A Field Study of Electrical & Internal Combustion Prime Movers

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The use of electricity as an energy source for pumping wells is rapidly expanding throughout the Permian Basin and is registering the greatest gains on wells producing from the depth interval of 1000 ft to 5000 ft. Many facets of electrical pumping have contributed to this increased popularity; some of the more readily recognized advantages are cleanliness, minimum maintenance by field personnel, ease and desirability of the cycling, and the possibility of higher subsurface pumping efficiencies. During the past few years the industry-wide trend to increase the number of wells serviced per pumper has created an increased demand for trouble-free operation, and electrical prime movers have answered that demand. In addition, electrical companies have recognized the oil industry as a desirable customer and have expanded their services so that electrical power has become more readily and more economically available. Because of these and other factors, oil operators have turned to electricity when replacing obsolete equipment, when expending existing lease facilities, and when making initial installations.

All these statements seems to say that electrical power is the ultimate answer to our pumping problems. However, the experienced operator realizes that such is not necessarily true. Both electrical and internal combustion prime movers have a definite place in oil well pumping, and either can be economical or uneconomical for a given set of conditions.

This electrical study covers 140 wells, scattered throughout Central West Texas and varying in depth from 400 ft to 5700 ft with the bulk pumping from 1000 ft to 4000 ft. Production ranges from sweet to sour, and production problems include paraffin, scale, and corrosion. Also daily volumes vary from 5 to 750 BPD and because of the widely scattered area and the difference in price schedules, a single rate schedule cannot be quoted as representative. The average monthly electrical cost for the 140 wells was $18.00 per month per well of which $3 to $5 represents maintenance and repair costs. As might be expected, some leases had higher repair costs than others, resulting from the presence of hydrogen sulfide, lightning, and overloaded systems.

The supply system normally consists of 7200 or 12000 volts and is reduced to a 440-volt 3-phase distribution system. However, there are some shallow wells on single-phase with a 220-volt system. All original lines are designed for a maximum voltage drop of 5 per cent at extreme wells. To prevent single-phasing, a delta bank is preferred where applicable, for in case of a ground this bank reverts to a wye-type system. The pumping wells are equipped with Class "C" motors and conventional oil field control panels, clocks and secondary lightning arrestors. For safety purposes, the electrical motor, panel and unit are grounded to the casing. No. 8 bare copper wire and 5/8-inch by 6-foot ground rods are used at pole and motor.

To evaluate electrical pumping, the cost will be separated into energy consumption charge and repair cost.

ELECTRICAL ENERGY COST

The energy consumption is either a direct charge per KWH used or KWH consumed plus a demand charge or power factor if load is a part of the billing.

The only way of reducing energy consumption is to improve pumping efficiency by time-cycling or reducing the total KW demand. Generally, both procedures can substantially reduce electrical costs. The hydraulic energy required to lift one Bbl of oil by continuous pumping or time-cycling is the same, but by time-cycling the friction caused by the rod string and unit is eliminated.

For example, Lease "A" had ten wells pumping from 2200 ft with 100 hp connected. Time-cycling was introduced; the pumping periods were staggered to reduce the demand charge; and a recording wattmeter was used to determine adequate pumping time to obtain production. Rather than ten wells pumping continuously, only four wells pumped at once, with a resulting reduction in the demand and energy consumption charge of $1800 in one year or $150 per month. Experienced were many intangible savings such as less rod, tubing, pump, and pumping unit wear; and these savings naturally extended the service life of the equipment. Also, by reducing pump-off situations, rod range load and destructive fluid or impact loads were reduced.

Time-cycling is definitely one of the advantages of electrical pumping. Caution should be observed, however, for, if in example of Lease "A", over 2 BPD from the total lease production of 110 BOPD, or 0.2 BOPD per well, are lost, then the advantage of time-cycling could also be lost. Thus, on many leases, production is lost when time-cycling is incorporated without knowledge of its particular limitations. As pumps cut-out and do not pump-off at the end of a cycle, then production is being lost, and this loss may not be readily detected until complete pump failure occurs. Therefore, if its benefits are to be fully realized, time cycling requires continual vigilance by the pumper. And periods must be increased as pumps wear or until they are serviced.

