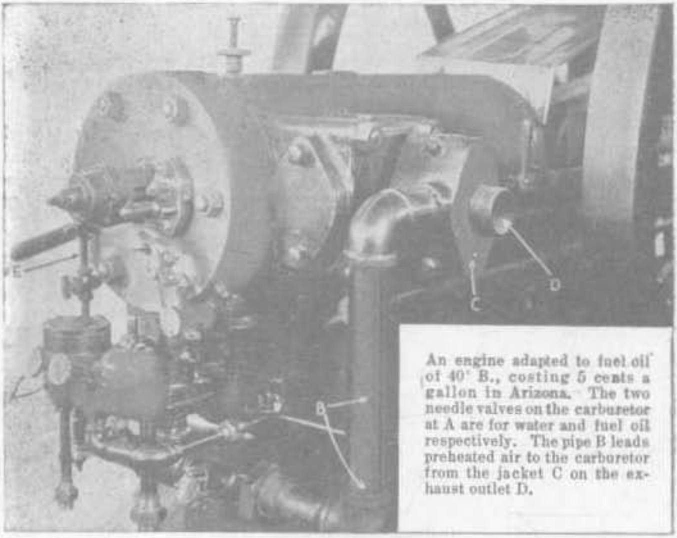
University of Arizona

Agricultural Experiment Station

Bulletin No. 74



An engine adapted to fuel oil of 40° B., costing 5 cents a gallon in Arizona. The two needle valves on the carburetor at A are for water and fuel oil respectively. The pipe B leads preheated air to the carburetor from the jacket C on the exhaust outlet D.

Oil Engines for Pump Irrigation

AND

The Cost of Pumping

By G. E. P. Smith

Tucson, Arizona, February 1, 1915

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AGRICULTURAL EXPERIMENT STATION

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PREFACE

The failing rainfall of southern California from 1892 to 1903 led to extraordinary efforts on the part of owners, more particularly of citrus orchards, to supply needed irrigating water and avert threatened losses. The nearby oil fields of this region, affording a cheap and convenient fuel supply, led naturally to the utilization of gasoline engines, the first forms of which had already been devised. Under the spur of necessity and favored by local circumstances, gasoline engines were improved and increasingly employed for pumping service in southern California and ultimately solved the problem of groundwater development in the region.

It is of interest in this connection to observe that the attention attracted to gasoline engines at this time led to their increased usefulness in other fields. The compactness of the machinery and the fuel supply proved adapted to transportation uses, resulting finally in the amazing development of motor vehicles. Still further improvements in automobile engines in compactness and power made practicable the development of the aeroplane and the consequent conquest of the air.

In connection with pumping operations, constant progress for the past twenty years has taken place in the direction of more economical, efficient and dependable machinery, and within the last three or four years in the direction, also, of the utilization of the various cheaper distillates incident to the oil refining industry. This last development, indeed, has resulted in part from the enormous demand for gasoline for automobiles and consequently rising prices therefor. The use of cheap distillates, with resulting increased range in pumping operations, is therefore to some extent reciprocal to the development of automobiles.

It is probably within the truth to say that, due to improved machinery and the use of cheaper distillates now available for pumping operations, that irrigating water may be raised at a fuel cost of from one-third to one-half the cost with gasoline. This makes possible the irrigation of large additional areas of land now lying undeveloped in the valleys of the semiarid Southwest. In 1890 irrigation in southern California was principally by means of surface waters; but at the present tijne (excluding the Imperial Valley, under the Colorado river) probably three times as much pumped water as surface water is used. In southern Arizona, taking into consideration extensive areas of land under which water lies at a depth of 100 feet or less, it is probably not too much to say that, excepting within the region irrigable from the Colorado River, more land will ultimately be irrigated by pumping than from surface waters.

It is therefore true that the apparent misfortune of drought in southern California twenty years ago has reacted with tremendous benefit not only upon agriculture by irrigation in the arid Southwest, but upon the power resources of the civilized world at large. It is therefore of interest in this publication to follow critically the details of oil engine construction and the availability of oil engines for the uses of the irrigation farmer.

R. H. FORBES*

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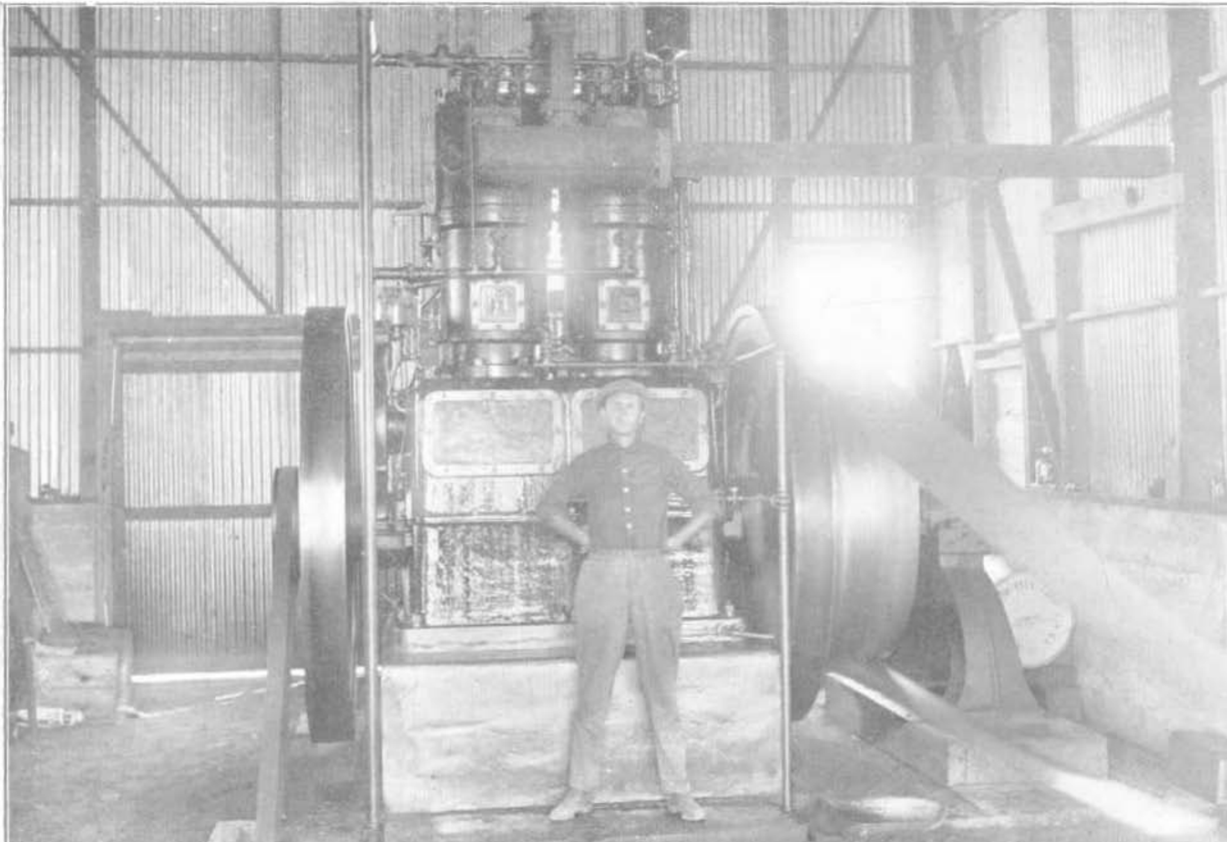


PLATE I.—AN IRRIGATION PUMPING ENGINE NEAR AVONDALE, ARIZONA.

Oil Engines for Pump Irrigation

By G. E. P. Smith

INTRODUCTION

The term oil engines as used in the title means the various types of internal-combustion engines designed to burn low grade petroleum distillates and even the crude petroleum oils from certain oil fields. These engines have been called crude oil engines, fuel oil engines, oil-burning engines, and oil engines. The last named term does not intrude on any other established name and is very simple. It is therefore to be preferred. The term crude oil engines is objectionable since most of these engines do not burn successfully the crude oils from the California or Texas oil fields. The term fuel oil is applied to the heavy oils from 14° to 20° Beaume that are burned under steam boilers, but it is also a generic term for all oils used as fuel.

Nearly all of the oil engines are of recent introduction. Very few of them have been in service more than two or three years, and it is impossible, therefore, to pass final judgment regarding their merits. However, these engines are being advertised widely and strong claims are made for them, as a result of which they are being purchased in great numbers by pump irrigators in Arizona and elsewhere. In the absence of widespread experience such as is common in the case of gasoline engines, it is obvious that some disinterested estimate of oil engines is desirable, both to assist a purchaser to know whether oil engines are adapted to the conditions of his power plant, and to enable him to judge intelligently the relative merits of the various oil engines that are on the market.

In the preparation of this bulletin the plan has been to become familiar with the oil engines already installed, to make various tests upon them to determine the fuel economy, the capacity, and the speed regulation, and to profit by the experience of the owners of the engines in ascertaining their dependability and their shortcomings. The broad question of adaptability to farm conditions depends on a wide range of factors, including not only those mentioned, but also many others such as the amount of expertness required, ability to run alone for several hours without attendance, and the probable length of life. In the present investigation the whole problem of adaptability to farm conditions has been attempted.

The investigation has been made from the standpoint of the farmer irrigator. Power tests on engines are made almost invariably in factories or under other equally favorable circumstances, with expert mechanics present to tune the engines up to the highest pitch of excellence. Such tests are exceedingly useful, especially for engine designers and builders. It is misleading, however, for a purchaser to accept the results of those tests as a basis for calculating his requirements on the farm. What the purchaser needs to know is just what can be expected of an engine under field conditions. Consequently the engines that have been selected for testing have been in all cases already installed and in service at pumping plants, apparently running at their best under the care of the farmer irrigators. Whenever practicable some representative of the manufacturers has been asked to be present at the tests.

In a comparison of oil engines with gasoline engines, no one would deny a preference for the latter, if they could be put on the same basis as to fuel cost. A well-built gasoline engine operated properly is the acme of dependability and cleanliness. Cases are known where gasoline engines run steadily many hours without any attendance whatever. In one instance the owner starts his engine and pump at evening, then drives to the nearby city, and returns In the morning to shut down the plant. It is of common occurrence to see engines started in less than one minute of time.

The consumption of gasoline, however, has increased vastly in recent years. During 1913 the number of automobiles in use in this country passed the million mark, while the number of motor trucks reached 65,000.* Motor boats and a host of other uses for gasoline engines have further increased the demand and emphasized the shortage of the supply. Meanwhile the production of crude oil in the United States has about reached a maximum, the total production at the present time increasing at the rate of only one percent a year. In some fields, indeed, notably in Pennsylvania and Texas, the production is declining. The refineries have endeavored to supplement the regular supply of gasoline by cracking heavy distillates in such manner as to yield gasoline as a product; and considerable gasoline is now being obtained by liquefying natural gas from gas and oil wells. But the growing demand has much exceeded the supply, with the natural accompaniment of rising prices. It is inevitable

*In 1914, the number of automobiles and motor trucks in the U. S. reached 1,711,339.

that the demand for gasoline will continue to increase in the future, and likewise the price.

In contrast with the stringency in the gasoline supply, there Is in the West an over-supply of heavier distillates This condition Is easily explained. In the process of distillation by which crude oil Is separated into its constituent parts, the oil is heated slowly; the gasoline passes off first, while the temperature approaches 250° P., then various grades of distillates, including engine distillates, lamp-oils, the new fuel oils, and, lastly, the lubricating oils vaporize, leaving the asphaltum residue, which is solid at ordinary temperatures. In some refineries only the gasoline and engine distillates are removed, the remainder being sold as boiler fuel oil. The percentage of gasoline is, in the case of California oils, very small, usually only two or three percent of the crude oil, while the percentage of distillates heavier than gasoline is much larger, about fifteen times the amount of gasoline. A certain amount of the heavier distillates is refined to remove impurities and to make it colorless, and is then sold as kerosene, but the demand for refined kerosene is small. The heavier distillates are produced also in large quantities in the process of making road oil and in other refinery operations, and great amounts are turned back into the fuel oil to be burned under boilers because there is insufficient demand for the distillates. The price of the distillates (January, 1915) is $2\frac{3}{4}$ cents a gallon for 38° to 43° Beaume and $2\frac{1}{8}$ cents a gallon for 26° to 34° Beaume, f. o. b. cars at the refineries. These prices are but little higher than the price of fuel oil for boilers.

A few years ago It was thought that the use of denatured alcohol as a fuel would be a solution of the farmers' power problem. But the general manufacture of alcohol from wastes presents many difficulties, and the cost cannot be brought down even to the point of competing with high grade gasoline. Moreover, the amount required per unit of power is greater, and it is necessary to maintain a higher rate of compression in the engine. So it may be definitely accepted that alcohol never will come into common use as an engine fuel.

The net result of the foregoing conditions is that for pump irrigation and similar power purposes the heavier oil distillates must be utilized for internal-combustion engines. All the gasoline engine manufacturers realize this condition and scores of them are preparing to put an oil engine on the market, or have already done so.

FUEL OILS

While there is but one grade of commercial gasoline there are many varieties of the heavier oil distillates suitable for oil engines and a knowledge of these oils will be useful to one who has to choose between them in purchasing a fuel supply for his engine. In some cases two oils under different trade names but made by different companies are almost identical in composition and in their physical characteristics. But each refinery markets a variety of oils, and oils from different fields may be very dissimilar even though having the same specific gravity.

FUEL OIL TESTS

The qualities of fuel oils for which tests are applied ordinarily are as follows:

1. Specific gravity
2. Flash point
3. Burning point
4. Thermal value (amount of heat per pound)
5. Solidifying point
6. Asphaltum content
7. Water and sand content

There are two scales in use for expressing specific gravity, the Beaume scale and the standard decimal scale. In the former the specific gravity of water is taken at 10°, while that of commercial gasoline is about 60°; in the latter, water is taken at unity, that is 1.000, while gasoline is about .737.

The specific gravity of oils is commonly measured on the Beaume scale, though this is decidedly inferior to the standard decimal scale* In this bulletin both scales are used. The formula for conversion is as follows:

$$\text{Specific gravity (decimal)} = \frac{140}{130 + \text{Beaume value}}$$

The flash point of an oil is the temperature at which vapor is given off in such quantity that it flashes when exposed to an open flame. A relatively low flash point, say below 100° F., is desirable for oil engines.

The burning point is the temperature at which the "flash" becomes permanent.

The thermal or calorific value is an index of the theoretic power in a pound of fuel. It is measured in British Thermal Units (B. T. U.) per pound of oil. The British Thermal Unit 19 the amount of heat required to raise a pound of water one degree Fahrenheit in temperature, more precisely, from 39° F. to 40° P. Its mechanical equivalent is 778 foot-pounds of work, equal to a horsepower for 1,41 seconds. Ordinarily oil contains a small amount of water, and when burned in an internal-combustion engine the water is vaporized and passes off as steam carrying away a measurable quantity of heat thereby. In all cases, also, water vapor is one of the products of combustion of the oil. If the heat of vaporization is deducted from the total heat in the oil the remainder is called the Lower Thermal Value; it represents the theoretic amount available for mechanical work. If the heat in the steam is not deducted, the total amount is called the Higher Thermal Value; it is the value obtained by means of the calorimeters in common use.

The solidifying point and the asphaltum residue are of interest in connection with fuel oils which are to be burned under boilers, but do not apply in testing the distillates that are suitable for oil engines.

Still another characteristic for which tests are made, viscosity, is of interest in connection with lubricating oils. For cylinder oils the viscosity should be determined at high temperatures. The sulphur content, too, is often determined, but is not considered of so much importance now as formerly. The sulphur in California oils varies from ,10 to 2.00 percent. Most of it remains in the asphaltum residue, and the percentage in tops or gas oil is exceedingly small.

The two qualities of greatest significance are the flash point and the thermal value. The former is an indication of the suitability of an oil for internal-combustion engines, particularly high-speed engines, and of the relative ease or difficulty of starting the engines. The thermal value indicates the relative economy of oils, though when oils are bought by volume and not by weight, the relative economy is dependent also upon the specific gravity.

The only test, however, that can be made easily is the specific gravity test. It is made by floating an hydrometer in the oil, and noting the scale reading of the part submerged. There should be an hydrometer in every community. With the limited number of oils which find their way to a single locality, the characteristics of these oils in the oil engines will soon be known by experience had with them, and thereafter the hydrometer test will be sufficient to identify the oil which a purchaser prefers for his engine, though it is desirable to make occasional tests of the fla$h point.

When using an hydrometer the temperature of the oil should be obtained also. A correction can then be applied to reduce the specific gravity to what it would be at 60° F., the standard temperature. Approximate rules for this correction are as follows:

For gasoline, allow one degree Beaume for each 10 degrees F.
For tops, Residium, and similar oils of about 40° B., allow one degree Beaume for each 12 degrees F.
For Star fuel oil and similar oils of about 25° B., allow one degree Beaume for each 15 degrees F.

The correction is to be added if the temperature of the oil is below 60° F. when tested, and subtracted if the temperature is above 60° F.

FUEL OILS AVAILABLE IN ARIZONA

A list of some of the fuel oils on the Arizona market with some of their characteristics is given in Table I. They all are products or by-products of refineries. The last one on the list is oil from the Oklahoma oil field; it has a paraffine base, while the oils from California and from the southeast Texas fields have an asphalt base.

TABLE I.—SOME CHEAP FUEL OILS AND THEIR CHARACTERISTICS

Name	Manufacturers	Specific gravity	Flash point	Burning point	Remarks
		°B.	°F.	°F.	
No. 1 tops	Kellogg Oil Co.	32	93	120	. . . . . .
No. 2 tops	Kellogg Oil Co.	39	108	135	. . . . . .
No. 2 tops	Kellogg Oil Co.	40	58	84	. . . . . .
Tops (or Residium)	Union Oil Co.	40	. . . .	. . . .	. . . . . .
Tops	Union Oil Co.	27	. . . .	. . . .	. . . . . .
Special gas oil	Standard Oil Co.	44	59	77	. . . . . .
Union gas oil	Union Oil Co.	44 6	. . . .	. . . .	. . . . . .
Star fuel oil	Standard Oil Co.	24	195	245	21% asphalt
Boiler fuel oil	Standard Oil Co.	17	174	. . . .	42% asphalt
Low grade Solar oil.	Texas Oil Co	37.5	200	233	. . . . . .
Kerosene	. . . .	47	115	. . .	. . . . . .
No. 640 fuel oil. . . .	Amer. Ref'g Co.	SO	180	230	Opaque

Most of the names given in Table I are the trade names. The name "tops" has a very flexible meaning. It was first given to the oil obtained by rapid and careless distillation from heavy crude oils in order to fit them better for use in locomotives. The resulting distillate was very irregular in specific gravity and in other characteristics. More recently this product has been standardized to some extent, and graded into two classes. Now the name is applied also to distillates of equal gravity obtained in the usual process of distillation in which the gasoline and engine distillate are removed first. Tops obtained by the latter process have a higher flash point than when derived by the former process. The corresponding fuel oil marketed by the Standard Oil Co. is called Special gas oil, while the Union Oil Co. has recently placed on the market a similar fuel oil called Union gas oil. These two oils have a gravity of about 44° B., but they do not differ essentially from No. 2 tops. Most of the figures given for specific gravity and for flash point are based on the few samples tested during the investigations covered by this bulletin.

Kerosene has become a standard fuel oil for farm engines in the Northwest, and special low grades of kerosene are furnished for the purpose. A correspondent in Wisconsin stated recently in a letter: "The last car of kerosene that we received here at the factory showed a test as follows: 154° flash, 41° B. gravity. All the cars that we get run between 39° and 41° gravity with the flash anywhere betweea 140° and 150°." It is evident from the description that the engine kerosene of the Northwest is practically the same sort of oil as the tops of the Southwest.

Boiler fuel oil is included in the list of oils in Table I in order to emphasize by comparison its low gravity and its high asphaltum content. Its characteristics are very variable.

Lubricating oils, also, are obtained in the process of distillation. Those requiring the most heat to vaporize and consequently coming off last are sold to lubricate hot surfaces such as engine cylinders, and are known as high fire test lubricating oils. Such oils have a specific gravity of about 25° Beaumé and the flash point should be about 400° F.

The problem of how to buy engine fuel oil needs some comment. The common practice is to purchase one, two, or three drums of oil at a time, waiting each time until the supply at the pumping plant is nearly exhausted. This plan requires the payment of 40 to 50 percent profit to the retailer. It is, perhaps, the best way for small engines. But farmers with engines of 15 horsepower or larger who run their plants over 1500 hours each year can well afford to buy at wholesale. The best plan is for three or four neighbors together to purchase a carload of 9000 or 10,000 gallons and to build at each pumping plant a tank with a capacity of about 3000 gallons. The oil can be purchased in the early spring and hauled home during cool weather before the rush of spring work.

A well built tank of galvanized iron, covered, is the safest. Such a tank holding 3000 gallons can be purchased for about $100. A concrete tank built in a dug pit is cheaper, and if built strongly and waterproofed, is preferable. But it requires a dense rich concrete with wash coats and a man who is not familiar with concrete construction should not undertake it alone.

