IRRIGATION PUMPING PLANT
EFFICIENCIES AND COSTS

by

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INTRODUCTION

Irrigation has become an important factor in the crop production and stabilization of agriculture in the areas of Kansas where adequate sources of water are available. With the exception of a few stream diversion works in Kansas, pumping plants must be employed to raise the irrigation water from its source to a point from which it can be distributed over the land. The cost of pumping this water constitutes a major item in the cost of irrigated crop production. The rapid expansion of irrigation and the nature of its development have caused many questions to be raised as to the cost of pumping water.

The greatest expansion of this irrigation development has occurred since World War II and has been concentrated in the western third of Kansas, particularly in the High Plains region of southwestern Kansas. Well supplies of water from underground sources have been found adequate for irrigation throughout much of this region. The depths to the water level below the land surface vary from a few feet in the river valleys to more than 150 feet in the uplands. The cost of pumping water increases directly but not proportionately with the pumping lift. Much of the recent development in irrigation has extended into the upland areas where total pumping lifts are greater than those commonly thought to be economical a few years ago. The increase in the use of the sprinkler type irrigation system throughout the state also has increased the pumping lifts.

Many factors have undoubtedly been responsible for the practice of irrigation increasing at a rapid rate even in areas where water costs are higher. Deficiencies in rainfall and in its seasonal distribution in Kansas has necessitated the practice of irrigation for the stabilization of crop production. Even with normal rainfall, water is the limiting factor in the production of crops. Controls over other production factors are rapidly being developed to increase crop production. The maximum value from these production factors can be obtained when soil moisture is maintained near optimum with irrigation. High prices for crops and ample available capital to enter into irrigation enterprises have been other factors favorable to irrigation expansion. Developments in water distribution and other irrigation procedures have contributed to a relative reduction in the costs and labor involved in irrigation. These and other factors have increased the possible returns from irrigation.

Associated with these contributing factors to irrigation expansion have been developments in the pumping of water. Continued improvements have been made in the design and construction of pumps, drives, and power units making longer service life and higher efficiencies possible in pumping units. Sources of power for pumping plants have been developed and given wider distribution at relatively low cost. Natural gas is a notable fuel in this respect, either as a direct source of power or for the generation of electricity for power. Liquefied petroleum gas is another fuel which has come into wide use in recent years. The use of diesel engines has increased with the need for larger power units.

Factors contributing to the cost of pumping have logically been divided into those related to the operation of the pumping plant and those related to the ownership of the plant. Operating costs are those which vary almost directly with the amount of operation of the plant and include such factors as fuel or power, lubricants, attendance, and repairs. These costs are affected primarily by total pumping lift, over-all plant efficiency, and the cost of the fuel or power. Costs of ownership are those incurred when the investment is made in a pumping plant and are considered independent of the operation of the plant. These costs consist of interest on the investment, depreciation, taxes, and insurance. The costs of ownership sometimes are called fixed costs but they are not actually fixed because depreciation increases with the amount of use and the costs per unit of water pumped vary with the annual hours of operation of the plant.

Developments in pump irrigation in Kansas have called for added information on pumping costs. Pumping costs are commonly underestimated, particularly the ownership costs of new developments. The economy of expanding irrigation into areas of high pumping lifts will depend in part on accurate information as to pumping costs. Information on the field performance of pumping equipment is needed as an aid in the selection and operation of a pumping plant that will produce, for a particular set of conditions, the lowest cost for irrigation water.

PURPOSE

The purpose of the study reported in this thesis is to provide information relative to the cost of pumping water for irrigation in Kansas and to evaluate the factors which control the pumping costs at existing installations. Such information would serve as a background for recommendations that could result in more efficient and economical operation of irrigation pumping plants.

The major objectives of the investigation were:

1. To determine the volume of discharge, total lift, and specific capacity (gallons per minute per foot of drawdown) of irrigation wells in selected pump irrigation areas of the state.

2. To determine the fuel or power consumption of power plants installed in pumping units.

3. To make cost studies based on the original cost of equipment, labor and upkeep, together with the data from the other two objectives.

REVIEW OF LITERATURE

Irrigation has been practiced intermittently throughout Kansas and continuously on limited acreages in southwestern Kansas since the early history of the state. The possibilities of utilizing the ground-water supplies of southwestern Kansas for irrigation purposes have been investigated since early days. In 1909, Bark (1) stated:

> The farmers of the Arkansas Valley are fortunate in having a practically inexhaustible supply of water comparatively near the surface.

With water levels of seven to 40 feet in this valley, Marcellus (13) stated:

> Irrigation development in that part of the state depends upon the ability to bring the water to the surface, and this naturally involves a number of mechanical problems which are more or less difficult to solve.

In regard to these early investigations, the bulletin, Deep Well Pumping Plants (4), stated:

> Many tests and experiments were made by both the federal and state governments, as well as by individuals. These indicated that irrigation by pumping from the so-called underflow was feasible only in the valleys or other shallow-water districts.

This same reference further stated:

> Prior to 1936 pumping from wells had been confined primarily to the alluvial river valleys where the ground-water supplies are relatively close to the surface. There is one notable exception -- the White Woman basin in Scott county, where several thousand acres have been under irrigation from wells for many years.

The trend toward irrigating from deeper wells in Kansas began in the middle 1930's and has accelerated since that time except for the period during World War II when equipment was not available and other conditions made further development impractical.

The rapid increase in the amount of irrigated land in the state of Kansas and the use of pumping plants in this expansion have been indicated by the results of several surveys made from 1949 to 1954. Regarding the results of a survey made in 1949, Hanson and Meyers (7) stated:

> This report showed 248,067 acres of irrigated land in the state, of which 187,053 were irrigated from wells, and 61,014 from streams.

According to this same reference a 1952 tabulation made by the Division of Water Resources of the Kansas State Board of Agriculture showed a total of 332,137 acres of land under irrigation.

A Manhattan Tribune-News item (26) released by the Kansas Water Resources Fact-Finding and Research committee reported that an inventory of the agricultural uses of water showed a total of 421,096 acres under irrigation on 2,817 farms in Kansas in 1954. Wells accounted for 2,678 of the reported 3,311 existing supply sources and were depended upon for the irrigation of more than 344,000 acres. Counties with the largest irrigated acreage were centered around Finney county which had the largest reported irrigated acreage of 81,800.

Many investigations have been made regarding irrigation pumping plants and their costs. Factors in the total cost of pumping and their division into operating costs and ownership costs or fixed costs have been amply described in most publications on pumping plants (12, 14, 18, 31). The effect of lift, over-all plant efficiency, fuel or energy costs, and other items on the operating costs of a pumping plant have been demonstrated by actual field data and theoretical calculations. The relation of plant size and plant use to ownership cost have been equally well demonstrated. As a basic principle to pumping costs, Code (2) stated:

> The smallest size of plant that will yield sufficient water when operated day and night during a month of maximum demand will be the most economical from the standpoint of initial and operating cost.

From a field study of 400 irrigation pumping installations conducted by the Nebraska Agricultural Experiment Station in recent years in order to determine well and pumping costs, Hamilton and Schrunk (6) concluded that:

> Power costs and unit water costs were found to be primarily influenced by the discharge head, and the total quantity of water pumped per season. The greater the annual usage of a pumping installation, the less influence fixed costs have upon total cost and the more important operating costs become.

Fuel or power costs vary almost directly with the pumping head or lift. For any particular set of pumping conditions, fuel or power consumption and costs are directly proportional to the over-all efficiency of the pumping plant, that is, the combined efficiency of pump, power unit, and drive. For comparative efficiency, unit fuel consumption per acre-foot per foot of lift as well as efficiency in percent have been commonly used. In 1943, Rowher (20) reported:

> Tests indicate that well-designed, efficient, modern pumping plants using the different types of fuel require about 35 cubic feet of natural gas, one-third of a gallon of gasoline, one-fourth of a gallon of distillate, one-seventh of a gallon of diesel fuel, or 1.7 kilowatt-hours of electrical energy to lift one acre-foot one foot.

Field investigations have shown that a wide variation in efficiencies exists in pumping plants. In 1938, Wood (30) stated:

> That there is a great lack of uniformity in design and operation in pumping plants at present is evidenced by a survey of costs, made in the Platte Valley some years ago, which showed some outfits with operating costs as low as 2.9 cents per acre-foot per foot of lift, while others averaged over 15 cents.

Data given by McCall and Davison (14) from investigations in 1938 and 1939 of deep-well pumping plants in southwestern Kansas showed wide variations in pumping plant efficiencies. At the 10 natural gas plants tested McCall and Davison (14), p. 9, found:

> The unit energy consumptions ranged from 24.8 cubic feet of gas per acre-foot per foot of lift to 65.4 cubic feet. Omitting the plant using 65.4 cubic feet of gas, - - - the range was from 24.8 to 38.4 cubic feet. The average, without including the same plant, was 31.1 cubic feet.

At the 13 plants tested driven by gasoline engines McCall and Davison (14), p. 10, reported:

> Considering the single-well plants only, the unit energy consumption varied from 0.20 gallons of gasoline per acre-foot per foot of lift to 0.56 gallons. Omitting the plant using 0.56 gallons, - - - the range was from 0.20 to 0.41 gallons, with an average of 0.31 gallons.

At the 20 electrically driven plants McCall and Davison (14), p. 12 found:

> The unit energy consumptions for these plants varied from 1.55 kilowatt hours per acre-foot of lift to 2.48 kilowatt hours. The average for the group was 1.88 kilowatt hours. - - - The tests indicate a considerable variance between the energy consumptions at even the newest installations.

From tests made in 1951 on 20 natural gas and 20 electric pumping plants in Arizona, Rehnberg (18), p. 15-16, found:

> Efficiency of the natural gas-operated units ranged from 5.7 percent to 14.6 percent. - - - An increase in efficiency from 10.4 percent (the average of all gas-operated wells) to 12.7 percent (the average of the seven most efficient wells) decreased the cost per acre-foot of water by one-fifth.
>
> The efficiency of the electric units varied from 30 percent to 61 percent. - - - An increase in efficiency from 46 percent (the average of all 20 electrically-operated wells) to 54 percent (the average of the seven most efficient electrically-operated wells) decreased the cost per acre-foot by about one-fourth.

Regarding the studies in Nebraska, Hamilton, and Schrunk (6), p. 248, stated:

> The selection of the pump and power unit best fitted for the prevailing conditions, and the efficient operation of the equipment was found in this study to be very important. Results show that over-all efficiencies vary from 32 to 68 percent. This variation was attributed primarily to mismatching the pump to the well, or to the motor, or both. Total power costs are directly proportional to the plant efficiencies.

Wood (30) stated:

> It is evident that, unless careful design is used, power costs will be excessive in many cases due to mismatching of motor and pump.

Regarding the effect of well yield on the pumping plant efficiency, the bulletin, Irrigation Pumping Plants (9) stated:

> A variation of a few hundred gallons per minute may cause a marked decrease in the efficiency of the pump and power unit. The proper selection of a pump and power unit especially designed for the well is therefore very important.

Over-all efficiency of a pumping plant will normally be reduced with age of the plant due to wear and other factors. After analyzing 19 pumping installations in an area of California where pump duty and wear are very sever, Lamb (10) concluded:

> Pump wear, occasioned by prolonged field operation, was evidenced by pump discharge and pump efficiency decreasing almost in direct proportion.

Separation of the pump efficiency and power unit efficiency from the over-all efficiency has not been made by actual tests at existing pumping plants by any known investigator. To do so would require the measurement of the brake horsepower delivered by the power unit while pumping and no technique for measuring this has been employed.

Other factors contributing to operating costs of a pumping plant (usually listed as lubrication, attendance, and repairs) have not been as fully investigated at existing installations as have power or fuel costs. These are rather elusive factors that are subject to many variations from plant to plant and can be determined with a degree of accuracy only if complete records are available for a period of years.

Records of the costs at an average of 176 pumping plants were obtained on the High Plains of Texas for the three year period, 1947-49. Magee, and others, (12) found that power costs made up 88 percent of the average operating costs at electric plants. Power and repair costs made up 98 percent of the average operating costs at these plants. At plants using automobile engines rated at more than 100 horsepower and using the different fuels; butane costs made up about 70 percent of the total average operating cost, gasoline costs were 76 percent of all operating costs, and the cost for natural gas made up 56 percent of the total operating cost for these pumping plants. At plants using industrial type engines, butane costs made up about 75 percent of the total operating cost. Engine and pump repairs, and oil for the engine were the other major items in the operating cost.

Complete records were obtained on costs of pumping for 20 natural gas and 20 electric pumping plants in Pinal county, Arizona for the year, 1951. Rehnberg (18), p. 3, summarized the costs from these records as follows:

> The operating cost per acre-foot of water ranged from about $4.50 at 150 foot lift to $9.50 for a 300 foot lift for the electric wells. - - - For natural gas wells, a comparison of lifts of 150 to 300 feet showed an increase in operating costs from $3.25 to $5.25.
>
> Power constituted the largest item of cash expense in pumping water for irrigation. The average 1951 total power bill for electrically-operated pumps was $3,623. This was 73 percent of the cash costs and 45 percent of the total cost of operating such pumps. The average 1951 total power bill for gas-operated wells was $2,178. This

> was 49 percent of the cash costs and 23 percent of the total cost of operating such pumps.
>
> Next to power, repairs were the largest item of expense, averaging $1,058 per year for electrically-operated wells and $1,225 for natural gas-operated wells.
>
> Lubricants amounted to $40 per year for electrically-operated wells and $370 per year for gas-operated wells.
>
> Attendance, that is, maintenance labor, was negligible for electrically-operated wells but averaged $193 for gas-operated installations.

As fuel costs make up the major portion of the operating expense, the operating cost advantage of one source of energy over another will be primarily dependent upon the relative prices of the energy sources in a particular area.

The ownership or fixed costs of pumping irrigation water have been calculated from investments made in existing installations by many investigators. Depreciation of the equipment, interest on the investment, taxes and insurance have been commonly regarded as costs which are largely determined when the pumping plant is installed and can be returned only through the value of the water pumped. Therefore, these ownership costs per unit of water pumped vary directly with the annual use made of the plant.

In the bulletin, Irrigation Pumping Plants, (9) it is stated:

> Irrigation water is used every year in those western Kansas counties where irrigation is practiced, and a pumping plant can be run almost the year around under a well-planned cropping program. Larger investments are therefore justified in order to get pumping plants that will give satisfactory service under continuous operation.

Depreciation of the pumping equipment has been most commonly calculated by the straight-line method which assumes that the decline in value of the installation was the same during each year of its useful or service life. Except in special cases, depreciation schedules commonly used ranged from 20 to 25 years for wells, from 10 to 15 years for pumps, from 20 to 25 years for electric motors, and from five to 15 years for internal combustion engines. Depreciation makes up the largest percentage of the ownership cost. Therefore, the difference in the service life of equipment estimated by the various investigators has caused varied results in the fixed costs found.

The interest charged on the average investment or depreciated value has most commonly been five or six percent. When equipment is depreciated by the straight-line method, the average investment is equal to one-half the initial cost.

Taxes and insurance have generally been found to be a small item in the total cost of pumping.

The total unit pumping costs have been found to be primarily affected by the factors which cause variations in ownership costs and operating costs. Regarding the variation in total costs per acre-foot of $5.65 to $17.10 for natural gas-operated plants and of $5.76 to $22.30 for electrically-operated plants, Rehnberg (18) concluded:

> Three factors were found to be closely associated with these variations. In order of importance they were the total distance that the water was lifted, the efficiency of the pumping unit, and the number of hours the unit was operated during the year.

Magee, and others (12) found:

> The cost per acre-foot of irrigation water was greatly affected by the yield of the well. High pumping costs were associated with low-yielding wells regardless of the type of power or the kind of fuel used.

In Deep Well Pumping Plants (4) it is stated:

> A review of the unit costs for the various plants shows, however, that the cost of the plant could be as much as 50 percent above or below the average of 3.8 cents per gallon per minute per foot of lift for all plants studied. The high unit-cost figures are usually found at those plants where the discharge is low and the lift is great or where the well has been put down a considerable distance below the normal water level. The low figures occur generally when the discharge is high and the lift small.