The other method of reducing energy consumption charge is by the use of capacitors to reduce line losses and improve power factors. Capacitors have been used very successfully on leases with overloaded systems allowing 25 per cent safe load above normal.

ELECTRICAL REPAIR COST

An electrical expenditure which is partially controllable is maintenance or repair cost which seems to vary from a negligible figure to 25 per cent of the total energy cost. However, after three years of evaluation on 140 wells, the average repair cost tended to stabilize at 15 per cent of the normal energy cost.

Many times engineers attempt to decide between electricity and internal combustion engines and assume that electrical equipment can be placed in service and operated without maintenance expenditure. This assumption is absolutely false. True, new leases tend to operate trouble-free with minimal repair costs, but these costs may increase depending upon service life, environment and loads, and become significant through the years regardless of adequate preventive maintenance programs.

Considering preventive maintenance to be an annual inspection program primarily to maintain an adequate safety program for the protection of personnel and secondarily to reduce electrical repairs is highly recommended. During the first year inauguration of such a program effected a repair cost reduction of $2000 on the 140 wells. And although this saving has been maintained for two years, the inspection program costs only $1 to $2 per well per year and is followed-up by the necessary remedial action.

Briefly, the annual inspection consists of a visual examination of primary and secondary distribution lines and individual checks on transformers, control panels, and motors. Particular attention is given voltage, amperage, well balance, heaters, secondary arrestors, contacts, time delay relays, motor bearings, and ground systems; these items are of vital interest and constitute the major sources of electrical equipment failures. Normally an inspection can be limited to 15 to 20 minutes per well, depending upon well density; and during the course of the inspection, an informal discussion with the pumper of the lease can be of benefit to both the inspector and the pumper. The pumper can alert the inspector to malfunctions observed in the normal operations, and the inspector can informally educate the pumper regarding proper procedures and maintenance.

Recommended are individual well sheets on which to record data, and the inspection reports shall be evaluated by supervisory personnel and the inspecting electrician. Other than cleaning dust from controls, tightening screws, and inspecting components, it is suggested that all repairs be made after reviewing the inspection sheets and summarizing the needed repairs. Thus when the electrician returns to the lease he has all components required to service without further delay each well on the lease.

Some of the normal causes which create costly repairs merit further discussion. Acts of God cannot be prevented, but should they develop into excessive expenditures, most costly equipment can be installed to retard re-occurrence. The main reason for transformer failures is lightning which causes the pot oil to break down chemically and form an emulsion that results in premature failures of the cores.

Too, birds have constantly caused electrical problems, especially in grain fields. For example, some operators have had to use rubber sleeves around the fuse disconnects to prevent short circuits. Bird nests are also troublesome at the transformer banks, and shields have been field improvised to discourage nesting.

Another problem results from the tendency to install spans of excessive length and to space too closely the primary and secondary wires so that arcing between phases occurs during dust storms. Ice loads, not common to all West Texas areas, also have caused some problems.

Generally speaking, in the West Texas area, over-extending span lengths can cause more problems that may cost more than the cost of one $30 pole with its hardware. For instance, the standard 330 ft span will eliminate down time and special service calls. Also, while a secondary distribution system is constructed, the vertical span should be at least 14 in. and preferably 16 to 18 in., between phases to combat wind conditions. The 16 to 18 in. spacing should definitely be used when stringing lines in a north-south direction because of harmonics developed by wind currents. And, it is important to remember that sagging wires and bad connections generally do not limit their failures to themselves, but single-phase one or several motors prior to blowing the fuse disconnects.

Overload transformers, the result of instantaneous starting of all motors or excessive operating loads, reduce the service life. Either additional pots are needed, or if transformers are only slightly overloaded, installation of capacitors will normally increase transformer maximum load by 25 per cent. Instantaneous loads can be eliminated by installing time-delay relays at each specific motor. Excessive loads on transformers tend to reduce voltage output and increase amperage to motors, an increase which helps shorten the prime mover's life.