OIL ENGINES

CLASSIFICATION

Oil engines can be classified in many different ways, according to the cycle, or the method of ignition, or the fuel feed, or some other principle or feature of construction. The following classification is based primarily on the cycle, and the subdivision of four-cycle (four-stroke-cycle) engines is based on the method of fuel feed. This results in three main groups. A few examples are given in each class, but no effort has been made to present a complete list of the oil engines now on the market.

The classification will be found advantageous to a purchaser, in that it gives a mental conception of the relationships between the various engines. The buyer should determine, first, what type of engine he desires, and then select an engine of that type. The ordinary method of considering each engine in an individual class leads to confusion and makes a selection more difficult.

CLASSIFICATION OF OIL ENGINES

I. Four-cycle

1. Fuel injection by compressed air—the Diesel group

American Diesel	Snow
Fulton-Tosi	De La Vergne (Type FH)
Allis-Chalmers	

2. Fuel injection by pump (only one engine of this type.)

De La Vergne (Type HA)

3. Suction fuel feed—modified gasoline engines

Fairbanks-Morse & Co	International Harvester Co.
Western	Otto
Rumely-Falk	Commercial
Alamo	

II. Two-cycle

1. Fuel injection by pump—hot-ball engines

Muncie	National
Simple	Crescent
Stover	Venn-Severin
Remington	Mietz & Weiss
De La Vergne (Type S)	Bessemer

THE DIESEL GROUP

The first group is of the general Diesel type. The Diesel engine dates from 1893. Although it is theoretically the paragon of internal-combustion engines, it requires massive construction, exceptionally close machining and expert attention, and its first cost is very high. Consequently its use is limited to large units, the smallest so far manufactured in the United States being 60 horsepower, and very few being less than 100 horsepower.

A brief introductory description of the Diesel engine will be given. Its main principle is that of combustion at constant pressure (or nearly so) as opposed to combustion at constant volume of the gases, which is the principle of the ordinary gas and gasoline engines. In the Diesel engine the clearance space is very small, and therefore the air charge is compressed on the compression stroke to very high temperature and pressure. The temperature reaches to above 1000° F. and the pressure to over 30 atmospheres, from 450 to 500 pounds per square inch. At the end of the compression stroke the fuel is injected into the cylinder gradually and burns as fast as it enters and comes into contact with the hot compressed air. There is no explosion. The fuel valve remains open for about a tenth of the power stroke, maintaining the high initial pressure during that time. After the valve closes, the gases work expansively during the rest of the stroke.

The injection of the fuel oil is effected by compressed air from a two or three-stage air compressor which usually is built attached to the side of the engine. Any sort of liquid fuel can be used, even though it contains as high as 50 percent of asphalt. The efficiencies obtained are exceedingly high, being twice as high as can be expected from the small gasoline engines in common use.

The De La Vergne engine, type FH, is a modification of the Diesel, In order to obviate the necessity for the extremely high compression pressure, a hot chamber without water jacket is built in the cylinder head. The walls of the hot chamber become dull red hot and the heat thus retained combined with the heat of a more moderate compression is sufficient to ignite the fuel, which is introduced in practically the same way as in the Diesel engine.

During the past two years several true Diesel engines have been put on the market. These include the Snow, the Allis-Chalmers, and the Fulton-Tosi, all of which are represented by installations in Arizona.

The engines of this group are practicable for pump irrigation only for large cooperative projects, either for generating electric power at a central station or in cases where a large volume of water is to be pumped with a high lift at one plant.

THE MODIFIED GASOLINE ENGINE GROUP

(THE CARBURETOR TYPE)

These engines are similar in construction to the common gasoline engines with suction spray carburetors and electric ignition, except for one or two additional features. The most important is the introduction of a small amount of water vapor into the gas charge. This is accomplished by changing the design of the carburetor somewhat, adding a second needle valve through which water is fed just as the fuel oil is fed through a needle valve. Usually, also, the air is preheated by being passed through a chamber surrounding the exhaust pipe close to the cylinder, or by passing part of the exhaust through a coil in the carburetor. These two features make it possible to burn California and Texas distillates as low as 38° Beaume with perfect success. Preheating of the air is of greater importance in the winter than in the summer. When operating on oils of low gravity, the time of ignition is set considerably earlier than for gasoline, and the clearance space should be reduced somewhat in order to increase the compression pressure to about 80 pounds, gauge pressure.

There are many gasoline engines in use today which can be converted into oil-burning engines by the addition of the above named features, at least the water feed. Some factories already make and offer for sale the new type of carburetors and exhaust blocks to replace those in use on old engines of their manufacture. Other factories will probably do the same in the near future. A less desirable method of converting a gasoline engine is by arranging a twisted wire or wick suspended beneath a pail of water, with its lower end just over the entrance to the air intake pipe, so that a drip of water is always being absorbed by the intake air. In several places this crude makeshift has been observed to be working satisfactorily with low grade Solar oil or tops. A better way is to tap a quarter-inch pipe into the water jacket and lead the water to the end of the air inlet pipe, controlling the drip with a pet cock. Most gasoline engines will burn distillates with a gravity as low as 50° Beaume without the water attachment. But the attachment, permitting the use of the more plentiful and much cheaper 40° oils, is an adjunct greatly to be recommended, and it is to be hoped that manufacturers generally will make and offer the double needle carburetors for converting engines already in use into oil engines.

The function of the water in the charge is not definitely known, though many explanations and theories have been advanced. Indicator cards taken on Engine No. 3 (see pp. 407-8) and on other oil engines (see pp. 392, 422) show that the explosions are not sharp and sudden as in gasoline engines, and the initial pressures do not reack so high. The explosions are softened down, producing a slower, burning effect, similar in part to the combustion in Diesel engines. The water may unite with the oil and air to form carbon monoxide and hydrogen, as in water gas, during the first stages of the combustion, and these products may burn in the latter stages of the combustion. Also, the water may act as a catalytic agent, insuring more complete combustion of the complex hydrocarbons. At any rate, its influence is very marked in several directions. It not only slows down the explosions and makes more perfect combustion, but it thereby prevents carbon deposits in the cylinder and on the valves, and it keeps the engine cooler and prevents preignition. Like anything else water feed can be overdone. Undoubtedly an excessive amount of water is a disadvantage.

In warm weather it is not difficult to start the oil engines on 40° oils, the flash points of which are not too high, but in cold weather the heavy distillates do not vaporize readily and it is necessary to start the engine on gasoline, either by priming it or by connecting the carburetor temporarily to a small tank containing gasoline. Some of the new type carburetors have a third needle valve for introducing gasoline when starting up.

The carburetors that are now to be found on oil engines are of the jet nozzle type such as have been used on gasoline engines for many years. There is opportunity for improvement in this regard. If carburetors could be especially designed to give more thorough atomization of the oil, perhaps with hot air, it is reasonable to expect that distillates as low as Stove oil (30° Beaume) could be burned successfully.

The critics of this type ot engines are fond of calling them made-over engines. The implied sarcasm loses its force, however, when a comparison is made of the running qualities of these engines with other engines. So long as distillates of 38° Beaume or better are used, they show perfect combustion and reliable operation.

THE HOT BALL GROUP

These engines work on the two-cycle principle, that is, there Is an explosion during each revolution of the crank shaft. The fuel Is injected into the engine by means of a small plunger pump instead of being drawn in through a carburetor. However, the most prominent feature is the hot ball attached to the cylinder head, by means of which the fuel oil is vaporized, and the charge ignited. A sectional view and plan of a hot ball is shown in Fig. 1, which is drawn to scale.

The general principles of the hot-ball engine are illustrated in Fig. 2, which is a sectional view of a vertical engine. The piping for the fuel feed, the exhaust, and the circulating water are omitted from the drawing. The hot ball is seen at the top. Its interior communicates with the cylinder through the constricted opening or throat. The exterior circular portion is protected by a hood.

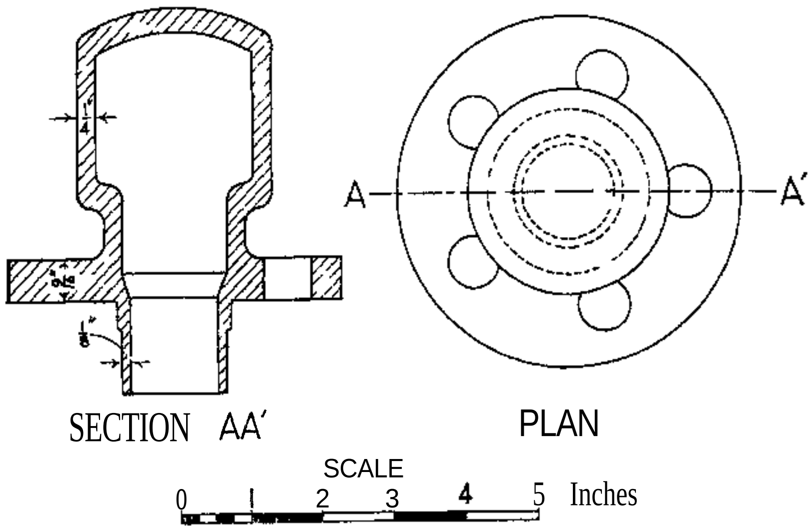


Fig 1 —Section and end view of hot ball on Engine No 7.

The fuel nozzle is shown at the right. It is a simple form, but most of the nozzles in use are of special design, with spring valves for cutting off the supply suddenly so as to prevent dribbling of the oil.

The crank and connecting rod are housed tightly in the crank case, the inlet to which is through the air intake strainer shown on the left. The outlet is through a passage-way in the cylinder walls shown on the right-hand side. When the piston rises to the head end of the cylinder it uncovers the air intake opening and air enters the crank case. As the piston descends it doses this opening and compresses the enclosed air until the inlet port is uncovered, when the compressed warmed fresh air rushes into the cylinder. At the same moment, the exhaust port being uncovered, the burned gases escape through the exhaust pipe and muffler.

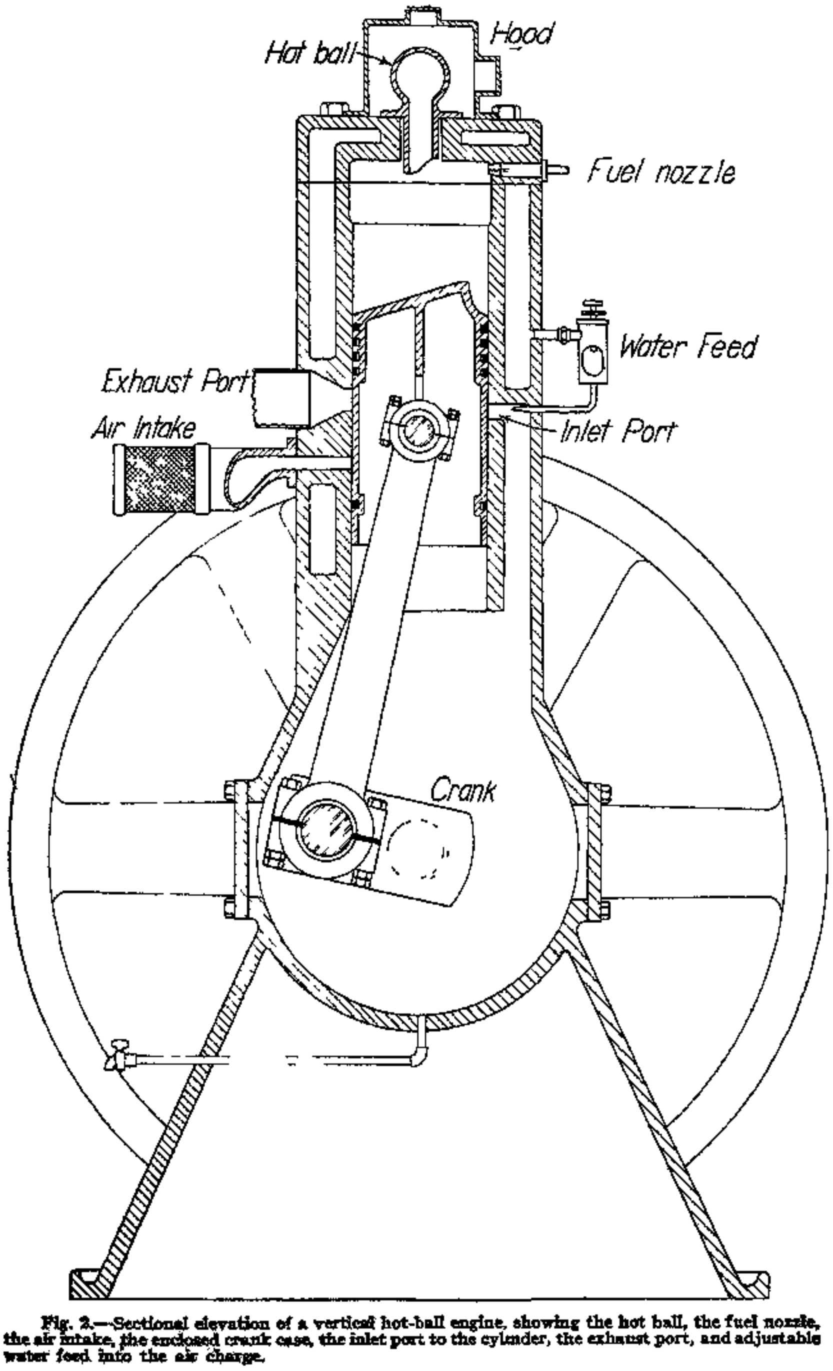


Fig. 2.—Sectional elevation of a vertical hot-ball engine, showing the hot ball, the fuel nozzle, the air intake, the enclosed crank case, the inlet port to the cylinder, the exhaust port, and adjustable water feed into the air charge.

The cycle of events in the cylinder proceeds as follows: on the upstroke the piston rises, compressing the air charge. When this stroke is nearly completed a charge of oil is suddenly squirted through the fuel nozzle against the hot throat of the hot ball. The oil is vaporized and mixes with the air, and the final heat due to compression together with the heat from the hot ball ignites the charge. This, of course, increases the pressure greatly. The piston descends until

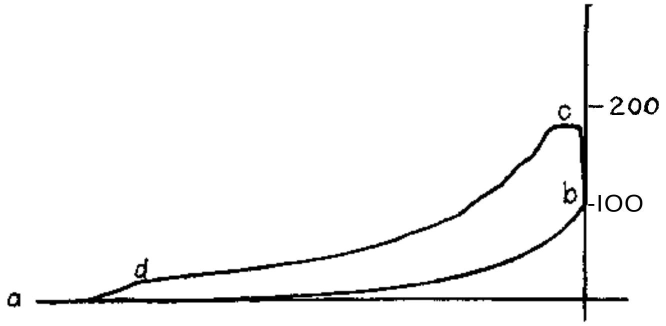


Fig 3.—Indicator card from a 20-horsepower Muncie oil engine. Card was taken when engine was heavily loaded and while small drip of water was being fed with the charge

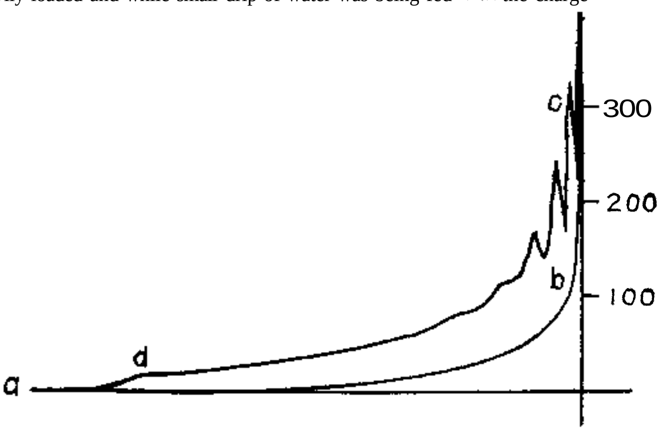


Fig. 4.—Card from same engine, heavily loaded, but with water feed valve closed.

it uncovers the exhaust port and, slightly later, the inlet port* The burned gases escape, another charge of air enters, and the cycle of events is repeated.

The curved form of the piston head is for the purpose of deflecting the entering air upward, since otherwise the fresh air would tend to rush out through the exhaust, leaving the cylinder practically full of the dead burned gases left by the previous explosion. The scavenging of the burned gases is incomplete, however, and larger cylinder capacity is allowed in the design of the engine.

Provision is made for mingling a small quantity of water vapor with the air just before it enters the cylinder. This feature is shown in a diagrammatic way at the right-hand side of the drawing. The amount of water fed into the charge is regulated usually by hand, but one manufacturer employs a thermostat. As the load increases and the amount of fuel oil fed is increased, the amount of water vapor should be increased also.

The effect of the water vapor in the charge is exhibited graphically by means of indicator cards. In Figs. 3 and 4 are two cards taken on a 20-horsepower Muncie oil engine on the Kennison ranch near Tucson. The upper card was taken with the water feeding regularly while the lower one was taken with the water feed valve closed. The compression line *ab* is practically the same on the two cards. The explosion line *bc* on the upper card is of moderate height, about 185 pounds, and terminates in a short horizontal line, showing that the fuel burns slowly as in the true Diesel type of engines, rather than explodes. From the lower figure it is apparent that the combustion in that case is sudden and violent. The oscillations set up in the indicator spring produce the wavy line. In the one case the combustion takes place at constant pressure of the gases, and that pressure is only 185 pounds per square inch. In the other case the combustion is at constant volume, and the maximum pressure exceeds 300 pounds per square inch. The extremely high pressure, being merely momentary, is like a dynamite explosion. It expends itself on the engine frame rather than in useful work. The area of the upper card is 16 percent greater than that of the lower card, showing that the engine was doing 16 percent more work, and yet the vibration and the strain on the engine were far less.

The expansion line to *d* and the exhaust line *da* are practically the same on both cards. The explosion occurred too early without the water feed, and slightly late with the water feed.

One effect of the water vapor is to prevent the engine, especially the hot ball, from overheating. When the water is shut off, the ball may become bright-red hot, causing too early ignition, and the engine pounds. When the water is fed, the ball remains at a dull red color, which is as it should be. An excess of water cools the engine too much and It misses explosions.

A disadvantage of the high degree of heat maintained in the cylinder is that the cylinder lubrication is more difficult than in the ordinary four-cycle engines. It is found that sight-feed oil cups are not dependable; forced feed lubrication is necessary. A better grade of lubricating oil should be used, and more of it.

As with all two-cycle engines the speed of these engines is high, and the flywheels are lighter in weight than those of four-cycle engines of equal power.

The engines are started by first placing a blow torch underneath the hot ball and heating it for from 10 to 40 minutes until the ball is dull red in color; the fuel pump is then worked by hand a few strokes to inject some oil into the cylinder, and then when the flywheels are rocked back and forth, the engine starts readily, though not always in the right direction.

Heavier oils can be burned in these engines than in the modified gasoline engines. Tops of 30° Beaume are much used and 24° oil can be used in some of the larger engines.

Hot-ball engines have many unique features which stand in contrast with the commonly criticised features of standard four-cycle engines, and which therefore promote their sale.

It is a matter of doubt, however, whether the hot-ball engines as manufactured in most of the factories have escaped yet from the experimental stage. This being the case, it is a question whether our farmer irrigators are justified in purchasing hot-ball engines extensively at this time. The farmer's engine (in Arizona) is from one to fifty miles from a machine shop where repairs can be had, as a rule no skilled mechanic is conveniently near, oftentimes indeed it is difficult to get a man to assist in starting an engine. It should not be forgotten, too, that the pump irrigator is under the stem necessity of keeping his plant going, especially through the spring and summer months when a week's shut-down may cause the loss of some crop. Up to the present time the majority of pumping plants using hot-ball engines have not been profitable investments, though in some cases other causes than the engine have contributed to their failure.

COMPARATIVE DATA

Some pertinent information concerning oil engines has been brought together in Table II, Under each type are given several illustrative examples, the sizes given being as nearly uniform as possible. The data cover the bore, stroke, speed, weight, ignition, compression pressure, and approximate retail price at Tucson.

The bore, stroke and speed together constitute a measure of the engine's power for the reason that the power of each explosion is limited by the quantity of air which the cylinder receives and rejects in each cycle. The larger the quantity of air, the larger the amount of fuel that can be burned. Some engines make up in number of revolutions what they lose by reason of having a small cylinder capacity. This method of rating assumes the use of the same fuel and therefore the same compression. Steam engines are sold by bore and stroke, the piston speed being assumed constant, and there is good reason for applying a similar rational method of rating to internal-combustion engines. Under the present custom, some manufacturers rate their engines higher than do other manufacturers. At any rate, engine catalogs should state the dimensions (which they do not) so that purchasers can make the comparison tor themselves.

The weight, also, is an important attribute of an engine. If the details of construction are equally good, then a heavy engine will be likely to require fewer repairs and will have a longer life than will a lighter-built engine. A light engine has some advantage for portable service. Theoretically, two-cycle engines ought to be lighter and to require smaller cylinder capacity than four-cycle engines. The data given in Table II indicate that about the same weight and cylinder capacity are required in both types, and it is presumable that the explanation lies in the fact that the two-cycle engine does not eject the burned gases of each explosion thoroughly, in other words, it does not scavenge well.

A complete list of oil engines would be very long. A prospective buyer can obtain the comparative data for any other engines which appeal to him and the table will thus serve as a basis for judging oil engines. Additional matters to be considered by a purchaser are the character of the engine details and the reputation of the engines as obtained from other users. The prices quoted are approximate only, for prices are often changed, and they depend, moreover, upon the terms of payment.

