this, but these are reasonable figures for engines that are tuned regularly. At these performance levels, diesel engines should develop about 16.49 HP-hr of energy per gallon of fuel, while LP gas engines should deliver about 9.39 HP-hr per gallon.

Manufacturer's performance data for natural gas engines have been confirmed by a number of efficiency tests in Oklahoma. A typical engine efficiency should be about 26 percent. This means a typical engine should deliver 102 HP-hr per 1,000 cubic feet of natural gas (gas energy content assumed to be 1,000 BTU per cubic foot).

Experience has shown that lubricant and filter costs will be about 15 percent of the fuel cost. Fuel, lubricant, and filter costs in terms of cost per horsepower-hour are:

$$\text{Fuel, (\$/HP-hr)} = \frac{\text{1.15 X diesel price (\$/gallon)}}{16.49}$$

$$\text{Fuel, (\$/HP-hr)} = \frac{\text{1.15 X LP gas price (\$/gallon)}}{9.39}$$

$$\text{Fuel, (\$/HP-hr)} = \frac{\text{1.15 X natural gas price (\$/1000 cu. ft.)}}{102}$$

These fuel costs do not include either the fuel storage tank costs in the case of LP gas and diesel, or the cost of piping natural gas to the engine.

Electric power schedules are nearly always based on an annual standby charge and a schedule of rates for energy consumed. The standby charge is based on the horsepower rating indicated on the motor nameplate or the actual measured power demand. Some power suppliers apply the money collected as standby charges against energy consumed, while other suppliers charge for all energy consumed in addition to the annual standby charges.

Large three-phase electric motors average 85 to 95 percent efficiency in converting electrical energy to mechanical energy depending upon motor size, design, and loading. Assuming 90 percent motor efficiency, electrical energy per horsepower-hour can be estimated by:

$$\text{Energy (\$/HP-hr)} = \text{(0.83 X electricity (\$/kWh))}$$

These energy costs do not include any power line construction costs and assume that annual standby charges are applied against energy consumed. If standby charges are not applied to energy consumed, it is necessary to adjust power costs by dividing the standby charge by the annual hours of operation times rated motor horsepower and adding this value to cost of energy consumed.

$$\text{Stand-by (\$/HP-hr)} = \frac{\text{Stand-by charge (\$)}}{\text{Hrs of use X rated HP}}$$

Total Costs

Total power cost (TPC) is the sum of depreciation; repairs; taxes, insurance, and interest; and fuel and filter costs. Using the relationships already established, the total power cost ($/HP-hr) for a diesel engine operated 3,000 hours per year with diesel fuel costs $3.76 per gallon (according to the Energy Information Agency for 2014) would be:

$$\text{Depreciation} = \frac{0.1278 \text{ X } \$160}{3000} = \$\ 0.00682$$

$$\text{R\&M} = \frac{6\% \text{ X } \$160}{100\% \text{ x } 3000} = \$\ 0.00320$$

$$\text{T\&I} = \frac{1.5\% \text{ X } \$160}{100\% \text{ x } 3000} = \$\ 0.00080$$

$$\text{Fuel cost} = \frac{1.15 \text{ X } \$\ 3.76}{16.49} = \$\ 0.2622$$

$$\text{Total Power Cost (\$/HP-hr.) Total} = \$\ 0.2730$$

The same procedure can be followed to determine power costs for LP gas and natural gas engines, as well as electric motors. Rather than making calculations, the nomograph in Figure 1 can be used to estimate total power cost in dollars per horsepower-hour for power units operated approximately

Figure 1: Nomograph for Estimating Pumping Costs

(based on 2,000 operating hours per year)