The individual pumping well problems caused by motor failures generally are results of lighning, motor bearing, or over-heating. Secondary arrestors can help protect the pumping panel and motor from lightning, but care should be taken to insure that the arrestors are in service and, when destroyed, that they are promptly replaced.

Motor bearings are normally of the pre-lubricated type, and failure results from excessive side loads. This excessive load is created by improper belt tightness or as a result of high motor temperatures which prevent adequate bearing lubrication.

If a 5 hp electric motor is found to have a noisy bearing and is serviced, a normal repair cost is $37.50. The same motor, if allowed to continue to operate with rough bearings, will short circuit the rotor through the stator and burn out the motor windings. The repair cost to re-wind the motor would be a minimum of $100 to $120. And, for larger sized motors, the re-wind costs increase proportional to capital investment and definitely warrants periodical inspection and education of the pumpers.

A major problem in the control panels, not generally realized, is the use of heaters too large for the particular motor being operated; this use causes premature motor failures. The correct heater size for each motor size has been calibrated and engineered for the equipment's protection. Motors are purchased by hp, but they are actually rated by their ability to deliver power and keep the temperature rise in a predetermined range. As the load is increased above the rating, the motor cannot adequately cool itself; therefore, a mechanical breakdown occurs in the insulating material and short circuits. This breakdown might occur a week or a year after applying a constant overload, but it will drastically decrease the normal service life.

The other two main parts of a control panel are the line starter and under-voltage or time-delay relay. Both protect the motor from single-phase conditions and low starting voltages by staggering the starting sequence of all lease motors when power is returned. A large number of pumping panel troubles are caused by excessive dust accumulations and loose connections. However, both are cleaned and corrected by a lease inspection program.

High repair costs are definite signs of an inefficient electrical system and should be investigated to determine what are the reasons for their existence and what can be done to reduce this cost.

Electrical pumping is not proposed by its most enthusiastic advocates as a cure-all to replace all other methods of artificial lift, but rather it is to be utilized where it is applicable. Many benefits have been and are to be gained from correct applications, but engineers must be open-minded and approach all electrifications on a sound economic basis. The specific need and individual nature of the particular problem should be considered, and each system should be economically independent of any other. Therefore, when figuring electrical installations, one must calculate maintenance cost as well as energy cost to obtain a true perspective of this valuable tool.

GAS ENGINE MAINTENANCE COST

Prior to expansion of electrical power transmission and adequate motors, industry was required to use internal combustion engines on all methods of artificial lift, regardless of fluid quantity or depth. As electrical power became more readily available and also while natural gas was becoming a valued product, one has seen a major trend toward lifting shallow and medium depth wells by using electricity. This competition has resulted in the development in medium and deep well pumping of internal combustion engines which utilize the available hp to a much higher degree.

The following internal combustion engine study represents 80 wells pumping from 4200 ft to 8000 ft with the majority at 6000 ft to 7000 ft, at fluid rates varying from 10 BFPD to 450 BFPD. Engine types include single cylinder and multi-cylinder, and the average engine age is five years with a range of one to fourteen years. The engines are operated approximately one-half-million hr per year, and lift one-third of a million Bbl of fluid. The total maintenance cost is 3-1/2 cents per operating hr or $20 per engine per month. This cost represents $2 per 1000 hp hr with a total oil consumption of 3/4 gal per 1000 hp hr.

In making a study of engine maintenance costs, the most significant value for comparative purposes is the cost per hp-hr. Other values such as cost per hr, per barrel, and per hp can be misleading, depending upon the particular circumstances. Other factors which should be considered and evaluated include such items as age, pumping depth, load, type and quality of fuel, etc. The influence of those factors as applied to the 80 engines included in this survey will be discussed.

The age of the engines was equally divided; therefore maintenance versus age did not indicate extraordinary range of cost. However, engines with less than 1 1/2 years show approximately one-half the maintenance cost as on some of the older engines. The average hp consumed per engine was obtained after detailed study of dynamometer cards, fluid volumes lifted, depth, size pumps, type production, gas-oil and gas-fluid ratios and fluid levels. The hp consumed clearly indicated that maintenance does increase but not on a straight line relationship to hp consumption and oil used. As shown in Table I, the operation cost on a monthly or hourly basis of Engine "B" would have been high. However, considering cost per 1000 hp-hr, and oil consumption per 1000 hp-hr, this type engine is in line with smaller engines for oil well operation.