TABLE II.—COMPARATIVE DATA ON OIL ENGINES

Engine	Rated power	Diameter of cylinder	Stroke	Speed	Piston displacement per minute per H P	Shipping weight	Shipping weight per H P	Ignition	Compression pressure	Approximate retail price 1914
	H P.	In.	In.	R.P.M.	Cu. in.	Lb	Lb.		Lb. per sq. in.	
				4-CYCLE						
				Injection by Compressed Air †						
Diesel (3 cyl.)...............	120*	12	18	225	15,266	48,000	400	Compression	500	$10,000
De La Vergne (Type FH) ...	65*	14	24	225	12,800	33,500	515	Hot chamber	280	5,000
Snow‡.................. ...	60*	13½	21	...	12,240	32,000	533	Compression	490	4,000
				Suction Fuel Feed						
F. M. & Co. (Type N)........	15	8¼	14	250	12,490	4,750	317	Make and break	...	575
Western........	16	7¼	14	300	10,837	3,570	223	Bosch jump		625
Rumely Falk	15	7½	12	375	13,260	4,050	270	Make and break		650
Alamo...........	15	8½	12	280	12,710	4,400	293	Make and break	50 to 70	775
Commercial...................	15	7	14	300	10,776	3,600	240	Make and break		570
Lauson........................	14	8¾	12	275	14,150	2,900	207	Make and break		600
I. H. C.......................	15	8	14	275	12,900	5,150	343	Make and break		650
				2-CYCLE						
				Pump Injection						
Muncie........................	20	9	13	285	11,600	5,100	255	Hot ball		.....
Stover........................	12	7½	10	325	11,962	2,750	229	Hot ball		500
De La Vergne (Type S)......	12½	8	10	450	18,100	2,700	216	Hot chamber		780
Crescent†.....................	15	9	9	400	15,250	5,000	334	Hot ball	80 to 130	1,000
Venn Severin................	15	8	10	350	11,800	3,100	207	Hot ball		500
Mietz & Weiss...............	18	10	12	340	17,800	6,200	344	Hot ball		1,100
Bessemer‡	15	8½	15	190	10,780	4,450	297	Hot ball		600
Bessemer‡....................	40	12	18	250	12,730	12,600	315	Hot head	180	.....
Primm‡.......................	15	9	12	300	15,270	3,750	205	Hot Plate	80	700
Anderson	20	10	14	.....	......	5,500	275	Hot dial	.....	815

†No water injection. *Smallest size listed in catalog. ‡With crosshead.

PLATE II.—MISCELLANEOUS APPARATUS FOR ENGINE TESTING

The can with three spouts permits close measurement of the fuel consumption. Flash point tester, hydrometer, tachometer, and platform scales for Prony brake are shown.

TESTS OF OIL ENGINES

Tests were made upon seven engines to determine their fuel economy, capacity, and other characteristics. The general method of making the tests is described briefly as follows. The driving pulley was removed, if necessary, and the brake pulley was set on the engine shaft. Platform scales were placed so as to carry the brake load. The fuel supply pipe was disconnected and rearranged to take the fuel from a small tank. Thus the fuel "input" and the power "output" could be measured accurately. The load on the engine was changed at intervals, the program being usually to test the engine at ¼-load, ½-load, ¾-load, full load, and overload. In the last named test the capacity of the engine was determined partially.

The history of each engine was obtained and its idiosyncrasies and the difficulties previously encountered in its operation. Likewise the balance of the engine, the cleanliness of the exhaust, the wear on the cylinder, and other matters which might throw light on the reliability of the engine and the probable length of its life, were carefully noted. No engine that had been long in service was selected for testing, nor an engine that was absolutely new, but preferably one that had been used sufficiently to be in the best possible condition, with a "running fit."

Ordinarily the engine was operated during the test by the regular attendant, though in three cases agents of the manufacturers gave some assistance, and in two cases the engine was run by the writer. The results obtained for fuel economy are not ideal for the various engines tested, but the results do represent fairly what pump irrigators can expect of the engines under field conditions.

The tests were made under one handicap. The engines, in all cases except two, were needed for pumping water and hence the tests were confined to one day. The short time thus allowed did not permit of varying the several contributing factors of fuel consumption. The various valves were set, therefore, so as to give what the operator considered to be the proper sound, color of exhaust, temperature of cylinder, and other conditions.

DESCRIPTION OF APPARATUS

The equipment for making the tests was designed to be as light and portable as possible. In several instances it was hauled for many miles from the railway in order to reach an irrigator's pumping plant.

SPEED

During the first tests a revolution counter held by hand against the end of the main shaft was depended upon for obtaining the speed. Later a Veeder ratchet engine counter was employed. On account of its continuous action, it is superior to the hand counter. A Schuchardt & Schutte hand tachometer was exceedingly useful in studying the balance and governing of the engine.

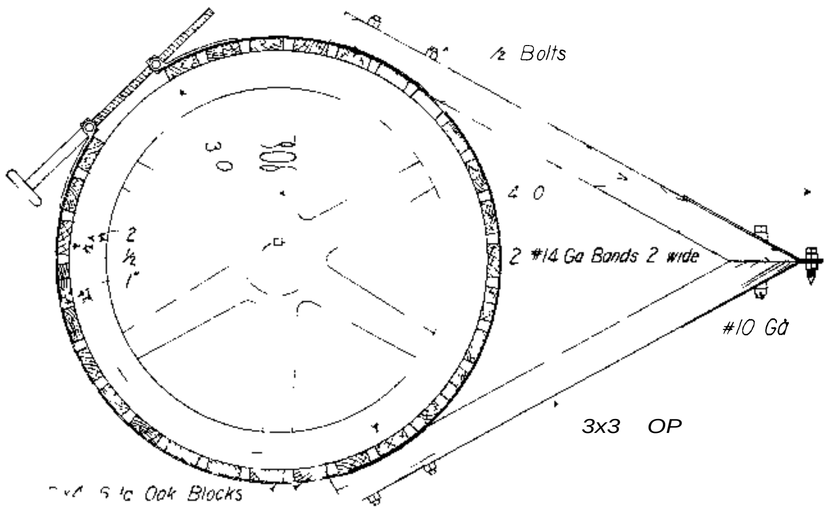


Fig 5—**Prony** brake and water jacketed pulley used for brake tests on all engines **except** Engine No 6

POWER

The power was measured by the aid of a Prony friction brake, the design of which is seen in Fig. 5. The friction was taken by oak blocks 2″x 4" x 6" long, held together by two bands of 14 gauge iron. A long threaded connecting rod with hand wheel permitted adjustment of the friction load. The wedge shaped bearing point was set on a level with the center of the shaft and directly over the center of the scale platform.

A special pulley was used with the brake. The pulley rim has flanges projecting in and out, the inside flange holding the cooling water, and the outside flange serving to keep the water away from the oak blocks and to retain the lubricating oil.

A larger pulley and brake of the same type were used for testing Engine No. 6.

Platform scales were used in all cases. The scales were tested by official sealers for Tests Nos. 3, 6, and 7, and by means of a standard 50 lb. weight for Test No. 5. In the three other cases the scales were not tested; they were, however, borrowed from reliable merchants.

It is desirable always to introduce some sort of spring device between the brake and the scale. A pair of light wagon-seat springs mounted on a short 4" x 4" post served effectively to cut out the engine vibrations.

FUEL CONSUMPTION

The fuel consumption was taken by volume, rather than by weight as is done usually. The gallon measure was standardized before the tests, and the accuracy in filling the measure was equal at least to that of weighing to the nearest ounce. Glass graduates were used for the fractional gallons.

The specific gravity of the oil and its temperature were taken at intervals. Hence, the volume used can be transformed into weight used, should anyone desire to do so.

It is impossible to measure the oil in the regular engine tank because the changes of volume due to changes in temperature of the whole mass are large relative to the small volume used. This necessitated using a special small fuel tank. The one shown in Plate II has three short spouts soldered into the top, one being for the supply pipe, one for the overflow from the engine, and one for filling.

INDICATED POWER

This was measured on Engines Nos. 3 and 7 only. A Crosby combined steam and gas engine indicator was used and cards were taken every five minutes. Gas engine cards are unsatisfactory, however, since the expansion lines differ widely on account of the varying character of the gases left in the cylinder and of the entering charge. A fair estimate of the indicated power might be obtained if cards were taken every minute or half minute and then averaged, but this is hardly practicable.

COOLING WATER

The amount of cooling water used and the increase in temperature were measured, when practicable. The engine thermometers purchased for this work were found to be in error from 10° to 15°.

They were calibrated, however, so as to be serviceable. The inference is that a cheap engine thermometer should be tested by placing it in hot water together with another thermometer that is known to be right.

The determination of the heat (power) lost through the circulating water makes it possible to know the approximate power loss in the exhaust gases, for the indicated power plus the water loss and the exhaust loss must approximate the theoretic power in the fuel consumed. It was attempted to measure the temperature of the exhaust gases directly during the test of engine No. 7, but when the temperature reached the limit (750° F), the thermometer was withdrawn in order to save it from breaking

The amount and temperature of the carburetor feed water were measured in several of the tests.

ENGINE NO. 1

A 20-HORSEPOWER 9" X 13" MUNCIE OIL ENGINE

This engine is the property of J. W. Angle of Willcox, Arizona, and was tested on his ranch near Willcox on March 31, 1913. The factory serial number of the engine is 337. The engine was new, but had lain idle for several months at Willcox. It had been set up and put in running order just prior to the test.

During the test the engine was run by C. W. Bush, a neighbor, who owns and operates a 12-horsepower Muncie engine. Considerable difficulty was had in bringing the engine to good running conditions, and an entire day was used up in these efforts. The bleeder valve was found to be leaking and required tightening, and the fuel nozzle was replaced by a new one.

The fuel oil used was a low grade translucent distillate from California. Its specific gravity was .817 at 88° F., which reducing to standard temperature, is equivalent to 39.0° Beaume. It retails in Willcox at 7c. a gallon. The fuel feed pipe was disconnected from the engine base, which serves as a fuel reservoir, and was fed from a 5-gallon can.

The cooling water circulation on Engine No, 1 is forced by a Deming No. 1 rotary pump, taking its suction from the discharge pipe of the well pump. But, for the test, a galvanized iron tank, 30" diameter by 8′ high, was obtained, and the water, taken from the bottom of the tank, was forced back into the top.

THE MUNCIE *OIL* ENGINE

The Muncie oil engine was one of the first two-cycle oil-burning engines to be manufactured. The factory is at Muncie, Indiana. It is of the horizontal type.

In the main, the design of the Muncie engine follows the general description of hot-ball engines given on page 390. The hot ball is a spherical flanged casting about 5 inches in diameter with metal about one-half inch thick and is bolted onto the cylinder head. It also holds in place a flanged spoon or lip which projects into the cylinder several inches. When the engine is running, the hot ball is kept at a low red heat, and the projecting spoon is probably at a temperature equal to that of the hot ball. Ignition is by means of these hot castings assisted by the heat of compression. The fuel nozzle is on the upper side of the cylinder directly over the spoon. The fuel oil is injected into the cylinder by sudden action of the fuel pump, and the spurt of oil is directed against the spoon. This occurs just before the inner dead center and the oil should be vaporized to form an explosive mixture with the air by the time dead center is reached. The air is first drawn into the crank case during the compression stroke of the piston; it is compressed on the explosion stroke and delivered into the cylinder through a by-pass in the cylinder walls. This by-pass receives a drip of hot water from the water jacket, or the drip may discharge into the cylinder in front of the inlet port. The exhaust is downward from the cylinder through a 4" pipe.

The fuel injection pump is attached to the side of the cylinder. It consists of a brass body and a tool steel plunger operated by the repeated blows of a bumper which is driven by the main shaft. The length of travel of the bumper rod after it strikes the plunger is controlled by the governor. The limit of travel of the plunger outward is adjustable by hand, and this hand adjustment enables the operator to change the speed of the engine.

In order to start the engine when cold, the hot ball is heated with a gasoline blow torch for 10 to 30 minutes, fuel oil is then injected by hand and the flywheels are rocked back and forth until the engine starts.

The adjustments while running are on the stop which regulates the length of the fuel pump stroke, on the drip of water which feeds into the by-pass, and on the circulating-water valve.

The compression pressure, as found in one instance (see page 392), was 100 pounds.

The log of the test is not published in full because of the space required. An inspection of the speed readings shows that the speed variation under full load or three-quarters load was one percent. The temperature of the circulating water as recorded varied from 136° P. to 147° F, but the recorded temperature was somewhat lower than the cylinder since the thermometer was placed at the outlet, about 20 feet distant from the engine. The amount used was 12 gallons a minute. Temperature of fuel oil was from 80° P. to 85° F. The time required to start the engine on the second day was 30 minutes.

A summary of the tests is given in Table III.

TABLE III.—SUMMARY OF TESTS ON ENGINE NO. 1

No. of test	Length of test	Net load on brake	Average speed	Average power developed	Rate of fuel consumption
	Min.	Lb.	R.P.M.	H.P.	H.P. hrs. per gal.
1.	60	93.5	277.5	19.99	5.93
2.	30	93.5	276.7	19.94	6.25
3.	63	78.5	278.3	16.83	6.05
4.	31	53 5	279.0	11.50	5.30
5.	30	38.5	279.4	8.27	5.32

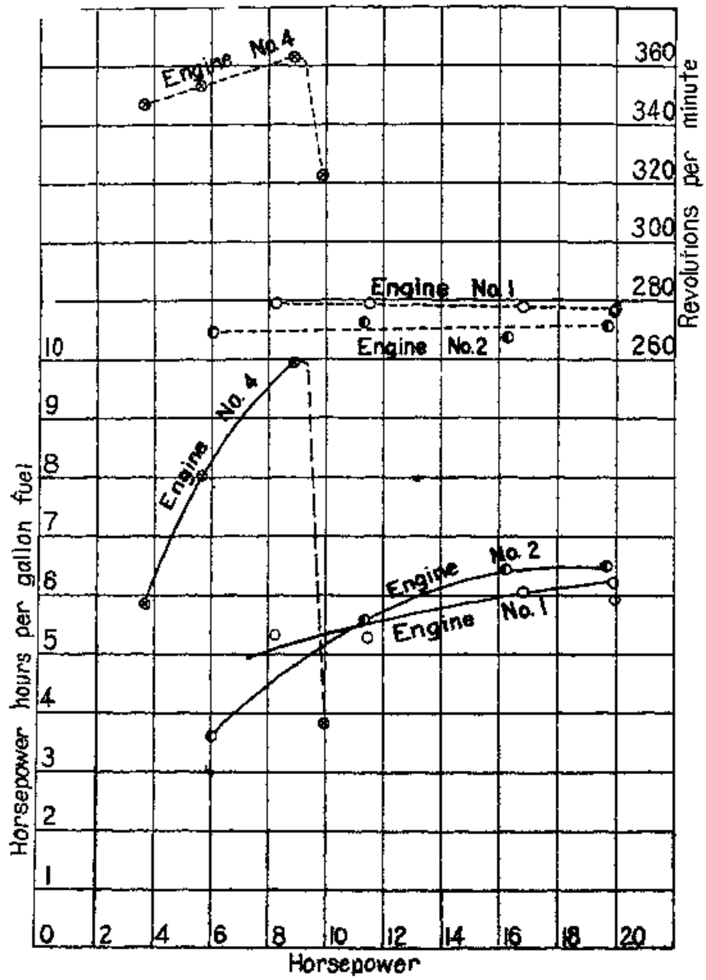


Fig. 6.—Graphs of fuel economy and speed regulation for engines Nos. 1, 2, and 4. Nos. 1 and 2 are 20-horsepower Muncie oil engines and No. 4 is a 12-horsepower Stover oil engine. All three engines are of the 2-cycle type with hot-ball ignition.

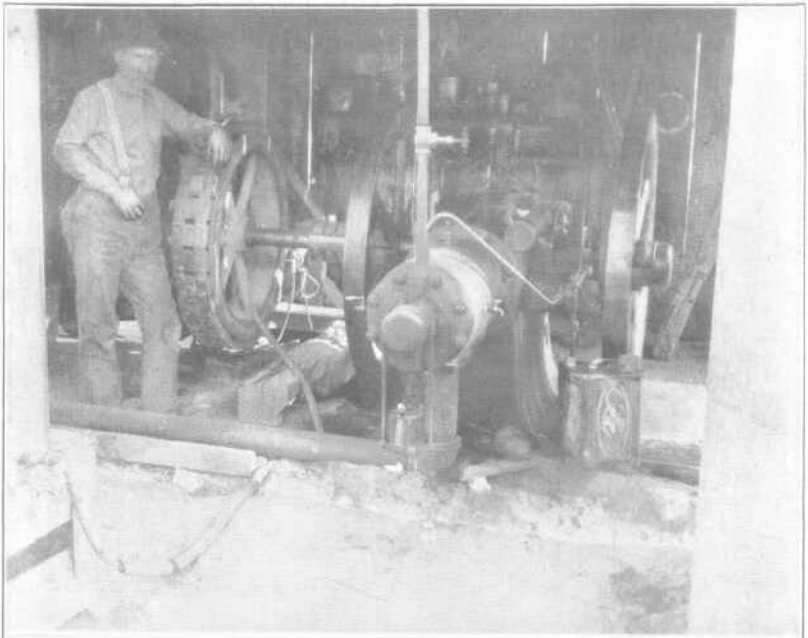


PLATE III.—ENGINE NO. 2 DURING TEST

Fig. 1 (Above).—Engine with Prony brake and fuel can.
Fig. 2 (Below).—Exhaust from engine under full load, showing individual puffs of smoke and steam ejected with great force.

A graph of the values for the fuel consumption indicate that No. 1 is too low and No. 5 is too high. No. 1 may have been low on account of the fact that the engine was not thoroughly and uniformly heated up prior to the test, and the jacket water was too cool. The rule followed was to keep the cylinder just as hot as could be borne by the palm of the hand.

The exhaust smoke at its best was thin bluish-black, but became black when too much fuel was being fed If the bleeder valve were opened too much, the cylinder cooled down, missed explosions, and the speed decreased. If not corrected, the engine stopped. If the bleeder valve were closed too tightly, the engine pounded badly, due to time of explosions coming before dead center. Since the time of the test, part of the well discharge has been used for circulation, so as to give constant temperature, and the engine runs on steady load a considerable time without attention.

The altitude at the place where the test was made is 4200 feet above sea level. The capacity of an oil or gas engine at such elevation is about 14 percent less than at sea level.

ENGINE NO. 2

A 20-HORSEPOWER 9" X 13" MUNCIE OIL ENGINE

This engine belongs to J. B. Cantrell of Willcox, and is numbered 276. It was tested on his ranch May 3, 1913. The engine had been in service one year, but had been run only about 300 hours. The fuel consumption while operating the 5-inch centrifugal pump has been found to be thirty gallons per ten-hours run.

During the test the engine was operated by the owner. Grievous delay was caused by the torch being out of condition The engine was ready to test at noon but on account of the poor torch it was eleven o'clock the following day before the engine could be gotten hot enough to start. The test at full load was terminated suddenly by the break-down of one of the air-intake valves.

The oil used was quite similar to that used in the previous test, and was purchased at the same price. Its specific gravity, however, was .838 at 76° F., which is equivalent to 35.8° B. at 60° F. The heavier gravity had a marked effect on the exhaust, for both at full and partial loads the exhaust smoke was heavier and blacker than that from Engine No. 1. The exhaust under full load is shown in Plate III. The cylinder charges are ejected with great force, and the separate puffs are shown with distinctness in the figure.

The method of testing was the same as in the previous test. The only difference of importance between the two engines is in the cooling system. Engine No, 2 depends upon thermo-siphon action with a G. I. tank 3'-8" diameter and 7' high, while No. 1 has a circulating pump.

Four tests were made, three-quarters load, half-load, one-quarter load and full load. The summary of the tests is given in Table IV.

TABLE IV.—SUMMARY OF TESTS ON ENGINE NO. 2

No. of test	Length of test	Net load on brake	Average speed	Average power developed	Rate of fuel consumption
	Mm	Lb	R P M.	H.P.	H P hrs. per gal.
1	60	79	267.8	16 3	6.44
2	60	54	272 4	11 33	5.58
3	35	29	269.5	6 02	3.62
4	13	94	271.8	19 7	6 5

The fuel consumption is plotted in Fig. 6. It will be observed that the points form a very consistent curve which would pass through the origin if extended. The speed was somewhat lower than that of Engine No. 1. The rated speed in 285 R. P. M.

ENGINE NO. 3

A 15-HORSEPOWER FAIRBANKS, MORSE & CO., OIL ENGINE

This is a horizontal, throttle-governed, 4-cycle oil engine. It is catalogued as Type N and is numbered 122066. It belongs to P. Jones of Tucson, and was tested on his ranch June 2, 1913. The engine had been in service about six months. The consumption of fuel when driving the pump is 1.52 gallons per hour. The engine is not loaded heavily in regular service.

During the test the engine was operated by the owner. No time was lost in starting the engine, but the test was not begun until the circulating water was hot. The water circulation is the thermo-siphon system and the connections were such that the amount of water circulated and the loss of power through the circulation could not be measured. The cooling tank is 3′-6″ diameter by 8′ high. The effective height tending to create circulation is 4′-3″. Thus the circulation could be increased greatly by raising the tank, if such increase were desirable.