Improvements in pumping equipment and changing prices have caused a general reduction in the cost of pumping water. From a study of the cost of operation of a group of pumping plants in Colorado during 1929 and 1930, Code (2) showed that the average total annual cost of operation, including fixed charges, was 15 cents per acre-foot per foot of lift for electric motor-driven plants and 20 cents for engine-driven plants. Code (3) showed that water can be pumped at an annual cost of less than five cents per acre-foot per foot of lift from complete records on two well-designed plants in Colorado, one electric motor-driven and one diesel-driven.

With natural gas rates graduated from 30 cents to 23 cents per 1,000 cubic feet and charges for electricity at one cent per kilowatt hour, Rehnberg (18), p. 3, found:

> The total cost of an acre-foot of water pumped during 1951 in Pinal County varied from about $7.50 for a 150 foot lift to $16.50 for 300 feet for electric wells. - - -

> For the natural gas wells the cost per acre-foot varied from about $6 at 150 feet to $12.75 at 300 feet.
>
> The cost advantage of natural gas over electric wells was much less at the shallower lifts. At the deeper lifts, the cost advantage of gas over electricity increased. This relationship was a result of the high initial installation cost for a natural gas unit coupled with a steeply graduated natural gas cost-rate.

From the studies in Texas, Magee, and others (12) concluded:

> The lowest average cost per acre-foot of water pumped was for units operated with natural gas. Units operated with electricity had the second lowest cost. During this study, butane was cheaper for pumping water than gasoline.

The results of other cost analysis studies indicate that the comparative economy of one source of energy over another is closely tied to the relative costs of the different fuels and electricity. These relative costs per unit of energy vary widely from area to area and from year to year.

METHOD AND PROCEDURE

Selection

To accomplish the purpose of this study, an irrigation pumping plant testing program was set up for measuring the factors related to plant operation and for obtaining cost data at existing installations. The installations with the greater pumping lifts were of particular interest as there is less information available and the problems of pumping cost are greater for these installations. However, to obtain comparative data, pumping plants of varying lifts would have to be included in the study. It was also desired to obtain data on pumping installations using gasoline, diesel fuel, liquefied petroleum gas, natural gas, and electricity as a source of power in order that a comparison of the costs involved could be made.

After contacting county agricultural agents, representatives of the Water Resources Division of the Kansas State Board of Agriculture and the State Geological Survey of Kansas as a preliminary investigation of the areas where testing would be feasible, eight counties in southwestern Kansas were selected in which to make the study. A survey card was sent out to a list of known irrigators in these counties. The list was compiled from information received from the Agricultural Economics department of the college and county agents. Of the 400 cards sent out, over 140 were returned giving the general information requested on the well and pumping plant and an indication of the interest in cooperating with the testing program. From the information on the cards returned, the plants were grouped according to their age, total lift, and fuel used. Plants were then selected for tests that would be representative of these groupings, giving particular attention to those for which a test was specifically requested and those recommended by county agents.

Tests could not be made on all of the plants selected due to unfavorable weather conditions during the periods chosen to make tests in 1950 and 1951. Because of the abundant precipitation, some of the selected plants could not be reached by car or could not be operated because of the lack of a way to dispose of the water pumped during the test. Other plants that were accessible and could be operated were substituted for those selected to the extent that weather conditions made tests themselves possible. But, in general, a good distribution of tests were obtained in the groupings made that would represent a cross section of the plants in use in the area.

Performance Tests

The major field measurements required at each pumping installation for this study were the discharge of the pump, static and pumping water levels in the well, and the fuel or power consumption of the power unit. Other pertinent measurements such as the speed of the pump were also checked.

As tests were to be made at existing installations with varied setups, portability and flexibility, in addition to field accuracy, were considered in the selection of the measuring devices used. The devices selected proved to be easily transported and installed for measurements, and were adaptable to the varied setups encountered. The measuring devices were constructed or purchased and calibrated by Richard A. Schleusener, a former instructor in the department of Agricultural Engineering.

Pump Discharge. To measure the discharge of the pumps, three different water measuring devices were carried in order to have an adaptable device for the various pump discharge set-ups. The devices used were sharp-edged circular orifices, Hoff current meter, and pitot tube.

Orifices of 3, 4, 5, 6, and 8 inch diameters were machined from eighth inch brass plate and a holding plate and clamp constructed to hold the orifice plates over the end of discharge pipes. To measure the head on the orifice in use, a hole was tapped on the horizontal centerline of the discharge pipe 24 inches from the orifice into which was inserted a one-eighth inch pipe fitting with rubber hose connection to a glass sight tube. This permitted viewing of the water level and measurement of the height of the water column above the center of the orifice. Each orifice plate was calibrated against a standard water measuring device in the hydraulics laboratory of Kansas State College. Typical test set-ups of orifice plates are shown in Plate I.

An orifice plate was used to measure the pump discharge whenever possible. For those discharge pipes whose ends were embedded in concrete or otherwise obstructed at the end to the orifice holding clamp, a Hoff current meter was used to measure the discharge. The area of the discharge pipe was traversed with a four-bladed propeller on the meter to measure the mean velocity of the water. The procedure followed is that recommended by Rowher (22). The relationship between the propeller revolutions per second and the velocity of the water was obtained from the rated calibration made on this meter by the hydraulics laboratory of the National Bureau of Standards.

When the end of the discharge pipe was submerged or connected to a sprinkler or pressure line, a pitot tube was inserted either horizontally or vertically into the pipe to measure the discharge. The tube itself was connected through hoses to a manometer on which the velocity head could be read directly. A traverse of the pipe was made, taking velocity readings at radial distances of the radius times the $\sqrt{.10}$, $\sqrt{.30}$, $\sqrt{.50}$, $\sqrt{.70}$, and $\sqrt{.90}$ on both sides of the centerline of the pipe, to obtain the observed mean velocity of the water. The true mean velocity was then obtained from calibrations made at the hydraulics laboratory of the college. This device was also constructed at the college according to the recommendations of Russell (24), p. 241.

Whenever possible, two of the water measuring devices were used at each test to serve as a check on the results. The maximum variation in the results recorded by two different devices was five percent, but more commonly ranged from zero to two percent.

Water Levels. To measure the water levels in the wells, a two wire electric line device powered by four flashlight batteries was constructed. When the two prongs on the end of the electric wire touched the water, the electrical circuit was completed showing a rheostat controlled deflection on a galvanometer. One prong was shielded by a perforated rubber tube to prevent contact being made between the two prongs except when immersed in water.

EXPLANATION OF PLATE I

Fig. 1. The orifice plate connection to the pump discharge pipe used to measure the discharge of an electric pumping plant.

Fig. 2. The orifice plate connection on a natural gas pumping plant.

Fig. 3. The fuel measurement set-up of test container, scale and two-way valve in the fuel line at an L-P gas pumping plant.

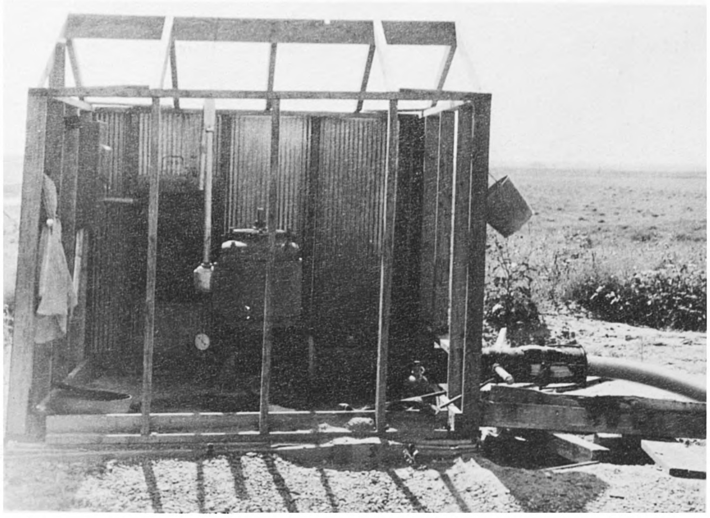

Fig. 1

Fig. 2

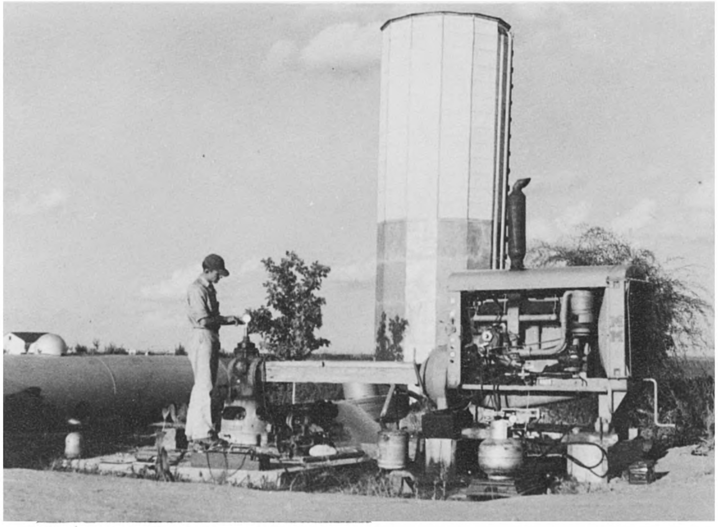

Fig. 3

Very satisfactory results were obtained with the line and only a few wells offered obstructions to the lowering of the device into the well. At several wells, an air line was installed with the pump. These were used to measure water levels when they blocked the opening into the well for the electric line.

Power or Fuel Consumption. A fuel weighing method was used to measure the consumption of diesel fuel, gasoline, and liquefied petroleum gas. A two-way valve was placed in the fuel line so that fuel could be drawn from the normal supply tank or a test container. The normal supply tank was used for the fuel supply until a consumption test was desired. For a test, the valve was turned to draw fuel from the test container for an interval of three to six minutes measured with a stop watch. At the end of the test interval, the valve was turned to draw fuel from the supply tank, thus leaving the unit in continuous operation. By weighing the test container on a scale (graduated to read to 0.01 of a pound) before and after the test, the weight of fuel consumed in a given time was measured. A typical test set-up is shown in Plate I. Hydrometers were used to obtain the A.P.I. gravity of the liquid fuels and a pressure gauge was used to measure the vapor pressure of L-P gas. With this information and the temperature of the fuel, it was possible to determine the heat content of the fuel and its weight per gallon by using various tables and standards

(11, 17, 19, and 27). With this information the fuel consumption measured in weight per unit of time could be converted to gallons per hour and the unit fuel consumption or over-all efficiency calculated using the other data obtained.

The watt-hour meter of electrical pumping plants was used to measure the power consumption by timing a definite number of revolutions of the meter disk with a stop watch. The speed of the disk being directly proportional to the power used, the results could be converted to the kilowatt-hours consumed per hour.

The natural gas meters were similarly read to obtain the cubic feet consumed per hour at natural gas plants. Variation in the pressures at which the natural gas was supplied probably caused some error in the meter readings. Where correction factors were applied to the meter readings by the gas suppliers, they were used in the calculation of the gas consumption.

Meter readings may not be sufficiently accurate to compute efficiency from an engineering standpoint but are satisfactory in making a cost analysis as they are the basis for the actual power costs paid.

Source of Cost Data

Data on the installation cost of the well and all equipment associated with the pumping plant were obtained from the owner or operator at each pumping installation tested. These costs were usually obtained from actual records, although a breakdown of the costs for each separate item of equipment was not always available. The owners estimate of the expected service life of the equipment and the annual hours of use of the plant was also recorded.

Data on the operating costs of repairs, lubrication, and attendance were usually based on the owner's estimates as few records on these items were available. The fuel prices normally paid throughout the pumping season were obtained from the owner or operator. The rate schedules for natural gas and electricity were obtained from the supplying companies.

Data pertinent to the costs incurred and the study in general, such as the dates of installation, depth and type of well, type of drive, etc., were also recorded when available. The data sheets used in the field and the summarization sheet will be found in the appendix (project 203 forms 1 to 5).

RESULTS

Location and Classification

The data in this investigation were obtained during the summers of 1950 and 1951 at existing pumping plants located in eight southwestern Kansas counties. Tests were made on 31 pumping plants during the summer of 1950 by Richard A. Schleusener and George H. Larson, former instructor and professor, respectively, of the department of Agricultural Engineering. During the summer of 1951, 30 plants were tested by the author and other assistants. The number of plants investigated in each county were as follows: Finney, 20; Grant, 11; Gray, 1; Haskell, 8; Kearny, 4; Meade, 2; Scott, 11; and Seward, 3. In addition, one plant serving a sprinkler system in Riley county was tested.

The approximate location of the plants studied in southwestern Kansas is shown in Fig. 1. Each plant was assigned a plant number consisting of an abbreviation of the county in which located and a number assigned to the plant.

The 61 pumping plants included in the study were classified according to their age, total lift, and the fuel used as shown in Table 1. The designations of A or B for the age group and I, II, or III for the lift group are used throughout this thesis. There were only 15 plants tested that were older (B) than the dividing year of 1945 selected for the two age groups; the remaining 46 plants were installed since 1944 (A). In the lift groups selected, 17 plants had total lifts less than 75 feet (I), 26 plants had lifts between 76 and 150 feet (II), and 18 plants had lifts over 151 feet (III).

The failure to secure an even distribution of plants tested in the different groupings made was due to several factors. Unfavorable weather conditions during the periods of testing made it necessary to substitute other plants for those selected. Because of the heavy rainfall, very few of the fuel burning plants had been kept ready for operation. At other plants there were no means available for handling the water

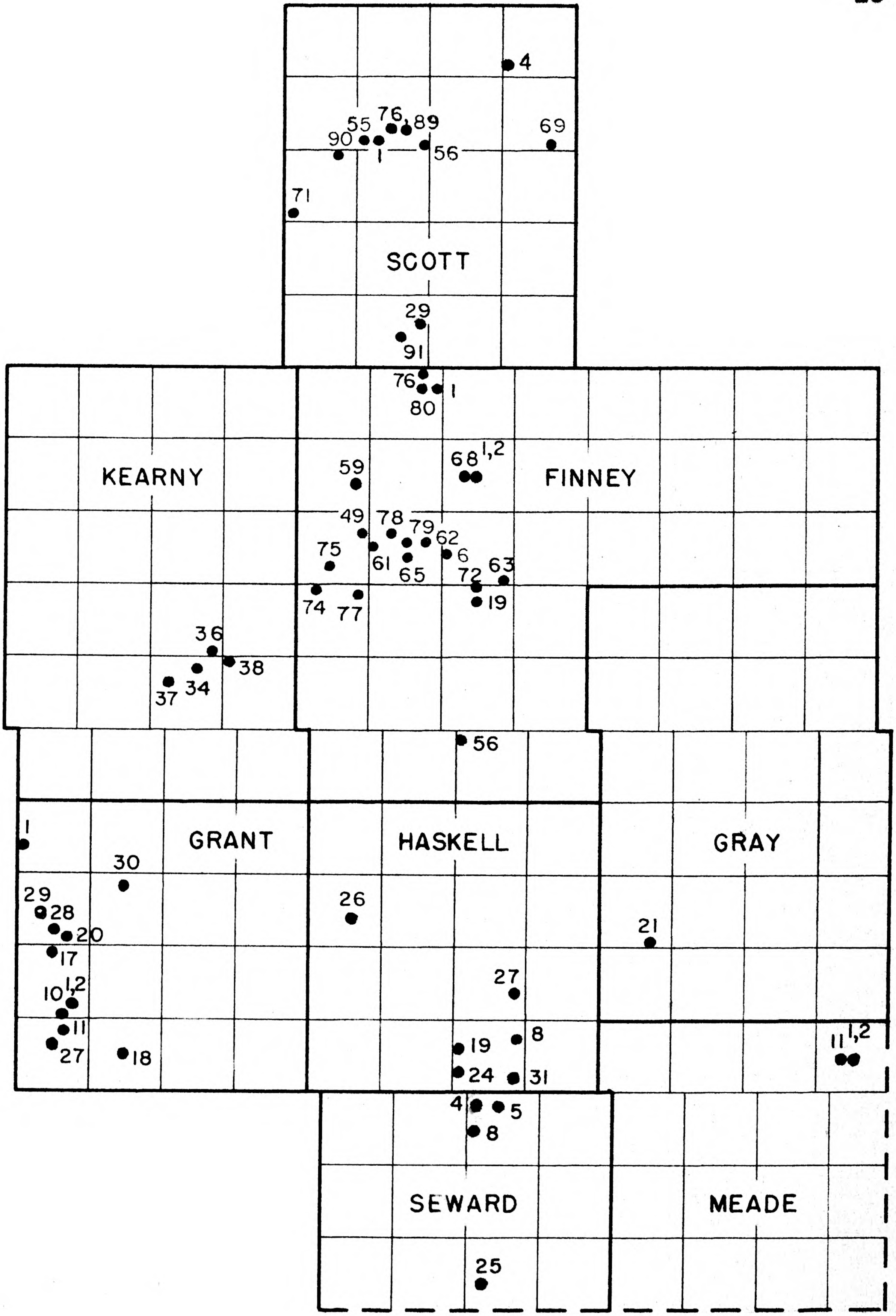

Fig. 1. Map showing the approximate location and plant number of the 60 pumping plants tested in southwestern Kansas.