Barrels of oil produced is not a significant value, other than obtaining percentage of total fluid lifted. Barrels of fluid and cost per barrel of fluid could be used, but can be very misleading. A high-volume, high-fluid-level well would naturally have a low cost per barrel of fluid. However, one-half of the money could be spent on maintenance of an adjacent well and should it be a low-volume producer a higher cost per barrel of fluid would be obtained.

The repair cost included in this study represents any type of work other than origianl installation to the engine. Included are major overhauls, magnetos, clutch, water pumps, radiators and related items. Also, if part of the work were performed by company or contract labor the time was converted to a monetary figure. Also miscellaneous labor maintenance represents work

TABLE NO. I

SINGLE CYLINDER ENGINE MAINTENANCE DATA

	Total Ave.	A	B	C	D
Number of engines	54	20	6	26	2
Rated hp	12/45	12/18	30/45	18/33	15/26
Average age	3.03 yr	4.82 yr	4.53 yr	0.83 yr	9.26 yr
Cost/BF	0.63¢	1.450¢	0.562¢	0.343¢	3.44¢
Cost/Month	$14.65	$12.40	$31.50	$10.43	$27.70
Cost/Op hr	2.63¢	2.2¢	5.23¢	1.87¢	8.43¢
Cost/1000 hp hr	$1.59	$2.09	$1.97	$0.94	$7.03
Gals./1000 hp hr	0.628 g	0.638 g	0.783 g	0.356 g	2.167 g

TABLE NO. II

PERCENTAGE OF COST FOR SINGLE & MULTICYLINDER ENGINES

	Multi-Cylinder	Single Cylinder
Number Engines & Ave. Age	17-8 yr	54-3 yr
Pct. Used on Repairs	58.8%	40.5%
Pct. Misc. Labor	8.4%	14.5%
Pct. Oil Cost	28.1%	33.2%
Pct. Filter, Anti & Misc.	4.7%	11.8%
	100%	100%

performed in conjunction with the operation of gas engines and includes hauling of oil and water, starter repair, gas line repairs, cleaning of air filters, installation of antifreeze, oil and filter changes. Oil consumption was obtained from pumpers' reports and compared with delivery tickets. However, oil consumed represents daily additions and monthly oil changes and cannot be used as actual oil consumed in the cylinders, but it can be used for oil used in operation of this engine. It has been found that the correct lubricants can reduce repair costs by eliminating carbon deposits, increasing plug life, and considering other related items. The costs of filters, spark plugs, and antifreeze were divided proportionately to all engines and represents $18.96 per engine per year.

The cost per operating month could be a realistic value of motor maintenance for small and medium volume wells, but would be exaggerated on a cost per Bbl of fluid basis or cost per operating hr for intermittent operation. The cost per operating hr represents actual hrs each type engine ran per year, and the cost is greatly increased by time cycling. However, it can be generally summarized that intermittent operation on small producers rapidly approaches the cost of continuous operation for a similar well, because daily starting of engines is harder on magnetos, plugs, and etc. Too, there are generally more service calls, so that reduction in pumping time does not necessarily result in a proportional reduction in total operating cost.

The cost per 1000 hp hr helps compare all motors on a relatively sound engineering basis. Such is shown in Type "A", an 18 hp engine, as compared to Type "B", a 45 hp engine with costs of $2.09 and $1.97 respectively. Oil consumption is shown in gallons per 1000 hp hr and again compared Type "A" and Type "B" engines with each consuming 0.638 and 0.783 gal per 1000 hp-hr, respectively.

All costs mentioned above are of the maintenance nature. No value has been assigned to fuel which is dependent upon availability and upon whether the gas is sold or flared. To obtain a total engine operational cost, fuel cost must be calculated for the specific engine and added to the above figures.