The oil used was No. 2 tops, and was bought at 7½ c. per gallon in 50 gallon lots or larger. The specific gravity was .815 at 74° F., equivalent to 40.6° Beaume at 60° F. The flash point was 59° F. The calorific value, determined by the U. S. Bureau of Mines, by request, was 19,503 B. T. U. The combustion appeared to be perfect and there was absolutely no visible smoke from the exhaust pipe. Regarding the reliability of the engine and its ability to run without attendance, the owner stated that he sometimes drives to the city and is gone from the pumping plant for several hours, but always finds the engine operating smoothly on his return. It is his usual practice to oil the engine twice daily.

The graphs for fuel consumption and speed are shown in Pig. 7. The fuel pump throws about seven times as much oil into the mixer as is required, the excess overflowing back into the storage tank. During the test this excess was caught and poured back by

TABLE V.—SUMMARY OF TESTS OF ENGINE NO. 3

No. of test	Length of test	Net load on brake	Average speed	Average power developed	Temperature circulating water	Rate of fuel consumption
	Min.	Lb.	R.P.M.	H.P.	°F.	H.P. hrs. per gal.
1	60	75.8	230.4	13.44	162	6.90
2	50	65 6	250.5	12.66	172	6.49
3	45	52 5	256.4	10.38	170	6.03
4	30	37.4	259.7	7.48	170	5.35

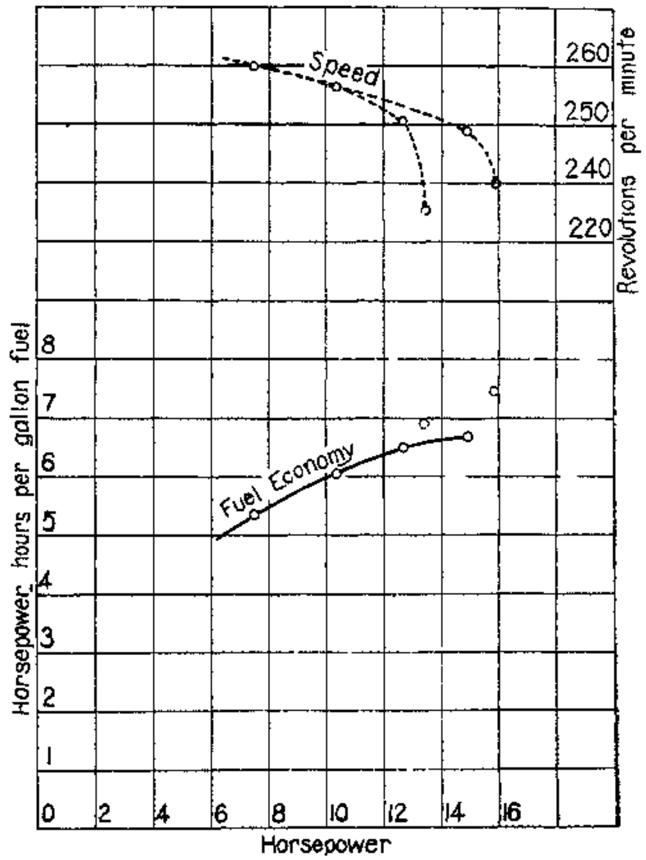


Fig. 7.—Graphs of fuel economy and speed for Engine No. 3, a 15-horsepower Fairbanks, Morse & Co. oil engine.

hand into the temporary fuel can, and inevitably there was considerable waste by spilling and by evaporation. This loss is hard to estimate but it could not have exceeded 3 percent of the fuel consumed. Another correction which should be made in the fuel consumption is for the temperature of the fuel oil. The temperature varied from 90° to 108° P. Using the average, 100° F., then the consumption in gallons at 60° would be 2 percent less, and the fuel economy would be 2 percent better.

The amount of lubricating oil used during the 5 1-3 hours run was .10 gallon. At 45 cents per gallon it represents a cost of .84 cents per hour, which is one-thirteenth of the cost of fuel oil under regular operating conditions at this plant.

The unsatisfactory feature of this test was that the engine would not maintain the rated speed when the full load test was made. Consequently the maximum power developed was 10 percent below the rated power of the engine. The altitude, 2300 feet above sea level, would cause a loss of 8 percent in capacity. It was determined to try the engine again after the alfalfa fields had had another irrigation, and to regulate the feed valves with more care before and during the tests,

SECOND TEST OF ENGINE NO. 3

In the re-test of this engine, it was operated by the erector who originally installed the plant. He had little difficulty in adjusting the engine without changing the governor so that the engine carried full load, and even 6 percent overload. A practical conclusion to be drawn from this experience is that while an engine may have all the power that is claimed for it, it must be kept in good condition and expertly adjusted in order to develop its highest power. If, therefore, a farmer is not somewhat of a mechanic as well, he should buy an engine cf a capacity 10 to 20 percent in excess of his needs.

The overflow from the carburetor was led by pipe back into the temporary fuel can and hence there was no waste. The last column in Table VI should be increased 2 percent to reduce to standard temperature of fuel oil.

TABLE VI.—SUMMARY OF RE-TEST OF ENGINE NO. 3

No. of test	Length of test	Net load on brake	Average speed	Average power developed	Temperature circulating water	Rate of fuel consumption
	Min	Lb.	R P M	H P.	°F.	H P hrs per gal
1	60	77 9	248 9	14 94	158	6,67
2	40	85 9	239 9	15.86	160	7 45

A Crosby indicator was attached to the engine during this test, and indicator cards were taken every five minutes. Professor B. A. Snow of the University of Arizona provided the indicator from the equipment of the Mechanical Engineering Department, and took the cards. At 3:40 P. M. the revolution counter became fouled, and at 4:45 P. M. the indicator string broke; thus the indicator records were limited to 40 and 30 minutes respectively.

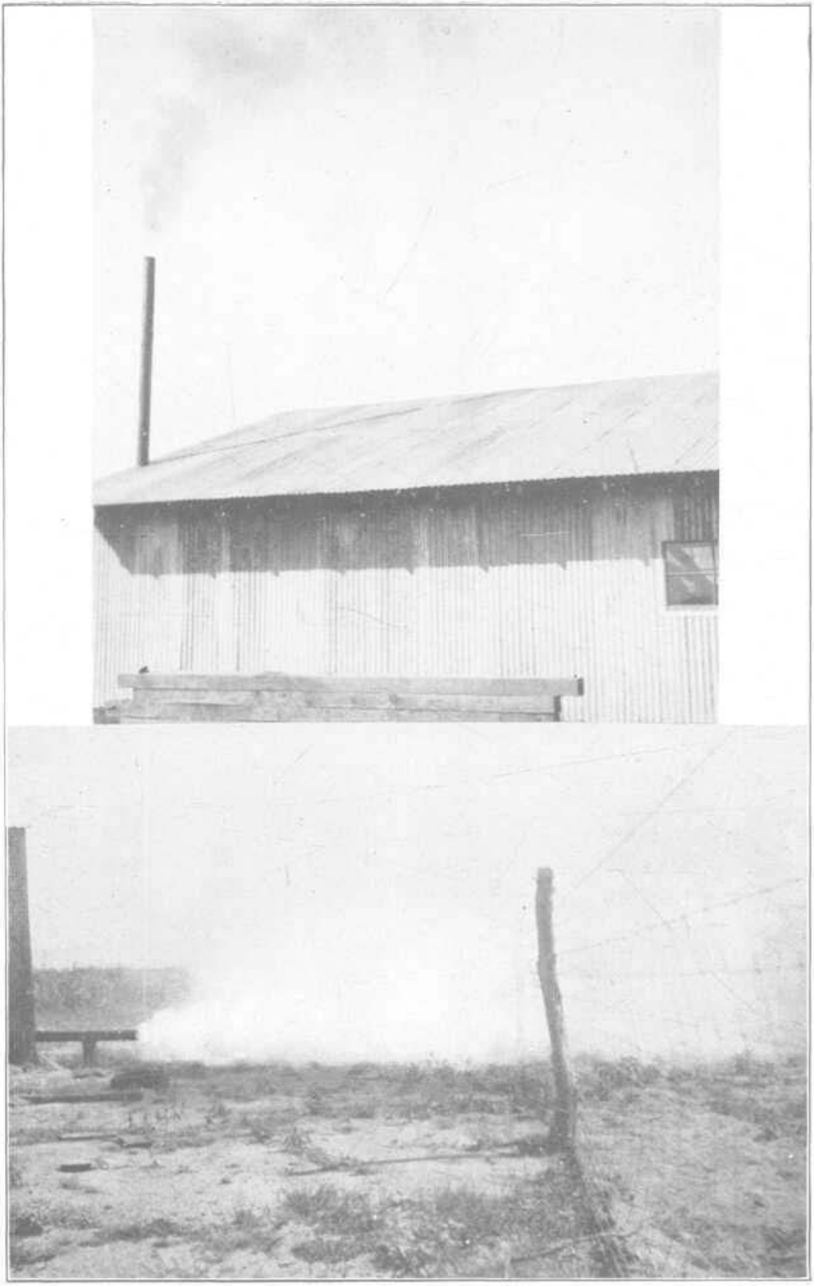


PLATE IV.—EXHAUST FROM TWO HOT-BALL ENGINES

Fig. 1 (Above).—Exhaust from Engine No. 6 at three-quarters load.
Fig. 2 (Below).—Exhaust from Engine No. 4 at full load.

TABLE VII.—TEST OF MECHANICAL EFFICIENCY, ENGINE NO. 3

Card No.	Time	Speed by tacho-meter	Mean effective pressure	Indicated horsepower	Brake horsepower	Efficiency
	P.M.	R.P.M.	Lb	H.P.	H P.	%
1	3:00	232	71 2	15 85		....
2	3:05	250	67 9	16 3	.....	....
3	3:10	...	70 7	17 0		....
4	3:15	250	75 7	18 2		....
5	3:20	250	73 9	17 7		....
6	3:25	250	69 4	16 7	.....	....
7	3:30	245	73 1	17 2	.....	....
8	3:35	245	89 3	21 0	.....	....
9	3:40	245	73 6	17 3		....
Average	......	......	....	17 25	15 00	83.8
1	4:15	235	78 7	17 8	.....	....
2	4:19	250	75 0	18 0	.....	....
3	4:25	235	78 7	17 8	.....	....
4	4:33	248	77 3	18 4	.....	....
5	4:35	242	79 5	18 5	.....	....
6	4:40	230	79 5	17 6	.....	....
7	4:45	240	75.0	17 3	.....	....
Average	....	....	....	17.9	15.78	88.1

In the above table the average brake horsepower is computed for the time covered by the indicator tests. On account of the lack of uniformity in the explosions and in the speed there is a chance for error in the comparison of the brake and the indicated powers. Nevertheless, the values of the mechanical efficiency as given, are probably very nearly true. They are high, and it is apparent that the engine was in good order at the time of the test.

It is noteworthy that the best fuel economies were associated with the lowest speeds. This fact is indicative of the mechanical loss due to friction, and is an argument for low piston speed.

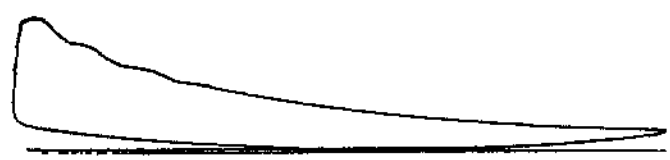


Fig. 8.—Indicator card from Engine No. 3, with water feed in the gas charge.

In Figs. 8 and 9 are exhibited two indicator cards, one taken during the second test when the humidifying water was being fed into the charge, and the other just after the test when the water feed was shut off. The Dieselizing effect of the water is plainly evident. The cards show, too, that the time of ignition and the lift of the exhaust valve should be set a little earlier.

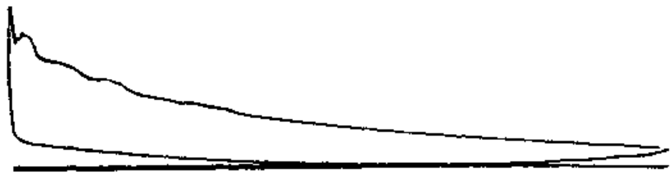


Fig. 9 —Indicator card from Engine No 3 with water feed shut off.

ENGINE NO. 4

A 12-HORSEPOWER 7½″X 10″ STOVER OIL ENGINE

This is the property of W. G. McCampbell of Bowie, It was tested on his ranch October 14, 1913. The engine was nearly new, having been run about 100 hours. The factory number is CL 43362. The only difficulty of importance prior to the test was the bursting of one hot ball. During the test the engine was operated by the owner, who had received personal instructions from the manufacturers' erecting engineer.

The fuel oil used was low grade opaque distillate from California known as No. 1 tops. Its specific gravity was .864 at 63° F., which is equivalent to 31.8° Beaume at 60° F. The oil was purchased at Willcox at 7½ c. a gallon.

The Stover is entirely similar in principle to the Muncie engine, which is described on page 400, The design of the Muncie has been copied largely in the Stover.

The engine is water-cooled by thermo-siphon action, the tank being 2′-6″ in diameter by 5′ high.

TABLE VIII.—SUMMARY OF TESTS ON ENGINE NO. 4

No. of test	Length of test	Net load on brake	Average speed	Average power developed	Rate of fuel consumption
	Mm.	Lb.	R P.M.	H P.	H.P. hrs. per gal,
1	60	39 8	323 0	9 89	3 85
2	60	31 8	363 4	8 88	9 97
3	60	20 8	353 8	5 65	8 01
4	30	13.8	347.5	3.69	5.87

The time elapsed after lighting the torch before the engine was hot enough to start was 26 minutes. The circulating water rose *in* temperature rapidly to 122° F. and thereafter rose slowly to 138° F. at the end of the test. The temperature of the fuel oil was 65° F. for the first test and 79° for the other three tests.

Close attention to the water-feed valve was required to prevent either knocking of the engine on the one hand or missing of explosions on the other hand. The exhaust smoke was very dense and heavy most of the time. The exhaust at full load is shown in Plate IV, Pig. 2.

An important feature of this test is the high fuel economy at one-half load and three-quarters load. The high mark attained of 10 horsepower-hours per gallon is excellent and should encourage other pump irrigators to endeavor to so adjust and operate their engines as to secure high efficiency.

An unfavorable aspect of the test was the inability to carry the full rated load. At the conclusion of the four tests a further effort was made, the scales being set with such a weight as would give 12-horsepower at 375 R. P. M. When the brake was tightened the engine made a good try and held up to speed for nearly a minute, then the speed decreased to 320, and by no readjustment of the valves could the engine be speeded up. The altitude at the McCampbell ranch is 3700 feet.

The governing of the engine is woefully defective, the speed ranging from 320 when heavily loaded to 400 when running idle. At any particular load the speed can be changed by changing the stroke of the fuel pump piston, but manifestly the engine would be unsuited for driving a variable load which required fairly constant speed. During the separate tests there were many momentary reductions in speed of from 2 to 5 percent due to a few explosion-misses or to a series of knocks.

As in some previous tests a record was kept of the lubricating oil used during the 6-hours run. The amount was .62 gallon. A smaller amount would have been sufficient, but the manufacturers' "Instructions" state that an excess of lubricating oil is cheaper than repairs* The oil used per hour was .10 gallon, one-ninth of the amount of fuel oil per hour used in the three-quarter load test. The cost ratio in this case was as 5 to 7, that is, the cost of lubricating oil was five-sevenths of the cost of fuel oil.

ENGINE NO. 5

A 15-HORSEPOWER FAIRBANKS, MORSE & CO. OIL ENGINE

Engine No, 5 is situated on the University Farm near Tucson, and is used for pump irrigation. On account of its location and the season of the year when tested, January, a longer and more thorough series of tests was made upon it than upon any of the other engines. The engine was nearly new, having been installed the previous July, and having been operated only 580 hours. It is set on a heavy concrete foundation in a fireproof brick building. The floor is of concrete and the entire building is kept clean, orderly, and attractive, a model of a small farm pumping plant.

The engine is of the horizontal, type NB class, and is numbered 132887. It is similar to Engine No. 3, except in the method of water-cooling. Instead of thermo-siphon action, there is a pipe connection from the elevated to|a,$e-serviee water tank, and the water, after it passes through the engine jacket, is led by pipe into the well. A globe valve permits of regulating the circulation or closing it off. Current for ignition is from a wet battery of four cells. The ignitor is adjusted so that the spark occurs when the crank is 19° in advance of the "dead center" position.

The fuel oil used was No. 2 tops costing 7c. a gallon at retail. The specific gravity was .830 at 49° F., equivalent to 39.4° Beaume at standard temperature. The flash point was 104° F., and the burning point 124° F. The combustion was perfect apparently, for at no time was there any visible discharge from the exhaust pipe outlet.

The farm superintendent states that the engine has given no trouble of any kind. It is started usually by the laborer who does the irrigating and is visited once every hour or two hours to observe the lubrication and to fill the oil cups. A common grade of gas engine cylinder oil is used, costing $0.37 per gallon in 55-gallon lots.

During the first two runs the engine was operated by the farm superintendent, and during the last four runs by an engine erector representing the local agents. At other times the engine was run by the writer. With air temperature at about 45° F., it required

TABLE IX.—SUMMARY OF TESTS ON ENGINE NO. 5

No.	Length of test	Net load on brake	Average speed	Average temperature of cooling water	Average power developed	Fuel consumption	Rate of fuel consumption
	Min	Lb.	R.P.M.	°F.	H P.	Gal	H.P. hrs. per gal.
1	60	61 8	284 1	162.5	13.52	1 689	8.00
2	30	68 8	249 0	150	13 19	778	8.47
3	30	68 8	251.8	153	13 34	746	8 94
4	30	68 8	252 0	132	13 35	700	9.53
5	30	75 8	254.1	149	14.83	742	10 00
6	30	75 8	253 1	157	14 78	736	10 04
7	30	75 8	252 6	157 7	14 74	.736	10 01
8	30	75 8	252 1	174 o	14 71	.723	10 17
9	30	56 8	254 3	141.6	11 12	633	8 78
10	30	56 8	253 3	153.3	11 08	.637	8 70
11	30	56.8	254 1	161 6	11 11	639	8 71
12	30	56 8	259 2	158	11 33	.807	7 02
13	30	37 8	257 9	166	7 51	.531	7 07
14	30	37 8	257 3	165 8	7 49	539	6 96
15	15	24 8	261 4	161 5	4 99	211	5 91
16	15	24 8	260 8	142	4 98	.243	5 12
17	15	83 8	236 3	161	15.25	.496	7 68
18	15	83 8	240 9	153	15 54	499	7 79
19	20	75 8	258 4	139	15 08	.565	8 89
20	20	75 8	257 8	169	15 04	.520	9 64
21	20	83 8	250 0	174	16 13	.593	9 06
22	30	83.8	247,8	170	15.99	.881	9.07

about 5 minutes of running on gasoline before changing to tops. In the summer it is customary to start the engine on tops directly.

The results of the various fuel economy tests are given in the Summary of Tests, Table IX, and the relation of fuel economy to

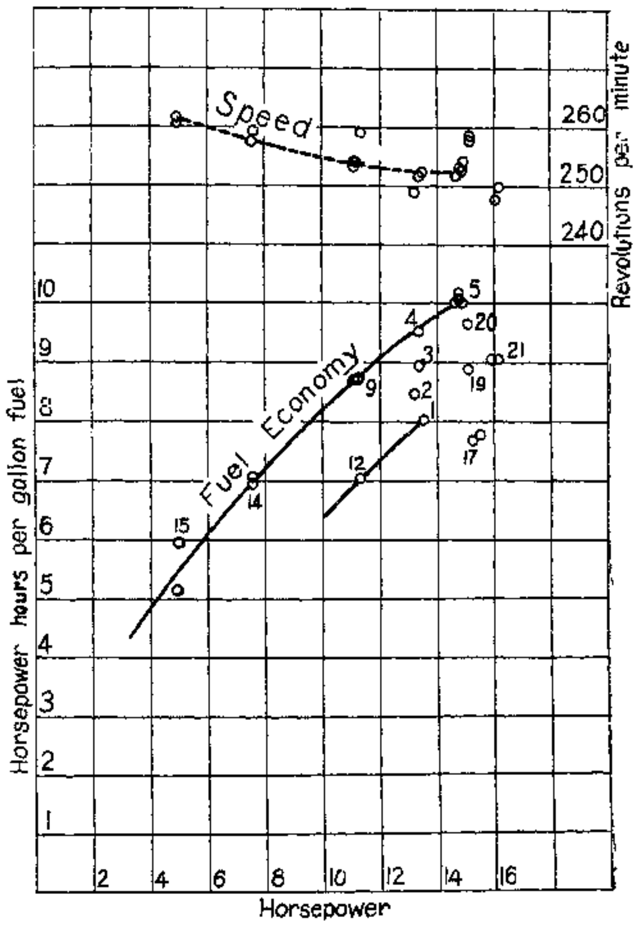


Fig. 10—Graphs of fuel economy and speed for Engine No. 5. The tests are numbered in the order of their occurrence. The higher fuel economy curve was obtained by the most careful adjustment of the engine, while the lower curve indicates about what should be expected under field conditions.

brake load is shown by the center graph of Fig. 10. There were 22 tests in all. The first one was made under the usual operating conditions, the engine being about nine-tenths loaded. The farm superintendent had changed the connection of governor rod to throttle-valve in order to speed up the centrifugal pump. Undoubtedly the over-speed of the engine was an unfavorable condition, for every gasoline engine should be run at the speed for which the engine is designed and built. The fuel consumption was one gallon per 8.005 brake horsepower-hours.