Table 1. Classification of 61 pumping plants tested by age, total lift, and fuel used.

	Electric	Natural gas	Diesel	L-P gas	Gasoline
A - Installed since 1944(46 plants)					
I - Total lift: Less than 75 feet					
	Fi- 1*	Sc-29*		Fi-80*	Ke-38*
	Fi-62			Me-11#1	
	Fi-76				
	Fi-78				
	Ke-37				
II - Total lift: 76-150 feet					
	Fi-49	Sc- 1	Gt- 1	Sc-89	Sc-91
	Fi-59	Fi-56	Gt-27	Gt-11	
	Fi-61	Gt-17			
	Fi-65	Gt-18			
	Fi-68#1	Gt-28			
	Fi-68#2	Gt-30			
	Fi-74	Gy-21			
	Gt-20				
III - Total lift: Over 151 feet					
	Gt-10	Sc-55	Sc- 4	Fi-63	
		Sc-90	Sc-69	Hs-19	
		Hs-25	Hs- 8	Hs-24	
		Hs-26	Sw- 4	Hs-27	
			Sw- 8	Hs-31	
				Sw- 5	
				Rl- 1	
B - Installed before 1945(15 plants)					
I - Total lift: Less than 75 feet					
	Fi- 6			Me-11#2	
	Fi-19				
	Fi-72				
	Fi-77				
	Fi-79				
	Ke-34				
	Ke-36				
II - Total lift: 76-150 feet					
	Sc-56	Sc-76	Gt-10#2		
	Sc-71		Gt-29		
	Fi-75				
III - Total lift over 151 feet					
				Hs-10	
Totals	24	13	9	13	2

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[1] This number consists of an abbreviation for the county in which located and the number assigned to the plant.

that would be pumped during a test. Still other plants could not be reached because of road conditions. Gasoline was used as a source of power at pumping plants to a very limited extent. Three phase electric service was not widely distributed in the areas with the greater pumping lifts. Because of the high initial cost of diesel engines and the high equipment cost for L-P gas and natural gas engines, few of these sources of power were used at the shallower wells. L-P gas and natural gas were not as available, generally, prior to 1945. However, the plants tested were fairly representative of those in use under the different grouping conditions.

Well Performance

The measurements pertaining to the performance of the irrigation well that were made at each pumping plant studied are shown by counties in Table 2. These measurements were necessary in order to determine the unit fuel consumption or over-all efficiency of the pumping plants and the pumping costs. The measurements themselves, and the calculations that can be made from them, give an insight to the conditions under which irrigation water is being pumped in the southwest part of the state.

A battery of several wells connected to a single centrifugal pump was in use at five of the plants tested. The remaining 56 plants had single wells in which deep-well turbine pumps were used. The single wells were all gravel packed wells with the predominant sizes of casing being 16 or 18 inches.

Table 2. Well performance data.

Plant no.	Type^1 of plant	Depth of well (ft.)	Date well drilled	Static water level (ft.)	Draw-down (ft.)	Total^2 lift (ft.)	Pump discharge (gpm)	Water H.P.	Specific capacity (gpm/ft)
				Finney county					
				A - I					
Fi- 1	E-T	152	1948	-	-	60.9	1156	17.8	-
Fi-76	E-T2	131	1939	-	-	71.3	1206	21.7	-
Fi-80	LP-T	92*	1946	21.4	30.3	51.7	1005	13.1	33.2
Fi-78	E-T	-	1947	17.5*	32.5*	54.3*	1200	16.5	37.0
Fi-62	E-T2	302	1947	21.7	13.8*	35.5*	1960	17.6	142.0
				A - II					
Fi-74	E-T	-	1950	-	-	-	1004	-	-
Fi-65	E-T3	185	1948	44.0	50.0	99.0	776	19.4	14.7
Fi-61	E-T	333	1948	34.0	46.5	81.5	750	15.4	16.1
Fi-68#2	E-T5	145	1948	64.5	34.3	98.8	729	18.2	21.2
Fi-49	E-T	230	1948	32.0	48.0	80.0	1450	29.3	30.2
Fi-56	NG-T3	280	1946	70.0	62.0	137.5	2059	71.5	33.2
Fi-59	E-T3	205	1947	48.5	33.8	87.3	1290	28.4	38.2
Fi-68#1	E-T	-	1947	49.1	25.5	80.6	1033	21.1	40.6
				A - III					
Fi-63	LP-T2	270	1948	120.0*	40.0*	160.0*	1353	54.7	33.8
				B - I					
Fi-79	E-T4	-	1942	-	-	61.1	962	14.8	-
Fi-72	E-T2	111	1940	29.7	20.5	50.2	475	6.0	23.2
Fi-19	E-T	120	1920	38.0	15.5	54.5	633	8.7	40.8
Fi- 6	E-T2	319	1939	25.0*	20.0*	48.0*	1029	12.5	51.4
Fi-77	E-B2W	70	1943	-	-	20.0	1545	7.8	-
				B - II					
Fi-75	E-T	-	-	-	-	-	799	-	-
Average				36.2	32.1	74.0	1121	21.92	39.71
				Grant county					
				A - II					
Gt-30	NG-T	308	1949	59.5	76.5	140.0	1025	36.3	13.4
Gt-20	E-T2	-	-	61.0	21.2	84.2	755	16.1	35.6
Gt-28	NG-T	420	1949	-	30.0*	137.0	1145	39.6	38.2
Gt-18	NG-T	395	1946	125.0	21.5	146.5	866	32.1	40.3
Gt-27	D-T4	397	1948	98.0	36.0	134.0	1499	50.7	41.6
Gt-17	NG-T4	462	1950	67.0*	46.0	114.0	1935	55.7	42.1
Gt-11	LP-T4	375	1947	94.0	24.0	119.0	1072	32.3	44.7
Gt- 1	D-T2	342	1947	55.0	39.5	96.5	2000	48.7	50.6
				A - III					
Gt-10#1	E-T	385	1948	94.0	71.0	165.0	713	29.7	10.1

Table 2. (Cont'd)

Plant no.	Type[1] of plant	Depth of well (ft.)	Date well drilled	Static water level (ft.)	Draw-down (ft.)	Total[2] lift (ft.)	Pump dis-charge (gpm)	Water H.P.	Specific capacity (gpm/ft)
				Grant county					
				B - II					
Gt-10#2	D-T3	240	1941	79.0	40.0	122.0	594	18.3	14.9
Gt-29	D-T	360	1944	60.0*	30.0*	90.0*	840	24.4	15.3
Average				79.3	39.6	122.6	1131	34.9	31.53
				Gray county					
				A - II					
Gy-21	NG-T3	246	1946	70.0	17.0	88.0	1356	30.1	79.7
				Haskell county					
				A - III					
Hs-26	NG-T7	412	1950	-	-	305.0*	1228	94.5	-
Hs-31	LP-T4	346	1950	164.0	66.0	230.0	469	27.2	7.1
Hs-27	LP-T5	387	1949	185.5	79.5	270.0	867	59.1	10.9
Hs-19	LP-T5	410	1950	206.0*	59.0*	265.0*	685	45.8	11.6
Hs-25	HG-T5	-	1950	200.0*	35.0*	235.0*	870	51.6	24.8
Hs- 8	D-T6	423	1947	171.0	50.0	221.0	1314	73.5	26.3
Hs-24	LP-T4	368	1950	193.0	25.0	220.0	1915	106.5	76.7
				B - III					
Hs-10	LP-T4	200	1939	160.0	14.0	175.0	1015	44.9	72.5
Average				182.8	46.9	240.1	1045	62.9	32.84
				Kearny county					
				A - I					
Ke-37	E-B4W	65	1950	-	9.6	28.5	2598	18.7	-
Ke-38	G-B3W	34	1950	-	10.0	23.9	1735	10.5	-
				B - I					
Ke-34	E-B4W	-	-	-	-	29.0	1758	12.9	-
Ke-36	E-B2W	35	-	-	-	25.4	1325	8.5	-
				Meade county					
				A - I					
Me-11#1	LP-T3	149	1946	42.2	16.8	59.8	1273	19.2	75.8
				B - I					
Me-11#2	LP-T	200	1915	15.5	53.5	69.0	903	15.8	16.9
				Riley county					
				A - III					
Rl- 1	LP-T3	56	1947	26.0	14.0	218.0	798	44.0	57.0

Table 2. (Concl.)

Plant no.	Type[1] of plant	Depth of well (ft.)	Date well drilled	Static water level (ft.)	Draw-down (ft.)	Total[2] lift (ft.)	Pump dis-charge (gpm)	Water H.P.	Specific capacity (gpm/ft)
Scott county									
A - I									
Sc-29	NG-T2	177	1946	38.3	25.2	64.0	1380	22.3	54.7
A - II									
Sc-91	G-T2	150	1948	49.8	34.5	84.3	1220	26.0	35.4
Sc- 1	NG-T5	178	1946	99.1	21.7	126.8	836	26.8	38.5
Sc-89	LP-T4	208	1946	93.8	22.2	122.0	925	28.5	41.6
A - III									
Sc- 4	D-T5	179	1947	127.3	48.8	176.1	348	15.5	7.2
Sc-55	NG-T3	170	-	109.9	37.1	153.0	477	18.4	12.9
Sc-69	D-T3	160	1948	86.5	66.4	152.9	857	33.1	12.9
Sc-90	NG-T	172	1950	100.5	38.0	152.5	664	25.6	17.5
B - II									
Sc-71	E-T4	-	-	90.7	-	-	1059	-	-
Sc-76	NG-T3	190	1944	91.3	35.3	126.6	740	23.6	21.0
Sc-56	E-T3	140	1944	74.0	17.9	97.9	689	17.1	38.5
Average				87.4	34.7	125.6	836	23.7	28.02
Seward county									
A - III									
Sw- 5	LP-T3	358	1948	168.0	26.0	195.0	1189	58.5	45.7
Sw- 4	D-T	385	1947	177.5	8.0	186.0	846	39.8	106.0
Sw- 8	D-T4	382	1947	184.0	12.0	197.0	1517	75.4	126.0

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[1] NG = Natural gas, G = Gasoline, LP = Liquefied Petroleum gas, D = Diesel fuel, E = Electricity for type of power unit. T2 = Turbine pump with 2 stages, B3W = Battery of 3 wells (centrifugal pump).

[2] Total lift = static water level plus drawdown plus elevation of center of discharge above measuring point = distance from pumping water level to center of discharge.

[3] Specific capacity = rate of yield in gallons per minute per foot of drawdown.

Indicates some estimate involved in measurement such as the use of the air line installed with the pumping plant to measure the water levels.

A measurement of the pump discharge was obtained at each plant tested and a measurement of the total lift obtained at all but two of the plants tested. The water levels in the well were measured from the pump base. The total lift was taken as the difference in elevation between the pumping water level in the well and the center of the discharge pipe. Total lift as used in this thesis therefore, does not include the minor additional heads such as the velocity head or the friction head loss in the pump column and pipe. If the plant was not already in operation, measurements were not taken until the plant had been operated at least 30 minutes or until the pumping water level became stabilized.

The pump discharges ranged from 348 to 2598 gallons per minute and averaged 1110 gallons per minute for all plants tested. The range and average of pump discharges were very similar between counties. The total lifts at single wells ranged from 35.5 feet up to 305 feet with the greater pumping lifts being in Haskell and Seward counties. In general, the measured pump discharges were lower than what the owners thought they were or had been told they were at the time of installation. Whereas, the water levels measured were generally in agreement with the owners thinking.

From the total lift and pump discharge measurements it was possible to calculate the theoretical or water horsepower required at the pumping plant according to the formula:

$$\text{Water horsepower} = \frac{\text{discharge in g.p.m. x total lift in ft.}}{3960}$$

The water horsepower is the horsepower output of the pumping plant. The wide range of 6.0 to 106.5 for the water horsepower values is further evidence of the variation of the pumping conditions at the plants tested.

The specific capacity or the gallons per minute produced per foot of drawdown is a measure of the ability of a well to produce water. These values ranged from 7.1 to 126.0 for the wells measured. The specific capacity as well as the depth to the static water level affected the pumping lift. For a specific water-bearing formation, the primary factors which influence the specific capacity of the well are the type of well, the rate at which the well is pumped, and the depth the well penetrates into the formation. For the type of well and rates of pumping used, there is little relationship between the depth of formation tapped by the wells and the specific capacity values at the plants tested. This would indicate a wide variation in water-bearing materials throughout the area.

Fuel and Power Consumption

The power units installed at the pumping plants tested were of the same general type within the various sources of energy used. The internal combustion engines were heavy duty or industrial type power units such as those used in tractors and all but three were connected with a drive shaft to a right-angle gear drive on the pump. The other three plants used belt drives. About one-half of the power units were installed with heat exchangers for cooling the engine with well water in place of the fan and radiator. Three-phase motors direct connected to the turbine pumps were used at all electric pumping plants.

Measurements of the fuel or power consumption per unit of time were obtained at 53 of the 61 pumping plants studied. To determine comparative energy consumption values, measurements of pump discharge and total pumping lift were necessary in addition to the energy consumption per unit of time. Measurements of all three factors were obtained at 51 of the plants investigated.

The energy consumption per unit of time for a pumping plant is determined by the rate of pumping, the total pumping lift, and the over-all efficiency of the pumping plant. The rate of pumping and the total lift determine the theoretical or water horsepower required at the pumping plant. The over-all efficiency of the plant is the combined efficiency of its component parts of pump, drive, and power unit.

To compare the relative efficiencies of pumping plants having different power requirements the energy consumption of the plants tested was calculated on the basis of the units of energy per hour required per water horsepower and on the basis of the units of energy required per acre-foot of water pumped per foot of pumping lift. The over-all efficiency of the plants was also calculated by using the water horsepower as the output and the horsepower equivalent of the energy consumed as the input. The formula used for calculating the over-all plant efficiency of the electric plants was as follows:

$$\text{Plant efficiency} = \frac{\text{water H.P.} \times 0.746\ \text{Kw/H.P.}}{\text{Kw Input}} \times 100$$

For internal combustion engines the plant efficiency was calculated as:

$$\text{Plant efficiency} = \frac{\text{water H.P.} \times 2545\ \text{Btu/hr./H.P.}}{\text{Units of fuel/hr.} \times \text{Btu/Unit}} \times 100$$

The relationship between the three methods of reporting fuel or power consumption is shown in Plate II for electric plants, in Plate III for natural gas plants, and in Plate IV for L-P gas and diesel plants. The individual values and averages for the plants with turbine pumps that were tested are indicated on the relationship line.