Accessory items which have been field tested have been partially beneficial. Excellent results have been obtained by using automatic oil-level controllers; such controllers have actually reduced oil consumption. An exhaust gas-water make-up unit does an adequate job, but it requires yearly maintenance if it is to perform as intended. The water make-up units were intended not to furnish large quantities of water to compensate for leaking radiator cores or water pumps, but only to provide for normal evaporation.

On all engines it would be beneficial to incorporate a semi-annual inspection program which would consume approximately 30 minutes per engine or cost approximately $5 per well per year. The inspection would expose problems which normally develop into down time.

ENGINE REPAIRS

Some of the frequent problems occurring in engine maintenance are as follows:

1. Magneto repairs average one per engine per year with some averaging as high as once every three to four months. Magnetos should have a minimum service life of six months to a year if the correct timing and type magneto is selected. To meet the need of our industry, there are available many makes and designs of magnetos. The main cause of premature failure of magnetos is in maintaining an improper spark plug gap, an improper setting which causes high voltage on the coil, develops excessive heat and causes coil failures or oxidation which short circuit the contact points. Low-tension type magnetos tend to reduce this problem and have greatly extended the service life.

2. Two common causes of clutch failure are belts which are too tight and cause excessive side loading, and throw-out bearing assemblies which do not completely disengage. In addition, excessive clutch lubrication can cause flooding of the bearings and prevent normal cooling, and thus raise the bearing temperature and reduce the lubricant to its pour point. When this problem occurs the bearing has no lubrication and generally fails.

3. Radiator failures should be identified as the result of vibration or corrosion. However, since leaking radiators are more frequently caused by vibrations than by corrosion, improved motor supporting will enhance longer core life. On the other hand, corrosion elements are reduced in the fall of the year by draining water and installing antifreeze which has a corrosion inhibitor. And, it should be recognized that as make-up water is added additional corrosion inhibitors or surfactant chemicals will be required. This same corrosion protection will increase water pump service if electrolytes are the destructive elements.

4. Spark plugs are the most commonly used but least considered component in the selection of equipment. A spark plug is a quality piece of equipment which is designed to accomplish proper detonation. However, during operation, the spark gap will change its setting and will require continual re-gapping. Many times, rather than change a once-used plug, a new replacement is used which also has to be gapped. Proper plug selection must be considered according to heat range, loads, and type fuel for best performance, but one factor which is usually neglected is plug tightness; the recommended torque is 85 ft lb, equivalent to a 190 lb force on a 6 in. crescent wrench. Most plugs are found to be made up with 25 to 40 ft lb which are inadequate. Plugs should be adequately tightened to assure proper distance of plug and top stroke of the cylinder and, more especially, to dissipate heat from around the plug. Periodically a taper tap should be run into the plug hole to remove carbon deposits and to assure proper seating.

5. Periodical inspection of internal combustion engines will greatly reduce repair costs and extend the service life of the engines. Small items which cause inconvenience and result in down time are bad hose connections, worn electrical wiring, leaking radiators and water pumps, and worn belts. But all these can be serviced through an inspection program prior to failures while miscellaneous checks can be made on motor temperature, oil pressure, vacuums, air filter, oil baths, and magneto spark gap.

The above survey can be accomplished on a series of engines for 30 minutes per well at a cost of approximately $3 and should be performed either quarterly or semi-annually. A more detailed study could be made yearly to check the internal part of the engines and to prevent complete engine failures.

SUMMARY

Electric motors and internal combustion engines occupy a demanding area of the artificial lift program, and do excellent jobs. These prime movers fall under the rule of economics, and waste can result if biased decisions of engineers, superintendents, or foremen guide the selection of prime movers. It is not the intention nor desire of the author to favor one over the other, but to this difficult subject he wishes to encourage an approach based as much as possible upon factual data. Some of the factors which should be considered to make a realistic selection of the correct prime mover for a well or group of wells are the pumping load, polish rod hp required, company's surplus equipment, quantity of production during the producing life, and possible secondary recovery operations. In addition, the type and quality of the fuel, whether flared or sold, type of electrical power and schedule rates must also be considered. And finally, a realistic maintenance cost for each type of driver used must be anticipated.