After the first test the governor connection was set so as to give a speed of about 250 R. P. M., and the scale load was changed so as to retain the engine loading about the same as in the first test. The second test shows a marked improvement in fuel economy. The following two tests were made with the same speed and load but the water, air, and fuel valves were adjusted back and forth with the object of finding the most efficient settings. The water valve was opened finally just enough to keep the engine from knocking. By means of temporary paper scales on the milled heads of the two needle valves, it was possible to adjust them to a hundredth of a revolution. Too much air was found to be as harmful as too little. The fuel economy improved with each of the four tests, as is shown forcibly in Fig. 10.

Next in order were four tests at full load. Before making these it was necessary to adjust the governor connection again. By more painstaking adjustment it was possible to close the fuel valve to the same position as in the previous set of tests, and the fuel economy was increased to over 10 horsepower-hours per gallon of fuel oil. The four results vary but slightly from each other. The best result was the one in which the jacket water was the hottest, but the difference was slight.

During the seventh test the quantity of jacket water was measured. The amount was .93 gallon a minute, and, since the temperature rise was 106° F., the loss of power therein was 19.4 horsepower. The total theoretic power in the fuel consumed in the seventh test was 70 horsepower, so it appears that the thermal (brake) efficiency was 21 percent and the loss in cooling water was 28 percent. Nearly 50 percent of the theoretic power, therefore, was lost in the exhaust, allowing for a small amount lost in bearing friction and by radiation.

A test for speed regulation with one governor setting gave the following results. The fourth column shows the percentage of speed variation from the speed at full load.

Test	Net load	Speed	Regulation
	Lb.	R.P.M.	%
Ten percent overload	83.8	237	6,0
Full load	75,8	252	0,0
Three-quarters	56 8	257	2,0
One-half	37.8	260	3.2
One-quarter	18.8	263	4.4

The test shows 3.2 percent increase in speed at half load and 4.4 percent at quarter load. It is evident that the ordinary setting of the governor springs will not do for overload conditions.

The design of the governor is shown in Fig. 11. The left-hand figure is an end view and the right figure is a vertical section. The two weights are carried on the outside of the flywheel and are held together by two springs. The weights are pivoted on the inner side of the flywheel and carry arms which engage a sliding collar on the main shaft. This collar has a loose ring which guides the forked arm of the lay rod connected to the throttle-valve. The action is as follows. An increase of speed causes the weights to move outward, the collar is moved slightly toward the right, and the lay rod is rotated slightly in such manner as to partially close the throttle-valve. The lack of sensitiveness in this governor may be due to friction or to lost motion or to the detailing of the parts. Shaft governors are better adapted to high speed engines than to low speed ones.

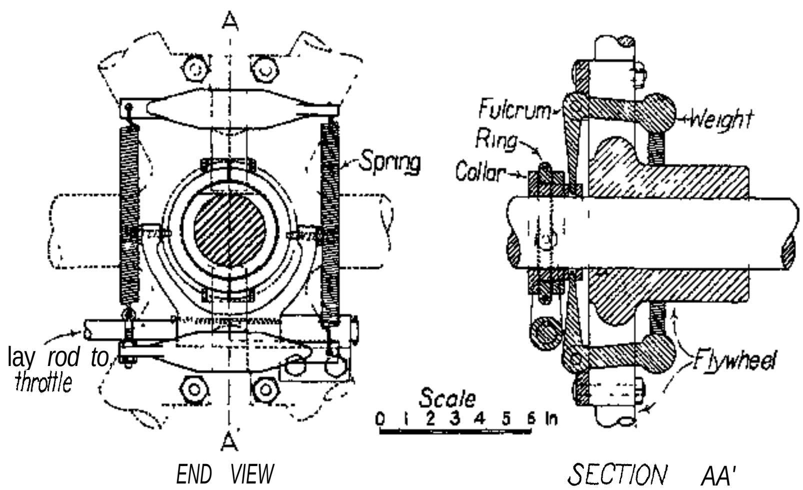


Fig. 11.—Design of the shaft governor of Engine No. 5. The lay rod extends to the head end of the engine where it controls the throttle valve between the carburetor and the cylinder.

After the full load tests, four tests were run at three-quarters load. Tests 9, 10, and 11 showed good economy, about 8.75 horse-power-hours per gallon fuel. For test No. 12, the needle valve was opened intentionally .06 of a turn wider to observe the symptoms of wasteful running. As shown in Table IX the fuel economy was decreased 20 percent, and yet there were no symptoms to indicate that the engine was not doing its best. The exhaust gases were absolutely invisible, and the sounds of the engine were normal. The inference to be drawn from this test is that, inasmuch as the majority of engine operators never make any tests to determine the exact best settings, they are using an unnecessarily large amount of fuel oil. It *fa* not enough that the engine runs, and runs smoothly; the operator should experiment with the adjustments until the engine carries its load with the closest possible setting of the fuel needle valve. . It is quite probable that the fuel consumption could have been increased another 25 percent without causing a smoky exhaust or other sign of waste.

Tests 13 and 14 were made at half load and Nos. 15 and 16 at one-third load. The disagreement in the last case may be due in part to the short duration of the tests. The graph in Fig. 10 shows clearly how the fuel economy varies with the load. During the tests at one-third load the governor "hunted" considerably, that is, it oscillated back and forth with a regular periodicity of 18 per minute. Each seventh explosion was very strong, while the succeeding ones were of diminishing intensity finally ending in two "misses."

Nos. 17 and 18 were an effort to carry overload but the speed dropped to 240 R. P. M. and the overload was not of importance. The fuel economy, also, was unsatisfactory, So the governor springs were released all possible, and after two trials at full load the overload was tried again with much better results, as seen in Nos. 21 and 22, While doubtless the engine will carry 10 percent overload, it does so with difficulty, the engine requires closer attention, and overloading is not to be recommended.

The consumption of lubricating oil was at the rate of .033 gallon an hour. On the basis of the first test representing average daily operation, the ratio of lubricating oil consumed to fuel oil consumed is one to fifty, while the cost ratio is one to ten.

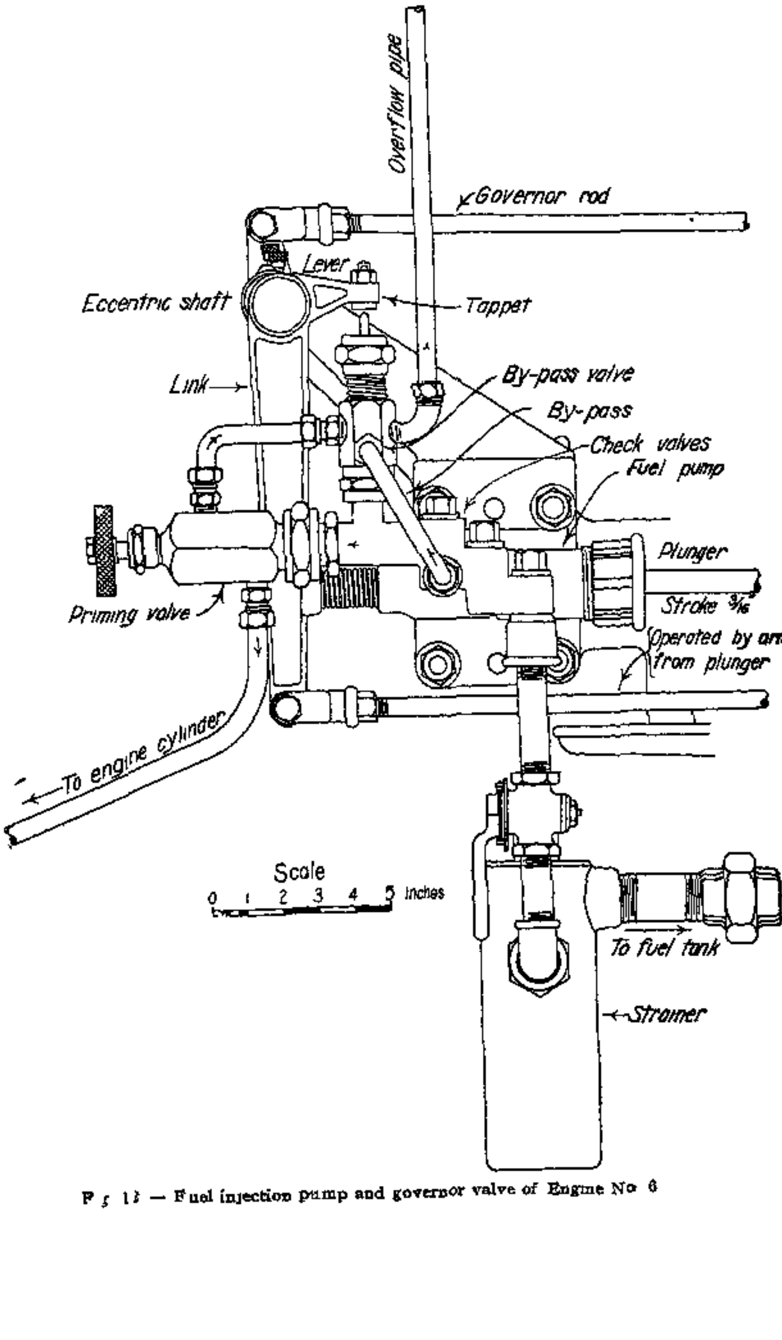
It should be noted that the graph of fuel economy in Fig. 10 is higher than would have been obtained under the conditions of daily operation of the engine. It represents a special effort to obtain high economy. Doubtless the expert operators at the factory could obtain a showing considerably better. It is of value to know what an engine is capable of doing, and perhaps the results here obtained will be an incentive to pump irrigators to endeavor to cut down their fuel consumption. By doing so, they will at the same time, maintain cleaner engines, reduce the wear on valves and cylinders, and prolong the life of their engines. For comparison with the other engine tests of this bulletin, a parallel curve drawn through the points 1 and 12 should be used.

ENGINE NO. 6

A 40-HORSEPOWER BESSEMER OIL ENGINE

This engine is the property of H. R. Smith of Casa Grande and was tested on his ranch nine miles south of Casa Grande on February 2, 1914. The engine was nearly new. It had been installed the previous July, but had been operated only about 150 hours. Contrary to expectation, the engine was needed for pumping water at the time of the test, and hence a single day's run for testing purposes was secured.

The engine is of the hot-ball type, but is much larger than any of those previously tested and has a number of features which require special mention. In the first place, the hot ball projects inward instead of outward as in the 1912 model of the Bessemer engine. This is said to give much better combustion with less carbonizing* The engine has a cross-head like that of steam engines and the piston rod is packed where it passes through the crank end of the cylinder. The preliminary compression of the air, therefore, is done in the cylinder, in front of the piston, and not in the crank case as in other hot-ball engines. The cooling water is taken from the pump discharge through a 1″ pipe, the latter being tapped for a branch supply-



F g 13 — Fuel injection pump and governor valve of Engine No 6 ing cold water for feeding into the air charge. The governing is done by varying the ratio of fuel to air, i. e., quality governing, as is the case with the other hot-ball engines tested, but on the Bessemer a fly-ball governor is used instead of the usual shaft or flywheel type, and, instead of varying the stroke of the pump, there is a variable by-pass which returns part of the oil to the fuel tank. The exhaust is led into a covered pit outside the engine house, the pit having a vertical pipe outlet to carry the exhaust gases above the elevation of the house.

The fuel injection pump and governing arrangement are somewhat intricate and require special explanation. They are illustrated in Fig. 12. The pump is seen to lie just back of the three vertical check valves. The plunger is operated from the right by repeated "bumping" blows of a rod driven from the main shaft. The fuel oil is forced at high pressure through the priming valve body, thence through a long brass tube to the nozzle valve on the under side of the cylinder at the head end. This nozzle valve (not shown) is held by a strong spring which prevents dribbling but when the valve is lifted slightly by the pressure in the oil, the oil is shot out in a full circle of fine spray inside the engine cylinder. The fuel pump takes its supply from a small elevated tank, by gravity, through an oil strainer and emergency valve. The pump stroke is uniform at all times and under all loads, but to provide for part loads when less oil is needed in the cylinder, a by-pass is arranged to take a portion of the oil and divert it upward through the over-flow pipe back into the elevated fuel tank mentioned above. The by-pass is controlled by a valve which is operated by the governor. The tappet, as shown in the figure, is on the short lever arm of a link. This link is operated in a uniform manner by an arm on the pump plunger, but the fulcrum, being on an eccentric shaft, is under the control of the governor rod. At full load the tappet is supposed to just touch or to slightly open the by-pass valve. If the load is decreased and the speed increases slightly, then the governor rod moves to the right, the fulcrum is lowered, the tappet opens the valve, oil is diverted through the by-pass, and only enough oil is forced into the engine cylinder to carry the load at the normal speed. Stopping of the engine is best done by opening the priming valve, thus allowing the oil to be forced through the second by-pass (not named in the drawing), and into the overflow pipe. The pump and accessories are constructed mainly of bronze and hardened steel, and, though complicated, are quite effective. The Bessemer Co., formerly used a simple plunger pump similar to those of the Muncie and Stover engines.

The engine is started by means of compressed air, the engine being too heavy to turn over by hand. A few revolutions with the compressed air bring the engine up to speed, after which the air is cut out and the engine is operated on the regular fuel charges, A small air compressor is provided, belted to a two-horsepower distillate engine, but the compressor can be belted also to the main engine. The air is stored in a vertical tank and is raised to a pressure of 160 pounds per square inch in order to start the engine without fail. To raise the pressure from 100 lb. to 165 lb. required 23 minutes operation of the compressor. The time required to heat the hot ball with the gasoline torch is 30 minutes. The compression pressure of the engine is said to be 180 pounds per square inch, and the preliminary compression is said to be 14 pounds.

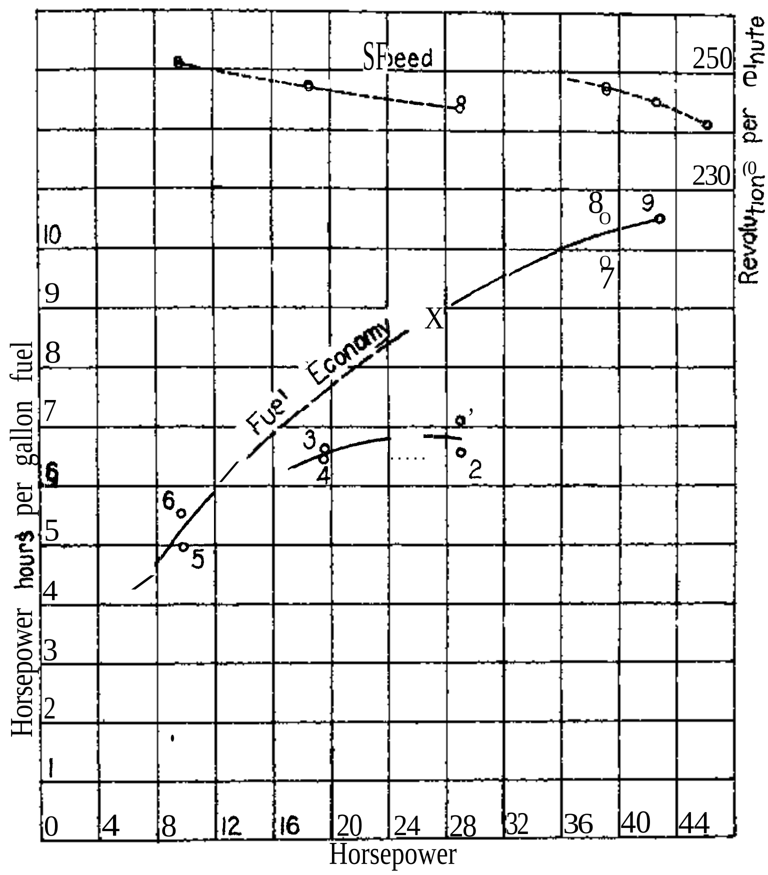


Fig. 13. — Graphs of fuel economy and speed for Engine No. 6.

Other accessories provided with the engine are a small pump for the circulating water and another pump for lifting the fuel oil from the main storage tank into an elevated tank from which it flows to the engine by gravity.

The oil used for the test was Star fuel oil purchased in Casa Grande. The price of this fuel in carload lots is 4c. a gallon f. o. b. Arizona main-line points. The oil had lain in the tank at Casa Grande for over a year, which may account for its low gravity, 22.6° Beaume at 60° F. Star fuel oil usually tests 24° Beaume. The flash point was found to be 170° F. and the burning point 200° F.

The discharge from the exhaust was of a greyish-brown color and did not vary greatly for the different loads. Star fuel oil is reported by other tests to contain from 20 to 25 percent solid asphaltum residue, and it is worthy of special note that it is possible to burn fuel of such character in internal-combustion engines.

The owner has had no serious trouble with this engine to date. He has left it for an hour or two at a time, but always finds it working smoothly upon his return. The lubrication is well arranged. The cylinder is oiled from a force feed lubricator which also takes care of the governor and cam shaft; the crank is lubricated by splash and the main bearings are ring-oiled. The owner operated the engine during the test. The engine stopped twice due to overheating but in both cases it was caused by unwarranted efforts to cut down the feed water. In this type of engine the feed water appears to be absolutely essential, as much so as is the circulating water, in keeping the engine cool.

The summary of the various tests is given in the accompanying table and the graph is shown in Fig, 13. The first tests were run at three-quarters load. The fuel economy is seen to be only 7 horsepower-hours per gallon. This result is low for an engine of forty horsepower. The one-half load, one-quarter load, full load, and overload were run in the order shown in the table. The economy at full load was good. There is a lack of consistency in the results which is difficult of explanation, for it is probable that the economy at three-quarters load should have been much better with careful manipulation of the valves. Probably too much water was fed with the charge; possibly the engine should have been warmed up longer before the beginning of the test; and it may be that the test represents what can be expected of the engine in the hands of the average rancher who has not been carefully instructed in the operation of the engine.

All the tests were run with one setting of the governor and therefore they ought to show the speed regulation correctly. The regulation was only 1½ percent from full load to one-quarter load.

TABLE X. — SUMMARY OF TESTS ON ENGINE NO. 6

No.	Length of run	Net brake load	Speed	Average power developed	Temp, cooling water	Fuel consumed	H.P. hrs, per gallon fuel
	Min.	Lb.	R.P.M.	H P.	°F.	Gal.	
1	30	122	245 0	28 97	134	2,04	7.10
2	30	122	243.7	28 81	146	2.20	6.56
3	30	81	247.6	19 43	143	1.47	6.61
4	25	81	247.4	19 42	133	1.25	6.45
5	20	40	250.7	9 72	148	.65	4,98
6	20	40	251 0	9 73	140	.58	5.54
7	30	163	247 0	39 02	127	2 00	9.75
8	30	163	247 8	39 14	132	1 86	10 52
9	30	180	245 0	42 73	139	2 03	10.51
10	..	197	241.3	46.07	.....	.....	......

This is exceptionally close governing, but as shown in Fig. 13 there is an inconsistency in the speed curve also. The engine carried 15 percent overload easily, and only lack of time and darkness prevented trying heavier loads.

In comparing this engine with those previously tested, due weight should be given to its larger size, its higher cost per horsepower, and the higher compression pressure. On account of these great differences the Bessemer engine is hardly to be classified with the cheaper, more simply constructed, smaller engines.

ENGINE NO. 7

A 20-HORSEPOWER 9½" X 10" CRESCENT OIL ENGINE

The Crescent oil engine was tested at the pumping station of the El Paso and Southwestern Railroad at Tucson on February 21, 1914. It is one of seven similar engines purchased by that company for the pumping stations along the Western Division of the road. The engine was installed June 1913, and had been operated approximately 600 hours prior to the time of the test.

The Crescent engine is similar in principle to the Muncie engine, but the cylinder is built in a vertical position instead of horizontal. The stroke is short and the engine speed is high, which would tend to give a more uniform temperature to the cylinder walls. The engine is not built to use water in the charge and the manufacturers state that their engine does not need water injection. However, the experience had with the Crescent engines in Arizona indicates that there is great advantage to be gained from adding water. Indeed, without water they do not operate well on the fuel oils that have been tried, namely, Texas and Oklahoma distillates. Consequently the railroad company has equipped its seven engines for water injection.

The exhaust is led into a large cast-iron tank muffler, from which it is discharged vertically above the roof. Lampblack and tarry material accumulate in the bottom of the rnufHer and are removed from time to time through a hand-hole. Occasional lumps of the spongy deposits are discharged from the exhaust pipe and fall on the roof or on the ground.

The oil used for the test was Texas L. G. Solar Oil, the color of which by transmitted light is yellow-orange, and by reflected light deep green. The specific gravity was 36.8° Beaume. The flash point was 187°F. and the burning point 243°F. The calorific (higher) value, as determined by the U. S. Bureau of Mines, was 19719 B. T. U. The cost of the oil was 7½ cents per gallon, f. o. b. El Paso in carloads. At one of the pumping stations a comparison was made between the amount of water that could be pumped with this oil and the amount with Oklahoma oil, which costs 4¾ cents f. o. b. El Paso. The latter oil showed a fuel economy 5½ percent lower then the Texas oil, but on account of its much lower cost it has been adopted for future use.