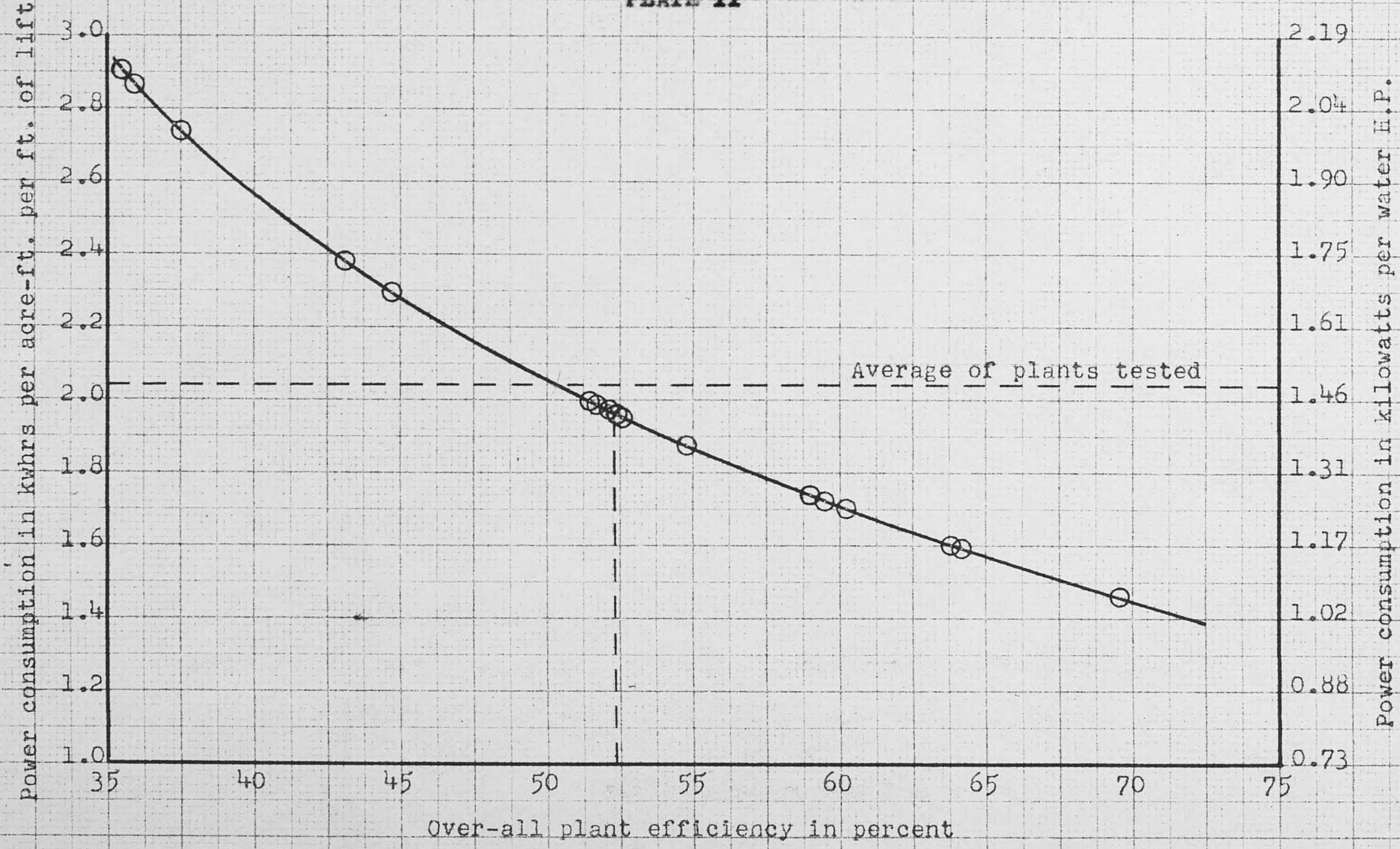
The relationship between the unit energy consumptions (units per acre-foot per foot of lift and units per hour per water horsepower) and over-all plant efficiency is such that the relationship line plots as a curve. The slope of this relationship curve points out the greater possible reduction in unit energy consumptions with the less efficient plants than with the more efficient plants. Higher efficiencies than those indicated to be obtainable by the tests would not materially reduce the energy consumption below that of the more efficient pumping plants.

The failure of the averages for the unit energy consumptions to agree at the relationship curve with the average over-all plant efficiency of the plants tested is due to the nature of their relationship in that each average was calculated from

EXPLANATION OF PLATE II

The relationship between the various units of electric power consumption and over-all plant efficiency with the values and average indicated for the 17 electric pumping plants measured.

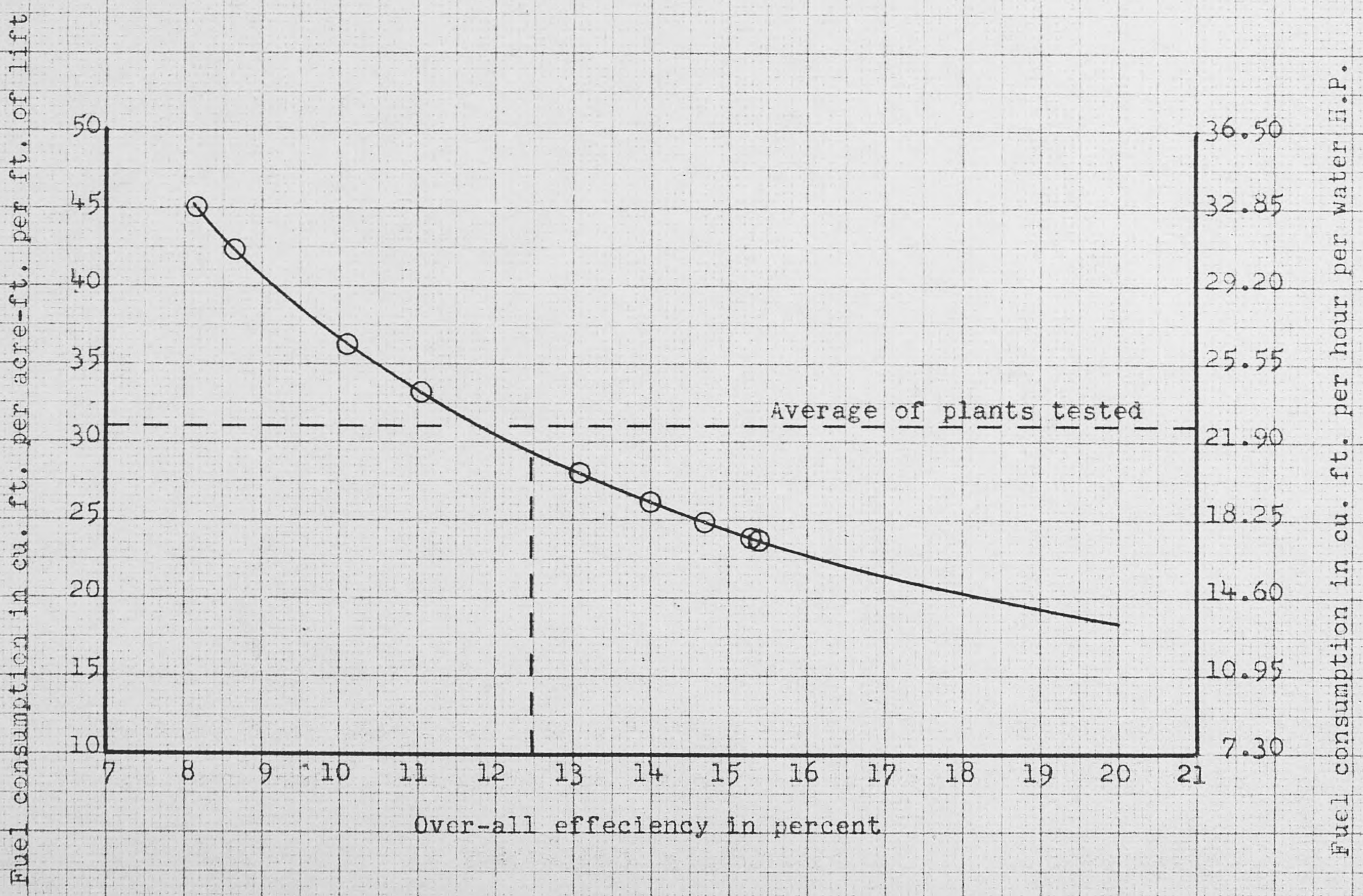
PLATE II


Power consumption in kwhrs per acre-ft. per ft. of lift
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Power consumption in kilowatts per water H.P.
2.19
2.04
1.90
1.75
1.61
1.46
1.31
1.17
1.02
0.88
0.73
Average of plants tested
35
40
45
50
55
60
65
70
75
Over-all plant efficiency in percent

EXPLANATION OF PLATE III

The relationship between the various units of natural gas consumption and over-all plant efficiency with the values and average indicated for the 10 natural gas pumping plants measured.

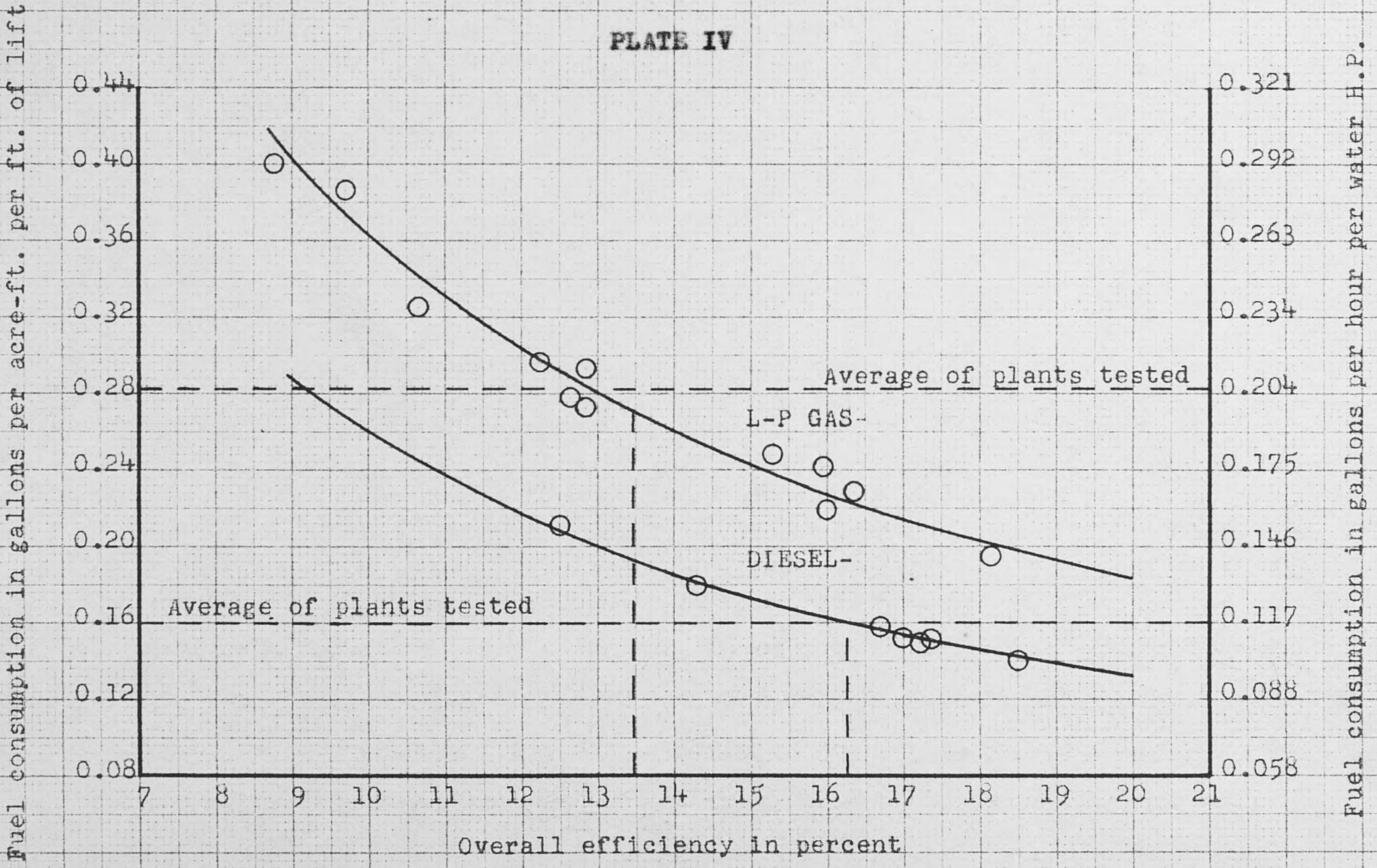
PLATE III


Fuel consumption in cu. ft. per acre-ft. per ft. of lift
50
45
40
35
30
25
20
15
10
Average of plants tested
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Over-all effeciency in percent
36.50
32.85
29.20
25.55
21.90
18.25
14.60
10.95
7.30
Fuel consumption in cu. ft. per hour per water H.P.

EXPLANATION OF PLATE IV

The relationship between the various units of L-P gas and diesel fuel consumption and over-all plant efficiency with the values and averages indicated for the 12 L-P gas and seven diesel pumping plants measured. The relationship curves are based on an average heat value of 96,500 Btu per gallon for L-P gas and 136,670 Btu per gallon for diesel fuel.

PLATE IV


Fuel consumption in gallons per acre-ft. per ft. of lift
0.44
0.40
0.36
0.32
0.28
0.24
0.20
0.16
0.12
0.08
Fuel consumption in gallons per hour per water H.P.
0.321
0.292
0.263
0.234
0.204
0.175
0.146
0.117
0.088
0.058
Average of plants tested
L-P GAS-
DIESEL-
Average of plants tested
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Overall efficiency in percent

the individual plant values. The relationship curves are based on the average heat values of the fuels used. Individual diesel and L-P gas plant values vary from the curve due to the differences in the heat value of these fuels used.

The individual results indicated in Plates II, III, and IV show that a wide variation existed in the over-all efficiencies of the plants tested regardless of the source of energy. The unit fuel or power consumption of the less efficient plant was nearly twice that of the more efficient plant except for the diesel plants which had a relatively narrower range in plant efficiencies.

The power or fuel consumption and related information are shown in Table 3 by age and lift groups for the pumping plants using the various sources of energy. The data give only a slight indication that the plant efficiencies were lower at the older plants as would be expected due to wear of the plant and to less efficient equipment being available.

Differences in plant efficiencies would not be expected to be associated with differences in pumping lifts or discharges if the pumping equipment was selected for the particular conditions at each well. Many of the measured discharges were lower than the owner's reported rated capacity of the pump when installed. The pumping plants with very low yields have relatively low plant efficiencies. These discrepancies may be attributed to wear of the pump bowls, improper adjustment of the impellers, or mismatching of the pump bowls to the well conditions.

Table 3. Power or fuel consumption.