The summary of tests is given in Table XI. The first six tests were made under full load, two-thirds load, and one-third load conditions. The full load tests were made with an extravagant amount of circulating water, inasmuch as the attendant in charge was loath to allow the engine to get very warm. The fuel economy curve is given in Fig. 14.

The three last tests, Nos. 7, 8, 9, were made on the following day; the object of these tests was to study the effects of shutting off the feed water. After test No. 7 had been run the feed-water valve was closed and the circulating water was increased, but in five minutes the engine began to knock. In ten minutes the engine knocked

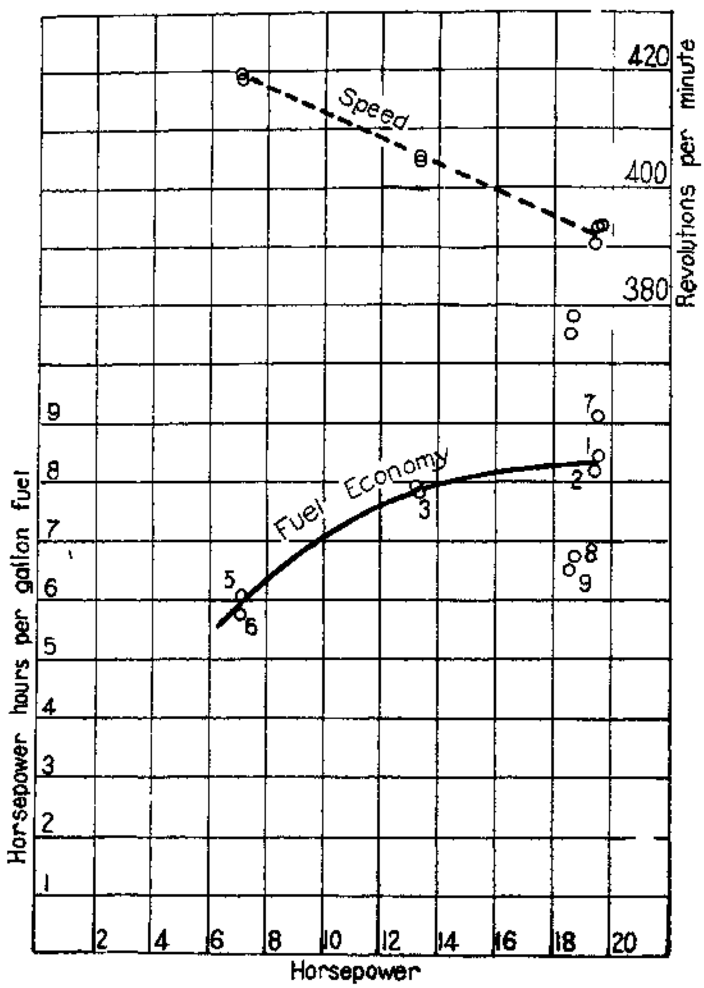


Fig. 14.—Graphs of fuel economy and speed for Engine No. 7. All tests were made with water feed in the charge except Nos. 8 and 9. In those two tests the fuel economy is seen to be very low.

badly, the exhaust smoke was black and thick, the speed had decreased from 390 to 285 R. P. M., and the engine was just ready to stop. Then the feed water was allowed to enter for one-half minute. The effect was instantaneous. The knock ceased, the speed came up to normal, and the smoke cleared, followed bv flakes of soot, which evidently were detached from the cylinder walls as an effect ot the steam. The circulating water was further increased so that the jacket was held down to a temperature of 128° F., but without the feed water the piston knocked, indicating a foul cylinder and pre-ignition of the charge. However, the engine ran within 5 percent of normal speed and two tests were made under these conditions. The fuel economy was nearly 30 percent poorer than in test No. 7, when water was injected.

The test for capacity proved very satisfactory. The engine carried 17 percent overload easily.

The governor is of the same type as those of the first five engines tested. The speed regulation from full load to one-third load was 6.7 percent. There was a further reduction in speed of 6 percent for the overload.

The time required to start the engine, including the preparation of the torch, was 19 minutes.

The lubricating oil used was at the rate of .16 gallon per hour. Assuming a cost price of 40 cents a gallon, and a fuel consumption of two gallons per hour, the cost ratio is approximately four to ten.

TABLE XI.—SUMMARY OT TESTS ON ENGINE NO. 7

No.	Length of test	Average speed	Net brake load	Brake horse-power	Fuel oil con-sumed	H.P hrs per gal. fuel	Amt. of feed water	Circulating water*		
								Amt.	Temp.	Loss
	Min.	R.P.M.	Lb.	H.P.	Gal.		Gal.per hr.	Lb per min.	°F.	H.P.
1	30	393 9	65 3	19.63	1.161	8 45	7.8	21.9	108	23.5
2	30	390.6	65 3	19.46	1 191	8.17	6.2	20.1	116	25.4
3	25	405.4	43.3	13.40	.714	7 82	8.2	9.1	136	15.8
4	25	404.7	43.3	13.37	.704	7.91	.....	9.2	125	13.6
5	25	419.3	22.3	7.14	.489	6.08	4.5	7.0	136	12.2
6	25	418,8	22 3	7.13	,516	5.75	.....	7.2	140	13.2
7	30	393,7	65.1	19.56	1,075	9.10	11.5	9.9	139	17.9
8	15	378.1	65.1	18.78	,696	6 75	0.0	25.4	129	39.8
9	15	375.3	65.1	18.64	.714	6.53	0.0	25.6	126	38.4

*Temperature of circulating water at entrance 62.5°F.

Through the courtesy of Professor W. S. Aldrich, indicator cards were taken during most of the tests. Two of the cards are shown in Figs. 15 and 16. The upper card was taken during test No. 7 while much humidifying water was being taken in the charge; the lower card was taken during test No. 9, with no humidifying water. The areas are nearly tt$aal»Ant the shapes of the cards differ widely. The lower one is a typical gas engine card.

The initial compression was about 60 pounds, but frequently a card showed much higher compression. It is probable that the engine is designed for about 100 pounds compression, but that a leaky piston reduces the pressure on most of the strokes. It was noted that the higher compression line was followed always by a higher combustion and expansion line. In cases where the cards were allowed to take several consecutive cycles no two of the expansion lines would agree, and often they formed a regular series one over the other indicating a cycle of the cycles. The best cards were obtained when the hot ball was at a bright cherry-red color.

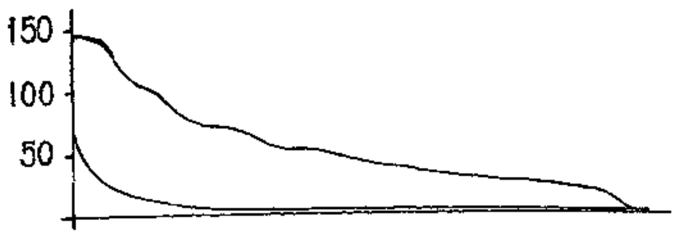


Fig 15.—Indicator card from Engine No 7 with water feed in the charge

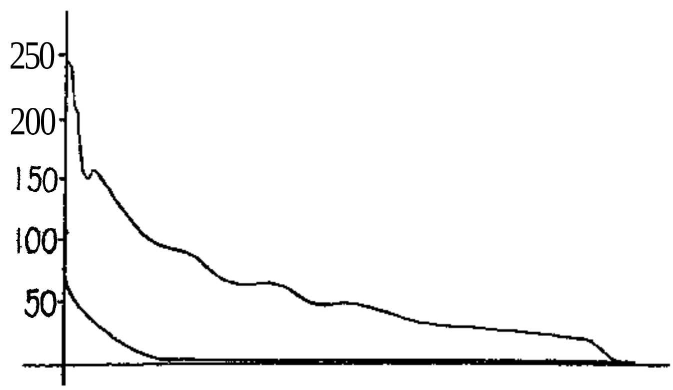


Fig 16.—Indicator card from Engine No. 7 without water feed

The exhaust curve, as shown in Fig. 15, shows ample opportunity for the burned gases to escape. It is hardly probable, however, that they are shoved bodily out, but rather that they mingle more or less with the incoming charge. This hypothesis accounts for the variable expansion lines.

The mechanical efficiencies computed from the indicated and the brake powers are exceedingly low, and the author prefers to admit the possibility of some error in taking the cards rather than to publish the low efficiencies. The values obtained, however, are consistent with each other. It may be that the great loss is in the crank-case compression, though ordinarily this does not exceed 10 percent of the full load indicated power.

The highest value of the mechanical efficiency obtained was that of test No. 7. During this test the maximum amount of feed water was being used. At the same time there was the minimum amount of circulating water (for full load) and the temperature of the cylinder was the highest.

In Table No. XI is a column giving the computed power lost in heating the circulating water. The amount of this lost power Is about equal to the brake horsepower in the tests with humidifying water, and is nearly twice as great without the humidifying water.

The amount of power carried away in the evaporated feed water cannot be computed exactly, for the temperature of the exhaust gases was not determined. A thermometer had been inserted in order to get the exhaust temperature, but was not of sufficient range and was rescued just before the mercury touched the top of the tube. Computing the loss to steam at 212° P., the results are 28.3 horsepower for test No. 1; 29.8 for No. 3, 16.2 for test No. 5, and 41.8 for test No. 7. A comparison of the exhaust temperatures of tests Nos. 8 and 9 with those of the preceding tests would be enlightening.

OIL ENGINE CHARACTERISTICS

The term oil engine characteristics is meant to include the general operating features of oil engines such as fuel economy, reliability, length of life, and speed regulation. The following discussion is based in part on the tests related in Chapter III, but in part, also, on the literature of the subject as found in technical magazines and elsewhere.

FUEL ECONOMY

The fuel economy shown in the tests for three-quarters load to Ml load varies from 6 to 10½ brake horsepower-hours per gallon of oil consumed. The latter figure was obtained with Engine No. 6, which is a large engine and has a higher compression than the other engines tested. It was obtained, however, under ordinary running conditions. Engine No. 5, a small engine with low compression, gave results almost as good when the valves were carefully adjusted though under normal conditions the engine operated at about 8 brake horsepower-hours per gallon. Engine No, 4, a 12-horsepower engine, showed an economy practically equal to that of No. 5. These results are very encouraging as they indicate the possibility of obtaining good economy even in the farmer's small power plant. When the tests were started it was not expected that an economy exceeding 8 horsepower-hours per gallon would be found anywhere. Previous observations on gasoline engines had shown that the average farm engine is very wasteful, and that the consumption of fuel is much more than is usually stated for the engines by the manufacturers.

The low results given by Engines Nos. 1, 2 and 3 are due probably, not so much to any inherent defects of the engines, as to incompetency in operating them. Nos. 1 and 2 are almost identical in design with No. 4, and No. 3 is the same as No. 5 in make, type, and size. Nos. 1, 2 and 3, therefore, should have given as good efficiencies as Nos. 4 and 5. The prevalent idea that it is easy to operate a gasoline engine needs modification. There is a wide difference between making an engine run and getting the best possible results from it.

Another fact that is demonstrated by the tests is that the fuel economy of oil engines is at least as good, and probably a little better, than that of gasoline engines. The most careful tests with gasoline engines of 15-horsepower size show an economy of from 5 to 10 horsepower-hours per gallon, the latter figure being obtained with the most careful setting of the valves. Theoretically, there is more power in a gallon of 40° oil than in a gallon of gasoline. The U. S. Bureau of Mines publishes these formulas for lower calorific value:

For gasoline, low B. T. U. - 17,030+40(°B.-10)

For kerosene, low B. T. U. = 17,190+40(°B.-10)

Adopting the above values gives the following comparison between gasoline and 40° distillate.

TABLE XII.—HEAT VALUES OF GASOLINE AND LOW GRADE DISTILLATE

	Specific gravity	B. T. U. per lb.	Lb. per gal. at 60°F.	B. T. U. per gal.	Theoretical power per gal.
	°B.				H.P. hrs.
Gasoline	60	19,030	6 14	117,000	46.0
Distillate	40	18,390	6 86	126,100	49.6

However, while the low grade distillate is seen to have considerably more power theoretically, the presumption has been that the greater difficulties of utilizing the oil in internal-combustion engines result in a much lower thermal efficiency. It is important, therefore, that the tests show that the fuel economy with oil is as good, even somewhat better, than is obtained with gasoline.

Comparing the hot-ball engines with the modified gasoline type, there is not sufficient evidence to prove that either one gives higher economy than the other. It Is shown that either type can be operated wastefully by a careless or incompetent rancher, and either type will give high efficiency under careful control.

The factor which influences the fuel economy most is the setting of the fuel inlet valve in the case of modified gasoline engines or the fuel pump stroke in the case of hot-ball engines. This was well illustrated in the special test recorded on page 413, in which the needle valve was opened purposely in order to observe the effect. It was found that opening the valve .06 of a turn beyond the right setting increased the fuel consumption 25 percent. In the case of many engines there are no graduations on the needle-valve head and no way to know whether the valve is set just right except by the sound of the exhaust, a method which does not permit of close refinement. The owner of such an engine should divide the circular edge into eight to ten parts and mark them well with a three-cornered file. Then, after once finding the optimum position for his ordinary running conditions, he can set the valve there without delay each time when he starts the engine.

Other factors, also, must affect the fuel economy but to a much less extent. The compression pressure is shown by theory to be a very important factor. However, the compression pressure of Engine No. 6 is said to be 180 pounds per square inch, yet the economy was but slightly better than that of Engines Nos. 4 and 5, which have a compression pressure of from 50 to 75 pounds.

Other investigations have shown a considerable gain due to increasing the compression of the charge. Strong and Lauson, with gasoline fuel, found a gain of 8 percent in fuel economy when the compression was increased from 70 pounds to 92 pounds.

The permissible compression is dependent on the character of the distillate used. The limiting compression for gasoline is 70 pounds per square inch gauge pressure, higher compression causing preignition. For tops, compression much higher than 70 pounds can be used, the exact amount depending partly on the flash point of the oil.

The time of ignition is known to have some effect on fuel economy. Engines with electric ignition should have an adjustable timer so that the spark can be advanced or retarded while the engine is running. During the test of Engine No. 5 the ignition lead was 20°, and this amount gave a sharp strong explosion but without any knocking. For heavier distillates and for higher speed engines, the lead should be increased even up to 45°. So far as observable from the tests, equally good economy can be obtained from hot-ball ignition and electric ignition.

The relation between the fuel economy and the proportion of full load has been pointed out already. All the fuel economy curves are consistent in this regard. It is obvious that with an engine lightly loaded good fuel economy cannot be attained.

FUEL SUITABILITY

Low grade distillates are low gravity distillates, and in general the term implies a high flash point, incomplete refining, and some asphalt. The lower the gravity, however, the greater is the possible supply and the cheaper is, and will be, the cost.

Hot-ball engines of the Muncie type, with moderate compression pressure burn distillates of 30° to 32° Beaume. They appear to run more steadily on such oils than on 40° oils, but with more smoky combustion. With the compression of 180 pounds in Engine No. 6, 24° oil with 21 percent asphalt is burned successfully. One Muncie engine owner tried a barrel of 24° oil. He reports that "while the engine runs all right on the fuel, it has much more filth in it and not only runs things about the engine sooty, but also everything around the place." It is evident that 24° California oil is unsuitable for the engine, for the production of so much soot must imply an exceedingly dirty cylinder, which would soon become worn and lose its compression. Another man attempted to burn boiler fuel oil in a hot-ball engine, but found it impractical. He then tried boiler fuel oil and low grade Solar oil, half and half, but even the mixture failed to burn at all clean.

The modified gasoline engines with electric ignition operate without difficulty on 38° to 42° oil. In one instance a 60-horsepower engine of this type was found to be operating on 34° oil, but smaller engines require somewhat better grades. The difficulty with the heavier oils is that they encourage the formation of tarry deposits around the valves, preventing them from closing tightly. The low grade Solar oil of 37.5° Beaume is about the lower limit for oil engines of this type.

De La Vergne engines, type FH, are in use at Douglas, Arizona, at Nogales, and at the Pioneer Smelter near Tucson. At Douglas, 31° Oklahoma oil is used. At Nogales, 18° oil is being tried, but with unsatisfactory results. In the Tucson installation California boiler fuel oil was tried, but gave much trouble, and thereafter 24° oil has been used. These engines have a compression of 280 pounds per square inch.

True Diesel engines, having about 500 pounds compression, are able to burn the heavy California boiler fuel oil, the gravity of which is not below 18° Beaume. Diesel engines are in use for pumping the Bisbee water supply, in a cotton oil mill at Phoenix, and two installations are in service at Tucson. The fuel used at Bisbee and Phoenix is Star fuel oil of 24° Beaume, which gives entire satisfaction; 15° boiler fuel is being tried at Tucson

MECHANICAL EFFICIENCY

Mechanical efficiency is the ratio of the power delivered by the engine to the power developed by the gas against the piston head. It represents the percentage of power remaining after the losses due to friction, both mechanical and fluid. These losses include piston friction, friction in the main bearings and the friction of the gases in the carburetor and in passing the intake and exhaust valves. The mechanical efficiency is the quotient,

$$\frac{\text{Brake horsepower}}{\text{Indicated horsepower}}$$

The mechanical efficiency is of less interest to the farmer than is fuel economy. It is merely one of the factors governing fuel economy.

The mechanical loss in an engine is proportional in part to th y, number of revolutions. Hence, a 4-cycle engine appears wastef es. of power, since the first revolution of each cycle is made without ar e power development. However, other considerations appear to ove is balance this disadvantage. an

Engines Nos. 3 and 7 were tested for mechanical efficiency, 03 of a 4-cycle engine, the other a 2-cycle. The mechanical efficiency oss the 2-cycle was considerably lower than that of the 4-cycle engine nt

The mechanical loss is quite constant whether an engine is loaded heavily or not. Thus, Engine No. 3 loses 2¼ horsepower at full load, and the loss would be 2¼ horsepower at half load or quarter load. The proportion of power lost is greatest at light loads, and therefore it is not economical to run an engine at light loads. Among pumping plants it is rare to see an engine heavily loaded. Most of the engines in irrigation service in Arizona are too large for the loads which they carry.

CAPACITY

The capacity of an engine is limited by the amount of fuel that can be burned, the amount of fuel is limited by the amount of air that can be taken into the cylinder; and that in turn depends upon the cylinder volume and the number of revolutions, in other words, upon the piston displacement per minute. The sixth column in Table II gives the piston displacement per minute per horsepower. The value for each engine is obtained by multiplying together the piston area, length of stroke and number of revolutions, and dividing by the rated power. An engine with a high value for piston displacement can be expected to carry considerable overload. Assuming that the engines use the same fuel, and hence the same compression, and that the flywheels, valve areas, and other features are designed for the speeds recommended, it is apparent that some engines are rated fcy the manufacturers much more liberally than others.

The analysis in Table II shows, too, that the 2-cycle engines have a piston displacement equal to or greater than the 4-cycle engines. Since the 2-cycle engines, in general, do not carry any greater overload, it is obvious that the power production per explosion is only half as great as in 4-cycle engines of the same piston displacement. The reason for this is to be found, doubtless, in the imperfect scavenging and recharging of the 2-cycle engines.

In two cases, Engines Nos. 3 and 4, the owners were unable to adjust the engines so as to develop the rated horsepowers. Engine No. 3 was re-tested by an expert engineman and carried 6 percent overload, and Engine No. 4 should develop its rated power equally well with Engine No 1, with which it is comparable in every way. The conclusion seems warranted that it is not possible always for a rancher to develop full rated power even with a new engine, and, therefore, it is desirable in purchasing to select an engine with 10 to 20 percent more power than is needed.

SPEED REGULATION

Oil engines are governed either by changing the proportions, that is, the richness of the gas mixture, or by changing the amount of the mixture admitted each cycle. The former is called quality governing, the latter is quantity governing.

Of the engines tested, all of the 2-cycle engines employ quality governing, varying the amount of fuel injected for each charge by varying the length of the fuel pump stroke. The 4-cycle engines tested have butterfly valves in the intake pipe and throttle the gas supply at light loads; this is quantity governing. Theoretically, quantity governing gives closer regulation. However, there is no evidence in the tests of such superiority.

Apparently much more importance attaches to the mechanical design of the governor. With the exception of the Muncie engines, all the engines with flywheel governors of the centrifugal type that were tested have poor speed control. Many of the governors are crude and are entirely unsuitable for governing a variable load where close regulation is needed, such as electric lighting or cotton ginning. On the other hand they have the advantage of few parts to get out of order, and it must be admitted that close regulation is not essential for pumping water.

Engine No. 6 has a fly-ball governor and a superior injection pump; the regulation is excellent. The Falk oil engine likewise has a fly-ball governor. A 20-horsepower Falk engine was recently examined at Tucson. Its speed regulation was only 1.6 percent from full load to half load.

In all the engines tested the amount of water fed into the charge was regulated by hand for the different loads. The heavier the load, the more feed water is required. Any variable load, therefore, requires that the feed-water supply, in addition to the fuel supply, be governed. Only a few engines attempt this at present. It is desirable that all oil engines be redesigned in the future so as to give the double governing.