Electric Powered Pumping Plants
(Single well, deep well turbine pump)

Plant no.	Age	Lift (ft)	Yield (gpm)	Water H.P.	Units[1] per acre-ft per ft. of lift	Units[1] per hour per water H.P.	Heat value (Btu/unit[1])	Plant eff. %
					A - I			
Fi-62	'47	35.5	1960	17.55	2.85	2.08	3412	35.9
Fi-78	'46	54.3	1200	16.50	2.37	1.73	3412	43.1
Fi- 1	'48	60.9	1156	17.75	1.99	1.45	3412	51.6
Fi-76	'48	71.3	1206	21.70	1.72	1.25	3412	59.5
Average					2.23	1.63	3412	47.5
					A - II			
Fi-68#2	'48	98.8	729	18.15	2.29	1.67	3412	44.7
Fi-61	'48	81.5	750	15.41	1.95	1.42	3412	52.5
Fi-65	'48	99.0	776	19.40	1.87	1.36	3412	54.8
Gt-20		84.2	755	16.05	1.73	1.26	3412	59.0
Fi-68#1	'47	80.6	1033	21.05	1.70	1.24	3412	60.2
Fi-49		80.0	1450	29.30	1.60	1.17	3412	63.8
Fi-59	'47	87.3	1290	28.40	1.47	1.07	3412	69.6
Average					1.80	1.31	3412	57.8
					A - III			
Gt-10	'50	165.0	713	29.70	1.96	1.43	3412	52.3
					B - I			
Fi-72	'40	50.2	475	6.03	2.89	2.10	3412	35.5
Fi-79	'42	61.0	962	14.80	2.74	2.00	3412	37.5
Fi- 6	'39	48.0	1029	12.47	1.98	1.44	3412	51.7
Fi-19	'40	54.5	633	8.71	1.95	1.42	3412	52.6
Average					2.39	1.74	3412	44.3
					B - II			
Sc-56	'44	97.9	689	17.05	1.60	1.16	3412	64.1
Grand average					2.04	1.49		52.3
(Battery of wells with centrifugal pump)								
					A - I			
Ke-37	'50	28.5	2598	18.70	2.14	1.56	3412	47.8
					B - I			
Fi-77	'41	20.0	1545	7.80	2.32	1.69	3412	44.1
Ke-36	'44	25.4	1325	8.50	2.32	1.69	3412	44.1
Ke-34	-	29.0	1758	12.90	1.98	1.44	3412	51.8
Average					2.21	1.61	3412	46.7
Grand average					2.19	1.59		46.9

Table 3. (Cont'd)

Natural Gas Powered Pumping Plants
(Single well, deep well turbine pump)

Plant no.	Age	Lift (ft)	Yield (gpm)	Water H.P.	Units[1] per acre-ft. per ft. of lift	Units[1] per hour per water H.P.	Heat value (Btu/unit[1])	Plant eff. (%)
					A - I			
Sc-29	'46	64.0	1380	22.30	26.20	19.10	950	14.00
					A - II			
Sc- 1	'46	126.8	836	26.75	36.40	26.55	950	10.10
Gy-21	'46	88.0	1356	30.10	33.30	24.30	950	11.05
Gt-17	'50	114.0	1935	55.70	28.10	20.50	950	13.10
Fi-56	'46	137.5	2059	71.50	25.00	18.25	950	14.70
Gt-30	'49	140.0	1025	36.25	24.05	17.50	950	15.30
Gt-28	'49	137.0	1145	39.60	23.95	17.45	950	15.35
Average					28.47	20.76	950	13.27
					A - III			
Sc-55	'47	153.0	477	18.40	45.10	33.00	950	8.15
Hs-26	'50	305.0	1228	94.50	26.20	19.10	950	14.00
Average					35.65	26.05	950	11.08
					B - II			
Sc-76	'44	126.6	740	23.60	42.40	31.00	950	8.65
Grand average					31.07	22.68	950	12.44

Diesel Powered Pumping Plants
(Single well, deep well turbine pump)

Plant no.	Age	Lift (ft)	Yield (gpm)	Water H.P.	Units[1] per acre-ft. per ft. of lift	Units[1] per hour per water H.P.	Heat value (Btu/unit[1])	Plant eff. (%)
					A - II			
Gt- 1	'47	96.5	2000	48.70	0.146	0.107	137,800	17.35
Gt-27	'48	134.0	1499	50.70	0.140	0.103	134,600	18.50
Average					0.143	0.105	136,200	17.93
					A - III			
Sc- 4	'47	176.1	348	15.50	0.177	0.129	138,100	14.30
Sw- 8	'47	197.0	1517	75.40	0.149	0.109	138,100	17.00
Sw- 4	'47	186.0	846	39.80	0.147	0.107	138,100	17.25
Average					0.158	0.115	138,100	16.18
					B - II			
Gt-10[#2]	'41	122.0	594	18.30	0.206	0.150	135,000	12.50
Gt-29	'44	90.0	840	24.40	0.156	0.113	135,000	16.70
Average					0.181	0.132	135,000	14.60
Grand average					0.160	0.117	136,670	16.23

Table 3. (Concl.)

Liquefied Petroleum Gas Powered Pumping Plants
(Single well, deep well turbine pump)

Plant no.	Age	Lift (ft)	Yield (gpm)	Water H.P.	Units[1] per acre-ft. per ft. of lift	Units[1] per hour per water H.P.	Heat value (Btu/unit[1])	Plant eff. (%)
					A - I			
Fi-80	'46	51.7	1005	13.10	0.400	0.293	101,000	8.78
Me-1W#1	'46	59.8	1273	19.23	0.386	0.282	93,200	9.71
Average					0.393	0.288	97,100	9.25
					A - II			
Gt-11	'47	119.0	1072	32.25	0.277	0.202	99,700	12.65
Sc-89	'46	122.0	925	28.50	0.294	0.214	92,600	12.85
Average					0.286	0.208	96,150	12.75
					A - III			
Hs-19	'50	265.0	685	45.80	0.296	0.216	96,400	12.25
Hs-31	'50	230.0	469	27.20	0.272	0.199	99,700	12.83
Hs-27	'49	270.0	867	59.10	0.248	0.181	92,000	15.30
Rl- 1	'47	218.0	798	44.00	0.241	0.176	91,000	15.95
Sw- 5	'48	195.0	1189	58.50	0.219	0.160	99,700	16.00
Hs-24	'50	220.0	1915	106.50	0.195	0.142	98,600	18.15
Average					0.245	0.179	96,230	15.08
					B - I			
Me-1W#2	'36	69.0	903	15.75	0.229	0.167	93,200	16.35
					B - III			
Hs-10	'39	175.0	1015	44.90	0.325	0.237	100,800	10.65
Grand average					0.282	0.206	96,500	13.46
					Gasoline Powered Pumping Plants			
					(Single well, deep well turbine pump)			
					A - II			
Sc-91	'48	84.3	1220	26.00	0.243	0.177	123,700	11.63
					(Battery of wells with centrifugal pump)			
					A - I			
Ke-38	'48	23.9	1735	10.50	0.317	0.230	124,150	8.90

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[1] Units:
Electric plants . . . . Kilowatt-hours
Natural gas plants . . . . Cubic feet
Diesel, L-P gas, and gasoline plants . Gallons

An attempt was made to secure the characteristic curves for the pumps tested from the pump companies. However, these were obtained for only six pumps. A comparison of the measured pump discharges with the rated pump discharges obtained from these curves is shown in Table 4. The characteristic curve obtained for the pump at the L-P gas plant may have been for more pump states than were actually installed. Other studies have shown that wear of the bowls causes pump discharge and pump efficiency to decrease almost in direct proportion. The comparison in Table 4 indicates that wear of the pump bowls or improper adjustment of the impellers in the bowls were contributing factors to the lower over-all plant efficiencies measured.

Table 4 A comparison of the measured pump discharge and the rated pump discharge at six plants tested.

Plant efficiency (%)	Measured discharge (g.p.m.)	Rated discharge (g.p.m.)	Measured discharge in % of rated discharge
		Electric Plants	
43.1	1200	1580	76
59.0	755	900	83
		Diesel Plants	
16.70	840	1290	65
17.25	846	1070	79
		Natural Gas Plant	
11.05	1356	1870	73
		L-P Gas Plant	
12.83	469	1110	43

Few of the owners reported any test being made of the well to determine its characteristics before the pumping equipment was purchased. Such a practice would indicate that the wide variation in the pumping plant efficiencies at the plants studied may be attributed largely to the mismatching of the pump to the well. This mismatching of pump to well may be due to improper selection of the pump or to a decrease in the specific capacity of the well since the pump was installed. The characteristic curves for the six pumps showed the less efficient plants to be operating at lower lifts and discharges than those for which the pump efficiency was maximum.

An estimate of the effect of over-size pumping equipment on over-all plant efficiencies may be made by comparing the water horsepower and the motor or engine rated horsepower at the plants tested. Power units are selected for pumping plants that have a rated horsepower for continuous duty at the proper speed approximately equal to the water horsepower divided by the combined efficiency of the pump and drive. It is impossible to obtain a motor or engine with the exact power requirements and some reserve power is often allowed in the selection; however, any large variation in the ratio of water horsepower to rated horsepower would indicate that the pump as well as the power unit was larger than that needed for the well output.

A comparison of the over-all plant efficiencies and the ratio in percent of the water horsepower to the power unit rated horsepower is shown in Table 5 for the various plants for which the information was available. Rated horsepower was taken from the name-plate of electric motors and was taken from the characteristic curves obtained from the manufacturers for the internal combustion engines. The latter's rated horsepower was that recommended by the manufacturer for continuous duty at the speed it was operated at the pumping plant.

Table 5. The over-all plant efficiency and the ratio in percent of the water horsepower to the power unit rated horsepower for the various plants.

Electric		Natural gas		Diesel		L-P gas	
Plant eff. (%)	W.H.P. R.H.P. (%)	Plant eff. (%)	W.H.P. R.H.P. (%)	Plant eff. (%)	W.H.P. R.H.P. (%)	Plant eff. (%)	W.H.P. R.H.P. (%)
35.9	35.5	8.15	36.1	14.30	45.6	8.78	37.4
43.1	55.0	10.10	36.2	17.00	58.0	9.71	37.0
44.7	45.5	11.05	49.4	17.25	50.5	12.25	45.8
51.6	59.2	13.10	49.2	17.35	55.3	12.65	41.0
52.3	59.4	14.00	55.6	18.50	62.5	12.85	39.6
52.5	51.5	14.00	59.0			15.30	61.0
54.8	64.6	15.30	56.7			16.00	57.5
60.2	70.2	15.35	54.3			18.15	60.2
63.8	73.3						
69.6	71.0						
Averages							
52.9	58.5	12.63	48.3	16.88	54.4	13.21	47.4

The large variation in the ratio percentages of water horsepower to rated horsepower were quite consistently associated with the variations in the measured over-all plant efficiencies. This would indicate the pump as well as the power unit was over-sized in its selection or operation for the well capacity.

Plants having above average efficiency also had water horsepower to rated horsepower ratio percentages above the average. This ratio percentage was 64.5 percent or above for the electric plants having higher than average efficiencies and was above 50 percent for all other plants of above average efficiency using internal combustion engines.

Improper carburetor settings for the load on internal combustion engines at the pumping plants undoubtedly affected the variation obtained in the plant efficiencies measured; however, different carburetor settings were not tried in the tests. The speed of the engines may not have been regulated by the operator to the speed for which the pumping plant was designed or selected. This would also reduce the efficiency of the pumping plant.

Pumping Costs

Cost of Operation. The prices paid during the years 1950 and 1951 for the different fuels were quite variable between the plants tested. The cost rate for natural gas was six to 8.5 cents per 1000 cubic feet at plants where the owner had a gas well on his land, whereas, the cost-rate was 20 to 21.5 cents per 1000 cubic feet at plants where the natural gas was purchased from a supply line. The prices paid for diesel fuel ranged from eight to 14 cents per gallon and the prices paid for L-P gas ranged from six to nine cents per gallon. The average prices paid for these fuels were 16.3 cents for natural gas, 11.4 cents for diesel fuel, and 6.6 cents for L-P gas. The unit fuel costs in cents per acre-foot per foot of lift were calculated for each plant tested on the basis of the individual fuel prices paid at each plant. A summary of the unit fuel costs is included in Table 6.

Three different power rates were applicable at the electric plants tested. These rate structures had a yearly minimum charge of $6 to $10 per connected horsepower as a guaranteed use per year for which electric power was received. The cost-rate per kilowatt-hour was graduated by the yearly consumption of kilowatt-hours per connected horsepower. The connected horsepower was equivalent to the motor rated horsepower at the plants tested. The effect of the kilowatt-hours used per connected horsepower per year on the average cost per kilowatt-hour is shown in Fig. 2 for the rates of the three power companies. The lower power rate was applicable at all but three of the electric plants tested. At these three plants, two were under the medium power rate and one was under the highest power rate.

Due to the graduated cost-rate for electric power, unit power costs in cents per acre-foot per foot of lift varied with the annual hours of use made of the plant. Their relationship at individual plants did not follow directly the relationship shown in Fig. 2 due to variations in the ratio of water horsepower to motor rated horsepower at the plants. That is, the relationship between the annual hours of use and the annual

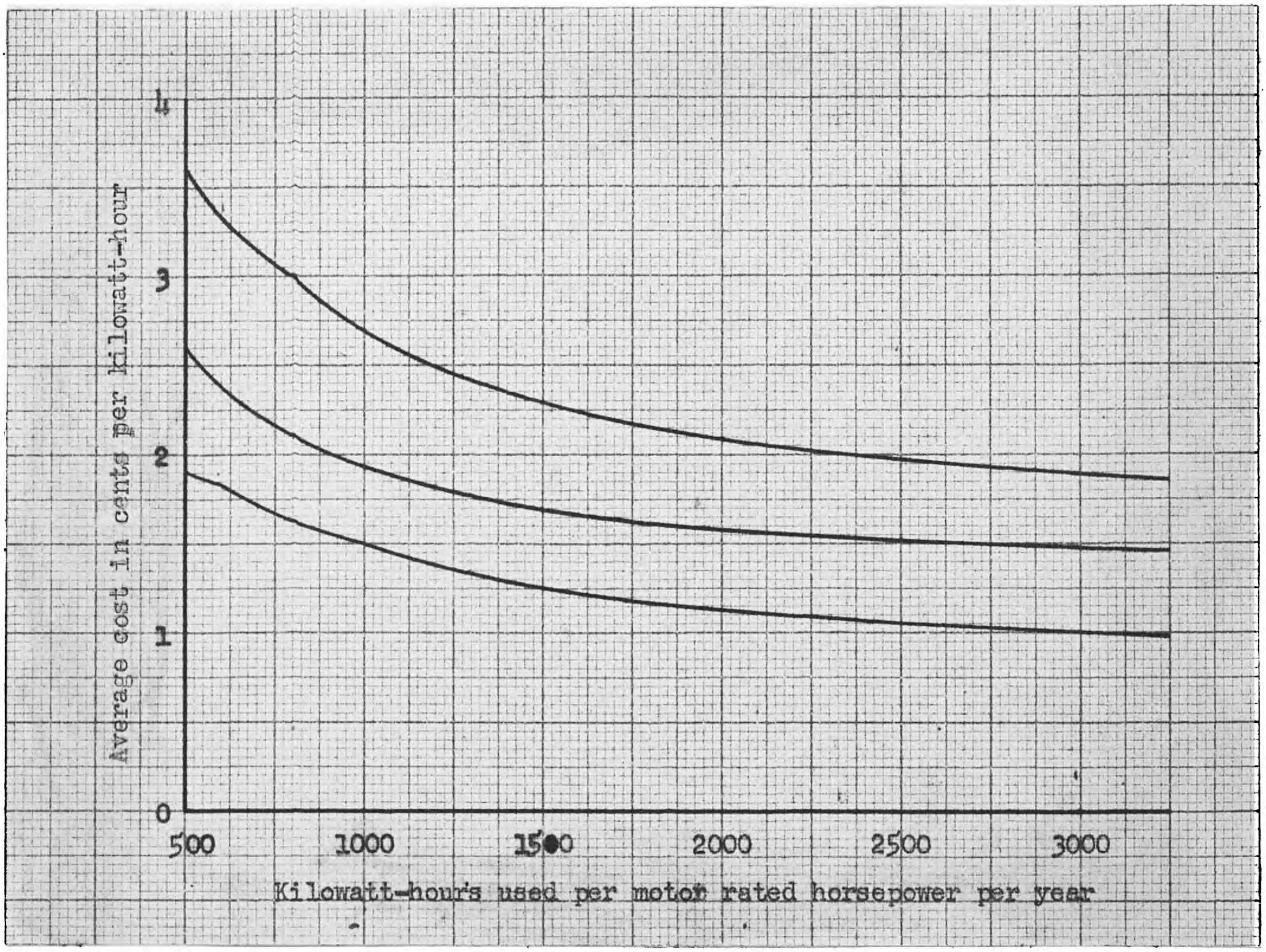


Fig. 2. The effect of the kilowatt-hours used per connected horsepower per year on the average cost of electricity in cents per kilowatt-hour for the three power rates in affect at the plants studied.

kilowatt-hours consumed per rated horsepower would vary with the water horsepower to rated horsepower ratio. This would cause a different average cost per kilowatt-hour for the individual plants. A summary of the unit power costs for varying annual hours of use is shown in Table 6 for the electric plants tested that had single wells with turbine pumps.

Attendance and lubrication were reported to be practically negligible costs at electric pumping plants. Few repairs had been made at the plants tested except to repair damage caused by electrical storms. Major repairs were reported for only one pump. In the calculation of the unit operating costs, repairs were charged at 0.1 cent per acre-foot per foot of lift for all electric plants. Attendance and lubrication also averaged approximately 0.1 cent per acre-foot per foot of lift for the plants tested.

Attendance at pumping plants using internal combustion engines was reported to take from one to 10 man-hours per 100 hours of operation. An attendance charge of three cents per hour of operation was used for all plants in the calculation of unit costs. Lubricating oil for these plants cost from 0.12 cents to 6.5 cents per hour of operation. The average cost per hour for oil was 3.9 cents for diesel engines, 3.1 cents for L-P gas engines, and 2.9 cents for natural gas engines. The individual plant oil cost was used in the calculations. Repair costs at internal combustion engine plants were surprisingly low. Outside of defective equipment replaced by the manufacturer, few major repairs had been made on the engines. Some owners made minor replacements or repairs every year to insure a dependable source of power. In the calculation of unit operating costs, repairs were charged at 0.2 cents per acre foot per foot of lift for all plants with internal combustion engines.

A summary of the unit operating costs in cents per acre-foot per foot of lift is shown in Table 6. The averages of the fuel and operating costs for diesel and L-P gas plants were nearly equal but were more than three times higher than the average fuel cost and more than double the average operating cost at natural gas plants. The average unit operating costs of electric plants were reduced almost in half by extending the annual hours of use from 500 to 3000 hours. At 3000 annual hours of use, the average operating costs of electric plants were still about 10 percent higher than those for diesel and L-P gas plants.

Table 6. Summary of the unit fuel or power costs and operating costs in cents per acre-foot per foot of lift.

Type of energy	No. of tests	Annual hrs. use	Energy cost			Operating cost		
			Max.	Min.	Av.	Max.	Min.	Av.
Electricity	17[1]	500	6.38	2.93	4.37	6.66	3.15	4.70
		1000	4.80	2.45	3.49	5.12	2.65	3.74
		2000	3.61	1.82	2.64	3.90	1.98	2.86
		3000	3.12	1.58	2.34	3.18	1.75	2.53
Natural gas	10	-	1.04	0.14	0.54	1.59	0.47	0.99
Diesel	7	-	2.88	1.19	1.88	3.54	1.53	2.39
L-P gas	12	-	3.21	1.17	1.86	3.92	1.46	2.32

[1] Electric pumping plants with single wells and turbine pumps.

The average fuel or power cost constituted 93 percent of the average operating costs for electric plants, 55 percent for natural gas plants, 79 percent for diesel plants and 80 percent for L-P gas plants.

The relative prices that must be paid for the various sources of energy would greatly affect the comparative operating cost economy of using one source of energy over another.

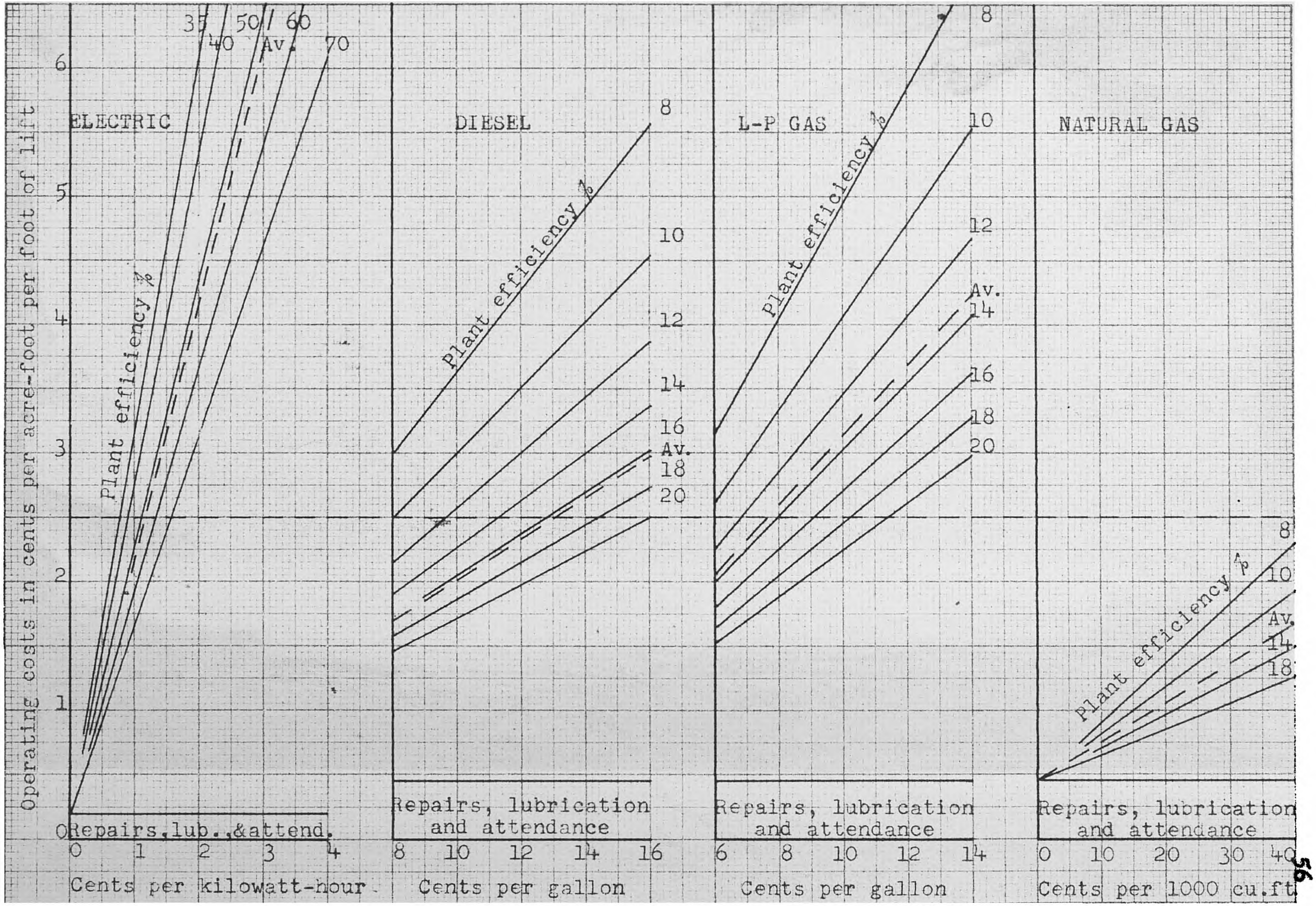
Utilizing the data secured in this study, an alignment chart was prepared for determining the operating costs of the various plants having different energy costs per unit and over-all plant efficiencies. This alignment chart is shown in Plate V. The average unit costs of attendance, lubrication and repairs for the plants studied was used as a basis for these costs on the chart. Corrections for different values for these costs can be made by adding or subtracting the desired change from the results obtained. The average over-all plant efficiencies measured are shown as a basis for cost comparison. The example line on the chart shows that electricity at approximately 1.1 cents per kilowatt-hour, diesel fuel at approximately 12.8 cents per gallon, and L-P gas at approximately 7.5 cents per gallon would result in an operating cost of 2.5 cents per acre-foot per foot of lift at plants of average over-all efficiency. This operating cost would be about double that at an equivalent natural gas plant where 25 cents per 1000 cubic feet was paid for the natural gas.

<u>Cost of Ownership</u>. The initial cost of installing all component parts of the pumping plant was obtained at 45 of the 61 pumping plants included in the study; however, ownership costs were calculated only for the 36 plants that were installed since 1944 and which had single wells with turbine pumps. The initial investment at these plants ranged from $3,328 for a plant of shallower lift up to $15,886 for a plant of higher

EXPLANATION OF PLATE V

Plate V is an alignment chart for determining the operating costs in cents per acre-foot per foot of lift of the various type pumping plants for varying energy costs per unit and over-all plant efficiencies. The average plant efficiencies are indicated for use in determining the comparative economy of the various sources of energy.

PLATE V


Operating costs in cents per acre-foot per foot of lift
0
1
2
3
4
5
6
ELECTRIC
Plant efficiency %
35
40
50
Av.
60
70
Repairs, lub., & attend.
0
1
2
3
4
Cents per kilowatt-hour
DIESEL
Plant efficiency %
8
10
12
14
16
Av.
18
20
Repairs, lubrication and attendance
8
10
12
14
16
Cents per gallon
L-P GAS
Plant efficiency %
8
10
12
Av.
14
16
18
20
Repairs, lubrication and attendance
6
8
10
12
14
Cents per gallon
NATURAL GAS
Plant efficiency %
8
10
Av.
14
18
Repairs, lubrication and attendance
0
10
20
30
40
Cents per 1000 cu.ft.

pumping lift. Initial investments were over $10,000 at 13 plants and between $5,000 and $10,000 at 17 of the pumping plants.

Differences in the depths of wells below the pumping water levels influenced these initial investment costs for a given size plant. Total cost of the wells ranged from $971 to $5,544. The complete costs of installing the wells ranged from $6.15 to $16.00 per foot of depth and averaged $11.85 for all plants.

The initial cost of the pumping equipment, including the cost of the pump, drive, power unit and auxiliary parts such as fuel supply tanks or lines, ranged from $1300 to $10,431. When reduced to the basis of the dollar investment per water horsepower, the equipment costs ranged from $88 to $269 per water horsepower and averaged $118 for electric plants, $148 for natural gas plants, $180 for diesel plants, and $143 for L-P gas plants. Equipment costs on this basis were generally lowered with increases in pump discharges and total lifts of the plants but were also closely associated with the over-all plant efficiencies. Only four of the plants with below average efficiencies had lower than average equipment costs per water horsepower. This is further evidence that larger pumping equipment than needed for the well output had been installed and operated at many of the plants studied. Two of the plants with higher than average efficiencies had more than average equipment costs per water horsepower.

The service life of the pumping plants estimated by the owners ranged from five to 15 years for pumps, drives, and power units and from 15 to 25 years for electric motors and wells. Many of the estimates were based on the straight-line depreciation schedules used in the computation of federal income tax which were commonly 10 years for the pumping equipment and 20 years for electric motors and depreciable parts of the well. Depreciation methods recently approved for income tax purposes("declining balance" and "sum of the digits" methods) allow a faster write-off of farm machinery costs during the first years. It is doubtful if these more rapid rates of depreciation would be as desirable to use on pumping plants as they would be for other farm machinery which is commonly replaced sooner in their period of usefulness. In the calculation of the ownership costs of the plants studied, depreciation was calculated by the straight-line method using a service life of 12.5 years for the pump, drive, and power units (eight percent of the initial investment per year) and 20 years for electric motors and wells (five percent of the initial investment per year). These service lives approximated the average of those estimated by the owners, except in the case of this average for diesel engines which was nearer 10 years.

Few owners reported paying any interest on the investment in the pumping plant but felt an interest rate of five to six percent would be a fair charge for this item. An interest rate of six percent on the depreciated value was used in the calculation of ownership costs, that is, the equivalent of three percent of the initial investment per year. Taxes and insurance costs were estimated by only a few owners. On the basis of the little information obtained on assessed valuations and tax rates, an annual charge of one percent of the initial investment was made for taxes and insurance.

The average annual operating time of the pumping plants was approximately 1000 hours per year during the three year period previous to the year in which the plant was tested but ranged from 300 to 2200 hours at individual plants. An electric power company reported that for a period of years, an average of 655 kilowatt-hours per connected horsepower were used per year. In the more recent years of below normal rainfall throughout the area, many irrigators have reported more than 3000 hours of operation per year for their pumping plants. The ownership costs in cents per acre-foot per foot of lift were calculated for intervals of 500 hours of annual use up to 3000 hours. These unit ownership costs were added to the unit operating costs of the individual plants to obtain the total unit costs of pumping irrigation water shown in Tables 7 and 8. Ownership costs on this basis vary directly with the annual hours of use.

Ownership costs were also reduced to the basis of the dollars per water horsepower. These varied from $14.15 to $44.80 at all plants and averaged $26.00 at electric plants, $25.90 at natural gas plants, $29.24 at diesel plants, and

$24.87 at L-P gas plants. The variation in the ownership costs per water horsepower were slightly different than the variation in the pumping equipment costs per water horsepower due to differences in well costs and ratio of electric motor cost to pump cost at the individual plants. These costs are included in Tables 7 and 8.

Total Cost. The total costs of pumping irrigation water at the plants studied were subject to the combined effect of the variations in the operating and ownership costs between plants. At an individual plant, the total cost in dollars per acre-foot is needed for determining the economical aspects of the water cost to the irrigation enterprise. At 1000 hours of annual operation (the average for the plants studied) the total costs per acre-foot ranged from $2.89 to $16.75 with a total cost of over $10.00 at eight plants, between $5.00 and $10.00 at 18 plants, and under $5.00 at 10 plants. If the plants were operated 3000 hours annually, the total costs per acre-foot of water were reduced to a range of $1.44 to $9.17 with total costs over $5.00 at 12 plants, between $2.50 and $5.00 at 13 plants, and less than $2.50 per acre-foot at 11 pumping plants.

For comparative purposes, the total costs of the plants were reduced to the cents per acre-foot per foot of lift for varying number of hours of annual use. These unit total costs of pumping are shown in Table 7 for the electric plants and in Table 8 for the natural gas, diesel and L-P gas plants. The

Table 7. Electric pumping plant costs in cents per acre-foot per foot of lift and related information.

Plant no.	Age	Yield (gpm)	Total lift (ft.)	Water H.P.	Plant eff. %	Owner. cost $ per W.H.P.	Annual hours use					
							1000		2000		3000	
							Oper. cost	Total cost	Oper. cost	Total cost	Oper. cost	Total cost
						A - I						
Fi-62	'47	1960	35.5	17.6	35.9	33.80	5.12	9.77	3.90	6.24	3.18	4.73
Fi- 1	'48	1156	60.9	17.8	51.6	26.45	3.36	6.98	2.55	4.36	2.24	3.45
Fi-76	'49	1206	71.3	21.7	59.5	16.00	2.87	5.06	2.18	3.27	1.93	2.66
						A - II						
Fi-61	'48	750	81.5	15.4	52.5	37.00	3.52	8.60	2.66	5.20	2.32	4.02
Fi-65	'48	776	99.0	19.4	54.8	23.40	3.22	6.42	2.42	4.02	2.20	3.27
Fi-49	'48	1450	80.0	29.3	63.8	22.30	2.74	5.81	2.07	3.61	1.84	2.86
Fi-59	'47	1290	87.3	28.4	69.6	19.80	2.65	5.36	1.98	3.33	1.75	2.65
						A - III						
Gt-10	'50	713	165.0	29.7	52.3	29.20	3.31	7.32	2.50	4.50	2.22	3.56
Average					52.3	26.00	3.35	6.92	2.53	4.32	2.21	3.40

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[1] Calculated on the basis of the lower power rate shown in Fig. 2.

Table 8. Pumping plant costs in cents per acre-foot per foot of lift and related information for natural gas, diesel, and L-P gas plants studied.

Plant no.	Age	Yield (gpm)	Total lift (ft.)	Water H.P.	Plant eff. (%)	Fuel cost in cents/ unit	Unit fuel cost	Unit oper. cost	Owner. cost $ per W.H.P.	Annual hours use 1000 Total cost	2000 Total cost	3000 Total cost
					Natural Gas Plants							
						A - I						
Sc-29	'46	1380	64.0	22.3	14.00	.0215	0.56	1.13	24.70	4.52	2.82	2.26
						A - II						
Sc- 1	'46	836	127.0	26.8	10.10	.0215	0.78	1.31	33.50	5.90	3.60	2.84
Gy-21	'46	1356	88.0	30.1	11.05	.0200	0.67	1.14	24.80	4.54	2.83	2.28
Gt-17	'50	1935	114.0	55.7	13.10	.0060	0.17	0.47	28.60	4.40	2.43	1.78
Fi-56	'46	2059	137.5	71.5	14.70	.0085	0.21	0.53	14.15	2.47	1.50	1.18
Gt-30	'49	1025	140.0	36.3	15.30	.0080	0.19	0.62	22.10	3.64	2.13	1.63
Gt-28	'49	1145	137.0	39.6	15.35	.0060	0.14	0.58	29.50	4.65	2.61	1.93
						A - III						
Hs-25	'50	870	235.0	51.6	12.20*	.0200	0.61	0.98	25.80	4.52	2.75	2.16
Sc-90	'50	664	152.5	25.6	12.20*	.0215	0.65	1.20	28.80	5.15	3.17	2.52
Sc-55	'47	477	153.0	18.4	8.15	.0215	1.04	1.59	38.00	7.17	4.38	3.45
Hs-26	'50	1228	305.0	94.5	14.00	.0200	0.53	0.83	15.05	2.89	1.86	1.52
Average					12.73	.0159	0.50	0.95	25.90	4.53	2.74	2.14
					Diesel Plants							
						A - II						
Gt- 1		2000	96.5	48.7	17.35	12.4	1.81	2.20	30.00	6.32	4.26	3.57
Gt-27		1499	134.0	50.7	18.50	11.2	1.57	1.94	28.10	5.79	3.86	3.22

Table 8. (Concl.)