RELIABILITY

Under this heading will be discussed the various operating features which determine the amount of care and attention, worry, and contingent expense required by oil engines of various types. That engines differ widely in the amount of attention required, in the frequency of troubles, and in the ability to run without attendance, is known to all operators. Particularly is it of importance that an engine shall not break down during the season of maximum use of water, when a week's shut-down may cause the partial or total loss of certain crops. Reliability is a characteristic not less important than fuel economy.

The term trouble has come into general use in connection with internal-combustion engines to denote the difficulties which occur from time to time and are evidenced by phenomena such as smoke, back-firing, overheating, loss of power, or by the refusal of the engine to run. The term trouble, then, is correlative to reliability.

Ordinary gasoline engine troubles are divided, according to location, into three classes: ignition, carburetor, and cylinder.

1. *Ignition troubles:* These occur most often but are seldom serious. Sometimes the electric circuit is broken, perhaps at a loose screw or by a broken wire; sometimes the insulation is broken, permitting a short circuit; often, indeed, the only trouble is that the batteries are worn out and should be renewed. If the operator adopts a systematic method in hunting for trouble, he will have no difficulty in locating it. For instance, in the case of known ignition trouble, the operator should test first the dry cells or other source of current; if they are sufficiently strong, he should test the spark obtainable just outside the cylinder, thus proving whether the circuit is complete to that point; if the circuit is complete, then the trouble is located in the igniter-block, or in the spark plug if high tension is used.

2. *Carburetor troubles:* These also are seldom serious being usually due to poor adjustments. The first requirement is that air and gasoline be furnished in such proportions as to form an explosive mixture. But it is found that the proportions may vary between wide limits and the mixture still be explosive. Therefore, much finer adjustments are required in order to give ideal running conditions. Fortunately, these conditions include maximum fuel economy, clean cylinder and valves, and long life, at the same time.

Carburetor troubles may be due to lack of gasoline as when the passages are clogged up or when the tank is empty, the last-named being a frequent occurrence, or the mixture may be too rich or too lean. The gasoline pump may need repacking, or water may have accumulated in the carburetor. If the operator adopts a system and proceeds carefully he will ascertain quickly the exact location of any carburetor trouble, and such troubles are easily remedied.

3. *Cylinder troubles:* These are frequently real troubles. They are due, usually, either to wear or to depositions of carbon or unburned heavy hydrocarbons. The intake and exhaust valves are subject to wear, and at frequent intervals they should be reground to fit the valve seats. They also become coated with a hard film of carbon, and this should be removed. The piston rings are subject to rapid wear if the lubrication is imperfect or if the combustion is bad. The ring grooves may become filled with tarry products and hard carbon, so that the rings are stuck fast. Likewise, from the same causes the interior of the cylinder becomes worn and scored. In either case the leaky piston results in decreased compression of the charge, and that in turn causes even poorer combustion and the difficulty is accelerated. The governor, the main bearings, or the crank bearing may cause trouble, but this seldom happens. Extraordinary troubles such as a cracked cylinder or a broken crank are very rare.

The modified gasoline engines using distillate of 40° Beaume and introducing water with the charge have been in common use about three years. Former gasoline engines that have been modified to burn low grade distillate, and engines with specially built carburetors, are common now throughout southern Arizona in the pump irrigation districts. A critical inspection of scores of these engines leads to the following generalizations:

1. The combustion of California tops and similar distillates is apparently complete, and there is no visible smoke from the exhaust pipe.

2, The hydrocarbons are not cracked, forming fixed carbon, and the cylinder interior is maintained practically as clean as in the case of gasoline engines.

3. The timing of ignition is under full control. The ignition occurs at a definite time in the cycle and there are no premature explosions.

4. Lubrication is as simple as with gasoline engines and no more costly.

5. Engines of small size, say under 25-horsepower, operate without attendance for two or three hours with no injury whatever. (While larger engines might run without attendance equally well, the investment in such engines is considerable and it is good policy to visit them every hour to feel the bearings and adjust the lubrication.)

6. Oil engines of this type are, in general, equally reliable for farm use, and as free from troubles as are gasoline engines.

Hot-ball engines, also, are common in southern Arizona. A few of them have been installed for three years and a larger number for two years. While they are free from some of the minor troubles of the gasoline type of engine, they have additional difficulties of their own. There are no batteries, electric connections, induction coils or spark plugs, but there are hot balls and gasoline blow torches. There are no carburetors but in place of them there are fuel nozzles and a plunger fuel pump. Instead of intake and exhaust valves in the cylinder, there are ports to be kept open, the crank case must be kept sealed tightly, especially around the main bearings, and there is a large poppet valve to admit air.

Hot-ball ignition held out the promise of being simple, positive, and economical, but very serious difficulties have arisen with it. The combustion, too, in the hot-ball engines is disappointing. Consequently, new troubles have been introduced. Perhaps they can be best appreciated by citing some individual experiences

1. A hot-ball 2-cycle engine purchased in 1912 Poor regulation; bad combustion; heavy smoke, difficulty in starting, 2 new sets of piston rings, abandoned after service in one irrigating season,

2, Engine purchased in 1912. Owner reported in 1913 that he had melted one hot ball and one brass fuel nozzle which dropped down into the cylinder; that be could not leave his engine for more than one-half hour at a time; susceptible to changes in temperature of feed water.

3. Combustion bad, much smoke, piston rings and cylinder worn until compression was poor, new rings and new cylinder provided; stud bolts came loose and crank case was torn to pieces.

4. Purchased in 1913. Trouble in starting until a new, larger torch was provided; melted two spoons; two cylinders worn out and re-replaced, now using third one; consumption of lubricating oil excessive

5. Seven hot balls broken; engine would not regulate after circulating water became hot; very poor combustion.

6. Poor combustion, exhaust filled with black powdery soot; after a few months in service, engine frequently stops; trouble found to be plugging of exhaust ports in cylinder with hard carbon deposit which had to be chiseled out.

7. Poor combustion; exhaust ports plugged with hard carbon deposits; one fuel nozzle melted.

8. Owner finds it necessary to clean out cylinder and ports once a week and to clean piston rings once in two or three months; burned out both main bearings.

9. Engine could not be regulated when feed water was taken from water jacket, so piping was rearranged to take feed water from well discharge; combustion poor, needs constant attention.

10. Engine ran away.

11. Exhaust pipe becomes choked with carbon deposits.

12. Usually takes an hour to start; record time was 35 minutest

13. Broke one hot ball; requires constant attention.

14. Cylinder head cracked by overheating.

15. Heavy smoke, requires constant attention.

16. Engine ran away; manufacturer furnished new governor and new fuel pump, both of improved design.

17. Poor combustion; fuel nozzle requires frequent cleaning; spongy carbon deposits thrown from exhaust settle on roof and on ground; broke one hot ball.

18. Broke two hot balls; fuel nozzle becomes foul.

19. Piston rings become gummed and stick.

20. Engine reversed suddenly while being started, breaking both flywheels.

The above illustrations indicate the general nature of the troubles peculiar to hot-ball engines. It is evident that the source of most of the troubles is imperfect combustion. This causes smoke, choking of exhaust ports, a dirty cylinder, stuck piston rings, wear of piston rings and wear of cylinder, and choked fuel nozzle.

The next most important defect is the difficulty of maintaining constant cylinder temperature. Often the temperature changes are quite sudden. They result in overheating, breaking of the hot balls, "cracking" of the hydrocarbons, premature ignition and knocking of the engine; or in late ignition, explosion "misses," loss of speed, loss of power, and sometimes in the stopping of the engine.

Several of the broken hot balls have been examined. One of them showed oxidation of the metal equal in amount to one-half the thickness of the metal, and the oxidation was about equally divided between the interior and the exterior; the others showed no oxidation.

The experience had with hot-ball 2-cycle engines in Arizona in 1913 and 1914 may be summarized as follows:

a. The combustion with California distillates of 30° to 43° Beaume is far from perfect. The engines, almost without exception, smoke more or less, and most of them quite badly. It may be that impinging of the fuel oil on the hot surface of the hot-ball lip increases the cracking of the oil.

b. The poor combustion leads to various cylinder troubles including deposition of carbon and rapid wear of the cylinder surfaces.

c. A comparison of hot-ball ignition and electric ignition shows more serious difficulties with the hot-ball ignition. The difficulties include delays in starting; broken hot balls, erratic timing, sometimes late, sometimes early, the latter causing pounding with consequent injury to the engine. Hot-ball ignition is more costly, largely due to the gasoline used in the blow torch and to the length of time required to heat the hot ball.

d. Governing by varying the length of stroke of the fuel pump lacks sensitiveness.

e. Lubrication is more difficult in hot-ball engines than in gasoline engines. More lubricating oil is required, a better grade should be used, and it should be fed by positive means as through an oil pump. The cost is from three to six times as much as m the case of gasoline engines.

/. Hot-ball engines require closer attention than modified gasoline engines.

g. Hot-ball engines will be improved as their shortcomings are recognized. At present they have not been developed to the degree of perfection desirable for irrigation pumping or general farm use.

SIMPLICITY

A very desirable feature in engines for farm service is simplicity of design. In general, the fewer the parts and the more accessible they are, the more readily the engine will be kept in good condition or repaired when any break occurs.

It is claimed that hot-ball engines are somewhat simpler in construction than modified gasoline engines. A comparison in this regard is afforded by the accompanying lists of integral parts of engines of the two types. The lists are printed in parallel columns with corresponding parts opposite each other.

INTEGRAL PARTS OF OIL ENGINES OF TWO TYPES

Hot-ball engines	Modified gasoline engines
Blow torch	Magneto
Hot ball	Spark plug
Air inlet valve	
Tight crank-case housing	Cam shaft
Pump rod	Fuel supply pump
	Carburetor
Fuel injection pump	Intake valve
Fuel nozzle	Exhaust valve
Cylinder	Cylinder
Piston	Piston
Connecting rod	Connecting rod
Crank shaft	Crank shaft
Flywheels	Flywheels
Governor	Governor
Pump lubricator	Cup lubricators

While the number of parts is practically the same in the two columns, an inspection of the lists shows that the hot-ball engines have one less moving parts. The exhaust valve of the modified gasoline engine has no moving counterpart in the other list, but the hot-ball engines have air inlet valves and require forced lubrication.

The magneto, though mechanically operated, has great advantages over the blow torch and hot ball. Small gasoline engines are equipped usually with batteries, either dry or wet, but this is poor economy; every engine of the carburetor type, whether large or small, should be equipped with a magneto. An oscillating high-tension magneto built onto the engine near the head end obviates the use of an induction coil or an igniter-block and the whole electric circuit is only a few inches in length. No other ignition system is so simple as this. Low tension magnetos gear-driven from the crank shaft, also, are most serviceable and are being adopted by many of the best engine builders.

Hot-ball engines require more uniform cooling than do the modified gasoline engines. This is due to the fact that the time of ignition in hot-ball engines is quickly responsive to the cylinder temperature and the "premature" explosions are particularly objectionable. Thermo-siphon cooling should not be used on hot-ball engines; a circulating pump is essential, and should take its supply from the well discharge line rather than from a circulating water tank. The feed water, also, should be taken from a source that is constant in temperature. For carburetor engines the thermo-siphon system is ideal and has the advantage of simplicity.

Most of the large oil engines are started by compressed air. This implies that the plant is equipped with an air compressor, usually with a small distillate engine to run it, a receiving tank with pressure gauge and safety valve, and an air pipe line of considerable length with check valves and special air starter valves. These luxuries add to the cost of the plant and they add greatly to the equipment to be kept in order. During the test of Engine No 6, it required over half an hour to start the small compressor engine and to bring the air pressure up to the pressure needed for starting the large engine. It is desirable to find a simpler method of starting than by air.

The Fairbanks, Morse & Co., quick starter consists of a match igniter and a small hand air pump. The match igniter or detonator is screwed into the side of the cylinder and operated by striking it with the hand. The hand air pump is bolted to the side of the cylinder and is used for compressing a charge of air and gasoline vapor into the cylinder just prior to striking the igniter head. Although this device appears to be crude, yet it operates very successfully, even on large engines. The method is not patented and a modification of it could be adapted to any engine. If the match igniter could be replaced by hand manipulation of the magneto or tripping the igniter at the right moment, the method would seem to be the best for farm engines. Engines of less than 20-horsepower, however, do not need any special starting mechanism. They should be started by turning the flywheel forward to draw in a charge (a rich charge in cold weather), then throwing the flywheel backward to compress the charge, tripping the igniter at the instant of maximum compression.

Some of the engines recently introduced for burning low grade distillates are equipped with complicated auxiliary devices which can be of little real benefit* These devices furnish good talking points for agents, but farmers should be slow to adopt them until they have had thorough trial for a few years elsewhere.

There is a movement among engine builders to standardize eertain parts so as to make them interchangeable on all engines. Already a standard insulated electrode has been adopted, and also a standard belt speed. This movement should be encouraged by engine users. The problem of obtaining repair parts will become easier.

DURABILITY

It is said commonly that a gasoline engine will last from eight to twelve years. Obviously the life of an engine cannot be foretold in years so easily, for the character of service differs widely. Some farmers pump water only a few days per week, or only a few hours per day, others operate their plants continuously night and day, which technically is the right way to do. Also, the length of the irrigating season vanes widely in different localities.

The life of an engine, in hours, depends upon three factors: the quality of metal and workmanship, the kind of service and the attention given to operation, and the fuel used. The first factor is of Interest to a purchaser. Pumping service is comparatively easy, and some manufacturers have been attracted to the opportunity of furnishing cheap engines for this trade. They have cast engine cylinders with about the same care as is given to stoves and ranges. The results, of course, are sandholes, cracked cylinders, and soft cylinders which wear away quickly. Close-grained hard grey iron is superior to common grey iron. Furthermore, cylinders should be turned true and machined with great care. They are greatly improved by grinding the interior. As a rule only small cylinders of high grade are so ground, but one manufacturer now grinds both cylinder and piston on all sizes up to 100 horsepower. However the majority of gasoline and oil engines are fairly well built and are delivered to the purchaser in good condition. The first factor named above, is beyond the operator's control and is of least interest to him.

The second factor, the kind of service and the attention given, is more pertinent. An engine that is very heavily loaded will not last so long as one lightly loaded. An engine on a light foundation is subject to much vibration, and an engine using a poor grade of lubricating oil is at a disadvantage. Overheating and knocking are very injurious to engines, and not infrequently it happens that a farmer lets an oil cup get empty. The housing of an engine is important, particularly in a country of occasional sandstorms. Dust, dirt, grime, rain and neglect are enemies of the gasoline or oil engine. Every engine should be cleaned up systematically once a week, at which time bolts and springs, valves and other parts should be examined.

The third factor, the suitability of the fuel, is of prime importance. It is false economy to try to burn cheap fuels that are too heavy or contain too much asphalt. California and Texas oils having an asphalt base are much harder to bum than Oklahoma and Kansas oils having a paraffine base, and for that reason probably some oil engines that have worked successfully in the central states have encountered difficulties in the far West.

The greatest factor in prolonging the life of an engine is clean combustion, that is, the complete combustion of the ftad used, with clean, smokeless, invisible exhaust. Bad combustion is due to two causes: first, if the fuel entering the engine strikes against very hot surfaces, the complex hydrocarbons are partially decomposed *with* the production of fixed carbon, some of which adheres to the metal surfaces, especially in the ports, valves, and ring grooves, causing hard ruinous deposits. Fragments of coke become detached and score the walls. Imperfect atomization, whereby the oil enters the cylinder in minute globules instead of as vapor, has the same effect. Second, heavy hydrocarbons of the fuel are vaporized and thrown out in the exhaust in an unburned state, or are deposited as tar on the engine walls. The lubricating oil, also, from the inside cylinder wall is likely to be vaporized but not burned.

A smoky exhaust signifies a foul dirty cylinder, injurious depositions, and rapid wear. After a comparatively small amount of wear the engine loses its compression. The cylinder can be rebored once, sometimes twice, or it can be replaced by a new cylinder. The life history of an engine is the history of its cylinders and piston rings, for other integral parts like the governor and fuel pump cam be maintained in good order with occasional slight expense.

The principal criticism of the 2-cycle gasoline engine always has been its imperfect scavenging and incomplete combustion. The latter defect is even more noticeable in 2-cycle oil engines. Then, too, there is no way to take up the wear around the cylinder ports. It seems fair to assume that the life of the average 2-cycle oil engine now in use in Arizona will be shorter than the life of the average 4-cycle oil engine.

The combustion in all oil engines is compromised by improper setting of the fuel control valves, the common error being the feeding of too much fuel. An instance is given on page 413 where in the twelfth test the needle valve was opened part of a turn for the purpose of observing the effect. Many instances have been observed where operators found that steadier running was obtained with a closer setting of the fuel valve, and at the same time the loss of heat to the cooling water was perceptibly decreased. Minimum fuel consumption means maximum length of life.

In the case of large horizontal engines the weight of the piston becomes an important feature, for, with increase in size, the increase in weight of the piston is much faster than the increase of bearing surface. Likewise, the increase in power is faster than the increase of bearing surface. Consequently, the cylinders of large horizontal engines wear oval and "grooved" on the bottom, the piston rings then no longer fit the cylinder and "blow-bys" occur. There is also a definite jump of the piston from the upper side to the lower side at the beginning of the power stroke. In an Arizona mining camp where 60-horsepower distillate engines were used continuously night and day, it is reported that new cylinders were required every six months. In the same kind of service a 16-horsepower distillate engine ran five years with a few changes of piston rings only.

Large oil engines of 40 to 100-horsepower are becoming common for irrigation pumping in Arizona. The single-cylinder horizontal type is being bought, but the selection of that type is questionable. Twin-cylinder engines and three-cylinder engines give high power with lighter pistons, they have more even regulation, and their disadvantages are less than would at first appear. One fuel supply system, one governor and one starter serve for all the cylinders. The flywheel weight for a twin-cylinder engine is only three-fifths as great as for a single-cylinder engine of same power.

Large engines with piston rod and cross-head are subject to much less cylinder wear than engines having the trunk-type pistons. The wear comes on the cross-head and frame, and can be compensated for occasionally by adjusting the shoes. A cross-head adds to the weight of the reciprocating parts and it adds greatly to the cost, and on a small engine it is not needed.

The horizontal type of engine and the vertical type each has Its champions. At present the trend of engine designing is toward the horizontal type, but good engines of each type are being built. The principal arguments for the vertical engine are the more uniform wear and the simplicity of lubrication; the arguments for the horizontal engine are accessibility, uniform lubrication and better balance. For large engines of equal power, the weight and the floor space required are about the same for the two classes of engines.

Manufacturers fail to grasp an opportunity in that they desert a purchaser as soon as the engine is delivered. They might learn from the automobile business that it pays to "stay with" their engines. In the first place, a farmer needs personal instruction. Lists of instructions and pamphlets (including this one) may be of some use, yet they are not enough. The man who is to run the engine should be shown. It is gratifying to know that one house selling engines in Arizona keeps experts in the field who make the rounds every two or three months and look their engines over and put them in condition if anything goes wrong. An engine salesman should be a mechanic. Such a man can not only write a contract, but he can install an engine and can give full instructions as to its operation. He can show the farmer how to grind the valves, and how to adjust the bearings, and he can ferret out and overcome any troubles that may arise*

COST OF PUMPING FOR IRRIGATION

One effect of the adoption of low grade distillates in place of gasoline for internal-combustion engines is to reduce the cost of pumping for irrigation. A consideration of the reduction in cost, its nature and its magnitude, is of value to those contemplating the purchase of a pumping plant and, more particularly, to those ranchers who are now using gasoline or engine distillate as a fuel but are considering the exchange or remodeling of their engines so as to utilize the cheaper fuels. Lower cost of pumping, when related to the rancher's farming operations, means a larger margin of profit. The effect is even farther reaching, for with cheaper fuels it becomes possible to extend agriculture to areas where groundwater is situated at so great depths as to make pump irrigation with gasoline engines unprofitable.

The whole question of cost of pumping merits some discussion, The Arizona Agricultural Experiment Station receives inquiries constantly regarding pumping costs. Twice, in 1904 and 1910, the Station has published bulletins covering tests made especially to determine the costs of pumping, but on account of the improvements in pumping machinery, the cost data published, even in 1910, is now quite obsolete. So, while making comparisons between pumping costs with gasoline and with Tops, consideration will be given also to the broader question so frequently asked, "What does it cost to pump?"

The difficulty encountered at once in this discussion is that at no two pumping plants are the conditions identical, and therefore it is dangerous to make generalizations based upon a few tests. The pumping lift, the size of the stream pumped, the character and efficiency of the pumping machinery, and many other factors influence the cost. There is a wide difference oftentimes between the actual cost of pumping and what it ought to cost. It is best, perhaps, to assume a set of conditions conforming to good practice and to exhibit the cost under these conditions. This will be done for two separate cases, one in which the actual or static lift is 40 feet and the other in which the lift fe 100 feet. For our purpose the former may be called a low-lift proposition, and the latter high-lilt. In each case the costs will be shown for three plants, namely, a gasoline engine plant, an oil engine plant, and an electric plant. The following assumptions will be made regarding the cost of wells, the pumps, the engines, the fixed charges, the acreage and duty of water, the fuel, and the attendance.