Plant no.	Age	Yield (gpm)	Total lift (ft.)	Water H.P.	Plant eff. (%)	Fuel cost in cents/ unit	Unit fuel cost	Unit oper. cost	Owner. cost $ per W.H.P.	Annual hours use		
										1000 Total cost	2000 Total cost	3000 Total cost
					Diesel Plants (Cont'd)							
						A - III						
Sc- 4	'47	348	176.1	15.50	14.30	12.3	2.17	2.93	44.80	9.06	5.99	4.98
Sc-69	'48	857	152.9	33.1	16.20*	10.0	1.55	2.00	33.00	6.53	4.26	3.50
Hs- '	'47	1314	221.0	73.5	16.20*	13.0	2.03	2.40	24.00	5.70	4.05	3.50
Sw- 8	'47	1517	197.0	75.4	17.00	8.0	1.19	1.53	19.70	4.22	2.88	2.43
Sw- 4	'47	846	186.0	39.8	17.25	10.0	1.47	1.88	25.10	5.33	3.61	3.03
Average					16.69	11.0	1.68	2.13	29.24	6.14	4.13	3.46
					Liquefied Petroleum Gas Plants							
						A - I						
Fi-80	'46	1005	51.7	13.1	8.78	6.0	3.21	3.92	31.40	8.21	6.05	5.36
Me-11#1	'46	1273	59.8	19.2	9.71	6.0	2.32	2.74	21.00	5.62	4.18	3.85
						A - II						
Gt-11	'47	1072	119.0	32.3	12.65	6.0	1.66	2.12	27.40	5.88	3.99	3.37
Sc-89	'46	925	122.0	28.5	12.85	9.0	2.52	3.01	26.20	6.61	4.81	4.21
						A - III						
Hs-19	'50	685	265.0	45.8	12.25	6.0	1.78	2.15	28.50	6.07	4.11	3.46
Hs-31	'50	469	230.0	27.2	12.83	6.0	1.63	2.32	36.30	7.28	4.80	3.98
Hs-27	'49	867	270.0	59.1	15.30	6.0	1.49	1.85	21.70	4.83	3.34	2.84
Sw- 5	'48	1189	195.0	58.5	16.00	6.0	1.31	1.66	20.80	4.51	3.09	2.61
Fi-63	'48	1353	160.0	54.7	18.00*	7.0	1.40	1.71	20.10	4.46	3.09	2.63
Hs-24	'50	1915	220.0	106.5	18.15	6.0	1.17	1.46	15.30	3.56	2.51	2.16
Average					13.65	6.6	1.85	2.29	24.87	5.70	4.00	3.45

* Estimate of plant efficiency based on owner's reported fuel consumption.

range in the unit total costs of all plants was from 2.47 cents to 9.77 cents per acre-foot per foot of lift at 1000 annual hours of use and from 1.18 to 5.45 cents at 3000 annual hours of use. The higher ownership costs were generally associated with the higher operating costs, thereby causing relatively greater differences in the total costs of the plants. The effect of the variations in the ownership costs of the plants on the unit total costs decreased as the annual hours of use increased. For all types of plants, the percentage difference in the range of operating costs was greater than the percentage difference in the range of ownership costs. This was also the case within natural gas and L-P gas plants but this percentage difference in range was slightly greater for the ownership costs within the electric and diesel plants.

The unit total costs of pumping water at a given annual hours of use varied more with the over-all efficiencies of the plants than with any other factor. This is due to the operating costs being determined largely by the over-all efficiencies and to the higher ownership costs generally being at the plants having the lower efficiencies. To remove the variation caused by the differences in prices paid for the fuels, the costs were recalculated for the plants with measured efficiencies on the basis of like fuel costs of six cents per gallon for L-P gas, 10 cents per gallon for diesel fuel and 20 cents per 1000 cubic feet for natural gas. The electric plant costs were based on the lower power rate shown in Fig. 2. To remove the variation in pumping costs caused by differences in well costs, the unit ownership costs of the wells were deducted. The ownership costs of the wells ranged from 0.24 to 1.45 cents per acre-foot per foot of lift. A comparison of the costs of the pumping equipment resulting from the calculations on this basis and the over-all plant efficiencies is shown in Table 9 for 2000 annual hours of use and the various type plants. The resulting association is rather pronounced considering the many other factors affecting the relationship. Plants with the higher costs in this relationship were those with very low pump discharges. Variations in the comparative purchase price of the pumping equipment appeared to be a more important factor in determining the total costs than did the pumping lift for which the equipment was installed.

For 2000 annual hours of use, the average unit total costs of the pumping equipment and the average unit total costs of the pumping plants for individual fuel prices as shown in Tables 7 and 8 were respectively: 3.46 cents and 4.32 cents for electric plants; 3.49 cents and 4.13 cents for diesel plants; 3.36 cents and 4.00 cents at L-P gas plants; and 2.31 cents and 2.74 cents at natural gas plants. These values are within 0.05 cents of being proportionately the same between the types of plants.

The average unit operating and total costs of the various pumping plants shown in Tables 7 and 8 versus the annual hours of use of the plants is plotted in Plate VI. The average unit ownership costs for the different plants are equivalent to the height of the total cost curves above their respective operating cost lines. It can be seen from the curves that as the annual hours of use increase, the less influence ownership

Table 9. A comparison of the unit costs[1] of the pumping equipment in cents per acre-foot per foot of lift for 2000 hours of annual use and the over-all plant efficiencies for the various type plants.

Electric plants				Natural Gas Plants			
Plant eff.	Oper. cost	Owner cost	Total cost	Plant eff.	Oper. cost	Owner cost	Total cost
35.9	3.60	1.36	4.96	8.15	1.45	2.07	3.52
51.6	2.35	1.72	4.07	10.10	1.26	1.81	3.07
52.3	2.33	1.16	3.49	11.05	1.14	1.14	2.28
52.5	2.46	1.29	3.75	13.10	0.93	1.62	2.56
54.8	2.16	1.16	3.32	14.00	1.09	1.06	2.15
59.5	2.01	0.98	2.99	14.00	0.83	0.76	1.59
63.8	1.91	1.08	2.99	14.70	0.82	0.73	1.55
69.6	1.82	1.10	2.92	15.30	0.99	1.01	2.00
				15.35	0.92	1.14	2.06
Averages							
55.0	2.33	1.23	3.56	12.86	1.04	1.26	2.31
Diesel plants				L-P gas plants			
14.30	2.52	2.21	4.73	8.78	3.12	1.65	4.77
17.00	1.83	1.00	2.83	9.71	2.74	1.15	3.89
17.25	1.88	1.45	3.33	12.25	2.15	1.29	3.44
17.35	1.85	1.64	3.49	12.65	2.12	1.01	3.13
18.50	1.77	1.31	3.08	12.83	2.32	1.61	3.93
				12.85	2.17	1.24	3.41
				15.30	1.85	0.97	2.82
				16.00	1.66	0.98	2.64
				18.15	1.46	0.79	2.25
Averages							
16.55	1.97	1.52	3.49	13.17	2.17	1.19	3.36

---

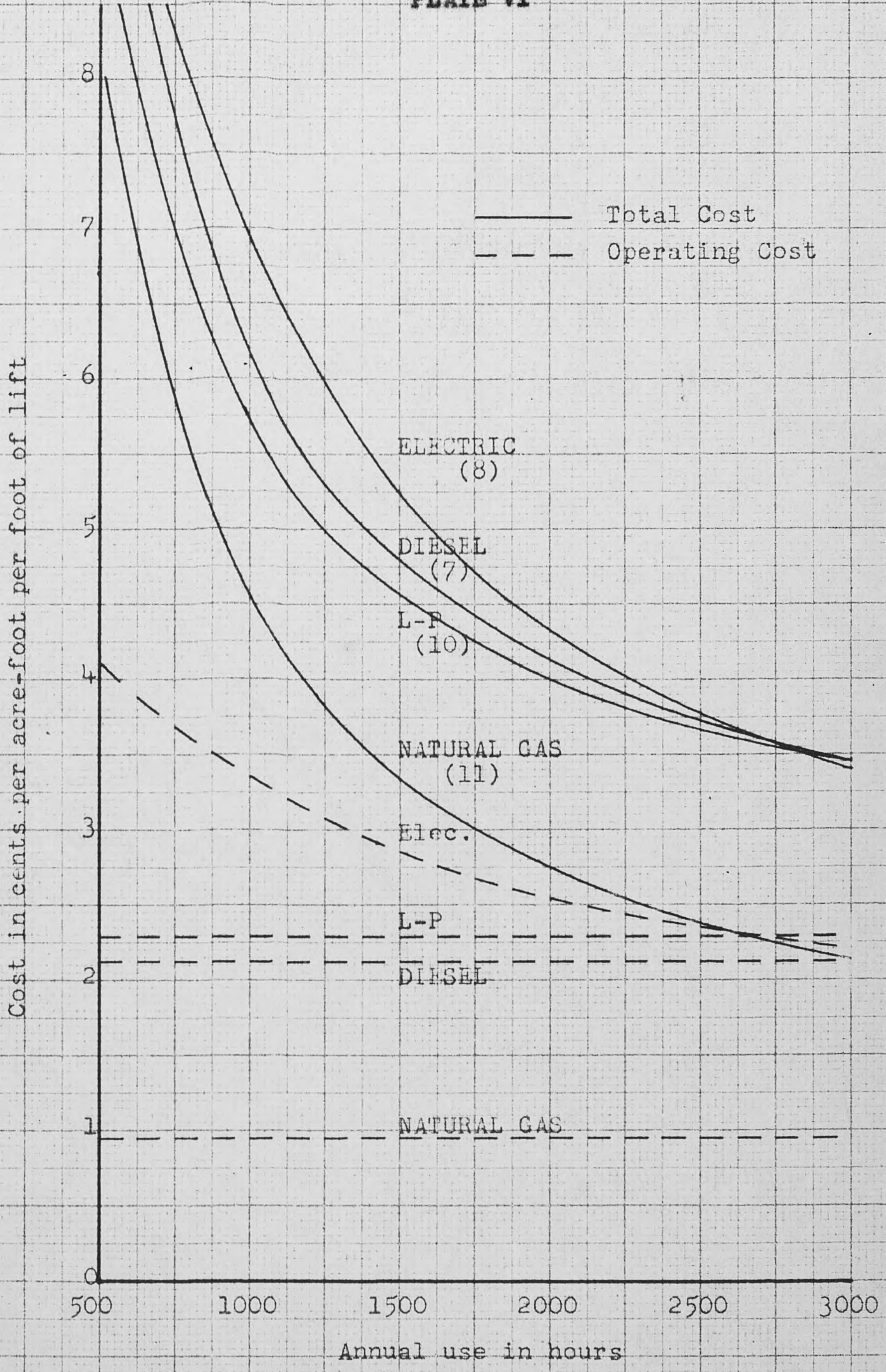
[1] Operating costs are based on L-P gas at six cents per gallon, diesel fuel at 10 cents per gallon, natural gas at 20 cents per 1000 cubic feet and electricity at the lower power rate shown in Plate V.

costs have on the total costs and the more important operating costs become. The annual hours of use at which the ownership costs and the operating costs become equal is indicative of the relative importance of ownership costs to the total costs at different plants. For the average unit costs of the different pumping plants, the approximate annual hours of use at which the ownership costs became equal to the operating costs were 1100 hours for electric plants, 1500 hours for L-P gas plants, and 1900 hours for diesel plants. At 3000 hours the average unit ownership costs were still 25 percent greater than the average unit operating costs for natural gas plants. The greater importance of ownership costs to the total cost at natural gas plants is also evidenced by the faster rate at which the total cost is reduced with the hours of use at these plants as compared to the other plants. The reduction of both operating costs and ownership costs at electric plants with annual hours of use combine to give a slightly faster reduction in total cost than that for L-P gas and diesel plants even though the ownership costs at electric plants are relatively less important. The difference in the relative importance of ownership costs at diesel and L-P gas plants is enough to reduce the total cost of diesel plants about one cent per acre-foot per foot of lift more than for L-P gas plants between 500 and 3000 hours of annual use.

EXPLANATION OF PLATE VI

The average unit operating and total costs of the different plants studied vs. the annual hours of use.

PLATE VI


Total Cost
Operating Cost
ELECTRIC (8)
DIESEL (7)
L-P (10)
NATURAL GAS (11)
Elec.
L-P
DIESEL
NATURAL GAS
Cost in cents per acre-foot per foot of lift
0
1
2
3
4
5
6
7
8
500
1000
1500
2000
2500
3000
Annual use in hours

These differences in the relative importance of ownership costs to the total cost between types of plants causes the comparative average total cost of the plants to change with the annual hours of use. The average unit total cost at 500 annual hours of use was 11.22 cents per acre-foot per foot of lift for electric plants, 10.14 cents for diesel plants, 9.11 cents for L-P gas plants, and 8.12 cents for natural gas plants. The average unit total costs of electric, diesel and L-P gas plants became more comparable in value as the annual hours of use increased, being reduced to almost equal values of 3.40 to 3.46 cents per acre-foot per foot of lift at 3000 hours. The average for the electric plants actually reverted to the lowest total cost for these plants at this use. It is also noted that at this use the average operating costs of electric plants were reduced to between the almost equal operating cost values of L-P gas and diesel plants. The average unit total cost of natural gas plants became comparably lower to the other plants total cost values with increases in annual hours of use. At 3000 hours the average unit total cost for natural gas plants was 2.14 cents per acre-foot per foot of lift which is equivalent to the average unit operating costs of the L-P gas and electric plants at this use.

SUMMARY

The 61 irrigation pumping plants studied in southwestern Kansas were not evenly distributed within the age, total lift, and fuel groups as selected, but were felt to be fairly representative of those in use in the region.

The pumping conditions at the plants tested throughout the eight counties were extremely variable as evidenced by the wide ranges in the pump discharges, total lifts, water horsepower requirements and well specific capacities measured.

The reduction of the fuel or power consumptions and the costs of the pumping plants to the unit values per acre-foot per foot of lift proved to be both helpful and valid in making comparisons between the plants of varying total lifts.

The averages of the over-all plant efficiencies measured were 52.3 percent for 17 electric plants, 12.44 percent for 10 natural gas plants, 16.23 percent for seven diesel plants, and 13.46 percent for 12 L-P gas plants.

There was a wide variation in the over-all efficiencies of the plants tested regardless of the source of power. The unit fuel or power consumption of the least efficient plant was approximately twice that of the most efficient plant for each type of power used.

This variation in the over-all plant efficiencies was attributed primarily to over-sized power units and pumps for the well capacity.

The variations in the over-all plant efficiencies and the prices paid for fuels resulted in a wide variation in the unit operating costs for the various types of plants.

The average unit operating cost for natural gas plants was less than one-half that of the diesel and L-P gas averages of 2.39 cents and 2.32 cents, respectively, per acre-foot per foot of lift. Due to the graduated cost-rate for electric power, the average operating costs of electric plants decreased sharply with the annual hours of operation but was still 10 percent higher than the averages for diesel and L-P gas plants at 3000 hours of annual use.

The average power or fuel costs constituted 93 percent of the average operating costs for electric plants, 55 percent for natural gas plants, 79 percent for diesel plants, and 80 percent for L-P gas plants.

The initial costs of 36 pumping plants with single wells installed since 1944 ranged from $3,328 to $15,886. The cost of the wells ranged from $6.15 to $16.00 per foot of depth. The initial cost of the pumping equipment ranged from $88 to $269 per water horsepower and averaged $118 for electric plants, $148 for natural gas plants, $180 for diesel plants, and $143 for L-P gas plants.

The higher unit ownership costs as well as the higher unit operating costs were generally associated with plants of lower efficiency, which resulted in a close association between the unit total costs and the over-all plant efficiencies within the various type plants.

The annual hours of operation was found to be a most important factor determining the total cost of a pumping plant. The greater the annual hours of use of a plant the less influence ownership costs had upon total cost and the more important the operating costs became.

The comparative average unit total costs between the various type plants changed with the annual hours of use due to the differences in the relative importance of ownership costs to operating costs between type of plants.

At 500 annual hours of use, the average unit total cost was 11.22 cents per acre-foot per foot of lift for electric plants, 10.14 cents for diesel plants, 9.11 cents for L-P gas plants, and 8.12 cents for natural gas plants. These average total costs for electric, diesel and L-P gas plants were reduced to a range of 3.40 to 3.46 cents per acre-foot per foot of lift at 3000 annual hours of use. At this use, the average for natural gas plants was reduced even further to 2.14 cents.

ACKNOWLEDGMENT

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This study was made possible with the cooperation of the many owners of the pumping plants who gave freely of their time in furnishing the information reported.

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APPENDIX

Data
Sheets

Project 203
Form 1

Plant No. ____________
Date ____________
Recorded by ____________

COST STUDY DATA

Owner ____________ Legal Description ____________

Address ____________ ____________

Estimated total use, last year, 1949, ____________ hours
Last ________ years = ________ hours

I. Oil.
- a. Consumption ________ quarts per 10-hour-day
- b. Consumption ________ quarts per change
- c. Hours between changes ________ hours
- d. SAE No. ________
- e. Price per gallon ________ cents

II. Power Unit Overhaul
- a. Hours since last overhaul ________ hours
- b. Estimated time between overhauls ________ hours
- c. Estimated cost of overhaul ________ dollars

III. LP-Gas Conversion Changes
- a. Head ________
- b. High altitude pistons ________
- c. Cold manifold ________
- d. Ignition timing ________
- e. Spark plugs ________
- f. Equipped with upper cylinder lubricator, ________

IV. Remarks ----- Troubles encountered.

V. Initial Costs

Equipment	Initial Cost	Year Purchased	Estimated Life, Yrs.	Estimated annual service and repairs	
				Dollars	Man-hours
Well					
Pump					
Power Unit					
Drive					
Pump House					
Miscellaneous					
Plant Total					

Project 203
Form 2

POWER UNIT DATA

Plant No. ____________
Date ________ ______
Recorded by ____________

Owner ____________________ Address ____________________ Legal Description ____________________
____

Make __________ Model __________ Date: new ________, installed __________ Outside temp. ______ °F.

Fuel __________ cost per gallon, ______ cents, API gravity ________ at ________ °F., Vapor Pressure ________ psi.

Rated H.P. ________, Engine Rated R.P.M. ____________, phase __________, volts __________ amps __________

Drive Ratio, Pump to Engine __________ Pump R.P.M. __________ Type of Drive ____________________

Electric or Gas Rate ____

TEST DATA

Test No.	Test Time of Day	Motor RPM	Manifold Pressure in HG	Engine Coolant Temp. °F	Cu.ft. nat. gas	Fuel Consumption lb. fuel	Fuel Consumption Min. Time	Fuel Consumption #/hr.	Fuel Consumption Gal/hr.	Energy Consumption Meter K = ______ Rev.	Min.	Kilowatt	HP Input	Water HP	Plant Efficiency

Remarks:

Note: Rev/min x .06 x K = Kilowatts $\frac{\text{Kilowatts}}{.746}$ = H[P. Input Plant Efficiency = $\frac{\text{water H[P.}}{\text{H[P. Input}}$ x 100

Project No. 203
Form 3

Owner ____________________
Address ____________________
Legal description __________
____

Plant No. ____________________
Date ____________________
Recorded by ____________________

IRRIGATION WELL PERFORMANCE DATA

PUMP DATA - General Information

Make __________ Model ____________________ Date installed ____________________

Type ____________, No. Stages __________, Rated Capacity ______gpm at _____rpm + ______ psi.

Well drilled by ____________________ Depth of well ______________
Estimated - yes or no

Address of driller ____________________

I. D. of Discharge Pipe __________ inches
Area of Discharge Pipe __________ sq. ft.

Well gravel packed ______________
Type of casing ______________
Type of casing perforations ________
Length of perforated section ______ ft.

Drawdown measured by ____________________

TEST DATA - Hoff Current Meter

Test		Meter			Water *	Q		Meter	Depth to		
No.	Time of Day	Rev.	Sec.	R.P.S.	Velocity feet/sec.	cfs	gpm	above datum feet	water level feet	TDH feet	Water H.P.

Remarks:

* N less than 2.50 V = 0.93 + 0.05

N more than 2.50 V = 0.95 N

Where V = vel, ft/sec
N = Rev/sec

Note: preliminary use only.
Subject to revision based on
meter rating.

Project 203
Form 4

Owner ______________________
Address ______________________
Legal Description ______________________
____

Plant No. ______________
Date ______________
Recorded by ______________

IRRIGATION WELL PERFORMANCE DATA

PUMP DATA - General Information

Make ______________ Model ______________ Date installed ______________

Type ______________, No. Stages ________, Rated Capacity ____gpm at _____ rpm
\+ ______ psi.

Well drilled by ______ ______________ Depth of well ______________
Estimated - yes or no

Address of driller ______________________

I. D. of Discharge Pipe __________ inches
Area of Discharge Pipe __________ sq. ft.

Well gravel packed - ______________
Type of casing ______________
Type of casing perforation ________
Length of perforated section ____ft.

Drawdown measured by ______________

TEST DATA - Orifice Plate Test

Orifice size ____________ inches

Test		Head		Q		Gauge above datum, feet	Depth to water level, feet	TDH feet	Water H.P.
No.	Time of Day	Inches	feet	c.f.s.	g.p.m.				

Remarks:

Project 203
Form 5

Owner ____________________
Address ____________________
Legal Description ____________________
____

Plant No. ____________
Date ____________
Recorded by ____________

IRRIGATION WELL PERFORMANCE DATA

PUMP DATA - General Information

Make __________ Model __________ Date installed ____________________

Type __________, No. Stages __________, Rated capacity _____gpm at _____rpm, + _____ psi.

Well drilled by ____________________

Depth of well ________
Estimated - yes or no

Address of driller ____________________

I. D. of Discharge Pipe __________ inches
Area of Discharge Pipe __________ sq. ft.

Well gravel packed - __________
Type of casing __________
Type of casing perforations__________
Length of perforated section ______ft.

Drawdown measured by ____________________

TEST DATA - Pitot Test

Test No.	Test Time of Day	Velocity Head feet	Velocity Feet/ sec.	Test No.	Test Time of Day	Velocity Head feet	Velocity Feet/ sec.
1				1			
2				2			
3				3			
4				4			
5				5			
6				6			
7				7			
8				8			
9				9			
10				10			
Total----------------				Total ----------------			
Average --------------				Average --------------			

Q=AV=______sq.ft. x _____ ft./sec.
Q=______________ cu.ft./sec.
Initial W.L. __________ ft.
Final W. L. __________ ft.
Ave. W. L. __________ ft.

Static Pressure _____psi. x 2.31=_____ft.
Gauge above datum __________ ft.
T. D. Head __________ ft.
Water H. P. = $\frac{Q \times 62.4 \times T.D.H.}{550}$ = water h.p.

= ______________ w.h.p.

Q=AV= _____ sq.ft. x ________ ft./sec.
Q= ______________ cu.ft./sec.
Initial W.L. __________ ft.
Final W. L. __________ ft.
Ave. W. L. __________ ft.

Static Pressure _____psi. x 2.31=_____ft.
Gauge above datum __________ ft.
T. D. Head __________ ft.
Water H.P. = $\frac{Q \times 62.4 \times T.D.H.}{550}$ = water h.p.

= ______________ w.h.p.

Remarks:

Proj. 203
Form 9
Page 1

AGRICULTURAL ENGINEERING DEPARTMENT
Kansas State College

Plant No.______

Summary Sheet

KANSAS IRRIGATION ENGINEERING PRACTICES

Owner______________________________Legal description to nearest quarter______________
Address____Location in quarter
Power unit data:
Make________________Model________________Serial No.____________________
Date: new__________, installed________________Outside temps.____________°F
Fuel__________cost per gallon________________cents, temp.____________°F
API gravity__________, Vapor pressure________________psi, lb/gal____________
Rated H.P.__________, Engine rated R.P.M.________________, phase__________,
volts__________, heat value________________, amps________________
Type of drive__________, electric or gas rate______________,meter R=________
Oil: a. Consumption____________________quarts per 10-hour day.
b. Consumption____________________quarts per change.
c. Hours between changes________________hours.
d. SAE No.______________.
e. Price per gallon____________________cents.
Power Unit overhaul:
a. Hours since last overhaul________________hours.
b. Estimated time between overhauls________________hours.
c. Estimated cost of overhaul____________________dollars.

Test No	Minutes since pumping started	Depth to water ft.	TDH ft	Rate Of pumping GPM	Water HP	Manifold vac In.Hg.	Fuel Consumption			cents /hr	Electric		
							lb /hr	gal /hr	cuft /hr		KW Input	HP Input	Plant Eff. %
1													
2													
3													
4													
5													
6													
7													
8													

Measuring Point____

Pumping rate measured by____________________drawdown measured by____________
Pump data: Make______________Serial______________Date installed____________
Type______________No. stages________________
Gearhead: Make________________Serial________________
Gear Ratio: pump________________to engine________________

Well drilled by____________________Address____________________
Date drilled____________________Depth of well________________Estimated?___
I.D. of discharge pipe__________inches. Well gravel packed?____________
Type of casing perforation______________Length of perforated section__________ft.

Remarks:

Proj. 203
Form 9
Page 2

Plant No. ________

Initial Costs

Equipment	Initial Cost	Year Purchased	Estimated Life, yrs.	Estimated annual service and repairs	
				Dollars	Man-hours
Well					
Pump					
Power Unit					
Drive					
Pump House					
Miscellaneous					
Plant Total					

IRRIGATION PUMPING PLANT EFFICIENCIES AND COSTS

by

RICHARD EUGENE HANSON

B. S., Kansas State College
of Agriculture and Applied Science, 1951

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1955

The irrigated acreage in Kansas has increased at an accelerated rate since World War II and has nearly doubled since 1949. More than three-fourths of the water for this irrigation has been pumped from underground sources. Much of the expansion in irrigation development has been in areas where the depth of the ground water below the land surface is relatively great. The cost of pumping water, which increases with the pumping lift, constitutes a major item in the cost of irrigated crop production. Continued improvements have been made in pumping equipment and relatively cheaper sources of power for pumping have been more widely distributed in recent years; however, pumping costs are commonly underestimated.

The purpose of the study reported in the thesis was to provide information relative to the cost of pumping water for irrigation in Kansas and to evaluate the factors that contribute to the pumping costs at existing installations.

To accomplish this purpose, a pumping plant testing program was initiated for measuring factors related to plant operation and for obtaining cost data at existing installations. After a preliminary investigation of the areas in which this testing program would be feasible, eight counties in southwestern Kansas were selected in which to conduct the study. Survey cards were sent out to a list of known irrigators in these counties. From the information on the returned cards, pumping plants were selected for the tests that would be representative of groupings made by date of installation, total pumping lift, and source of power used.

The major field measurements required at each plant for this study were the discharge of the pump, water levels in the well, and fuel or power consumption. Pump discharges were measured with either a sharp-edged circular orifice, Hoff current meter, or a pitot tube. Water levels in the well were measured with a two-wire electric line. A fuel weighing method was used to measure the consumption of diesel fuel, gasoline, and liquefied petroleum gas. Electricity and natural gas consumption was obtained by timing the revolutions of meter disks with a stop watch.

Initial costs of installing all the components of the pumping plant were obtained from the owner. The owners' estimate of operating cost items, annual hours of use, and expected service life was recorded for each plant and utilized in the cost analysis.

The data in this investigation were obtained during the summers of 1950 and 1951 at 61 existing pumping plant installations located throughout the eight counties selected for the study. However, unfavorable weather conditions made it necessary to substitute other plants for some of those originally selected. Consequently the plants tested were not evenly distributed within the age, total lift, and fuel groupings as selected, but were fairly representative of the plants in use throughout the region.

The pumping conditions at the plants tested were extremely variable as evidenced by the wide ranges in the pump discharges, total lifts, and well specific capacities measured. The theoretical or water horsepower requirements ranged from 6.0 to 106.5.

The fuel or power consumption and the costs of the pumping plants were reduced to the unit values per acre-foot of water pumped per foot of pumping lift. This proved to be valid as well as helpful in making comparisons between the plants of varying total lifts.

There was a wide variation in the over-all efficiencies of the plants tested regardless of the source of power. The unit fuel or power consumption per acre-foot per foot of lift of the least efficient plant was approximately twice that of the most efficient plant for each type of power used. This variation in the over-all plant efficiencies was attributed primarily to the mismatching of the pump and power unit to the well capacity. The averages of the over-all plant efficiencies measured were 52.3 percent for 17 electric plants, 12.44 percent for 10 natural gas plants, 16.23 percent for seven diesel plants, and 13.46 percent for 12 L-P gas plants.

In the calculation of the operating cost of each plant, the individual fuel consumption, fuel price and lubrication cost was used but average values were used for attendance and repairs. The average power or fuel cost constituted 93 percent of the average operating cost for electric plants, 55 percent for natural gas plants, 79 percent for diesel plants, and 80 percent for L-P gas plants. The average unit operating cost was 2.39 cents and 2.32 cents per acre-foot per foot of lift, respectively, for the diesel and L-P gas plants. The average for the natural gas plants was less than one-half this amount. Due to the graduated cost-rate for electric power, the average unit operating cost of these plants decreased sharply with the annual hours of operation but was still 10 percent higher than the averages for diesel and L-P gas plants at 3,000 hours of annual use.

Ownership costs were calculated for 36 of the tested plants that had single wells and that were installed since 1944. The initial cost of these plants ranged from $3,328 to $15,886. The well cost per foot of depth ranged from $6.15 to $16.00. The initial cost of the pumping equipment ranged from $88 to $269 per water horsepower for all plants and averaged $118 for electric plants, $148 for natural gas plants, $180 for diesel plants, and $143 for L-P gas plants.

The depreciation cost was calculated by the straight-line method using the approximate average service life estimated by the owners of 20 years for the wells and electric motors, and 12.5 years for the pumps, drives, and internal combustion engines. Interest on the investment was charged at six percent of the depreciated value, that is, three percent of the initial investment. Taxes and insurance costs were calculated as one percent of the initial investment. The higher unit ownership costs as well as the higher unit operating costs were generally associated with plants of lower efficiency, which was further evidence of over-sized pumping equipment for the well capacity at many of the plants studied.

At the average estimated annual use of 1,000 hours, the unit total cost of all plants ranged from 2.47 cents to 9.77 cents per acre-foot per foot of lift. The major factor found to be associated with this variation was the over-all efficiency of the pumping plant. The total pumping lift was one of the least important factors affecting the unit total cost on the per foot of lift basis.

The unit total cost of a pumping plant was reduced directly with increases in the annual hours of use of the plant. The greater the annual hours of use of a plant, the less influence ownership costs had upon total cost and the more important operating costs became. The comparative average unit total costs of the various type plants changed with the annual hours of use due to the differences in the relative importance of ownership costs to operating costs between types of plants. At 500 annual hours of use, the average unit total cost was 11.22 cents per acre-foot per foot of lift for eight electric plants, 10.14 cents for seven diesel plants, 9.11 cents for 10 L-P gas plants, and 8.12 cents for 11 natural gas plants. At 3,000 annual hours of use, these average unit total costs for electric, diesel, and natural gas plants were reduced to within a range of 3.40 to 3.46 cents, whereas the average for natural gas was reduced relatively further to 2.14 cents.