ASSUMED CONDITIONS

1. *Cost of wells:* This cost is exceedingly variable. In Pinal and Maricopa counties from $800 to $2000 is paid commonly for drilled wells, while in the township northwest of Willcox equally good wells are obtained for $300. Prices for drilling at San Simon vary from 50 cents to $1 a foot, while in the Santa Cruz Valley the usual prices are from $3 to $5 a foot. A well which was drilled at Pantano for the Southern Pacific Co. cost over $8000 and was abandoned because no water was developed The cost for the low-lift well will be taken arbitrarily at $800 and for the high-lift well at $1200.

2. *Pumps:* Centrifugal pumps will be assumed for both cases, a 5-inch horizontal single-stage pump for the low-lift and a 5-inch vertical two-stage pump for the high-lift. The horizontal type is preferable wherever the conditions permit its use. By depressing the engine in a pit and using an inclined belt, a horizontal pump can be set as deep as 25 feet below the surface. The suction lift can be as much as 25 feet but preferably not over 15 feet. Single-stage pumps with lifts of 100 to 110 feet have been installed recently in several localities, but it is bad practice. On lifts greater than 70 feet two-stage pumps should be used.

The size of the pumps adopted makes them suitable for irrigating any acreage up to 100 acres in Maricopa County or up to 150 acres at altitudes of 4000 feet, as in the Sulphur Spring Valley.

It will be further assumed that pumps of superior design are selected. A 5-inch pump recently purchased for the University Farm showed 68.4 percent efficiency when tested. Very few centrifugal pumps in Arizona, however, are giving more than 50 percent efficiency, for the average rancher is not discriminating when he purchases pumps. A good rule is to buy an efficient pump and, if economy is necessary, then economize on the engine. For the present estimates, 60 percent efficiency will be assumed for the pumps and 92 percent for the belt transmission. The friction head in the piping will be taken at 2 feet for the low-lift and 4 feet for the high-lift.

3. *Engines:* Gasoline and oil engines of the 4-cycle horizontal type, with magneto ignition, will be assumed, each engine to be set in a heavy concrete foundation and to be housed in a small building

of plastered adobe with galvanized iron roof The equipment for the electric plant is to consist of an induction motor, a transformer, a meter and a small switch-board The rated capacity of engines and motors will have 10 or 15 percent margin above the load requirements Fifteen horsepower will be required for the low-lift and 35-horsepower for the high-lift

4. *The fixed charges* are the depreciation, maintenance, interest, and taxes These charges must be met whether the plant is used much or little They are stated as percentages of the first cost and will be assumed as follows

TABLE XIII—FIXED CHARGES FOR PUMPING PLANTS
STATED AS PERCENTAGES OF THE FIRST COST

	Well	Gasoline engine plant	Oil engine plant	Electric plant
Depreciation	3 0	7 0	7 0	5 0
Maintenance	0 0	2 0	2 0	1 0
Interest	8 0	8 0	8 0	8 0
Taxes	0 5	0 5	0 5	0 5
Total	11 5	17 5	17 5	14 5

5. *The acreage* considered will be 40 acres. Most Arizona pumping plants serve smaller areas than this, but as a rule the plants are operated much less than half the time. Pump irrigation implies intensive agriculture and high-priced crops, and under those conditions 40 acres is amply large for one ranch but there is no reason why the plant described should not suffice for two adjoining ranches except for the difficulty of securing cooperation between the ranchers.

It may be argued that for 40 acres a smaller plant should be installed, say a 4-inch pump. But, any advantage in lower first cost is counterbalanced by the necessity of building a reservoir or the manifest waste of the irrigator's time in taking care of a small stream of water* It is difficult to get a small stream over 40 acres without a large percentage of loss by seepage from the ditches Then, too, pumps of small size are of lower efficiency than larger pumps.

A different case is that of supplemental irrigation, in which the rainfall is depended upon in large part to raise one or possibly two crops a year. Under supplemental irrigation the plant described can serve a larger acreage than that already stated.

The fixed charges per acre are obtained by dividing the total fi&ed charges by 40, the number of acres irrigated. The larger the acreage irrigated from a plant, the smaller will be the cost per acre.

6. *The duty of water* will be assumed at 4 feet depth per year, that is, 4 acre-feet of water per acre per year. Here again is illustrated the difficulty in stating costs of pumping. Were such costs to be based upon tests made in one locality they would be misleading to residents in other parts of the state where the conditions are radically different. As a basis of comparison the duty of water for alfalfa at five different places can be stated tentatively as follows:

TABLE XIV —DUTY OF WATER FOR ALFALFA IN ARIZONA

Locality	Altitude	No. of cuttings	Depth of irrigation per year
	Feet		Feet
Yuma	100	8	6 0
Phoenix	1100	7	4 5
Tucson	2400	6	4 0
Benson	3500	5	3 0
Willcox	4000	4	2 5
Lakeside	7000	2	1 0

The average duty of water in the Salt River Valley is higher than as stated in the table, due to the diversity of crops. Cotton and grain sorghums require less water than alfalfa, while the nearly worthless runout pastures of shallow-rooted grass require the most of all.

This Station measured the amount of water applied to one alfalfa field of 18 acres irrigated from a pumping plant. The total depth of application in 1914 was 9 feet. The stand of alfalfa was exceptionally fine and the yield was 8 tons per acre. But it is undeniable that much less water would have been ample if the field had been properly prepared to receive the water. Another field, on which 3.1 feet of water were applied, yielded 4.5 tons of hay per acre. This field suffered for water.

7. *Fuel:* It will be assumed that the engine distillate used in the gasoline engine costs 14 cents a gallon at the nearest railway point, and one cent a gallon will be added to cover hauling and waste, making 15 cents a gallon at the ranch. Tops can be purchased at 5 cents a gallon at the railway, making the cost 6 cents a gallon at the ranch. The fuel consumption in both cases will be taken at 8 horsepower-hours per gallon, an assumption which implies an engine in good condition and intelligent operation.

The charges for electric current will be computed according to the schedule of rates fixed by the Arizona Corporation Commission for all public service corporations. The rates per month are as follows:

First 100	kilowatt-hours,	10	cents	per	kilowatt-hour
Next 100	"	8	"	"	"
Next 100	"	6	"	"	"
Next 200	"	5	"	"	"
Next 250	"	4	"	"	"
Next 250	"	3.5	"	"	"
Excess 1000	"	2.8	"	"	"

The rates of the United States Reclamation Service in the Salt River Valley are considerably lower.

8. *Lubricating oil:* The cost will be taken at one-seventh the cost of fuel for the oil engine and an equal amount for the gasoline engine. For the electric plant the cost of lubrication of the motor will be quite insignificant, less indeed than that of the pump. Hence, a very small charge per acre will be made.

9. *The attendance:* It will be assumed that one-sixth of a man's time, at 25 cents an hour, is required for the small gasoline and oil engines, and one-fourth of his time for the large engines, while for the small motor and horizontal pump one-fifteenth of his time is required, and for the motor-driven high-lift plant one-tenth of his time.

COST OF PLANTS

The costs of the six plants, based on the foregoing assumptions are exhibited in Table XV. The costs are based on current prices in 1914.

TABLE XV.—COST OF PUMPING PLANTS OF SIX TYPES

	Low-lift—40 feet			High-lift—100 feet		
	Gasoline engine	Oil engine	Motor	Gasoline engine	Oil engine	Motor
Well	$800	$800	$800	$1200	$1200	$1200
Pump installed	200	200	200	720	720	720
7 in. piping and valve	65	65	65	120	120	120
Engine or motor installed	675	700	625	1350	1400	925
Belt, 6 in. and 10 in.	25	25	25	60	60	60
Oil tank, 3000 gal. capacity	....	100		...	100	...
House	110	110	70	200	200	100
Total	$1875	$2000	$1785	$3650	$3800	$3125

COST OF PUMPING

The investment in the pumping plants being now shown in Table XV, it is possible next to compute the fixed charges per year for each plant and the fired charges per acre. These fixed charges with the operating expenses are itemized in Table XVI. Besides the total cost per acre, the table gives the cost per acre-foot of water pumped and the cost per acre-foot per foot of lift. Thus, for the first plant the total cost per acre-foot is $4 15 and the cost of lifting that foot through each foot of lift is 10 4 cents

TABLE XVI.—COST OF PUMPING PER YEAR PER ACRE WITH SIX TYPES OF PUMPING PLANTS

	Low lift—40 feet			High lift—100 feet		
	Gasoline engine	Oil engine	Motor	Gasoline engine	Oil engine	Motor
Fixed charges	$ 7 00	$ 7 55	$ 5 87	814 17	$14 83	$10 43
Fuel (or current)	7 80	3 12	16 65	19 30	7 70	32 75
Lubricating oil	45	45	20	1 10	1 10	40
Attendance	1 33	1 33	53	2 00	2 00	80
Total cost per acre	$16 58	$12 45	$23 25	$36 57	$25 63	$44 38
Cost per acre-foot	$ 4 15	$ 3 11	$ 5 81	$ 9 14	$ 6 41	$11 09
Cost per acre per foot lift	$ 0 104	$ 0 078	$ 0 145	$ 0 091	$ 0 064	$ 0 11

Table XVI shows at once the reduction in cost of pumping by substituting low grade distillates for gasoline. For the low-lift plant the reduction is $4.13 per acre, which is 25 percent of the total cost of pumping with gasoline engines. For the high-lift plant the reduction is $11 per acre, about 30 percent of the total cost with gasoline engines. With staple crops, the value of which is less than $75 per acre, these reductions are of critical importance. Under the assumed conditions, electric power cannot compete with either gasoline or oil engines.

For comparison, the cost of irrigating water in the Salt River Valley project of the U. S. Reclamation Service will be stated. The annual charge for 4 acre-feet is $2, To this must be added the Interest at 8 percent on the value of a water right, which, tinder the Tempe Canal, and doubtless throughout the Valley, is not less than $100. The cost of water, therefore, is about $10 per acre annually. Under the Yuma project, also, and in the Upper Gila Valley the annual cost of water is about $10 per acre. In the case of large gravity systems with reservoir storage, the interest charge is the largest item of cost The total cost shown in Table XVI for oil engines on the 40-foot lift is very little more than the total costs under the gravity projects. The slight difference is wiped out by other advantages of the pumping plant, especially the freedom from weed seeds Pumping with lift of 100 feet cannot compete with gravity projects

It is observable that the cost per foot lift is slightly lower for the high-lift than for the low-lift. With the data given in the table it is possible to make close estimates for other lifts than 40 and 100 feet.

An alternative proposition for the high-lift plants is for a high efficiency double-acting plunger pump such as the Luitwieler or the Pomona. The heart-shaped cams of the Luitwieler pump produce a discharge of water that is continuous and steady and the load on the engine is uniform. Pumps of this class have efficiencies of 70 to 80 percent. In the present instance a 14-inch cylinder with 18-inch stroke would be required, and a 25-horsepower oil engine would give sufficient power. The total cost of the pump and piping would be $3100, and of the engine and belt $1100. Comparing now with the centrifugal pump, the fixed charges on the increased investment of $1900 would be $8.31 per acre, while the reduction in the cost of fuel would be only $2 per acre. Under other conditions, with higher lift and smaller capacity, the advantage would He in favor of the reciprocating pump. The so-called propellor pumps that are on the market are as costly as the two-stage centrifugal pump. Their efficiency is not known.

THE FIXED CHARGES

Reference to Table XVI reveals the fact that the largest item of cost when oil engines are used is that of fixed charges. The total cost per acre with the oil engine on the low-lift is $12.45, and of this amount $7.55 is for fixed charges. Now it is not always clear to the rancher that there is any such item of cost. He may think that the only expense is for fuel oil, lubricating oil, repairs and maintenance, and possibly attendance. But, let it be supposed that he has borrowed the $2000 required to sink the well and purchase the plant. Then every year he will have to pay the interest charge, at least $160, and this money must be charged against the gross income from the 40 acres just as truly an d surely as the cost of the fuel oil. The interest cost, then, is $4 per acre, greater even than the cost of the fuel. Likewise the depreciation of the plant cannot be ignored. An internal-combustion engine wall find its way to the scrap heap in 10 or 15 years whether it is used much or little. Engines and pumps soon become obsolete. At least 7 percent of the cost of an engine should be earned each year as a sinking fund, so that in 10 years the engine will have paid for itself, or, so that the first cost will be available again for the purchase of a new engine. A rancher should not deceive himself by ignoring these fixed charges. As pumping is now practiced in Arizona the fixed charges are greater than all the other costs put together.

Suppose, however, that the pumping plant is used to irrigate 100 acres instead of 40 acres. The plant is amply large for 100 acres, but it must be run continuously night and day through the hot months of May, June and July. The fixed charges are a definite amount per year, and, if this amount is divided among 100 acres instead of 40, the charge per acre will be $3.02 instead of $7.55, and the total cost will be reduced from $12.45 to about $8 per acre.

Now comes a most important deduction. A pumping plant should be used all possible. This is the farmer's opportunity *to* reduce the cost of pumping. Manufacturers have made a big reduction by modifying their engines so as to burn cheap low grade distillates. The farmer can make another reduction equally large by using his plant instead of giving it so much rest and idleness.

To illustrate the point, suppose one had a pair of draft horses and kept them tied in the barn. Could they earn anything? But an engine consumes neither hay nor gasoline when it is idle. True, but perhaps the man borrowed money to buy the team of horses. He must pay the interest thereon every year. And what becomes of the investment when the horses die? An engine or a team is earning money when it is in operation; it is costing money when standing idle. It is folly to shut down a pumping plant at noon, and to shut down at night is bad management.

It may be argued that, with the intensive agriculture usually practiced under pumping plants, a rancher cannot operate 100 acres. Then two or three ranchers should cooperate in one pumping plant. Under gravity systems each rancher does not have his own ditch from the river. One diversion dam and ditch suffices for a whole community. So, too, a 5-inch pump will deliver as much water as three families can use economically. Or, if a man wishes to apply all the water on his own quarter-section, let him lease parcels of land with water. A common contract is for providing land, water, and seed to a tenant, and receiving half the crop.

In conclusion, it should be repeated that Table XVI is based upon many assumptions. But the author personally is familiar with the majority of pumping plants in Arizona; he has tested many of them during the past eight years, and has consulted with hundreds of ranchers regarding their plants. It is believed, therefore, that the above discussion is the fairest presentation that it is possible to make of the cost of pumping in Arizona.

SUMMARY

FUEL OILS

1. The farmer must give up gasoline as a fuel for pumping engines, and must use cheap low grade distillates instead. The possible supply of these distillates is very great. Distillates of from 39° to 44° Beaume are the most advisable at the present time.

2. It is preferable to buy fuel by the carload instead of at retail. (This does not apply to gasoline or engine distillate on account of the much greater volatility and danger.) Storage tanks should be of galvanized iron or of water-proofed concrete.

3. The purchaser should test the oil for specific gravity and flash point. Apparatus for this purpose is inexpensive.

OIL ENGINES

4. A practical classification of oil engines is into three groups: Diesel engines, modified gasoline engines (the carburetor type), and hot-ball engines.

5. Diesel engines, though ideal mechanically, require too much expert care, and are not adapted to farm conditions.

6. Four-cycle gasoline engines with electric ignition and suction fuel feed can be modified to burn heavier distillates successfully by feeding water with the charge. Preheating of the charge, also, is necessary in cold weather; and the heavier distillates require higher compression and earlier ignition than gasoline in order to give the best results. The water feed is the most important factor.

7. Distillates of 39°-44° B. with a low flash point give excellent results in the modified gasoline engines. The cost including freight is about 4¾ cents a gallon in carload lots at main line points in Arizona and about 5 cents a gallon on branch railroads.

8. Gasoline engines already in service can be altered by replacing the fuel mixer and the exhaust block with specially designed ones, or by adding a home-made device for feeding water into the air inlet pipe. The fuel cost can be reduced thereby more than one-half, even though the oil is bought at retail.

9. The effects of the water in the charge are: softened explosions, more complete combustion of the fuel, a cleaner cylinder,

cleaner valves, uniform temperature with reduced loss of power in the jacket water, and no preignition. Despite the loss of power in the heat of vaporization of the feed water, the fuel economy of the engine is not lowered

10. Two-cycle engines with hot-ball ignition, and fuel injection at the end of the compression stroke can be operated on low gravity distillate, even down to 30° Beaume for small engines, and to 24° Beaume for large engines, provided the compression pressure is increased to 180 pounds per square inch. As in the case of 4-cycle engines, water feed is essential except perhaps when the engine is carrying less than one-third of its full load.

11. The time required for heating the hot ball with a blast lamp is from 10 to 40 minutes, some engines requiring a longer time than others. The total time that it takes for starting the engines is from 15 minutes to an hour.

12. Forced feed lubrication is necessary for hot-ball engines and is desirable for large 4-cycle engines.

13. Pump circulation gives much better results than the thermo-siphon system for hot-ball engines.

FUEL ECONOMY

14. Fuel economy of 9 or 10 brake horsepower-hours per gallon of fuel oil is possible with farm engines of either type, assuming the engine to be in good condition. In the average ranch pumping plant the fuel economy is about 6 or 7 horsepower-hours per gallon.

15. The determining factor of fuel economy is the adjustment of the fuel valves. It is possible to burn 50 to 100 percent more oil than is needed without any immediate signs of distress. Nearly all oil engines are operated with the fuel valves opened wider than is necessary It is essential also to maintain good compression in the engine, worn valves and piston rings should be attended to.

16. Mechanical losses of power in an engine are most important when the engine is only partly loaded. An engine should be run at from three-quarters to full load. A purchaser should compute his power requirements carefully and then add about 15 percent to determine the size to buy. At altitudes of from 3000 to 5000 feet, from 25 to 30 percent should be added to the computed capacity.

17. Manufacturers vary somewhat in the liberality of rating. There are very few engines which cannot be made to deliver their rated capacity at low altitudes, but some engines will stand considerable overload, others very little or none* The piston displacement

per minute per horsepower is the best indication of the capacity of an engine.

18. Oil engines for the pumping trade, with few exceptions, have poor speed regulation. Engines for electric service or for any important variable load should have more sensitive governors than those commonly used on farm engines.

19. The quantity of humidifying water should be controlled by the governor.

RELIABILITY

20. The reliability of an engine is of the greatest importance to a farmer, for the farm engine must run without that constant attendance which steam engines require. Engine troubles consume the farmer's time and temper, and they may be very costly.

21. Four-cycle oil engines with electric ignition are proving to be quite as reliable as gasoline engines. The combustion of the fuel oil is perfect, and there is no exhaust smoke. The explosions can be timed perfectly and they occur with great regularity. Compared with gasoline, the only disadvantage in burning tops is with respect to starting in cold weather, when it is necessary to run for from on to five minutes on gasoline and then change over to tops.

22. The experience had with hot-ball engines in Arizona to date has been unsatisfactory. The combustion is imperfect, usually bad. Hot-ball ignition has serious disadvantages. The evil effects of leaky compression are very great. Pump lubricators, water circulating pumps and friction clutch pulleys are required even on small engines. On careful analysis the hot-ball engines do not have any advantage in simplicity. Their useful life will be less than that of 4-cycle engines.

23. The life of an engine depends, partly, on the operator. A small change in the setting of the feed valves can make much difference in the fuel consumption, and few operators know just where to set the feed valves. An unnecessary amount of fuel means increased heat and wear, more frequent grinding of valves, and shortened life of the cylinder.

COST OF PUMPING

24. The use of tops in place of engine distillate decreases the cost of pumping from 20 to 40 percent.

25. The cost of pumping on a 40-foot lift, with 4 feet depth of application, varies from $8 to $20 per acre, according to whether the

plant is used much or little. Under the most favorable conditions the cost of pumped water is no greater than the cost of river water.

26. The cost of pumping on a 100-foot lift, with 4 feet depth of application, varies from $20 to $40 per acre. Ranches dependent upon so high a lift should be devoted to high priced crops such as orchard fruits and vegetables, or to crops whose water requirements are low such as millet, sorghums, corn and sugar beets; not over one-fourth of the acreage should be used for alfalfa.

27. Electric power at the rates prescribed by the Arizona Corporation Commission is much more costly than the use of oil engines.

28. The largest item of cost is the fixed charges. In order to reduce these charges, the plant should be used all possible. Never shut down at noon or at night through the irrigating season from March to July. One pumping plant should serve two or more ranches.

DESIRABLE FEATURES FOR AN OIL ENGINE

Four-stroke cycle.
Built-in magneto.
Waterfeed in the gas charge.
Adjustable preheating of the charge.
Time of ignition adjustable while running.
Vertical intake and exhaust valves.
Reliable governor of the throttling type.
Governor control of the humidifying water.
Close regulation, if for an electric load.
Large piston displacement per minute.
Flywheels that run true, no wobble, and balanced.
Cylinder of hard close-grained metal, well machined or ground.
Strong frame with high cut sides. The bench type is preferable for horizontal engines.
Copper gaskets.
Leather washers. Never use rubber around oil engines.
Split bushings and liners of bronze or anti-friction metal.
Simple inexpensive method of starting.
An engine thermometer on the jacket water.
Circulating water tank of ample size, or a circulating pump.
Valve in circulating water pipe-line.
Muffler, if surrounding conditions require it; otherwise no muffler
Provision for thorough lubrication, forced feed for large engines.
Reasonably slow speed and heavy, strong construction, or a compensating advantage in low price.
An established reputation for reliability and good wearing qualities,

Contract price should be for engine installed and ready to run and contract should provide for a day or two to be spent in instructing the purchaser how to operate and care for the engine.